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Crop Diversification for Enhancing Farm Income and Agro-ecosystem Stability

Amit Kumar Pandey, Ashutosh Singh and Pavan Shukla

Abstract

Crop diversification is the deliberate increase of crop species, varieties, and production practices on-farm through rotations, intercropping, relay cropping and agroforestry is a multifunctional strategy that simultaneously addresses farmer livelihoods and ecosystem stability. Diversification spreads production and market risk across time and space, improves resource-use efficiency, enhances on-farm biodiversity and ecosystem services (pest regulation, pollination, nutrient cycling), and can increase aggregate productivity per unit land. This review synthesizes concepts, mechanisms, empirical evidence, trade-offs, enabling policies and practical pathways for adoption, and closes with research priorities and policy recommendations to scale up diversification for resilient, profitable farming systems.

Introduction

Crop diversification has re-emerged in research and policy as a core strategy for sustainable intensification and resilience in agriculture. The term covers a wide range of practices: temporal diversification (crop rotations), spatial diversification (intercropping, strip cropping), compositional diversification (adding legumes, trees, vegetables), and landscape-scale diversity (mosaic of production types). This review focuses on how crop diversification can increase farm incomes and stabilize livelihoods while supporting agroecosystem stability (soil health, pest and disease regulation, pollination and biodiversity). Evidence is synthesized from meta-analyses, long-term field studies, and household level empirical work with an emphasis on mechanisms and practical implications.

Why diversification matters-core mechanisms

Risk spreading and portfolio effects: Diversifying crops creates a portfolio of revenue streams that rarely fail simultaneously; when one crop suffers a yield or price shock, another may compensate, reducing income variance and improving stability. Economically, diversification reduces household income risk and can improve resilience to climate shocks and market volatility (Makate *et al.,* 2016).

Resource-use complementarity and increased land productivity: In intercropping and mixed systems, species with complementary resource acquisition traits (root depth, temporal uptake, nitrogen fixation) can use light, water, and nutrients more efficiently than monocultures, often increasing total biomass or energy output per unit land (Martin-Guay *et al*., 2018).

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Ecosystem services provision: Greater species richness enhances beneficial insects (natural enemies of pests), pollinators, and microbial diversity that enhance nutrient cycling and reduce pest/disease pressure sometimes reducing the need for external chemical inputs (Letourneau *et al*., 2011).

Soil health and resilience: Rotations and the inclusion of legumes, cover crops, and deep-rooted species improve soil structure, organic matter, and nitrogen balance, supporting long-term productivity and buffering against erosion and drought.

Market and dietary diversification: Producing multiple crop types increases opportunities to access different markets and supports household dietary diversity where consumption of own-produced food is prevalent (Waha *et al*., 2022).

Forms of crop diversification and examples of practices

Crop rotations (temporal diversification): Alternating cereals with legumes, oilseeds, or fallows; classic example: cereal-legume rotations that reduce disease pressure and improve N supply.

Intercropping (spatial diversification): Simultaneous cultivation of two or more species in the same field (row, strip, or mixed). Examples: maize-bean, millet-cowpea, cereal-fodder intercrops.

Relay cropping and sequential cropping: Planting a second crop before the first is harvested to extend productive periods.

Agroforestry/ silvoarable systems: Integrating woody perennials (trees, hedgerows) with annual crops to diversify products (fruit, timber, fodder) and ecological functions.

Polycultures and mixed farming: combining multiple crop species sometimes including small livestock to diversify both production and nutrient flows.

Evidence on income enhancement and stability

Empirical studies at household and farm levels generally indicate that diversification can increase productivity, incomes, and resilience but results are context-dependent. Makate *et al*. (2016) used household-level data in Zimbabwe to show that crop diversification was associated with higher crop productivity and improved household income and food security, after correcting for selection bias in adoption. Global meta-analyses and syntheses show that intercropping can increase gross incomes and harvested energy per unit land compared to monocultures (Martin-Guay *et al*., 2018). Large-scale reviews indicate that agricultural diversity has positive effects on food security and access in a majority of cases, though effects vary by socio-economic context and scale (Waha *et al*., 2022).

Key quantitative findings from the literature include: intercropping systems often achieve a land equivalent ratio (LER) >1 (higher combined yield per area than component monocultures) and can increase gross incomes substantially, and diversified farms experience lower year-to-year income variability in many contexts (Martin-Guay *et al*., 2018; Makate *et al*., 2016; Waha *et al*., 2022).

Ecosystem and agronomic benefits that support stability

Pest and disease suppression: Increased plant dive-

rsity disrupts pest life cycles, supports predators and parasitoids, and reduces monoculture-associated outbreaks (Letourneau *et al*., 2011).

Pollination services: Flowering intercrops and field margin plantings can enhance pollinator abundance and stability of pollination-dependent crops.

Soil fertility and nutrient cycling: Legume inclusion and sequence diversification reduce reliance on synthetic N and improve soil organic carbon and structure over time.

Water use and microclimate buffering: Complementary root systems and canopy structures improve water capture and reduce evaporation, stabilizing yields in variable rainfall regimes.

Biodiversity conservation: On-farm diversity contributes to genetic and species conservation, providing spillover ecological benefits at landscape scales.

Economic trade-offs and constraints

While diversification offers risk-reducing and ecological benefits, several trade-offs and constraints can limit income gains in practice:

Labour and management complexity: Diversified systems frequently require more management knowledge and labour inputs for planting, harvest scheduling, and post-harvest processing increasing operational complexity and potentially labor costs.

Market access and price risks: Producing multiple crops exposes farmers to multiple market channels; without reliable demand or value chains, diversification may not translate into higher net incomes.

Scale and mechanization challenges: Mechanized agriculture optimized for monocultures may be less compatible with intercropping or fine-scale diversity, creating barriers for large-scale commercial farmers.

Short-term yield trade-offs: Some high-diversity systems may reduce the yield of a focal cash crop (yield stability and total system output often increase, but single-crop yield can decline) this can be politically sensitive where policies reward output of particular commodities (Letourneau *et al.*, 2011).

Enabling policies, markets and institutions

To enable successful crop diversification, coordinated support is needed across several areas. Investing in market development and value chains can lower transaction costs, making diverse crops more profitable. This includes building aggregation, storage, and processing infrastructure, as well as providing market information to farmers. Strengthening extension services and farmer networks is also crucial, providing agronomic guidance on species combinations, planting patterns, pest and disease management, and post-harvest handling. Financial instruments like multi-crop insurance and credit products can reduce risk and encourage adoption. Secure land tenure and incentives that promote long-term investments, such as agroforestry, are also essential. Finally, supporting research and seed systems for adapted varieties, including legumes, cover crops, and intercrop-compatible varieties, can accelerate locally appropriate diversification.

Design principles and practical pathways for farmers

Match diversification strategy to objectives: Prioritize income stability (portfolio of cash + niche crops), soil health (legume rotations, cover crops) or ecosystem services (flowering strips, habitat) depending on farmer goals.

Start small and iterate: Introduce pilot strips or relay crops before scaling; monitor labour, pest dynamics, and market response.

Choose complementary species and temporal niches: Pair deep-rooted with shallow-rooted crops, or short-duration with long-duration crops to reduce competition and increase total output.

Integrate post-harvest planning: Ensure storage, processing or market options for each additional crop to avoid post-harvest losses and price drops.

Adopt ecosystem-supportive practices: Conservation tillage, residue retention, and habitat corridors enhance the ecological benefits of diversification.

Case studies and illustrative examples

Smallholder Zimbabwe: Makate *et al*. (2016) showed that diversified smallholders achieved higher productivity and greater resilience in face of environmental variability through mixed cropping and legume integration.

Global intercropping meta-analyses: Martin-Guay *et al*. (2018) synthesized global intercropping studies and reported mean increases in gross incomes (~33%) and land output (~38%) compared with monocultures, demonstrating large potential for sustainable intensification.

Evidence synthesis for food security: Waha *et al*. (2022) reviewed 88 studies and concluded agricultural diversity positively affected at least one food-security dimension in the majority of cases, highlighting the importance of context in determining outcomes.

Research gaps and priorities

Despite substantial progress, several important research gaps remain in advancing crop diversification as a viable pathway for enhancing farm income and agroecosystem stability. There is a need for context-specific economic evaluations that incorporate detailed farm-level cost-benefit analyses, including labor requirements, input use, market access and price dynamics across diverse agro-ecological regions. Long-term soil and ecosystem monitoring is equally critical, requiring multi-year experiments to quantify changes in soil organic carbon, nutrient cycling processes, pest and disease dynamics, and overall system resilience under diversified cropping systems. Research is also needed to develop and adapt mechanization tools and technologies compatible with diversified planting patterns, intercropping arrangements, and mixed-crop harvesting, thereby addressing scalability constraints. In addition, policy impact assessments should examine how different incentive mechanisms such as payments for ecosystem services, diversified crop insurance schemes, and subsidy reforms influence farmer adoption decisions and long-term sustainability outcomes. Finally, greater attention must be given to social and gender dimensions, particularly in understanding intra-household benefit distribution, labour allocation patterns, and equity

implications of diversification strategies, to ensure inclusive and socially sustainable agricultural transformation.

Conclusion

Crop diversification is a powerful strategy for improving farm income while enhancing agro-ecosystem stability. By integrating multiple crops through rotations, intercropping, relay systems, and agroforestry, farmers can increase land productivity, optimize resource use, and reduce vulnerability to climatic and market uncertainties. Diversified systems spread economic risk, stabilize incomes across seasons, and contribute to soil fertility improvement, better nutrient cycling, enhanced water management, and natural pest and disease regulation. Productivity gains in diversified systems arise from complementary resource use, improved soil biological activity, and reduced crop failure risk. Legume integration enhances nitrogen availability and soil organic matter, while intercropping often increases total output per unit area. In addition, diversification supports beneficial insects, pollinators and soil microbes, thereby reducing dependence on external inputs and strengthening ecological resilience. However, outcomes depend on local conditions such as market access, labour availability, farmer knowledge, and institutional support. Without reliable value chains and supportive policies, diversification may not fully translate into higher net incomes. Therefore, integrated efforts are required, including region-specific agronomic research, strengthened extension services, improved market infrastructure, and policy incentives that recognize the ecological and economic benefits of diversified farming systems.

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A Brief Discussion on Post-harvest Management and Value Addition of Chia Seeds

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Abstract

Chia (*Salvia hispanica* L.) seeds have become an important functional food ingredient worldwide because of their high content of α-linolenic acid (ALA, omega-3), dietary fibre, protein and unique mucilaginous polysaccharides. Proper post-harvest management is essential to conserve nutritional quality, prevent losses from moisture/humidity, oxidation and microbial contamination, and to maximise the value that can be recovered by primary processing and downstream value-added products (oil, defatted flour, mucilage, encapsulates, edible films, bakery inclusions, nutraceuticals). This review summarises agronomy-to-market operations affecting post-harvest quality of chia, practical handling and storage recommendations, known quality hazards and analytical markers of deterioration, and an overview of value-addition routes with their technological rationale and opportunities for circular use of processing by-products. The goal is to provide a compact, evidence-based guide for researchers, processors and extension professionals working to preserve chia seed quality and to develop high-value chia products.

Introduction

Chia seeds, traditionally cultivated in Meso-america, now have a global market driven by demand for plant-derived omega-3s, dietary fibre and functional hydrocolloids. Their small size, high oil content (≈25-35%), and mucilage-producing soluble fibre distinguish chia from many other seeds and require tailored post-harvest handling to avoid spoilage and quality loss (Ullah *et al*., 2015; Knez Hrnčič *et al*., 2019). This review focuses on (a) post-harvest operations that determine seed quality, (b) critical control points and monitoring metrics, and (c) routes for value addition and by-product utilisation.

Brief compositional and functional overview

Chia seeds contain high levels of polyunsaturated fatty acids (predominantly α-linolenic acid), appreciable protein (≈15-25%), large amounts of dietary fibre (soluble mucilage and insoluble fibre), and phenolic antioxidants (Ullah *et al*., 2015; Knez Hrnčič *et al*., 2019). The very features that make chia nutritionally valuable also make it sensitive to:

Hydrolytic and oxidative deterioration: High PUFA content is susceptible to lipid oxidation (rancidity), especially when moisture, temperature, light or pro-oxidants are present.

Physical changes: Mucilage and hydration behaviour alter technological performance in foods.

Microbial growth and mycotoxins: if moisture is not reduced adequately, storage moulds and infection

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can develop. Consequently, every post-harvest operation must aim to (i) reduce seed moisture to a safe level, (ii) avoid mechanical damage and contamination, (iii) limit exposure to oxygen/ light/ heat, and (iv) prepare seeds for targeted value-addition pathways (oil, mucilage, bakery ingredients, films, etc.) (Ullah *et al*., 2015; Knez Hrnčič *et al*., 2019).

Harvesting and primary field handling

Harvest timing: Harvest when >90% of seed set is mature but before weather events (rain/humidity) that may cause sprouting and mould. Both premature and excessively delayed harvesting reduce oil quality and yield: immature seeds have lower oil while overly delayed harvest increases risk of mould and shattering (observed in multiple agronomic studies; see Ullah *et al.,* 2015).

Methods: Chia is usually harvested by cutting the whole plant and threshing. Minimise seed exposure on wet ground and avoid mechanical abrasion that can rupture seed coats and increase free oil exposure (which accelerates oxidation).

Cleaning at source: Remove stems, stones and foreign matter; mechanical triers/air cleaners or sieves adapted to the small (≈1-2 mm) chia nutlet size are useful. Early cleaning reduces storage pests and microbial load.

Drying the critical first post-harvest control

Target moisture: Most literature and practical guidance recommend drying to 7–8% moisture (wb) for safe storage and to minimise enzymatic and microbial activity. Some studies suggest ≤7% as safer for long storage; the exact target depends on storage temperature and expected duration.

Drying methods

Sun drying: Low cost but risky in humid climates due to unpredictable rain, insect access and uneven drying.

Forced-air (mechanical) drying: A-controlled approach; set low temperatures (≤40–50 °C) and use gentle airflow to avoid overheating and loss of volatiles and antioxidants. High temperatures can cause oil oxidation and off-flavours.

Low-temperature mechanical drying or desiccant dryers: Preferred when available. Controlled drying reduces risk of fissures in seed coat.

Drying rate and quality: Rapid drying at high temperatures may produce cracks and darkening, whereas slow drying in humid conditions invites mould growth. Visual inspection (colour change), peroxide value (for oil), and water activity measure-ments are practical QC tests.

Cleaning, grading and pre-processing

Cleaning: After drying, perform secondary cleaning (aspiration, sieving, density separation) to remove broken seeds and contaminants.

Grading: Size and density grading helps create uniform lots for processing (oil extraction vs. whole-seed sales). Remove immature or discoloured seeds these can concentrate moisture and defectively influence quality.

Dehulling: Chia seeds have a thin seed coat and may be sold whole or ground. Dehulling is not widely used industrially because chia's nutrition resides

largely in the whole seed and dehulling can reduce yield and alter mucilage characteristics; where dehulling is applied, gentle abrasion and careful screening are necessary to avoid kernel breakage.

Storage environmental controls and packaging

Atmosphere and temperature: Storage cool (≤20 °C) and dry (RH < 65%) conditions significantly slow lipid oxidation and microbial growth. Lower temperatures (refrigeration) further extend shelf life of chia oil-rich products but increase cost.

Moisture control: Use moisture-proof packaging for long storage. If stored in bulk, monitor moisture and aerate to avoid hot spots. Silos and bins must be clean and equipped for controlled aeration.

Packaging: For retail, barrier packaging with oxygen scavengers or nitrogen flushing preserves oil quality. Food-grade vacuum pouches, multi-layer laminates, or glass containers work well. For smallholder storage, clean jute or woven bags may be acceptable short-term if kept dry and elevated from floor moisture.

Shelf life markers: Monitor peroxide value, free fatty acid (FFA), sensory (rancid odour), and moisture content. Because chia oil is PUFA-rich, even whole seeds can show oxidative deterioration in months under poor storage; therefore, recommended shelf life varies with storage conditions and packaging.

Quality hazards and control strategies

Lipid oxidation: Control by limiting oxygen, light, heat; incorporate antioxidants (natural tocopherols) or use inert atmosphere packaging for oil/seed lots intended for longer storage.

Microbial growth and mycotoxins: Maintain low moisture and adequate cleaning; mycotoxin incidence is not widely reported in chia, but humid harvesting conditions have led to mould problems in some reports so preventive drying is essential (Ullah *et al*., 2015).

Pest infestation: Stored-product insects are a risk for seeds. Good sanitation, sealed packaging, and periodic monitoring (traps, sampling) are advised. Use integrated pest management (IPM) for storage (sanitation, temperature control, controlled atmosphere).

Mechanical damage: Avoid excessive abrasion in processing and transport; broken seeds release oil and increase oxidation risk.

Primary processing and value-addition routes

Chia seeds can be marketed as whole seed, milled flour, oil, mucilage, or processed into higher-value formulations. Key routes follow.

Cold-pressed and solvent/oil extraction

Methods: Cold pressing is widely used to obtain chia oil with acceptable sensory and nutritional profile; solvent extraction or Soxhlet gives higher yields but raises solvent-residue and oxidation concerns. Supercritical CO_2 extraction and subcritical propane/propane-based methods achieve high yields and cleaner extracts with better preservation of labile compounds (Knez Hrnčič *et al*., 2019).

Quality and stability: Because chia oil is rich in ALA, oxidative stability is low; consider refining, antioxidant addition, low-temperature storage, and

dark/oxygen-barrier packaging. Fractionation (to concentrate omega-3s), microencapsulation and blending with more stable oils are used to improve functional shelf life (Knez Hrnčič *et al*., 2019).

Applications: Nutraceutical omega-3 supplements, culinary oils (with caveats), functional food enrichment.

Defatted chia flour (by-product)

After oil extraction the defatted meal is protein- and fibre-rich and useful as:

- ✓ High-fibre functional flour in bakery and meat formulations.
- ✓ Protein ingredient for plant-based formulations.
- ✓ Substrate for edible film and biodegradable packaging (Muñoz-Tebar *et al*., 2021).

Muñoz-Tebar *et al*. demonstrated that mucilage from defatted flour yields higher extraction yield and produced films with favourable mechanical properties a promising route for circular valorisation of oil-extraction by-products (Muñoz-Tebar *et al*., 2021).

Mucilage extraction and applications

Extraction: Mucilage is obtained by hydrating chia nutlets in water, filtering and drying the gel. Extraction yields depend on pre-treatment and whether defatted flour is used (higher yield from defatted material) (Muñoz-Tebar *et al*., 2021).

Functional uses: Chia mucilage is an excellent hydrocolloid acting as a fat replacer, stabilizer, emulsifier and texture modifier. In bakery, mucilage can replace partial fat and emulsifiers without severely compromising sensory quality (Fernandes *et al*., 2017). Other uses: ice cream stabiliser, egg replacer in vegan formulations, viscosity agent in sauces, and wall material for encapsulation.

Bakery and food inclusions

Chia seeds (whole or ground), mucilage and defatted flour can be incorporated into breads, cakes, biscuits, cereal bars and pastas to enhance dietary fibre, omega-3 content and water retention. Fernandes *et al*. demonstrated that chia mucilage can replace significant portions of fat in breads and cakes with acceptable sensorial outcomes (Fernandes and Salas-Mellado, 2017).

Edible films and coatings

Edible films made from chia mucilage or defatted-flour mucilage can serve as biodegradable packaging and active coatings (e.g., carriers for antioxidants/antimicrobials), addressing both food preservation and sustainability (Muñoz-Tebar *et al*., 2021).

Encapsulation and delivery of chia oil

Microencapsulation (spray-drying, complex coacervation) or nanoemulsions (mucilage-stabilised) protect ALA-rich oil from oxidation and improve incorporation into aqueous foods. While microencapsulation of chia oil is already in research and some pilot applications, continued development is needed to reconcile oxidative stability with cost and scale (Knez Hrnčič *et al*., 2019).

Analytical monitoring and quality testing

For processors and quality labs, recommended routine tests include:

Moisture content / water activity: To ensure safe

storage (target ~7-8% moisture depending on temp and RH).

Peroxide value and anisidine value: To monitor primary and secondary oxidation products.

Free fatty acids (FFA): as an indicator of hydrolytic rancidity.

Fatty acid profile (GC): To verify ALA content and detect unusual degradations.

Microbiological tests: Mould counts when moisture risk is present.

Sensory evaluation: Rancid odour/taste detection.

Physical properties: Particle size, bulk density, and seed microstructure (for dehulling/grinding optimization).

Small-scale and value chain considerations (sustainability, economics)

Smallholders: low-cost, low-tech options (sun-drying followed by prompt sale to processors) are common; however, training in rapid, hygienic drying and clean bags can prevent losses.

Industrial processors: investing in controlled mechanical drying, closed cold-pressing lines and proper packaging provides premium oil and by-products suitable for export and nutraceutical markets.

Circular economy: integrate oil extraction, mucilage recovery and film formation to maximise value and reduce waste (Muñoz-Tebar *et al.,* 2021).

Regulatory and labelling: Ensure claims about omega-3 content meet local nutraceutical/food additive regulations; follow permitted extraction solvents and food safety standards.

Research gaps and future directions

Future research on post-harvest management and value addition of chia seeds should prioritise the development of cost-effective oxidative stabilization technologies specifically tailored for α-linolenic acid (ALA)-rich chia oil, including the optimization of natural antioxidants, advanced packaging systems, and micro- or nano-encapsulation approaches to enhance shelf stability without compromising nutritional quality. There is also a pressing need for large-scale, pilot-to-industrial validation studies on mucilage extraction processes that effectively balance extraction yield, functional performance, and economic feasibility, particularly for commercial applications in food and biodegradable packaging sectors. Shelf-life modelling of whole chia seeds under tropical and subtropical storage conditions, which are common in many developing-country production regions, is essential to generate predictive tools for quality deterioration and risk assessment. Comprehensive value-chain analyses quantifying production costs, processing efficiencies, by-product utilization, and economic returns for integrated oil–mucilage-film production systems would further clarify the commercial viability of such circular models for small and medium enterprises. Additionally, more in-depth investigations are required to understand how different processing techniques-such as grinding, thermal treatment, oil extraction, and extrusion affect the bioavailability and bioaccessibility of chia-derived nutrients, particularly α-linolenic acid and phenolic compounds, to

ensure that technological modifications do not compromise the functional health benefits associated with chia consumption.

Practical recommendations: For effective post-harvest management and value addition of chia seeds, harvesting should be carried out at full physiological maturity but prior to exposure to wet weather conditions, followed by rapid threshing and cleaning to minimize contamination and quality deterioration. Seeds must be dried promptly to approximately 7% moisture content (not exceeding 8%) using controlled mechanical drying wherever possible to ensure uniform moisture reduction and prevent microbial growth. During storage, chia seeds should be kept in cool, dry, and dark environments, preferably in oxygen-barrier packaging materials to limit oxidative rancidity, particularly for oil and ground products that are highly susceptible to lipid oxidation. In oil processing, cold pressing is recommended for food-grade markets, while supercritical or subcritical extraction techniques may be adopted for obtaining higher-quality extracts; in all cases, extracted oil should be immediately protected from light, oxygen, and heat, and antioxidant strategies may be employed to enhance shelf stability. Additionally, processors should valorize by-products such as mucilage and defatted flour for applications in bakery formulations and biodegradable edible films, thereby increasing economic returns and reducing processing waste. Routine quality control measures including monitor-ing moisture content, peroxide value, free fatty acids (FFA), and sensory attributes should be system-atically implemented to ensure product safety, stability and market acceptability.

Conclusion

Chia seeds are nutritionally valuable but fragile from a post-harvest perspective because of their high PUFA and mucilage content. Sound drying, cleaning, storage and processing choices preserve quality and open diverse value-addition opportunities from cold-pressed oils and nutraceuticals to mucilage-based fat replacers and biodegradable films. Integrated approaches that combine good post-harvest practices with circular utilisation of by-products (defatted flour, mucilage) promise both improved profitability and sustainability.

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Biodegradable Mulches for Weed Control and Soil Health Management

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Abstract

Biodegradable mulches (BDMs) are increasingly promoted as an environmentally preferable alternative to conventional polyethylene (PE) mulch films in specialty and horticultural cropping systems. They aim to deliver the agronomic benefits of plastic mulches (weed suppression, soil moisture conservation, soil temperature modification, improved crop yields) while avoiding post-season removal and accumulation of persistent plastic residues in soil. This review synthesizes current knowledge on BDM chemistry and types, mechanisms and rates of degradation, efficacy for weed control, impacts on soil physical-chemical-biological properties, environmental fate (including micro- and nano-scale residues), economic and practical considerations, regulatory and standards issues, and research needs. Emphasis is placed on comparing BDMs with conventional PE mulches, highlighting trade-offs (performance vs. environmental risk) and identifying where evidence is robust versus where long-term data are lacking. Practical recommendations for growers, researchers, and policymakers are provided at the end.

Introduction

Plastic mulches have been used for decades to suppress weeds, retain soil moisture, and warm soils, thereby improving crop establishment and yields. Because conventional PE mulches are persistent, removal and disposal pose environmental and economic burdens and lead to soil accumulation of plastic fragments. Biodegradable mulches (BDMs) films manufactured from biodegradable polymers or polymer blends designed to biodegrade in-field after incorporation promise to reduce post-harvest waste and soil plastic accumulation while providing similar agronomic benefits. This review evaluates the literature on BDM performance for weed control and their implications for soil health, drawing on lab, field, and modeling studies.

Types and formulations of biodegradable mulches

BDMs are diverse in chemistry and source. Major classes include:

Biobased polyesters and polyhydroxyalkanoates (PHAs): Poly(lactic acid) (PLA), polyhydroxy-butyrate (PHB) and related PHAs typically derived from fermentation products.

Aliphatic and aliphatic-aromatic copolyesters: Poly(butylene adipate-co-terephthalate) (PBAT), poly(butylene succinate) (PBS), PBAT/PBS blends, often combined with starch or other additives to tune properties.

Thermoplastic starch and starch-based blends: formulations with high biodegradability but often reduced mechanical performance.

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Cellulose- and paper-based mulches: Fully cellulosic paper mulch (kraft paper) or reed/composite paper mulches intrinsically readily biodegradable.

Composite blends and additive packages: Many commercial BDMs are blends (e.g., PBAT + PLA + starch) and include plasticizers, fillers, UV stabilizers, pigments and other additives to obtain desired tensile strength, flexibility, and field longevity.

Material selection determines mechanical properties, UV and hydrolytic stability, and biodegradability under soil conditions.

Mechanisms and rates of degradation

BDM breakdown occurs by two (overlapping) processes:

Abiotic fragmentation (photodegradation, hydrolysis, thermal ageing): Sunlight, temperature, and moisture create cracks and increase surface area.

Biotic biodegradation: Soil microbes (bacteria, fungi) secrete depolymerases, cutinases, esterases and other hydrolases that cleave ester or glycosidic bonds to yield oligomers and monomers which are mineralized to CO_2, water and biomass.

Degradation rates depend strongly on polymer chemistry (ester linkages degrade more readily), film crystallinity, thickness, presence of fillers or coatings, soil temperature, moisture, microbial community, and agricultural practices (tilling, residue incorporation). Some polyesters such as PBAT are enzymatically degradable, and recent biotechnological advances demonstrate efficient PBAT-degrading enzymes in lab settings (complete PBAT film decomposition in controlled enzyme treatments within days-weeks), although field rates are typically much slower and highly variable (temperature- and moisture-limited) (Yang *et al*., 2023).

Weed control efficacy - agronomic performance

BDMs serve as an opaque physical barrier (like PE) and therefore suppress weed emergence by:

- ✓ Blocking light at the soil surface (preventing weed germination),
- ✓ Reducing soil disturbance and thereby limiting weed recruitment,
- ✓ Increasing soil temperature and moisture that favour crop competitiveness over weeds.

Field comparisons typically show that well-installed BDMs provide weed suppression comparable to PE mulches during the cropping season. However, mechanical integrity matters: BDMs that fragment prematurely (e.g., under high UV or mechanical stress) may lose continuous coverage and allow weed escape patches. Performance is therefore linked to the service lifetime of the mulch the period during the crop cycle when the film remains intact and covers the soil surface. Many modern BDMs are engineered to provide 1 growing season of coverage and then degrade after incorporation, but variability exists by climate and formulation (Campanale *et al*., 2024).

Impacts on soil physical and chemical properties

As surface barriers, both BDMs and PE mulches affect soil microclimate (temperature, moisture, evaporation), aggregate stability, and gas

exchange. Reported effects include:

Soil moisture: Mulches reduce evaporation and often increase available water, improving water-use efficiency.

Soil temperature: Mulches raise topsoil temperature; magnitude differs between PE (often higher) and BDMs (depending on color/transmissivity).

Soil structure/aggregate stability: Increased moisture and altered wet–dry cycles under mulches can change aggregation; long-term impacts depend on residue accumulation and management.

Soil organic matter (SOM) and nutrient cycling: tilled-in BDM residues represent a small carbon input but can stimulate microbial activity and alter SOM dynamics. Evidence of SOM increase or decrease is mixed and likely context- and time-dependent. (Bandopadhyay *et al*., 2018).

Impacts on soil biological communities and functions

BDMs can influence soil biology in two ways: indirectly (microclimate effects while mulches are in place) and directly (addition of polymer fragments and additives after incorporation). Key findings:

Microbial activity: Several studies report enhanced microbial respiration and enzyme activity following BDM incorporation possibly a priming response to a novel organic substrate whereas other studies show little change. Taxonomic shifts (e.g., fungal enrichment) have been observed in some systems. (Bandopadhyay *et al*., 2018).

Community composition: Compositional shifts have been documented; however, direction and magnitude are inconsistent across studies, reflecting differences in polymer type, climate, soil background, and study duration.

Invertebrates and soil fauna: Effects are poorly resolved; some reports indicate reduced surface invertebrate activity under mulches, whereas incorporation of fragments may affect detritivore interactions.

Ecosystem functioning: The potential for altered C and N cycling exists (through stimulated decomposition or altered mineralization rates), but robust long-term field data are limited (most studies cover 1-3 seasons).

Environmental fate: fragments, micro-bioplastics and additives

BDMs are designed to mineralize, but field evidence reveals complex realities:

Incomplete degradation and fragments: Fragmentation can produce micro- and potentially nano-scale polymer particles (commonly termed micro-bioplastics). The rate of formation and persistence depends on polymer type and environmental conditions. Residual fragments may affect soil physical properties (e.g., infiltration) and interact with soil biota. (Campanale *et al*., 2024).

Chemical additives and leachates: Pigments, stabilizers, plasticizers and other additives may be released during fragmentation or biodegradation; their identity, concentrations in commercial films, and ecological effects are not always well-documented.

Potential pollutant carrier role: (Bio)plastic fragments can sorb pesticides, heavy metals, and organic pollutants, potentially altering their mobility and bioavailability in soils.

Biodegradation end-products: Enzymatic hydrolysis of polyesters can yield monomers (e.g., terephthalic acid from PBAT) that may be further metabolized or persist locally; recent enzyme engineering demonstrates pathways to fully depolymerize PBAT with recovery of monomers (Yang *et al*., 2023).

Comparative life-cycle and sustainability assessments

Life-cycle assessments (LCAs) comparing BDMs and PE mulches show trade-offs. BDMs reduce end-of-life waste and the need for manual film removal and disposal, but may have higher upstream environmental costs depending on feedstock and manufacturing processes. LCAs also highlight the sensitivity of outcomes to assumptions about in-soil biodegradation completeness and potential ecological impacts of residual fragments critical uncertainties that can sway the LCA results. (Campanale *et al*., 2024).

Standards, certification, and regulatory context

A central challenge is standardized testing and certification for soil biodegradability. Many existing standards (e.g., ASTM D6400) were developed for industrial composting and do not reflect typical agricultural soil conditions. Newer standards and guidelines specific to agricultural/soil environments (e.g., EN 17033 for biodegradable mulch films) aim to set biodegradation thresholds (for example, 90% degradation in soil within a specified temperature range/time), but field variability complicates universal requirements. Regulators and certifiers remain cautious because incomplete degradation could still lead to soil contamination.

Practical considerations for growers

Practical considerations for growers using biodegradable mulch films (BDMs) require a systems-based approach that integrates product selection, field management, soil conditions, and regulatory compliance. Growers should first select BDM formulations with a proven in-field service life that matches the crop duration and prevailing climatic conditions to ensure consistent weed suppression and crop performance throughout the growing season. Proper installation is equally critical: adequate film tensioning, correct bed preparation, sufficient edge burial, appropriate overlap between sheets, and effective row covering minimize mechanical stress and premature tearing, thereby maintaining mulch integrity. Post-harvest management is also essential, as timely incorporation of mulch residues into the soil through tillage enhances microbial contact and accelerates biodegradation. Soil type and climate strongly influence degradation rates; warm, moist soils with high microbial activity generally support faster breakdown, whereas cooler or drier environments may slow degradation and increase the risk of residual fragment accumulation. Continuous field monitoring during and after the

cropping cycle is advisable to assess mulch integrity, fragmentation patterns, and potential residue persistence in soil. Finally, growers operating within certified organic systems must carefully verify product compliance, as many BDMs may not be permitted due to their feedstock origin, polymer composition, or additive content; therefore, confirmation with certification bodies prior to adoption is necessary to avoid regulatory complications.

Knowledge gaps and research needs

Despite the expanding literature on biodegradable mulch films (BDMs), several important scientific and practical gaps remain that must be addressed to ensure their safe and sustainable adoption. There is a clear need for long-term, multi-year and multi-location field studies to assess residual fragment accumulation, impacts on soil physicochemical and biological properties, crop productivity, and greenhouse gas emissions under varied agro-ecological conditions, as most existing studies are short-term and geographically restricted (Bandopadhyay et al., 2018). Standardized, soil-relevant testing frameworks are also lacking; although laboratory biodegradation tests are available, certification benchmarks must better reflect real agricultural environments characterized by variable temperature, moisture, and tillage practices (Sintim and Flury, 2017). Ecotoxicological uncertainties persist regarding the identity, fate, bioavailability, and chronic effects of additives and micro-bioplastic fragments formed during degradation, highlighting the need for environmentally realistic exposure and long-term ecological assessments (Campanale *et al.*, 2024). Furthermore, mechanistic understanding of soil microbial communities and enzymes responsible for polymer depolymerization under field conditions remains incomplete; identifying key taxa and environmental drivers could support improved mulch design and management strategies (Yang *et al.*, 2023). Finally, greater emphasis is required on socioeconomic analyses, including cost-benefit evaluations, adoption barriers, farmer perceptions, and policy incentives, which ultimately shape large-scale implementation and sustainability of BDM technologies.

Recommendations - research, policy and practice

Sustainable adoption of biodegradable mulch films (BDMs) requires coordinated efforts among researchers, industry, policymakers, and growers. Researchers should prioritize multi-season, replicated field trials across diverse climates and soil types, integrating agronomic performance, soil health indicators, microbial dynamics, and degradation pathways to generate robust long-term evidence. Industry must ensure transparency by disclosing additive compositions and providing independently verified, soil-relevant degradation data. Films should be designed with predictable service lifetimes aligned to crop cycles, while feedstock and manufacturing choices should minimize upstream environmental impacts. Policymakers should adopt soil-specific biodegradability standards (such as EN 17033-type protocols), mandate clear labelling, and

promote long-term monitoring of soil residues where BDMs are widely used. Growers should rely on independent performance data from similar agro-climatic regions, incorporate mulch residues promptly after the season, and integrate BDMs within broader Integrated Weed Management strategies to enhance overall system sustainability.

Conclusion

BDMs offer a promising pathway to retain the agronomic benefits of plastic mulches while reducing the labour and environmental costs associated with persistent PE mulch removal and disposal. However, benefits are contingent on reliable in-field performance (weed control and durability) and predictable, complete biodegradation under diverse agroecosystems. Current evidence points to generally comparable short-term weed control and crop benefits but shows variable degradation behaviour and uncertain long-term soil ecological impacts. Addressing standardization, transparency of additives, long-term ecological monitoring, and mechanistic understanding of bio-degradation are essential to responsibly scale BDM use.

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Breeding Rice for Abiotic Stress Tolerance under Climate Change

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Abstract

Abiotic stresses such as drought, flooding, salinity and heat are exacerbated by climate change, providing threat to India rice production, which is essential to 1.4 billion people, due to the estimated losses of 10-15% of the yield by 2030, particularly in the vulnerable fields of Bihar. Rice sensitivity to critical developmental stages, conventional breeding using landraces such as Nagina-22, and advanced technology such as marker-assisted selection (Sub1 gene), genomic selection, CRISPR-Cas9 and gene pyramiding to multi-stress tolerance. Success stories mention varieties such as Swarna-Sub1 (resistant to floods), CR Dhan 804 (drought-flood) and Sahbhagi Dhan (drought-heat) that were implemented at the national level through IRRI-ICAR partnerships and increased the yield of the stressed regions by 20-30%. Combining them with climate-smart practices should provide hope on the resilient farming; encourages farmers, researchers and policymakers to implement and innovate to ensure food security.

Introduction

Rice is not just a food, it is the life blood of India and it feeds half a billion people covering 44 million hectares of huge fields. However, climate change is changing the scorecard: years of droughts burn root, torrents flood fields, salt sea water spreads into coastal fields, and heat waves sterilized grains. In the state of Bihar alone, 2024 floods destroyed 15 % of *kharif* rice, and frequent droughts in the uplands reduced the yields of several farmers by half. Rice, unlike other crops, is very sensitive to environmental variations, particularly the adverse ones that occur during these important growth periods as flowering and filling of grain. Even a couple of degrees of rise in temperature at night may severely decrease the quality of grain. On the same note, even an unexpected flooding of up to one week can destroy whole fields. These abiotic stresses -these are the cruel environmental hits in the absence of pests or diseases pose the threat to reduce national production of rice by 10-15 % by 2030. However, breeding laboratories have brought hope: researchers create breeds that laugh at these dangers and provide uninterrupted harvests despite the anarchy.

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Climate change is no longer an eventuality, but it is a current reality. Thus, it is important to create rice varieties that can resist abiotic stress in order to guarantee food security in the world.

Climate Threats to Rice Field

Drought Stress: Drought occurs when soil moisture becomes insufficient to meet plant water requirements. In rainfed rice, drought is one of the most destructive stresses. It affects the crop like

- ✓ Germination and seedling establishment
- ✓ Tillering and vegetative growth
- ✓ Flowering and grain filling

Submergence and Flooding: Flooding is common in lowland rice areas. However, complete submergence for more than 7-14 days can cause plant death due to oxygen deficiency. Floods have become more frequent due to unpredictable rainfall patterns.

Heat Stress: High temperature stress, particularly during flowering causes spikelet sterility. Night temperatures above 24-26°C can drastically reduce grain quality. Heat stress:

- ✓ Shortens grain filling duration
- ✓ Reduces grain weight
- ✓ Affects pollen viability

Salinity Stress: Salinity is a major problem in coastal regions and irrigated lands with poor drainage. Excess Na^+ ions disrupt nutrient uptake and cause:

- ✓ Poor seedling establishment
- ✓ Leaf chlorosis
- ✓ Reduced root growth
- ✓ Yield reduction

Stress Type	Mechanism of Damage	Bihar/India Hotspots	Typical Yield Loss
Drought	Root dehydration, fewer tillers	Uplands (Bihar, MH)	20-40%
Salinity (EC >4 dS m^{-1})	Ion buildup, stunted growth	Coastal (OD, Gujarat)	15-30%
Submergence	Anoxia, elongation waste	Gangetic plains (Bihar, UP)	30-60%
Heat	Pollen kill at >35°C	Plains during grain fill	10-50%

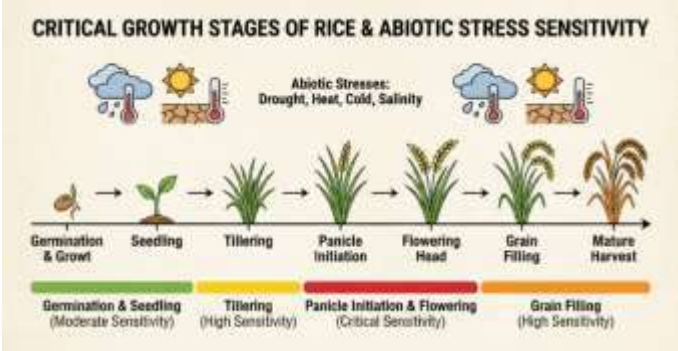


Fig. 1: Different Stages of Rice affected by the Abiotic Stress

Traditional Breeding Approaches

At the beginning of molecular tools, breeders were using traditional methods:

Selection from Landraces: Stress-tolerant landraces were historically preserved by the farmers. These traditional varieties were used to select the promising lines by the breeders.

Hybridization: Crossing of donor which is tolerant and high yielding varieties helps in transferring of the desired characteristics.

Backcross Breeding: Crossing with elite parents repeatedly assists in reviving good agronomic qualities and stress tolerance.

Limitations

- ✓ Time consuming (8-10 years)
- ✓ Traits are strongly affected by the environment
- ✓ Impairment in the choice of multivariate charac-

teristics such as drought-tolerance

Regardless of the constraints, the traditional breeding provided the basis for improving stress-resistant rice. It was scaled by science, and started with breeding where farmers selected difficult plants. Cross a high yield elite such as Swarna with a survivor such as Nagina-22 (drought landrace), cultivate thousands of plots under stress, dry beds, saline, flood basins and select winners in 10-12 years /generations.

Molecular Breeding and Modern Tools

Breeding has been accelerated in modern biotechnology on rice. Following are the methods:

Marker-Assisted Selection (MAS): MAS involves the use of DNA markers associated with genes of stress tolerance. Breeders are able to identify desirable genes early in the breeding at the seedling stage instead of waiting to occur in a manifestation. This makes it more accurate and shortens the breeding period.

QTL Mapping: Quantitative Trait Loci (QTLs) are the genomic regions that have been identified with complex traits like drought tolerance. QTLs are also used to identify the genetic makeup of stress tolerance and thus the breeder has a clear picture of how this occurs.

Gene Pyramiding: A combination of various stress tolerance genes into one type improves durability as well as performance in various conditions of stress.

Genomic Selection: This is an approach whereby the best lines are selected using whole-genome prediction models. It is particularly practical in cases of complicated traits that are governed by a lot of genes.

Genetic Modification (GM): GM rice is the insertion of genes into the others. As an example, scientists have introduced rice with bacterial genes to increase its value in terms of resistant to salinity so that plants can lose surplus sodium. GM approaches have been promising in laboratory experiments, with certain ones such as those that express the AtNHX1 gene demonstrating enhanced production in salty soils by 20-30%.

CRISPR-Cas9 Gene Editing: It is a ground-breaking technology that resembles molecular scissors and can cut rice genes. Indicatively, the introduction of a heat-tolerant line has been developed by editing OsERA1 gene and can be fertilized up to 35 ^{o} C. In contrast to GM, CRISPR does not always add foreign DNA, and thus it is more regulatorily acceptable.

Genes and Varieties Developed

Submergence Tolerance: The Sub1 gene was found and it transformed flood resistance rice breeding. It has been added to varieties like: Swarna-Sub1, IR64-Sub1. These types can endure two weeks of total submergence.

Drought Tolerance: Sahbhagi Dhan, DRR Dhan 42. These breeds have superior root structure and greater water-use efficiency.

Salinity Tolerance: Salt tolerant varieties are more stable with regard to ion balance during saline conditions. The resulting better varieties have assisted farmers in terms of decreasing the losses in

yields in the unfavorable environments.

Success Stories: From Lab to Field

Winning in real life demonstrates breeding. In India, flood resistant CR Dhan 801 has reshaped the Bihar floodplains where farmers used to lose 70 per cent of their crop. CR Dhan 804 (drought-flood): 2 t ha^{-1} Bihar rainfed; Sahbhagi Dhan (drought-heat): 25% gain central India. CR Dhan 801 (submergence-drought, 6.3 t ha^{-1}); Luna Suvarna (saline, 3.5-4 t ha^{-1}); CR Dhan 808 (water-scarce, Odisha-Bihar) and 2024.

Farmer testamentary statement by Patna KVK: CR Dhan 212 provided 4 t ha^{-1} aerobic at dry periods, varieties (2024 Gazette) now extend to Punjab to Tamil Nadu, bioenriched as Sabour Vijay Dhan (zinc-rich aerobic).

These achievements include collaborations: governments, NGOs and commercial companies are working with farmers to do on-ground testing. Community seed banks assure access, which puts women farmers in power, who contribute to rice farming in Asia in most cases.

Variety	Stresses Handled	Adoption (States)
Swarna-Sub1	Flood (15-17 days)	Bihar, Odisha, UP
CR Dhan 804	Drought + Flood History	Bihar, Jharkhand
Sahbhagi Dhan	Drought + Heat	MH, Odisha
DRR Dhan 75	Improved BPT 5204, general History	Nationwide
CR Dhan 807	Drought, herbicide-tolerant History	DSR systems

Combining Breeding and Climate-Smart Agriculture

It must be integrated with:

- ✓ Efficient irrigation systems
- ✓ Use of biofertilizers
- ✓ Soil health management
- ✓ Crop diversification
- ✓ Farmer participatory breeding

Breeding difficulties in Abiotic Stress

- ✓ Complex genetic control of stress traits
- ✓ Genotype × Environment interaction
- ✓ Multiple simultaneous stresses (heat + drought)
- ✓ Limited phenotyping facilities
- ✓ Adoption constraints among farmers

Conclusion

Rice production in the world faces a grave risk of climate change. Abiotic stresses include drought, flooding, heat, and salinity which are increasing in intensity and frequency. Conventional breeding has offered a solid foundation whereas molecular tools and technology of genome editing are speeding up the creation of stress resistant breeds. The future of rice is in a combination of traditional breeding, advanced biotechnology and climate-sensitive agricultural ways. Climate resistant rice is not just the product of science but the need to provide the future generation with food security.

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Role of Social Media in Disseminating Agricultural Information

Rheecha and Suraj Kumar

Abstract

India has had a revolution in the agricultural information dissemination as the use of social media has filled the long-standing gaps in traditional extension services to over 146 million farming households. Evolution through platforms such as WhatsApp, YouTube, and Facebook (where 70-80% of rural smartphone users now get real-time pest, weather, and market information) and features case studies of the fields in Bihar and Odisha, where 15-100% of the yield has shot up through the use of peer learning and visual aids on *Trichoderma* and IPM. Even with some of these challenges such as digital divides, misinformation, and literacy issues, empirical evidence indicated by Krishi Updates and Digital Green shows an increase in productivity, market connections, and empowerment of marginal farmers. The principles used to set up policy recommendations consist of infrastructure through BharatNet 5G, PMGDISHA literacy of 10 crore farmers, verified AI-moderated channels, and hybrid integration with Kisan Call Centers to allow inclusivity and sustainable scaling.

Introduction

The Indian economy is largely dependent on agriculture with more than 50% of the population depending on this sector. However, over generations, Indian farmers have been struggling with a challenge, which is access to timely, reliable and regionally relevant information. Although of value, traditional extension systems have been stretched over the years by the sheer size of the farming community in India, more than 146 million agricultural households dispersed over a wide variety of agro-ecological areas. Into this gap has stepped an unlikely solution shows that the same social media platforms that bring friends and families together have gently radicalised, bringing knowledge on agriculture to a flow across the subcontinent. Even LinkedIn, WhatsApp, YouTube and Facebook have become a surprise in the information arsenal of the farmer. By 2025, smartphone penetration in rural India reached 70-80%, with farmers using these tools for real-time queries on pests, weather, and prices.

Indian studies have been conducted recently to investigate the role of social media in information dissemination in agriculture. It uses research on the wheat fields in Bihar and the vegetable gardens of Odisha, the food bowl of Uttarakhand and the mountain farms of Himachal to understand how digital platforms are transforming the knowledge creators, recipients and beneficiaries in agriculture.

Evolution and Popular Platforms

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The incorporation of social media into agriculture started in the early 2010s blogs and development into current ecosystems of videos. YouTube is winning with the *Trichoderma* applications and hybrid rice breeding tutorials earning it billions of views every year. Techno helps farmers (60-70% of the population) use WhatsApp groups to send disease photos immediately, so that they can be diagnosed. Instagram and Facebook can be used in marketing, where live sessions will be established between growers in Patna and buyers in the urban setting. Twitter (X) contributes to policy advocacy, which has been the case in the case of the campaign #FarmersProtest. Adoption in India increased after COVID lockdowns in 2020 with 40-50% of young farmers working every day.

Landscape of Social Media Adoption in Indian Agriculture

Access and Patterns of penetration: A study of commercial vegetable growers in the Khordha and Puri districts of Odisha in 2024 is insightful and gives information on the socioeconomic profile of users of social media like farmers. The analysis of 90 respondents showed that most of them (56.67%) were middle-aged and 60% of the respondents lived in families of less than five people. The marginal landholders with an annual income of between 50,000 and 100,000 comprised 40% of the population of farmers, and most farmers (55.56%) had less than 2.5 acres of land. Importantly, 90% farmers were characterized by medium access to social media. This result contradicts the beliefs that only the rich or large-scale farmers are using social media- marginal farmers are using digital channels. Nevertheless, access is not even all over.

Platform Preferences and Usage Patterns: There are several platforms used by Indian farmers depending on their purposes. According to Krishi Updates, the online agricultural project, the best form of information distribution was to post information in Facebook, YouTube and LinkedIn and then to distribute it in communities of practice.

Social Media as a Tool for Agricultural Extension

Real Time Information Sharing

Social media enables rapid dissemination of information related to:

- ✓ Weather updates and climate advisories
- ✓ Pest and disease outbreaks
- ✓ Government subsidy schemes
- ✓ Market price fluctuations

Visual and Interactive Learning

Platforms like YouTube and Instagram provide visual demonstrations of:

- ✓ Improved cultivation practices
- ✓ Integrated Pest Management (IPM)
- ✓ Organic farming techniques
- ✓ Post harvest management

Peer to Peer Knowledge Exchange

Social media groups create virtual farming communities. Farmers share field experiences, innovative practices, and local solutions. This participatory approach strengthens informal learning networks and builds social capital.

Market Linkages and Agribusiness Promotion

Social media helps farmers connect directly with:

- ✓ Consumers
- ✓ Traders
- ✓ Input suppliers
- ✓ Agri-startups



Figure 1: Benefits of Social Media in Agriculture

Case Studies from India

WhatsApp as Extension Tool: In Indian studies, use of WhatsApp to disseminate wheat agronomy videos to farmers by extension workers in Bihar. Use of chat applications has power and limitations in agricultural extension. On the one hand, WhatsApp has facilitated a very effective video exchange with farmers that have been identified by the extension workers. The site was characterized as an inorganic addition to local Bihar cultures, such as the use of breakfast tea that had become so ingrained in the everyday practice of the test village that the use of the system as a source of agricultural information seemed more natural. But, interviewed extension workers were concerned in earnest. Videos shared on WhatsApp, they observed, enabled limited social inclusivity (to those who had already existed contacts), limited two-way communication, and, therefore, limited localisation of the farming advice.

Krishi Updates: Digital Agriculture Model

The best-organized attempt to use social media to benefit Indian agriculture is the Krishi Updates, an online extension service offering information, specific to the region, based on scientific research to farmers. Most farmers were contented with Krishi Updates dissemination model. More importantly, 90% of the farmers said they would recommend Krishi Updates to other farmers so that they would create a positive change in their communities. This great recommendation of the users themselves is a testimony to the efficacy of the model.

Single Changemakers: The Digital Revolution of Dr Madina Prasadarao

Outside the institutional efforts, social media has reached an amazing scale in the hands of individual agricultural professionals. Dr Madina Prasadarao, a veterinary practitioner who was an Assistant Director in the Animal Husbandry Department in Visakhapatnam has been able to create more than 350 YouTube videos, which have informed 40,000 farmers on the advanced farming techniques of livestock. Realizing the constraints of outreach in the COVID-19 pandemic, Dr Prasadarao started doing filmmaking and video shots. His online tools address important topics: preventive care of a disease, livestock hygiene, and the opportunity of accessing government programs. He is also a provider of free telemedicine services, answering more than 100 inquiries of farmers daily via Whats App. He has been acknowledged by being awarded

2023 Best Field Extension Officer of the south region.

Institutional Recognition: Chamba KVK Digital Outreach

India has now officially acknowledged the significance of social media in agricultural extension as its leading agricultural institutions have been officially acknowledged. Chamba, Krishi Vigyan Kendra (KVK), Himachal Pradesh was the winner of the Best Institution in the category of social media outreach among 72 KVKs of Zone-I (including Himachal Pradesh, Punjab, Uttarakhand, Jammu & Kashmir, and Ladakh) at the ICAR-ATARI Annual Zonal Workshop-2025.

Challenges and Limitations

Despite its advantages, social media in agriculture faces several constraints:

Digital divide: Limited internet access in rural areas.

Low digital literacy: Many farmers may not effectively use digital tools.

Misinformation: Unverified or misleading agricultural advice can spread rapidly.

Language barriers: Content may not always be available in local languages.

Data privacy concerns: Misuse of personal or farm-related information.

Policy Strategies and Recommendations

Infrastructure Enhancements: Roll out 5G and rural broadband through BharatNet which reaches 90 % of villages and subsidizes data packs used in ag apps. Make smartphones available under schemes such as PM-KISAN integration with telecoms, and also make available to non-owners, through FPOs, Krishi Sakhis and CSCs.

Digital Literacy Programs: Introduce country-wide education under PMGDISHA of 10 crore farmers, and focusing on smartphone application, verification, and localized apps through Bhashini. ICAR led courses on how to detect misinformation to get pest/disease advice, including certificates.

Verified Content Creation: Create official applications such as Kisan Suvidha 2.0 that include WhatsApp /YouTube channels that have AI moderators to share credible information about biofertilizers and crop breeding.

Policy and Monitoring Framework: Establish a national policy regarding social media: censor all content on a district level, prohibit non-ag use, and subsidize access to the internet by officers. The incentive concerning the use of platforms by FPOs that access eNAM in the context of markets,

Combination with Existing Schemes: Integrate social media into Kisan Call Centers (Multilingual toll-free) and Digital Village programs to extend on a hybrid basis.

Strategy	Actions	Expected Impact
Literacy Training	PMGDISHA expansion, app demos	50% adoption rise
Verified Channels	Govt badges, AI moderation	Reduce misinfo 70%
Infrastructure	Rural 5G, data subsidies	Universal access
Monitoring	District oversight	Quality control

Conclusion

The use of social media has fundamentally changed how agricultural information is disseminated becoming an optional means of information

flow to a central part of the contemporary farming ecosystem. It has the potential to improve productivity, resilience, and livelihoods and help to improve, in particular, smallholders in the Global South as it allows knowledge to be transferred more quickly, stronger networks, and better decisions. In order to achieve this potential to the maximum, the stakeholders have to invest in infrastructure, fight against misinformation, and ensure inclusivity. With the increasing digital penetration, which is presently in billions of users around the globe, social media is in a position to become the even more important mechanism in creating sustainable, informed agricultural systems. The future of agriculture is both interactive and knowledge-based as well as more connected.

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Integrated Nutrient Management on Growth and Yield of Onion (*Allium cepa* L.)

Amit Kumar Singh, Ritesh Prasad Mehta and Suraj Kumar

Abstract

Onion (*Allium cepa* L.) is a very significant bulb crop that is highly nutritional with high content of vitamins, minerals and antioxidants such as quercetin however there are problems with deficiency of nutrients due to the fact that root system is very shallow and requires a lot of feeding. Integrated Nutrient Management (INM) is a combination of inorganic (50-75% RDF) and organic (FYM, vermicompost, poultry manure) and biofertilizers (Azotobacter, PSB) resulting in maximum nutrient availability and vegetative growth, yield traits and quality. INM enhances nutrient absorption, soil health and increased, which economic viability would facilitate sustainability as opposed to the sole use of chemical inputs.

Introduction

Onion (*Allium cepa* L.) is one of the most notable commercial crops of the bulb type which is cultivated in the whole world as an ingredient that cannot be separated in preparing various dishes. It is highly rich in minerals, vitamins and phytochemicals such as flavonoids like quercetin that are very effective in antioxidant activity. The onion has been found to contain bitterness which was attributed to a sulfur compound known as allyl propyl disulfide. Onions are highly economical but the economic bottlenecks of sustainable production of onions are very high. Onion plant has a shallow, sparse and fibrous root system which can penetrate deep down into the soil profile. Consequently, it is a heavy feeder and needs a constant and readily available supply of nutrients in the upper root zone. Historically, Green Revolution was the reason why the consumption of inorganic fertilizers (N, P, and K) increased enormously. Although it has caused a temporary rise in yields, the unilateral reliance on chemical fertilizers provided resulted in multi-nutrient deficiencies, extraction of soil organic carbon, alteration of the soil microbial ecology and the pollution of the underground water by nitrate leaching. To solve these challenges, Integrated Nutrient Management (INM) has been widely adopted as an integrated, ecologically appropriate and

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economically efficient method.

Nutritional Roles in Onion Cultivation

The role of essential macronutrients and micronutrients is important to understand how effective INM module.

Nitrogen (N): It is required in the formation of proteins, amino acids and the chlorophyll that are needed. The sufficient supply of nitrogen in onions will be favorable to the growth of the vegetation at the initial stages in which it is anticipated to record an increase in biological stature and index of leaf area which will result in the growth of a bigger photographsynthetic foundation of the bulb.

Phosphorus (P): It plays a role in root growth, transfer of energy (ATP/ADP) and bulb development early. The low quality of the root system of onions and the inability to form dense root hairs naturally makes onion plant extremely reliant on the amount of phosphorus in the soil ($H2PO_4^-$and HPO_4^{2-}).

Potassium (K): It is an osmoticum, opens and closes stomata. It assists in raising the drought and disease resistance of the plant and enhances the size of the bulb, colour of the skin.

Sulfur (S): It is necessary secondary nutrient that is needed by onions. It is a constituent of sulphur-containing amino acids (cystine, cysteine and methionine) and is the direct cause of the pungency and volatile oil content.

Principle of Integrated Nutrient Management (INM)

Integrated Nutrient Management is maint-enance of soil fertility and plant nutrient supply at optimal level to maintain the desired productivity through maximizing benefits of all potential sources of organic, inorganic and biological components in integrated form.

Components of INM in Onion

Inorganic Fertilizers: Urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) that provide instant high soluble nutrients depending on the periods when the crop requires nutrients the most.

Organic Manures

Farmyard Manure (FYM): It is fine in nature resulting in its quick incorporation into the soil matrix.

Vermicompost: High in the acids of humic, enzymes and plant growth promoting hormones (auxins, gibberellins). This is because of its small grain structure and, thus, it is easily incorporated into the soil matrix.

Poultry Manure: It has a rather high content of N, P and K than FYM and it takes a shorter duration to undergo the mineralization process on soils.

Biofertilizer (Microbial Inoculants)

Nitrogen fixers: Free living Bacteria, such as *Azotobacter chroococcum* and associative symbiotic bacteria, such as *Azospirillum lipoferum* fix atmospheric nitrogen ($N_2 \rightarrow NH_3$).

Phorosphorous solubilizing bacteria (PSB): These species are *Bacillus* and *Pseudomonas* that produce low molecular organic acids (e.g. gluconic and citric acid) that dissolve insoluble fixed phosphorus in plant soluble forms.

Arbuscular Mycorrhizal Fungi (AMF): This is an

efficient form of ecto/endo mycorrhizal association, like the *Glomus fasciculatum* that is capable of extending hypha into the ground to scavenge P, Zn and moisture.

Effect of INM on Vegetative Growth Parameters

The vegetative stage of the onion will determine the "source" capacity (leaves) which will eventually make the carbohydrates for the "sink" (the bulb).

Plant Height and Leaf Count: A combination of 50-75% of RDF and organic manures and biofertilizers tends to produce the highest height of the plant and the number of leaves per plant. Instantly accessible nitrogen in chemical fertilizers accelerates the vegetative growth and the slow and gradual release of nitrogen in the organics maintains it.

Dry Matter Accumulation: Dry matter accumulation is significantly higher in INM treated plots. The improved microbial activity in rhizosphere helps to enhance the mineralization of organic matter resulting in the sustained uptake of nutrients throughout the crop cycle, avoiding the late season nutrient stress.

Impact of INM on Yield Attributes & Total Production

The final objective of commercial onion production is to maximize the marketable production of bulbs. INM has a synergistic effect on formation and development of the bulb.

Bulb Diameter and Weight: Bulb diameter (equatorial and polar) and average bulb weight are important yield parameters. The combination use of organics and chemical fertilizers guarantees the perfect C:N ratio in the soil. PSB increase the uptake of phosphorus which is crucial from the vegetative to bulbing stage. Sufficient P and K diet is associated with accelerated translocation of the photosynthates to the bulb scales across the leaves resulting in larger and fatter bulbs.

Total and Marketable Yield: Sole chemical fertilization tends to result in a higher percentage of unmarketable bulbs (split, double or thick necked). INM approach (e.g. 75% NPK + 25% N through Vermicompost + Azotobacter + PSB) can increase the total yield by from 15% to 25% compared to 100% inorganic fertilizer application. The improvement in soil physical properties (reduced bulk density, higher porosity) provided by organic matter allows the growing bulbs to expand with little resistance from the soil mechanically.

Impact of INM on Bulb Quality & Post-Harvest Storage

Onions are semi perishable and a substantial percentage of the onion crop can be lost at the storage stage as a result of rotting, sprouting and physiological loss in weight (PLW). INM has a role in post-harvest physiology by playing a defensive role.

Total Soluble Solids (TSS) and Ascorbic Acid: INM significantly increases the amount of TSS (ºBrix) and ascorbic acid (Vitamin C) content. The supply of secondary and micronutrients from organic manures optimizes the enzyme activities related to the metabolism of carbohydrates.

Pyruvic Acid (Pungency): Application of organic

matter containing sulphur (such as poultry manure) and increased availability of sulphur (due to microbial activity) increase the volatile Allyl Propyl Disulphide content that improves the market acceptability of pungent varieties.

Storage Longevity (Reduction in PLW): Excessive application of synthetic nitrogen leads to succulent, watery tissue production in the bulbs that are highly prone to fungal pathogens (e.g. *Aspergillus niger* causing black mold) and rapid loss of moisture. INM results in bulbs having a compact tissue architecture, thicker outer scales, and improved cuticle formation.

Impact on Soil Health and Agro Ecosystem Sustainability

Beyond the immediate crop cycle, the real value of INM is on the improvement of the soil environment, for the sake of long term sustainability.

Physicochemical Properties

Soil Structure and Moisture: Organic amendments encourage aggregation of the soil as binding agents. This reduces soil bulk density and enhances hydraulic conductivity and moisture retention - important for a shallow rooting crop such as onion.

Nutrient Availability: Organics act as a buffer to control the rapid leaching of NO_3^- and fixation of phosphates. Organic acids that form during decomposition chelate (prevent their precipitation) the soil micronutrients (Zn, Fe, Mn, Cu) making them available to the roots.

Biological Properties: Chemical fertilizers in single dose suppress the population of indigenous soil microorganisms. On the other hand, INM inoculates with a rich source of beneficial microbes and gives them a carbon substrate (organic manure) to thrive. This results in an increase in soil enzymatic actions (dehydrogenase, urease and alkaline phosphatase) expressing a biologically active and healthy rhizo-sphere.

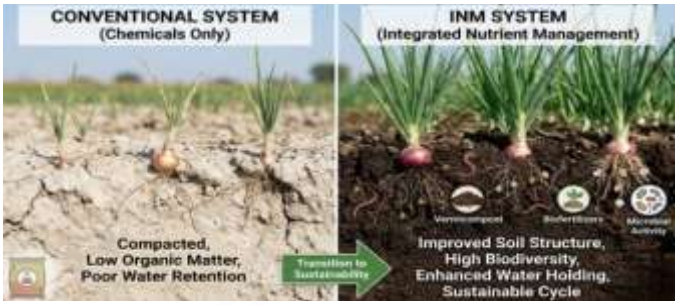


Fig. 1: Difference between Conventional system and INM system

Economic Viability

Although the initial expense of cultivating through organic manures and biofertilizers may slightly increase the initial cost of cultivation; the economic returns are strongly in favor of INM. The highest net returns and B:C ratio are always indicated under INM practices. This can be attributed to three factors: (1) increase in the overall yield, (2) increase in the percentage of marketable bulbs in the A grade that has high market prices and (3) decrease in the amount of losses incurred during storage enabling farmers to store their produce and sell at the time when prices are high in the market. Also, farmers conserve on inputs of chemical fertilizers in the long term due to restoration of soil native fecundity.

Conclusion

The not only a possibility but an agronomic necessity to switch on the conventional and chemi-cally intensive onion farming to Integrated Nutrient

Management. The combination of inorganic manures and organic manure and particular biofertilizers provides a very synergistic environment. It will make sure that the high nutritional needs of the shallow rooted onion crop are achieved at the same rate as its physiological development events. INM is able to address the issue of the lack of a gap between high productivity and ecological sustainability. At the same time, it restores the physicochemical structure and biological fertility of the soil. The commercial onion growers should consider the most scientifically appropriate approach to the commercial onion cultivation to ensure high economic returns and to protect the agro ecosystem for future generation; this would entail the application of region specific INM protocols.

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Role of Food Fortification in Combating Micronutrient Deficiencies in Developing Countries

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Micronutrient deficiencies- A silent crisis

Micronutrient deficiencies, also referred to as "hidden hunger," continue to be a significant public health concern despite advancements in food production around the world, especially in low- and middle-income nations. Although hidden hunger doesn't often manifest itself right away like calorie deficiency, it has a daily impact on the productivity and health of billions of people. The World Health Organization estimates that over 2 billion people globally are deficient in important vitamins and minerals, such as zinc, iron, iodine, and vitamin A, which are essential for immunity, growth, and cognitive development (WHO, 2022). Pregnant women, newborns and young children are particularly vulnerable to these deficiencies, which can result in anaemia, weakened immunity, delayed development, and heightened vulnerability to illness (Das *et al*., 2013).

Food Fortification

The intentional addition of vital vitamins and minerals to frequently consumed foods, including salt, flour and oil to increase their nutritional value and avoid deficiencies without needing significant dietary adjustments is known as food fortification.

Mass fortification: To target large populations, this strategy fortifies commonly consumed staple foods like flour, salt, oil, sugar, or rice with nutrients. Iron-fortified wheat flour, which is required in more than 80 countries, and iodized salt, which prevents goitre, are two examples. As demonstrated by India's salt iodization program, it is economical, sustainable, and frequently governed by the government, greatly reducing insufficiency rates without changing consumer behaviour.

Targeted Fortification: Nutrients are added to foods intended for vulnerable populations, such as supplements for expectant mothers, fortified school meals, and complementary foods for babies that are enhanced with iron and zinc. With levels designed to prevent excess in others, this tackles particular hazards such as maternal anaemia or growth stunting in children. Its relevance in social protection activities is exemplified by programs such as India's midday meals, which use fortified grains.

Point-of-Use Fortification: In homes, schools, or

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childcare facilities, micronutrient powders (such as those containing iron, zinc, or vitamin A) are added to prepared meals right before consumption. For semi-solid foods like oatmeal, this avoids industrial processing, guaranteeing fresh delivery and flexibility perfect for young children in low-resource environments. Users are empowered, but in order to avoid over-fortification, users must be educated on appropriate dosage (WHO, 2022).

Because fortification works through foods people already eat every day, it's considered one of the most cost-effective public health interventions available, especially in developing regions (WHO, 2022).

Developing countries are most vulnerable to such Hidden Hunger

The most prevalent micronutrient deficits occur in diets that are primarily composed of cereals with little variation. Most individuals eat staple grains, which are high in calories but low in vitamins and minerals (Podder *et al.*, 2025).

The following elements exacerbate the situation:

- ✓ Lack of access to wholesome foods and poverty
- ✓ Insufficient variety in diet
- ✓ A high prevalence of infectious illnesses
- ✓ Insufficient resources for public health

Fortification is especially useful in these situations because typical dietary modifications by themselves are frequently insufficient.

Common Micronutrients & Fortified Foods

Food fortification focuses on nutrients that are deficient in many populations. Examples include:

Iodine-Iodised Salt: Iodine is essential for thyroid function and brain development. Universal salt iodization has dramatically lowered goiter rates and related disorders in many countries.

Iron: Iron deficiency is a leading cause of anaemia. Fortifying wheat flour, rice, and other staples with iron increases iron intake and helps reduce anaemia prevalence.

Vitamin A: Vitamin A supports vision and immune function. Fortified cooking oil, sugar, and other staples help raise levels of this nutrient.

Folic Acid: Folic acid fortification in cereal grains is known to lower the risk of neural tube defects in newborns by supporting healthy fetal development (WHO, 2022).



Biofortification: A sustainable approach to combat micronutrient deficiency

Beyond industrial fortification, biofortification is the process of using conventional breeding or biotechnology to increase the nutrient content of crops. Golden Rice is a well-known example; it was genetically altered to make provitamin A in an effort to lessen vitamin A deficiency in areas where rice is a major grain (Kettenburg *et al.*, 2017). Iron-rich beans and zinc-rich wheat are examples of bioforti-

fied crops that show promise since they enhance nutrient intake at the source, benefiting even rural people that depend on homegrown foods.

Real Success Stories

Fortification has already delivered meaningful improvements:

- ✓ In Latin America, fortifying sugar with vitamin A and flour with iron helped reduce deficiency disorders.
- ✓ In Oman, mandatory fortification of wheat flour with iron and folic acid correlated with a dramatic drop in neural tube defects over a decade (WHO, 2023).

Such examples demonstrate that well-implemented programs can have lasting public health benefits.

How Fortification Works?

Fortification delivers widespread benefits:

- ✓ Reaches broad populations with no major behaviour change.
- ✓ When compared with medical treatments, it is cost-effective.
- ✓ Can rapidly improve nutritional status.
- ✓ Supports maternal health and child growth.
- ✓ Long-term healthcare costs are reduced.

Economic analyses showed that fortification strategies- including double-fortified salt and staple food enrichment- provided significant health gains at relatively low cost per disability-adjusted life-year (DALY) averted (Young *et al.,* 2022).

Challenges and Limitations

Fortification is effective, but it is not a panacea:

Choosing the appropriate food vehicle: The population being targeted must consume a large amount of the fortified food.

Quality management and monitoring: Fortified foods may not have enough nutrients if there is insufficient regulation.

Difficulties in bioavailability: Depending on the dietary matrix and nutrients used, not all additional nutrients are readily absorbed by the body.

Accessibility: Individuals who depend on subsistence farming or unofficial local marketplaces might not profit from industrially fortified goods (Berti *et al.,* 2014).

Role of Governments and Policy

Governments drive biofortification success through policies that promote breeding, seed distribution, and farmer adoption, mirroring fortification strategies like mandatory vs. voluntary approaches.

Policy Frameworks: Mandatory policies require seed certification, subsidies, or quotas for biofortified varieties in public programs, ensuring broad coverage similar to mandatory food fortification. Examples include Nigeria's 2023 directorate mandating biofortified crop expansion and India's integration into national agriculture-nutrition plans. Voluntary policies rely on incentives like price premiums or awareness, but mandatory ones achieve higher compliance and equity, as seen in Africa's push for iron beans and vitamin A maize.

Public-Private Partnerships: Governments partner with organisations like Harvest Plus, CGIAR, and donors (e.g., World Bank) for breeding, trials, and

scaling, as in the 2002 Biofortification Challenge Program. These collabor-ations provide technical support, funding, and market linkages, boosting adoption in India and Nigeria. Partnerships bridge agriculture, health ministries, and industry for seed systems and farmer training.

Regulatory Monitoring: Strong oversight involves varietal release standards, quality checks, and import monitoring to ensure nutrient stability and safety, akin to fortification compliance. African Union endorsements and WHO guidelines support enforcement, with penalties for non-compliance enhancing effectiveness. Routine inspections and data tracking measure impact on deficiencies.

Consumer Awareness: Campaigns educate on benefits, sensory changes (e.g., Golden Rice colour), and cooking methods, fostering demand and uptake among rural farmers. Government-led initiatives in Mozambique and Malawi combine this with subsidies, mirroring fortification education for sustained success (Saskia *et al.*, 2018).

Future Outlook

For the greatest impact, fortification should work in combination with:

- ✓ The process of biofortifying staple crops
- ✓ Nutrition education and dietary diversity
- ✓ Quality testing and digital monitoring

Methods to enhance nutrient distribution and access, particularly to the most disadvantaged people, are constantly being improved by research and innovation.

Conclusion: A beneficial approach for public health

A scalable, affordable, and scientifically supported strategy to lessen micronutrient deficiencies is food fortification, particularly in poor nations where hidden hunger is a problem. We can safeguard health, boost productivity, and improve millions of people's quality of life by carefully incorporating vital nutrients into common foods.

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Smart Farming and Precision Agriculture in Bihar: From Tradition to AI-Driven Revolution

Rahul Kumar and Suraj Kumar

Abstract

Problems of agriculture in Bihar has been low productivity, broken holdings, and climatic insecurity such as floods in North Bihar and droughts in South Bihar, although Bihar has fertile Gangetic soils and more than 75% of its population relies solely on agriculture. There is a technological revolution, which is being led by a new Fourth Agriculture Roadmap (2023-2028), Bihar AI Mission, NDVI mapping drone technology, agritech AI like DeHaat and changing reactive traditional agriculture to precision, data-driven and climate-resilient farming. Such efforts include crop diversification (e.g., millets), organic zones, smart irrigation with water savings up to 40%, and localized AI recommendations in local languages, such as small landholdings through Farming-as-a-Service and working toward nutritional security and sustainability.

Introduction

For decades, the story of agriculture in Bihar has been one of a profound paradox. The geographical location of the state is blessed with some of the most fertile soils in the world- those deep, mineral-bearning, alluvial soils of the Gangetic plains, which are enhanced by good sources of ground waters. However, with these natural endowments, the agricultural sector has in the past had low yields per hectare, incomplete land holdings and extreme susceptibility to climatic changes. Bihar has more than 75% of its population relying on the agricultural economic sector with the economic health of the state being inseparable to the soil. But today, there is a silent revolution that is being planted. With the increasing pressures of global climate change and inspired by the fast-paced technological progress, Bihar is moving away to move towards the traditional, intuition-oriented farming into a data-driven agriculture ecosystem. With the help of the Artificial Intelligence (AI), the Internet of Things (IoT), precision agriculture, and the overall policy frameworks such as the Fourth Agriculture Roadmap (2023-2028), the state is not only pursuing higher crop yields; it is pursuing sustainable and climate-resilient development.

Climate Challenge: What Makes Traditional Approaches Ineffective

The reason why smart farming is required in Bihar is that first one needs to know about the special meteorological and topographical problems in that area. The River Ganges literally divides the state into

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two different agrarian realities:

North Bihar (The Flood Zone): This area is crossed by several rivers such as the Koshi, Gandak and Bagmati that comes from Nepal and cause chronic and devastating floods. In addition, huge wetland depressions called Chaours are submerged during up to nine months of the year and therefore traditional agriculture is impossible on large areas of the year.

South Bihar (The Drought Zone): South of the Ganges, most of the time, the areas have to deal with unpredictable monsoons, extreme dry spells, and dropping water tables.

Conventional agriculture that strongly depe-nds on precedent and wisdom in general is no longer adequate to manage such swift climatic changes. The answer is Climate-Resilient Agricu-lture (CRA)- a science technique that seeks to adjust to climate variations as well as curbing climate changes through technology.

Blueprint of Transformation: The Fourth Road-map on Agriculture (2023-2028)

The supporting policy infrastructure is required to scale up technology. The Government of Bihar realized this and developed the Fourth Agriculture Roadmap in October 2023. The roadmap symbolises no longer having food security but having nutritional security and environmental sustainability. The pillars include the following:

Crop Diversification and Climate Resilient Crops : The roadmap is highly focused on the phase of shifting the water intensive paddy-wheat cycle by prioritizing "nutri-cereals" such as millets and all of which makes them scientifically viable to the changing climate of the South Bihar area.

Mukhyamantri Samekit Chaur Vikas Yojana: A brilliant example of ecological engineering. Rather than struggling with the water-filled Chaur wetlands of North Bihar, this plan is encouraging integrated aquaculture and also transforming these depressions into exploited fisheries and commercial wetland crops (such as Makhana or fox nut).

Jaivik Corridor Yojana (Organic Corridors): A significant source of pollution of the Ganges is the chemical runoff of synthetic fertilizers. The state is also coming up with special organic farming zones along the riverbed, which subsidize the growing of green manure (*Dhaincha*) to replenish the soil with nitrogen naturally so as to maintain the health of the microbes in the topsoil.

Silicon Revolution Meets the Soil: The Bihar AI Mission

Although the Agriculture Roadmap has given the funding and the direction, the actual technolo-gical breakthrough came in late 2025 when Bihar Artificial Intelligence (AI) Mission was launched. The state government ordered the introduction of AI in several high-priority departments in a historic move, and agriculture was going to be restructured on a grand scale.

Response to Reactionary Farming

Traditional farming is reactive: when a farmer notices a pest, he sprays pesticide. AI enables agriculture to be predictive. Consuming huge amou-nts of data, such as decades of meteorological data

and real-time satellite imagery, the health status of the soil along with the movements of certain pests around the globe, AI algorithms are able to predict the occurrence of agricultural events before they occur.

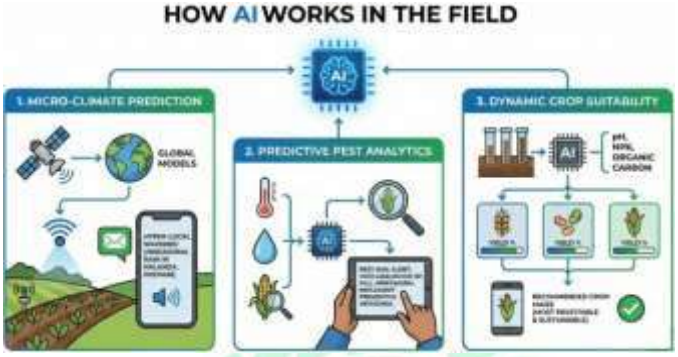


Fig. 1: Model behind how Artificial Intelligence (AI) works in the field

Precision Agriculture: Doing Less (With More): The art of delivering the correct treatment, at the correct location, and at the correct moment is known as precision agriculture. In the case of Bihar where 91% of agricultural labor force are small and marginal farmers (1-2 ha), it is important that maximum efficiency is realized per square meter.

IoT and Smart Irrigation

The amount of water is the limiting factor to agricultural production in the drought prone South Bihar regions. Smart farming is a new way that brings Internet of Things (IoT) sensors that are placed directly in soil.

The Science: These sensors are used to measure constant volumetric water content and soil matric potential. The sensors are able to send wireless messages to automated drip irrigation systems instead of flooding a field at a predetermined time, only when the moisture content of the roots falls below an important biological parameter. This has the potential to save 40% of water and avoid root rot that is caused by overwatering.

Drone Mapping and NDVI

It takes Unmanned Aerial Vehicles (UAVs) with multispectral cameras to start mapping fragmented fields in Bihar. These are cameras that record light within the Near-Infrared (NIR) wavelength range, which can be used to compute the Normalized Difference Vegetation Index (NDVI) using the software.

The Science: Plants with a lot of chlorophyll reflect more NIR light. Through developing an NDVI color map of a field, algorithms would be able to identify the exact areas of nutrient deficiency or disease several weeks before the human eye can detect the yellowing of the leaves. This can then be programmed to have drones spray fertilizers or pesticides on the affected regions only and this saves on cost of chemicals and toxicity to the environment.

Homeground Agritech: The DeHaat

The most advanced AI in the world is valueless when the end-user does not know where or can only know how to use it. Homegrown agritech startups, the most famous of which is “DeHaat”, are already working on the construction of the bridge between high-tech algorithms and the Indian farmer living in the countryside. It's origins in Bihar, and has since grown to have over 1.8 million farmers throughout India, yet it's still run deep to the Gangetic plains. It has a model of operation that is perfectly suited to the reality of rural agriculture that

is the Phygital (Physical + Digital) model.

Busting the language barrier with AI at the Grassroots

The localized AI advisory system by DeHaat can be considered its most important scientific input. It is not merely a crunching platform; the site uses Natural Language Processing (NLP) to convert complicated scientific knowledge into dialects.

The AI produces an automated conversational voice advisory in either Bhojpuri, Maithili or Magahi. Moreover, DeHaat centers which are operated by local micro-entrepreneurs avail the physical inputs (seeds, bio-fertilizers) prescribed by the AI and help to obtain the final harvest which in effect digitalizes the whole agricultural supply chain.

Digital Democratization: AI Agri Radio

As a smartphone penetration rate has increased, although not necessarily across older or marginalized farming communities, Bihar has of late launched the AI-based Bihar Agri Radio.

Table 1: Comparative Analysis: Traditional vs. AI-Driven Agriculture in Bihar

Parameter	Traditional Agriculture	AI & Precision Agriculture
Decision Making	Intuition, generational habits, and generalized almanacs.	Data-driven, utilizing localized sensors, historical data, and predictive ML models.
Resource Application	Blanket application of water and fertilizers (high waste).	Variable Rate Technology (VRT) via drones and IoT; precise, micro-targeted application.
Pest Management	Reactive (spraying chemicals after damage is visible).	Predictive (AI models forecast outbreaks; use of preventative bio-pesticides).
Information Flow	Slow, word-of-mouth, delayed government bulletins.	Real-time alerts via regional-language AI voice bots and SMS.

This project combines intricate data feeds (live market prices (Mandi rates), weather information and farming science) and applies AI voice recognition to air 24/7 and localized radio stations. The information asymmetry is quickly being eliminated through the use of such tools as the Agri Radio and the BIHAN App that is the property of the state.

Problems of the Future and the Way Ahead

The prospects are very encouraging, the friction of establishing a Silicon Valley-style technological ecosystem in a state with a complicated socio-economic realities is very high.

Fragmentation of Land: In Bihar the average size of landholding is 0.5 hectares, which is not economically. Solution: State is marketing "Farming as a Service" (FaaS). Farmer Productor Organizations (FPOs) also rent out high precision equipment through JEEViKA program and Custom Hiring Centres (CHCs), which in turn, makes precision agriculture an operation cost or an inevitable capital cost and not an impossible cost.

Data Quality and Connection: Artificial Intelligence can be only as good as the information. Although the situation is getting better with the historical data, it is a logistical mountain to have a dense network of high-fidelity weather and soil sensors in all 38 districts and connecting remote rural blocks through 5G is also a condition to the actual operation of the IoT.

Behavioral Change: The farming is highly cultural. It will take an enormous amount of trust-building to

convince a multi-generational farmer to leave a conventional crop cycle, at their recommendation offered by a smartphone application.

Conclusion

The story of Bihar is evolving. The state which was previously a symbol of agricultural stagnation is quickly becoming a test ground of climate resistant, tech enhanced agriculture. The state is trying to make a technological giant leap by combining the strong financial support of the Fourth Agriculture Roadmap with the advanced potential of the Bihar Artificial Intelligence Mission. The incorporation of accuracy tools, the marketing of environmentally friendly actions such as organic paths and planting of millet are proactively redefining the regulations of farming. Agriculture becomes no longer a struggle with the elements in Bihar. In its place, it is emerging as a very precise, scientific relationship with nature, so that the fertile soils of the Gangetic plains can be able to feed generations yet to come, and ultimately serve to grant economic justice and prosperity to the tillers of the soils, the farmers.

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Mechanical Weeding in Chilli: A Practical Pathway to Profitable and Sustainable Cultivation

Vivek Rajesh Kamat, G. Prasad Babu, Venkatesh Iddumu and M. Sheshu Madhav

Chilli (*Capsicum annuum* L.) is the most frequently grown spice crop in India and has a large impact on the livelihoods of rural people and the economy through exports. The potential economic value of chilli is undeniable, but to successfully grow and harvest a high-quality crop of chillies, a grower must be able to manage the early stages of plant growth carefully. Weed management is one of the most crucial and labor-intensive types of inter-cultural work performed on chilli crops, with the greatest need for weeding during the first 20-45 days following transplantation, when weed growth is greatest. During this period, weeds compete with chilli plants for light, moisture, nutrient availability, and space. If the weed populations are not controlled during this critical period of competition between the chilli and weed plants, reductions in the yield of the chilli crop can be as high as 30-60%. In addition, weed populations can increase the prevalence of pests and diseases, thereby increasing the costs associated with production.

In many instances, chilli producers use traditional methods of manually weeding their crops using a hand hoe or a khurpi. While effective, traditional weeding methods require a considerable amount of time and physical effort to complete and are becoming more expensive as the cost of labor continues to rise and the availability of seasonal farm labor continues to be unpredictable. On average, manual weeding requires between 25 and 35 man-days of effort for each hectare of land that is weeded, and usually takes two to three weeding rounds throughout the season. Repeated bending, stooping, and hand movements cause fatigue, back pain, and other long-term health issues, as the majority of those who labor in agriculture are women. To address these challenges, mechanized weeding has been developed as a practical, cost-effective, and sustainable method of weed management in chilli crops. Mechanized weed management reduces the dependency on manual labor and the intensity of physical work associated with weeding practices. By reducing the time needed to complete manual weeding, mechanized weed management allows for timely completion of weed management, improved soil health, and increased crop yields.

The role of Weed Management in Chilli

Weeds have the largest impact on chilli

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during the early growth stages when seedlings establish themselves slowly. During this time, uncontrolled weeds compete with chilli plants for the necessary resources of nutrients, water, sunlight, and space. Weed competition impacts crop yield, irrigation, and fertilizer applications and provides an alternative host to pests and disease organisms. Therefore, controlling weeds effectively for the first 20-45 days after transplanting is critical to supporting the successful establishment of the crop and maximizing potential yield. Although manual weeding remains a common approach to weed control, it is limited by a number of factors, including the high costs associated with this labor-intensive method of control, the drudgery of manual weed removal, and the scarcity of labor. These constraints have led farmers to seek mechanized approaches to weed control, and as a result, mechanized weed control is now considered a fundamental part of modern chilli production.

What is Mechanized Weeding?

Mechanized weeding employs hand- or power-operated machines to reduce weed populations within the crop row by disturbing the upper layers of the soil. The use of these machines allows weed populations to be uprooted or cut without damaging the crop, improves soil aeration, retains moisture, and reduces the overall labor requirement. The use of mechanized weeders is especially effective when used with chilli transplanting that is conducted in rows with a minimum row spacing of 45-60 cm as it allows for the most effective maneuvering of the weeder between rows. The use of mechanized weeding methods, as opposed to chemical methods, creates a more environmentally safe method of weed control, as mechanized methods do not leave any harmful residues and support the development of sustainable farming practices. In addition to contributing to sustainable farming practices, mechanized weeders are particularly applicable in the current economic environment of increasing labor costs and the continuing need for climate-smart, energy-efficient farming approaches.

Mechanised Weeding Methods and Machines Used

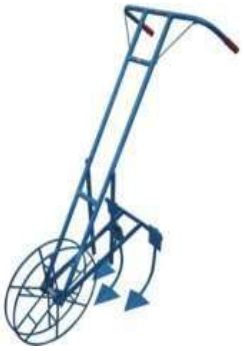
For Chilli plants, weeding methods and equipment for each operation are either hand-operated or power-operated; the proper method or equipment must be determined based on the farm area and type of soil.

Hand-operated weeding machines

Hand-operated weeders are the most basic form of mechanization. They are inexpensive, lightweight, and easy to operate; therefore, they are well suited for use on small marginal farms.

Most common types of hand-operated weeders

Wheel Hoe: This is a basic single or double wheel hoe with adjustable blades, which can be pushed along the row to cut and pull out the weeds. The width of the sweep on this tool usually ranges from 10 to 15 cm, depending on the width of the weeds growing in the inter-row areas.



Cycle Weeder: The cycle weeder is a push-type tool with rotating blades or small wheels fitted with tines; used mainly in cultivated light soils. The use of this tool allows the operator to work in a comfortable standing position and reduces operator fatigue while also providing a very efficient way to control the growth of weeds.



Twin-wheel weeder: This type of weeder is a variation of the cycle weeder, which uses two wheels and allows users to have greater stability as well as smooth operation; this makes it a more suitable tool for use in slightly uneven cultivated soils and helps minimize crop damage.



Advantages of hand-operated weeders

- ✓ It reduces the need for manual weeding by 50-65%.
- ✓ It effectively removes 75-85% of the weeds.
- ✓ It allows operators to work in an upright position and adopt a more comfortable posture.
- ✓ It is cost-effective and requires little maintenance.

Hand-operated weeders are particularly effective for inter-row weed control, although weeds very close to the plant base may require limited hand weeding or mulching.

Power-Operated Weed Machines: Power-operated weeders are an effective option for medium- and large-sized farms. These weeders are powered by engines, typically small diesel or petrol engines with 3-7 HP. Depending on the type of soil, crop spacing, and weed growth, they can be equipped with rotary blades, sweep tines, or star wheels.



Specifications of the power weeders

Engine: 3-7 hp, petrol/diesel

Blade type: Rotary or sweep blades

Row spacing: Adjustable ≥45 cm

Field capacity: 0.6-1.0 ha day^{-1}

Advantages of power-operated weeders

- ✓ Labour requirement is reduced to 2-4 man-days ha^{-1}
- ✓ Labour saving: 85-90% compared to manual weeding
- ✓ High weeding efficiency (85-90%)
- ✓ Allows timely operations during peak weed emergence
- ✓ Improves soil aeration, moisture retention, and soil tilth
- ✓ Reduces cost of cultivation and ensures profitability

Power weeders can be used in custom hiring centers (CHCs), making them accessible to smallholders without heavy capital investment. They are particularly useful during the critical crop-weed competition period, where delays in manual weeding can result in significant yield loss.

Working Principles of Mechanised Weeders

Mechanized weeders remove weeds through

Table 1: Performance of Weeding Methods in Chilli

Type of Weeding	Suitable Land Holding	Machine Specification	Field Capacity (ha day^{-1})	Labour Requirement (man-days ha^{-1})	Labour Saving over Manual (%)	Weeding Efficiency (%)	Limitations
Manual weeding (Khurpi)	All holdings	Hand tool, blade width 5-7 cm	0.03-0.05	25-35	-	85-90	Very labour-intensive; physically exhausting; high cost; time-consuming
Hand-operated wheel hoe	Small & marginal farms	Single/twin wheel, sweep blade 10-15 cm	0.15-0.25	8-12	50-65	75-85	Less effective on heavy/clayey soils; only inter-row weeds controlled; limited for large farms
Cycle / twin-wheel weeder	Small to medium farms	Push type, adjustable blades, row spacing ≥45 cm	0.20-0.30	6-10	60-70	80-85	Requires uniform rows; soil must not be too wet or too dry; weeds near plant base need hand-weeding
Power weeder	Medium & large farms / CHCs	3-7 hp petrol/diesel engine, rotary/sweep blades	0.60-1.00	2-4	85-90	85-90	High initial cost; maintenance required; not suitable for very small plots; operator training needed

shallow soil disturbance, which can be achieved in different ways.

Sweeping: Fixed or adjustable sweep blades uprooted weeds between the rows.

Rotary blades: Rotary weeders chop surface weeds efficiently.

Soil loosening: The soil is aerated while weeds are removed, which improves root development.

Moisture conservation: Loose soil crusts formed after weeding reduce evaporation losses.

The timing of mechanical weeding is therefore crucial. Typically, the first weeding is performed 20-25 days after transplanting, and the second is performed 40-45 days later. Wet soil can lead to clogging and crop damage, whereas excessively dry soil makes it difficult to remove weeds. The smooth operation of mechanised weeders is facilitated by maintaining a row spacing of 45-60 cm.

Advantages of Mechanised Weeding in Chilli

Mechanized weeding provides multiple benefits.

Significant Labor Savings: Mechanized methods reduce manual labor by 50-90%, depending on the type of weeder.

Cost Reduction: Reduces the total cost of weed management while maintaining crop health.

Drudgery Reduction: Operators work in a standing posture, which reduces fatigue and health risks.

Improved Soil Health: Soil loosening improves aeration, microbial activity, and root growth of plants.

Sustainability: Minimizes chemical use, reducing environmental pollution and carbon footprint.

Timely Operations: Critical for peak weed emerge-

nce periods to ensure higher yield.

Practical Tips for Effective Mechanised Weeding

- ✓ The row spacing (45-60 cm) should be maintained for smooth machine operation.
- ✓ Operate on slightly moist soil to facilitate weed removal and prevent crop damage.
- ✓ It can be combined with mulching or spot hand-weeding for weeds close to the plant base.
- ✓ Regular maintenance of blades, tines, and engines ensures efficiency and longevity.
- ✓ The speed and depth should be adjusted according to the soil type and crop growth stage.

Conclusion

Chilli farmers have benefited greatly from mechanized weed control because mechanization provides savings in terms of labor and monetary costs and increases the efficiency of weeding activity. Hand-operated weeders are mainly used on smaller, marginal farm operations, and powered machines are more appropriate for medium to large holdings, as well as through Community Harvesting Cooperatives. Utilization of maize growers' ability to integrate mechanized weeding with proper row spacing, on-time operations, and minimizing labor for the other two weed control methods (hand weeding and mulching), allows chilli growers to produce greater yields with superior quality produce while continuing to engage in more sustainable farming methods.

Mechanization is also an integral factor in increasing farm profitability, reducing drudgery associated with farming, promoting the implement-ation of Climate-smart Agriculture, and creating awareness of Modern Agricultural Technologies. The increasing price of labor sources combined with the growing demand for Sustainable Production Systems has made mechanized weeding of chilli not only an option, but also a requirement for modern, efficient, and profitable production.

Ripening and Post-Harvest Life of Tomato (*Solanum lycopersicum* L.)

Arohit Patel

Abstract

Tomato is a climacteric vegetable crop of worldwide significance, but it is very perishable because of its fast ripening and senescence process. The ripening process is ethylene-regulated and consists of a complex of physiological and biochemical processes such as color development, softening, sugar accumulation, and aroma production. The post-harvest life of tomato is affected by the harvest maturity stage, temperature, relative humidity, and atmospheric composition. Improper post-harvest handling practices cause large quantitative and qualitative losses. The aim of this review is to present the ripening physiology of tomato, the factors that affect the post-harvest life, and the practices to extend the shelf life and reduce post-harvest losses.

Introduction

Tomato (*Solanum lycopersicum L.*) is one of the most significant vegetable crops grown around the world due to its nutritional and economic value. Tomatoes are a rich source of vitamins (A and C), minerals, antioxidants, and biologically active compounds such as lycopene. However, tomatoes are highly perishable and have high post-harvest losses, especially in developing countries, due to their fast ripening, softening and microbial degradation. Tomato is a climacteric fruit/vegetable, which means that it continues to ripen after it has been harvested due to an increase in respiration and the production of ethylene. Although ripening increases the palatability of the fruit, it also reduces its shelf life. It is, therefore, important to have an understanding of the physiological and biochemical processes involved in ripening and senescence.

Ripening Physiology of Tomato

Climacteric Nature and Respiration: The ripening of tomatoes is related to the climacteric rise in respiration, which can be measured by the sharp rise in oxygen consumption and carbon dioxide production. The rise in respiration occurs during the breaker stage and contributes to the provision of energy for different metabolic processes that are linked to the ripening of tomatoes. The rise in respiration rate accelerates biochemical reactions but causes rapid senescence if the process is not regulated.

Role of Ethylene: Ethylene is the primary plant hormone that regulates the ripening of tomatoes. At the start of the ripening phase, the level of ethylene production rises as a result of the enhanced activity of enzymes such as ACC synthase and ACC oxidase. Ethylene triggers the expression of genes responsible for the ripening of tomatoes, which include the production of pigments, cell wall degradation, and

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the development of flavor. Even a small amount of external ethylene can trigger the ripening process, and hence the regulation of ethylene is critical during post-harvest handling

Colour Development: One of the most observable processes that takes place during the ripening of tomatoes is the development of color from green to red. This is due to the following: Degradation of chlorophyll

Synthesis of carotenoids, especially lycopene and β-carotene

The accumulation of lycopene is responsible for the red color of ripe tomatoes, which also have antioxidant properties. The ideal temperature for lycopene synthesis is between 20 and 25°C, while temperatures above 30°C inhibit lycopene synthesis.

Stage	Color	Description
1	Green	The surface is completely green in color. The shade of green may vary from light to dark.
2	Breakers	There is a definite "break" in color from green to tarnish-yellow, pink or red on less than 10% of the surface.
3	Turning	10% to 30% of the surface shows a change in color from green to tarnish-yellow, pink, red or a combination thereof.
4	Pink	30% to 60% of the surface shows pink or red in color.
5	Light Red	60% to 90% of the surface shows pinkish-red or red.
6	Red	More than 90% of the surface is red.

Textural Changes and Softening: Softening of fruits is another important process that is associated with fruit ripening. Softening of fruits can be accomplished by the breakdown of cell wall materials such as pectin, cellulose, and hemicellulose. The major enzymes responsible for this alteration are: Polygalacturonase, pectin methyl esterase, and cellulose. These enzymes cause a reduction in the rigidity of the cell walls and cell junctions, resulting in softening and making the fruits susceptible to injury and infection.

Changes in Sugars, Acids and Flavor: Starch is converted into sugars like glucose and fructose during the ripening process, making the tomato sweet. At the same time, the organic acids reduce in amount as they are used in respiration, making the tomato taste balanced and pleasant. The production of volatile compounds like aldehydes, alcohols, and ketones gives the tomato its characteristic aroma.

Senescence in Tomato

Senescence is the last phase after ripening, which is marked by the progressive loss of cell structure and function. Physiological alterations during senescence include membrane damage, loss of water, and reduction in metabolic rates. Biochemical alterations during senescence include enhanced lipid peroxidation, protein breakdown, and reactive oxygen species (ROS) accumulation. All these result in the loss of tissue integrity, development of off-flavors, and subsequent rotting.

Post-Harvest Life of Tomato

Definition and Importance: The post-harvest life of tomatoes is the period during which the fruits are of acceptable quality for consumption. This period is affected by factors such as tomato variety, stage of maturity, and environmental factors such as temperature, humidity, and gas composition.

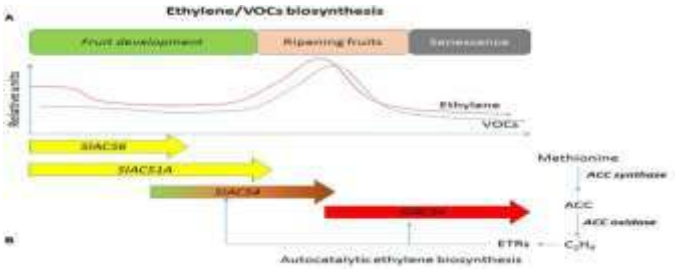
Harvest Maturity Effect: Harvest maturity is one of the factors that have a significant effect on the shelf life of tomatoes. Harvest maturity of tomatoes at the mature green stage has a longer shelf life and is ideal

for long-distance transportation. Harvest maturity of tomatoes at the pink or red ripe stage has good eating quality but a shorter shelf life.

Temperature and Relative Humidity**:** Temperature is the most significant factor that determines the post-harvest life. The storage of tomatoes can be done at a temperature of 12-13°C, which slows down the respiration and production of ethylene. Storage of tomatoes below 10°C causes chilling injury, which leads to pitting of the surface, uneven ripening, and development of poor flavor. The relative humidity of 85-90% is required to reduce transpiration losses.

Temperature °F (°C)	Relative Humidity Range
60 (16)	60% - 75%
65 (18)	65% - 80%
70 (21)	70% - 80%
75 (24)	75% - 85%
80 (27)	80% - 85%
85 (29)	85% - 90%

Role of Ethylene and Atmospheric Composition: Increased sensitivity to ethylene causes faster ripening and senescence of tomatoes with higher concentrations of ethylene. The controlled atmosphere storage technique, with reduced oxygen and increased carbon dioxide, slows down respiration and ethylene production. Modified atmosphere packaging is also beneficial in extending the storage life of tomatoes by providing a favorable atmosphere within the package.



Post-Harvest Management Strategies

Pre-harvest practices: Nutrient and water management improve fruit quality and storage life. Handling and harvesting: Avoids damage and rot. Temperature management: Storage at optimal temperatures improves storage life. Ethylene inhibition: Use of 1-methylcyclopropene (1-MCP) delays fruit ripening by inhibiting ethylene receptors. Packaging: Prevents loss of moisture and mechanical damage.

Conclusion

Ripening is an ethylene-regulated physiological process and this increases the quality of the fruit, while senescence leads to deterioration. The climacteric nature of tomatoes means that temperature and ethylene control are significant in post-harvest handling. The use of scientific post-harvest technology, which is based on the physiology of the ripening process, can significantly extend shelf life and improve market value.

Budget 2026-27: A Blueprint for a Confident and Caring India

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When the Union Budget 2026-27 was presented in February 2026, it sent out a clear message: India is ready to move from hesitation to action, from slogans to solutions and from short-term populism to long-term people-centric growth. Anchored in the vision of Viksit Bharat, the budget seeks to balance ambition with stability, growth with inclusion and reforms with trust. At a time when the global economy is uncertain, India's budget reflects confidence confidence in its people, its institutions and its future.

Growth with Stability at the Core: One of the most reassuring aspects of Budget 2026-27 is its focus on macroeconomic stability. The government aims to sustain a strong growth rate of around 7%, while keeping inflation moderate and public finances under control. Fiscal discipline remains a priority, with the fiscal deficit projected at 4.3% of GDP, signalling India's commitment to responsible economic management. Rather than reckless spending, the strategy is clear: invest wisely today to secure tomorrow.

Manufacturing: Building Strength at Home: A major thrust of the budget is on strengthening domestic manufacturing, especially in strategic and high-technology sectors. From semiconductors and electronics to pharmaceuticals, chemicals and rare earth magnets, the government is determined to reduce dependence on critical imports and make India globally competitive. The revival of 200 legacy industrial clusters, the expansion of the India Semiconductor Mission 2.0 and support for advanced manufacturing tools reflect a strong push toward self-reliance - not isolation, but resilience. Customs and tax reforms further support this vision by lowering costs, simplifying procedures and rewarding trusted manufacturers.

MSMEs: Small Businesses and Big Support: Recognizing that MSMEs are the backbone of India's economy, the budget introduces a robust support system to help them grow into national and global champions. A ₹10,000 crore SME Growth Fund, improved access to credit through digital platforms like TReDS and professional assistance through "Corporate Mitras" aim to ease financial stress and compliance burdens, especially in Tier-II and Tier-III cities. The message is simple: when small businesses grow, the nation grows.

Services Sector: Powering the New Economy: India's services sector ranging from IT and healthcare to tourism, sports and creative industries gets renewed attention. The budget promotes medical value tourism, expands AYUSH institutions, supports caregivers and invests in digital creativity through AVGC labs in schools and colleges.

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Tax incentives for IT services and data centres strengthen India's role as a global digital and services hub, creating jobs while attracting global investment.

Farmers and Rural India: Productivity with Prosperity: For farmers, the focus shifts from survival to sustainable income growth. Fisheries, horticulture, animal husbandry and high-value crops like cashew, cocoa, coconut and sandalwood receive targeted support. By integrating agriculture databases with AI-driven advisory systems, the Bharat-VISTAAR initiative aims to modernize farming and empower farmers with better information and market access. Rural development, in this budget, is not charity it is investment.

Infrastructure and Energy: Preparing for the Future: Infrastructure continues to be the engine of long-term growth. New freight corridors, expanded waterways, coastal shipping, and industrial corridors like Purvodaya are designed to improve connectivity and reduce logistics costs. At the same time, the budget takes a forward-looking approach to energy security and sustainability, promoting battery storage, solar manufacturing, nuclear power, and carbon capture technologies. Growth and green goals are no longer treated as opposites they move together.

People at the Centre of Development: Perhaps the most heartening aspect of Budget 2026-27 is its people-first approach. From mental health institutions and trauma care centres to skill development for caregivers, persons with disabilities and women entrepreneurs, the budget recognizes that economic progress must translate into dignity and opportunity for every citizen. Initiatives like SHE Marts and Divyangjan-focused schemes underline the belief that inclusion is not a side issue it is central to nation-building.

Trust-Based Governance and Ease of Living: The budget deepens reforms that simplify life for ordinary citizens and businesses. Easier tax compliance, decriminalisation of minor offences, faster customs clearance and digital single-window systems reflect a shift from control to trust-based governance. By reducing fear and friction, the government aims to unlock productivity and voluntary compliance.

A Budget with a Long View: Budget 2026-27 is not about dramatic announcements or instant applause. It is about steady, confident steps toward a stronger India. By combining reforms with compassion, investment with inclusion, and ambition with prudence, it offers a roadmap for transforming India's potential into performance. In many ways, this budget tells a quiet but powerful story: India is no longer just preparing for the future it is shaping it. The Union Budget 2026-27 is a forward-looking blueprint that comb-ines growth, resilience and inclusion. By prioritizing structural reforms, people-centric development, trust-based governance, and fiscal prudence, the budget lays a strong foundation for India's transition towards a Viksit Bharat. It signals continuity with reform momentum while adapting to emerging economic and technological realities.

Fruit Flies and their Management in Mango and Tomato

Diksha Abrol

Introduction

Fruit flies belonging to the genus Bactrocera (Tephritidae: Diptera) are among the most destructive pests of fruit crops worldwide, causing significant economic losses due to direct fruit damage and trade restrictions (Clarke *et al*., 2011). Mango and cucurbits are important crop is highly susceptible to fruit fly infestations, leading to reduced market value and yield losses. The injury to guava fruit occurs primarily through oviposition punctures, followed by larval feeding and development inside the fruit. The maggots feed on the pulp, causing internal decay, premature fruit drop and secondary fungal or bacterial infections, rendering the fruit unmarketable (Dhillon *et al*., 2005). The life cycle of *Bactrocera spp*. complicates its management, as the larvae develop inside the fruit, making direct control difficult. Upon completing their larval stage, they exit the fruit and pupate in the soil, where they may also over winter, further complicating monitoring and intervention strategies (Ekesi *et al*., 2006). The adult flies are present throughout the year, with population peaks varying depending on climatic conditions, host availability, and natural enemy activity (Vayssières *et al*., 2009). Monitoring fruit fly populations is crucial for developing integrated pest management (IPM) strategies, as population dynamics influence the timing and effectiveness of control measures (Manrakhan *et al*., 2017).

Fruit fly: *Bactrocera (Dacus) dorsalis*

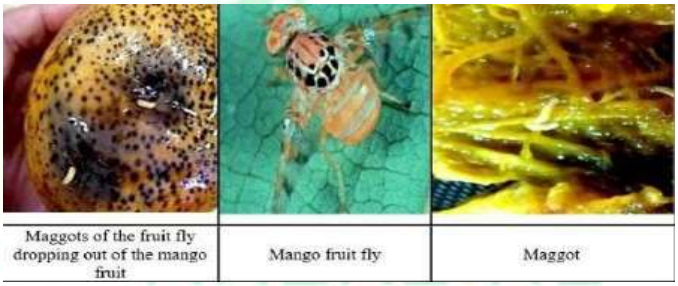
Symptoms of damage

- ✓ Maggot bore into semi-ripened fruits with decayed spots and the dropping of fruits.
- ✓ Oozing of fluid
- ✓ Brownish rotten patches on fruits.

Identification of pest

Larva: Yellowish apodous maggots.

Adult: Light brown with transparent wings



Maggots of the fruit fly dropping out of the mango fruit | Mango fruit fly | Maggot

Management

- ✓ Collect fallen infested fruits and dispose of them by dumping them in a pit.
- ✓ Provide summer ploughing to expose the pupa
- ✓ Monitor the activity of flies with methyl eugenol sex lure traps.
- ✓ Bait spray - combining any one of the insecticides and molasses or jaggery 10 g l^{-1},
  - Malathion 50 EC 2 ml l^{-1},
  - Dimethoate 30 EC 1 ml l^{-1},
  - Carbaryl 50 WP 4 g l^{-1}. two rounds at 2-week intervals before ripening of fruits.

Biological control

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Field release of natural enemies, *Opius compensates* and *Spalangia philippinensis*

Fruit flies: *Bactrocera cucurbitae*

Symptoms of damage

- ✓ Maggots feed on the pulp of the fruits
- ✓ Oozing of resinous fluid from fruits
- ✓ Distorted and malformed fruits
- ✓ Premature dropping of fruits, and also unfit for consumption



Identification of pest

Eggs: Laid singly in clusters on fruits

Larva: Dirty white apodous maggot

Pupa: Pupate in soil

***Bactrocera cucurbitae*:** Hyaline wings with brown and grey spots at the apex.

***Bactrocera ciliata*:** Ferruginous brown body. Smaller than *Bactrocera cucurbitae.*

***B. zonata*:** Body yellowish with a pale yellow band on the 3rd tergite.

Management

- ✓ Collect infested and fallen fruits and burn them in deep pits.
- ✓ In endemic areas, change the sowing date as the fly population is low in hot, dry conditions and at its peak during the rainy season
- ✓ Expose the pupae by ploughing and turning over the soil after harvest
- ✓ Use a ribbed gourd as a trap crop and apply carbaryl 0.15% or malathion 0.1% on congregating adult flies on the undersurface of leaves.
- ✓ Use attractants like citronella oil, eucalyptus oil, vinegar (acetic acid), and lactic acid to trap flies.
- ✓ Use poison baiting in severe infestation
- ✓ Mix methyl eugenol + malathion 50 EC at a 1:1 ratio and keep 10 ml of the bait in polythene bags @ 25 ha^{-1}.
- ✓ Use a fly trap
- ✓ Keep 5 g of wet fishmeal in polythene bags (20 x 15 cm) with six holes (3 mm dia)
- ✓ Add 0.1 ml of dichlorvos.
- ✓ Dichlorvos should be added every week and fishmeal renewed once in 20 days @ 5 traps ha^{-1}

Conclusion

Fruit flies are among the most destructive pests of mango and cucurbit crops, causing severe quantitative and qualitative yield losses. Species such as *Bactrocera dorsalis* in mango and *Bactrocera cucurbitae* in cucurbits significantly reduce marketable produce and pose major challenges to growers due to their high reproductive potential and wide host range. Cultural practices such as field sanitation, timely harvesting, and destruction of infested fruits play a crucial role in reducing fruit fly populations. The use of methyl eugenol and cue-lure traps, along with protein bait sprays, proved effective in monitoring and suppress-

ing adult populations. Biological control agents and botanical insecticides further contribute to environmentally safe management. Chemical insecticides, when used judiciously and as part of an IPM program, can provide effective control while minimizing adverse effects on non- target organisms and the environment. Adoption of an integrated approach not only reduces fruit fly infestation but also enhances fruit quality, yield, and economic returns to farmers. Overall, sustainable management of fruit flies in mango and cucurbits requires a holistic, eco-friendly, and area-wide IPM approach, supported by farmer awareness and timely implementation of recommended practices.

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Microclimate Modification in Fruit Crops: Principles, Techniques and Relevance under Climate Variability

Sangeeta Lakshmeshwara, Krishnaveni K. S. and Bhavya N.

Abstract

Microclimate modification refers to the intentional alteration of the immediate environment surrounding crops to enhance plant growth, productivity and fruit quality. In fruit crops, key microclimatic factors such as solar radiation, temperature, relative humidity, wind speed and soil moisture play a critical role in regulating physiological processes including photosynthesis, transpiration, flowering and fruit development. Rising climate variability and the increasing occurrence of extreme weather events have heightened abiotic stresses in fruit production systems, underscoring the need for adaptive management approaches. Microclimate management through orchard design, cultural practices and protected cultivation provides an effective means of alleviating climatic limitations. Practices such as mulching, shade netting, windbreaks, irrigation-based cooling and canopy management help regulate both aerial and soil microclimates, thereby improving yield stability and fruit quality. This article reviews the key microclimatic components influencing fruit crops, major modification techniques, their physiological effects, and associated constraints. Particular emphasis is given to microclimate management as a climate-resilient strategy for sustainable fruit production.

Introduction

Microclimate refers to the climatic conditions around plants that can differ from the overall climate of a region (Raihan, 2023). In fruit crops, factors such as air and soil temperature, humidity, sunlight, wind speed, and soil moisture strongly affect plant growth, flowering, yield, and fruit quality. Because fruit crops are perennial and remain exposed to environmental stresses for extended periods, they are particularly vulnerable to climatic extremes.

Global climate change has led to a rise in the occurrence of heat waves, droughts, frost events, and erratic rainfall, which negatively impact fruit production worldwide (IPCC, 2021). Higher temperatures incre-ase respiration rates and decrease net photo-synthesis, while moisture stress and temperature extremes disrupt flowering, fruit set, and fruit development. In this context, microclimate modification has emerged as an effective agronomic approach to reduce abiotic stress and maintain yield

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stability. Microclimate modification includes both short-term and long-term interventions aimed at transforming unfavourable environmental conditions into more suitable ones through appropriate orchard design and management practices (Ghadekar *et al.*, 2018).

Components of microclimate and their influence on fruit crops

Solar radiation: Solar radiation serves as the main energy source for photosynthesis and plant growth. Both the intensity and spectral quality of radiation play an important role in regulating flowering, fruit set, and fruit development (Chalkias *et al.*, 2013). Excessive solar radiation may lead to sunburn, sunscald, and degradation of fruit colour pigments, whereas inadequate radiation restricts carbohydrate production and lowers fruit quality. Diffuse radiation has been shown to be more effective for canopy photosynthesis than direct radiation, especially in dense orchard systems.

Air temperature: Air temperature regulates photosynthesis, respiration, transpiration and enzymatic activity in fruit crops. High temperatures increase respiratory losses and induce flower and fruit drop, whereas extreme heat leads to sunburn injury and tissue damage (Alicia *et al.*, 2020). Low temperatures can cause frost and chilling injury, adversely affecting flowering and fruit development. Maintaining optimum canopy temperature is therefore essential for stable fruit production.

Relative humidity: Relative humidity plays an important role in regulating transpiration, plant cooling and overall water relations. Low humidity enhances water loss, which can result in wilting and fruit cracking, while high humidity creates favourable conditions for fungal diseases such as powdery mildew and rust. Maintaining optimal humidity levels is therefore essential for physiological balance and fruit quality.

Wind: Wind influences the orchard microclimate by regulating air movement, evapotranspiration and canopy temperature. While moderate wind enhances gas exchange and helps reduce disease incidence, strong winds increase water loss, cause mechanical damage, and interfere with pollination.

Soil temperature and soil moisture: Soil temperature plays a crucial role in seed germination, root development, nutrient uptake and microbial activity. Optimum soil temperatures (20-30 °C) promote root permeability and efficient nutrient absorption, whereas low soil temperatures limit root activity and delay plant establishment (Onwuka, 2016). Soil moisture availability directly affects plant water status, nutrient movement, and overall yield.

Microclimate modification techniques in fruit crops

Mulching: Mulching is an effective method for altering the soil microclimate in fruit crops. Organic mulches help regulate soil temperature and improve soil structure, while inorganic mulches conserve soil moisture and control weeds. Mulching has been shown to promote root growth, enhance nutrient uptake, and increase fruit yield in various fruit crops

(Prakash and Ramachandran, 2010).

Shade nets and protected structures: Shade nets help regulate light intensity and lower canopy temperature, reducing heat stress and preventing sunburn damage. They also alter light quality and relative humidity within orchards. In fruit crops such as apple, grape, and citrus, the use of shade nets has been shown to improve fruit colour, reduce cracking, and increase marketable yield (Sharma *et al.*, 2018).

Windbreaks and shelterbelts: Windbreaks decrease wind speed within orchards, reducing evapotranspiration and protecting plants from mechanical damage. Lower wind stress helps maintain stable canopy temperatures and relative humidity, thereby enhancing photosynthesis and fruit set (Veste *et al.*, 2020). Additionally, windbreaks help prevent soil erosion and improve water-use efficiency.

Irrigation-based microclimate modification: Micro-sprinkler irrigation and overhead misting systems help lower canopy temperature through evaporative cooling while increasing relative humidity. These methods enhance stomatal conductance, photosynthesis, and fruit retention during heat stress periods.

Canopy management and orchard design: Canopy management practices, including pruning, training, spacing, and row orientation, play a major role in shaping the internal microclimate of orchards. Optimized canopy structure enhances light penetration and air circulation, helping to reduce disease incidence while improving fruit colour and sugar content.

Impact on Fruit Yield and Quality: Microclimate modification has a direct influence on the physiological processes that govern fruit yield and quality. By regulating temperature and solar radiation, these interventions enhance flowering, fruit set, and fruit development. Optimized soil moisture and relative humidity further improve photosynthetic efficiency, nutrient uptake, and water use. Collectively, these effects lead to larger fruit size, better firmness, improved colour, and reduced incidence of physiological disorders such as sunburn, fruit cracking, and uneven ripening (Ghadekar *et al.*, 2018). Additionally, microclimate management can extend the fruiting period, improve post-harvest shelf life, and enhance overall marketability of the produce.

Limitations and Future Scope: Despite their clear benefits, microclimate modification techniques have certain limitations. Protected structures, shade nets, and advanced canopy management systems involve high initial investment and require skilled labour for proper operation. Plastic mulches pose disposal challenges and environmental concerns, while irrigation-based cooling systems demand reliable water sources and additional energy inputs (Sharma *et al.*, 2018). Furthermore, some techniques may be less effective in extreme or highly variable climates if not combined with other management practices.

Future research should focus on developing cost-effective, crop-specific, and region-specific microclimate management strategies. Innovations in biodegradable mulches, solar-powered cooling

systems and smart orchard monitoring (e.g., sensors for temperature, humidity, and soil moisture) could improve efficiency and sustainability. Integrating microclimate modification with precision agriculture, climate forecasting, and other climate-smart practices will be key to enhancing resilience in fruit production under increasingly unpredictable environmental conditions.

Conclusion

Microclimate modification is a vital tool for improving fruit crop productivity and quality. Techniques such as windbreaks, mulching, shade nets, irrigation-based cooling and canopy management effectively regulate temperature, humidity, radiation, wind, and soil moisture. These interventions help mitigate abiotic stresses, improve photosynthesis, and stabilize yields under variable climatic conditions. When combined with sustainable orchard management practices, integrated microclimate management can ensure climate-resilient, high-quality, and economically viable fruit production in the future. Additionally, adoption of technology-driven monitoring and adaptive strategies will further enhance the efficiency and sustainability of these interventions.

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Management of Soil Organisms for Sustainable Agricultural Productivity

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Introduction

There has been tremendous growth and development in the field of agriculture during the last few decades. In India, the shift from poverty ridden populace to self-sufficiency in food grains is often termed as green revolution. Most of the people attributed this success to improved varieties, chemical fertilizers, assured irrigation, plant protection measures and the likes of external inputs. Thus the role played by the soil microorganisms in this process has long been neglected. As a result the deteriorating soil health in particular and overall sustainability of the agricultural production system in general has gained alarming proportion in recent times. Like any other production system, agriculture is also dependent on energy. The agricultural productivity is governed by how efficiently the energy is utilized during the crop cycle. In the agricultural production system, the energy cycle begins when the sun's energy is captured by the aboveground plant-based food web. Nutrient availability is governed by the detritus-based belowground food web. The water cycle is also influenced by the interaction of plants, soils, and soil organisms. Thus, it is imperative that we should understand soil biology for enhancing agricultural productivity.

Functions of the soil organisms

Nutrient cycling: In a healthy soil ecosystem, soil biota regulates the flow and storage of nutrients in many ways. For example, they decompose plant and animal residue, fix atmospheric nitrogen, transform nitrogen and other nutrients among various organic and inorganic forms, release plant available forms of nutrients, exchange and mobilize nutrients etc. Even applied fertilizers may pass through soil organisms before being utilized by crops.

Soil stability and erosion: Soil organisms play an important role in forming and stabilizing soil structure. In a healthy soil ecosystem, fungal filaments and exudates from microbes and earthworms help bind soil particles together into stable aggregates that improve water infiltration, and protect soil from erosion, crusting, and compaction. Macropores formed by earthworms and other burrowing creatures facilitate the movement of water into and through soil. Good soil structure enhances root development, which further improves the soil.

Water quality and quantity: By improving or stabilizing soil structure, soil organism dynamics help reduce runoff and improve the infiltration and filtering capacity of soil. In a healthy soil ecosystem, soil organisms reduce the impacts of pollution by buffering, detoxifying, and decomposing potential pollutants. Bacteria and other microbes are increasingly used for remediation of contaminated water and soil.

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Plant health: A healthy soil ecosystem has a diverse soil food web that keeps pest organisms in check through competition and predation. Some soil organisms release compounds that enhance plant growth or reduce disease susceptibility. Plants may exude specific substances that attract beneficial organisms or repel harmful ones, especially when they are under stress.

Complexity and function: Many soil biological functions emerge from the complex interactions of soil organisms and are not predictable by adding up the activity of individual soil organisms. How well the soil community performs each of these functions depends in part on the complexity of the biological community. Complexity is a factor of both the number of species and the different kinds or functions of species. Greater complexity may imply more diversity of functions and therefore more stability. For example, when multiple populations of microbes convert ammonium to nitrate, even if one population dies out, the function (nitrification) will continue to be performed.

Communities of soil organisms

Soil organisms can be grouped by functions as described below:

- ✓ **Decomposers:** Bacteria, actinomycetes and saprophytic fungi degrade plant and animal residue, organic compounds, and some pesticides. Bacteria generally, but not exclusively, degrade the more readily decomposed (lower C:N ratio) materials, compared to fungi, which can use more chemically complex materials.
- ✓ **Grazers and predators:** Protozoa, mites, nematodes, and other organisms "graze" on bacteria or fungi; prey on other species of protozoa and nematodes; or both graze and prey. Grazers and predators release plant-available nutrients as they consume microbes.
- ✓ **Litter transformers:** Arthropods including insects, spiders, mites, springtails, centipedes, and millipedes shred and consume plant litter and other organic matter, increasing the surface area accessible to decomposers. The organic matter in their fecal pellets is frequently more physically and chemically accessible to microbes than was the original litter. Some litter transformers, especially ants, termites, scarab beetles, and earthworms, are "ecosystem engineers" that physically change the soil habitat for other organisms by chewing and burrowing through the soil. The microorganisms living in the guts of such litter transformers break down the plant residue, dung, and fecal pellets consumed along with the soil.
- ✓ **Mutualists:** Mycorrhizal fungi, nitrogen-fixing bacteria, and some free-living microbes have co-evolved together with plants to form mutually beneficial associations with plants. Mycorrhizae are associations between fungi and plant roots in which the fungus supplies nutrients and perhaps water to the plant, and the plant supplies food to the fungi.
- ✓ **Pathogens, parasites and root feeders:** Organisms that cause disease make up a tiny

fraction of the organisms in the soil, but have been most studied by researchers. Disease causing organisms include certain species of bacteria, fungi, protozoa, nematodes, insects, and mites.

Factors controlling biological activities in soil

People can adapt management strategies to affect the factors that control soil biological communities. Soil biological activity is determined by factors at three different levels such as:

- ✓ At the scale of individual organisms, biological activity is determined by conditions such as temperature and moisture in the microbial habitats.
- ✓ At the scale of populations, biological activity is determined by the amount of habitat diversity, the types of habitat disturbances and the diversity and interactions among various soil populations.
- ✓ At the scale of biological processes, functions such as nutrient cycling or pest control are affected by the interaction of biological populations with physical and chemical soil properties.

For example, consider the effect of tillage on earthworms at each of these scales. At the scale of individual organisms, a single tillage event may kill as many as 25 percent of individual earthworms. At the scale of populations, a single tillage pass may have little effect after a few months as the earthworms reproduce and rebuild their population. At the scale of soil processes, tillage will weaken soil structure over time and reduce the amount of surface residue available to fungi and earthworms. As fungal and earthworm activity declines, soil stability declines and alters the microhabitats for other organisms.

Microscale factors

The following environmental factors affect the types and activity levels of soil organisms. These factors may vary over short distances in the soil. Consider how each factor is impacted by climate, soil texture, time of day or season, and management practices including tillage, crop rotation, and irrigation.

Food (nutrients and energy): All organisms require a source of food that supplies nutrients and energy. A small group of bacteria get their energy from inorganic nitrogen, sulfur, or iron compounds, rather than from sunlight or organic compounds. These bacteria are important in cycling some nutrients required by plants. Soil organisms also require varying amounts of macronutrients and micronutrients. The amount of all these nutrients and the quality of nutrient sources will favor some organisms over others, depending on each species' requirements and preferences.

Oxygen: Animals and most soil organisms are obligate aerobes, meaning they require oxygen. Some bacteria are obligate anaerobes, meaning they require oxygen-free conditions to function. Many organisms are facultative anaerobes, meaning they can switch metabolic pathways and function as either aerobes or anaerobes depending on environmental conditions. Anaerobes use nitrate, sulfate, or iron instead of oxygen as an electron acceptor. Aerobic

respiration is the most common form of metabolism and typically produces ten times more energy per unit of organic matter than that generated through anaerobic metabolism.

Other physical factors: Moisture, temperature, light, pH, and electrical conductivity (salinity) are other critical factors determining the level of biological activity within an ecosystem. Each species has different optimal conditions, but overall bacterial activity is highest at temperatures between 20°C and 40°C, at pH levels between 6 and 8, and when pore spaces are about 60% water-filled. Soil texture and porosity determine the amount of space available for soil organisms and for the movement of air and water through the soil. Thus, porosity, aeration, and moisture levels are linked.

Community-scale factors

The microscale factors listed above directly affect soil organisms. However, to understand soil biological function we also have to consider large-scale factors such as heterogeneity of habitat, disturbances, and biological interactions.

Heterogeneity of resources: Heterogeneity can refer to variation in food sources or any of the other microscale conditions listed above. Heterogeneity of soil habitats creates diversity and complexity in the structure of the soil food web. Plant diversity is an important means for creating heterogeneity because plants affect the food sources, the physical habitat (e.g. root structures and soil structure), and the chemical attractants and deterrents for soil organisms.

Disturbance: All forms of land uses are subject to natural and human disturbances. The frequency, severity, and timing of disturbances determine their effect on soil biological activity. Conventional cropping systems are highly disturbed systems. Low-input, conservation tillage systems with crop rotations may be an example of an intermediately disturbed ecosystem.

Interactions with other organisms: Soil populations are affected by interactions with other soil organisms. One type of biotic interaction is competition for limited food and habitat. A second type is predation by larger organisms, such as nematodes and mites. A third type is mutualism interactions beneficial to both parties, such as those involving mycorrhizae, symbiotic nitrogen fixers, many rhizosphere microbes, and microbes living in earthworm guts. When land management practices disproportionately affect one group of organisms over another, they impact the interactions among soil organisms.

General management strategies

The diversity and functioning of a soil biological community are likely to improve when certain strategies are used. Management plans should consider both the timing of management practices and disturbances, and the duration and degree of their effects on soil biology. The effects of management and disturbances vary by season, and the capacity of the soil community to recover from a particular practice or disturbance ranges widely.

Manage organic matter: Regular inputs of organic

matter are essential for supplying the energy that drives the soil food web. Each source of organic matter favors a different mix of organisms. Thus, a variety of sources may support a variety of organisms. The location of the organic matter whether at the surface, mixed into the soil, or as roots also affects the type of organisms that dominate in the food web. Under any land use, organic matter inputs to the soil can be increased by improving plant productivity and increasing annual biomass production. In particular, good root growth is important for building soil organic matter. High biomass production should be combined with other organic matter management practices including minimizing residue removal and tillage, growing cover crops, and adding manure, mulch, or other amendments.

Manage diversity: The diversity of plant assemblages across the landscape and over time promotes a variety of microbial habitats and soil organisms. Up to a point, soil biological function generally improves when the complexity or diversity of the soil biological community increases. Many types of diversity should be considered, such as diversity of land uses, plant types, root structures, and soil pore sizes. Diversity is desirable over time as well as across the landscape. Diversity can be increased with appropriate grazing management, patchy or selective tree harvest, vegetated fencerows, buffer strips, strip cropping, and small fields. These landscape features provide refuges for beneficial arthropods. Diversity over time can be achieved with crop rotations. Rotated crops put a different food source into the soil each year, encouraging a wide variety of organisms and preventing the build-up of a single pest species.

Keep the ground covered: Ground cover at or near the surface moderates soil temperature and moisture; provides food and habitat for fungi, bacteria, and arthropods; and prevents the destruction of microbial habitat by erosion. Minimize the length of time each year that soil is bare by maintaining a cover of living plants, biological crusts, or plant residue at the surface. Living plants are especially important as cover because they create the favourable rhizosphere where soil biological activity is concentrated. Microbes around roots take advantage of plant exudates and sloughed-off root cells. Maintaining a rhizosphere environment is one of the important benefits of using cover crops. In addition to preserving microbial habitat, cover crops help build and maintain populations and diversity of arthropods by preserving their habitat for an extended portion of the growing season.

Manage disturbances: Some soil perturbations are a normal part of soil processes, or are a necessary part of agriculture and other land uses. However, some disturbances significantly impact soil biology and can be minimized to reduce their negative effects. These disturbances include compaction, erosion, soil displacement, tillage, catastrophic fires, certain pesticide applications and excessive pesticide usage.

Considerations for specific land uses

The effects of management practices, opera-

tions and natural disturbances often are specific to particular land uses.

Cropland: The highly disturbed soils of cropland may have as many bacteria and protozoa as other ecosystems, but tend to have far fewer fungi, nematodes, and arthropods. Reduced tillage and perennial cropping systems will support more of these larger soil organisms.

Crop biomass additions: Roots and surface residue from crops are convenient and valuable sources of soil organic matter and food for soil organisms. Recent research suggests that root contributions are more significant for building soil organic matter than are contributions from aboveground plant residue. Surface residue encourages the decomposers, especially fungi, and generally increases food web complexity. Residue provides food and habitat for surface-feeding organisms, such as some earthworms, and for surface-dwellers, such as some arthropods. It also changes the moisture and temperature of the soil surface, and protects soil organic matter from erosion.

Animal manure: Manure provides food and habitat for a variety of larger soil organisms. Manure in any form is a significant source of nutrients. Its application substantially changes the mix of organisms in the soil compared to plant sources of organic matter. The implications of these differences are not clear, but they probably affect disease levels and nutrient cycling. Over application of N or P (whether from organic amendments or synthetic fertilizer) can suppress certain soil organisms, especially mycorrhizal fungi, as well as lead to degradation of air and water quality.

Compost: Compost can be used to inoculate the soil with a wide variety of organisms and to provide a high quality food source for them. Some species thrive in both compost and soil, but many prefer one or the other. For example, the redworms (*Eisenia foetida*) commonly used to make vermicompost do not survive well in soil. The quality of compost varies substantially depending on the material used, peak temperature during the composting process, and the level of aeration. Organic materials decomposed with little oxygen (e.g. liquid manure) will contain a very different set of organisms and compounds than well-aerated compost.

Sewage sludge: Like manure, sludge can be an excellent food source for organisms. However, high levels of metals or salts in some sludge kill or reduce the activity of some organisms.

Cover crops: Cover crops have several positive effects on soil communities. Most soil organisms live in the rhizosphere. By planting cover crops the rhizosphere environment is available to soil organisms for a longer portion of the year. Cover crops typically increase the amount and diversity of roots and aboveground growth that become part of soil. Because of each crop's unique physiology, populations of specific soil organisms will increase or decline depending on the crop. For example, some cover crops exude compounds that inhibit disease causing organisms.

Inorganic fertilizers: Fertilizer provides some of

the nutrients needed by soil organisms and will favor those species that can best utilize the forms of nutrients found in fertilizers. The effect of acidity, alkalinity, or salt of some fertilizers tends to reduce populations of fungi, nematodes, and probably protozoa. Judicious fertilizer use can be positive for overall biological activity because it increases plant growth and organic matter inputs to the soil.

Genetically modified (GMO) crops: Each type of GMO is likely to have a different effect on soil biology. For example, Bt crops seem to have little direct effect on the composition of the soil biological community, yet decomposition rates of the crop residue differ from that of other corn varieties perhaps because of changes in plant lignin composition, which may indirectly affect soil organisms via changes in food resources. However, soil type and crop variety seem to be more important than the presence of the Bt gene in determining decomposition rates.

Drainage: Improved drainage tends to improve microbial activity by increasing oxygen availability. Poorly drained soils have a high level of anaerobic microsites and therefore a higher rate of denitrification compared to well drained soils.

Irrigation and salt build-up: Where irrigation increases plant yield, it increases biomass production and soil organic matter, and therefore tends to increase biological activity and to alter the biological community structure. However, irrigation water can contain salts. To prevent salt accumulation that can reduce biological activity and crop yield, additional water must be applied to leach these salts from the root zone. Some irrigation techniques, such as furrow irrigation, require extreme soil disturbance that is detrimental to biological habitat.

Soil inoculants: Some commercially available inocula are intended to increase populations of specific soil organisms. Inoculants will have little effect or only a temporary effect if the organisms cannot compete in their new environment. Because they must have supplies of organic matter as a food source, soils low in organic matter will not see long-lasting results unless a recurring supply of organic matter is added to the system. Furthermore, many functions performed by soil organisms result from the interactions of organisms, not from a few individual species.

Land leveling: Land leveling may have effects similar to erosion and sedimentation because biologically active surface soil is removed from some areas and deposited in other parts of the field. It may also expose subsoil with a less desirable texture or lower organic matter levels. This effect can be reduced by intense soil building practices after land leveling or by removing and stockpiling the topsoil just prior to land leveling and then spreading it over the newly leveled surface.

Terraces and grassed waterways: Permanent vegetative structures add diversity to a landscape and thus can enhance the biodiversity of the area. They serve as a refuge for larger soil organisms such as arthropods and pest predators. However, like land leveling, the soil movement involved during constru-

ction of terraces can significantly disrupt soil biological habitat.

Tillage and no-till: Tillage enhances bacterial growth in the short term by aerating the soil and by breaking apart soil aggregates to expose organic matter that had been protected from microbial decay. The bacterial activity increases the loss of carbon respired as CO_2, and triggers population explosions of bacterial predators such as protozoa. Ultimately, recurrent tillage reduces the amount of soil organic matter that fuels the soil food web. The mechanical action of tillage tends to temporarily reduce populations of fungi, earthworms, nematodes, and arthropods. Over the long term with repeated tillage, these populations are likely to decline because of the lack of surface residue rather than because of the mechanical action of tillage.

The environment for soil organisms can differ significantly in no-till compared to conventionally tilled soils. For example, because the surface soil structure is not regularly disrupted, no-till soils are more likely to have:

- ✓ Anaerobic micro-environments
- ✓ Cooler spring soil temperatures because of greater surface cover
- ✓ More macropores to facilitate infiltration
- ✓ Greater soil moisture and carbon near the surface, and
- ✓ Uneven distribution of organic matter throughout the topsoil.

In addition, surface compaction may be a problem if compaction was present before the conversion to no-till, and if biomass inputs are low or traffic patterns are not controlled. Organic matter decomposition rates are lower in no-till vs. conventionally tilled soils because of the lower level of soil disturbance. The lack of disturbance and the presence of surface residue encourage fungi and large organisms such as arthropods and earthworms. No-till soils generally have a higher ratio of fungi to bacteria.

Fallow periods: Because microbes concentrate around living roots, fallow periods of even a few weeks at the beginning or end of a growing season reduce an important microbial habitat. During long fallow periods, most arthropods will emigrate or die of starvation. Some organisms can form cysts, allowing them to lie dormant until conditions become more favorable. Mycorrhizal fungi also "starve" during a fallow period and take time to recover after the fallow period ends. Growing non-mycorrhizal plants is equivalent to a fallow year from the perspective of mycorrhizal fungi. Plants that do not support mycorrhizae include brassicas (mustard, broccoli, canola) and chenopods (beets, spinach).

Summary

Soil organisms are integral to soil processes, including nutrient cycling, energy cycling, water cycling, processing of potential pollutants, and plant pest dynamics. These processes are essential to agriculture and forestry, and for protecting the quality of water, air, and habitat. Therefore, the effects of their actions on the health and function of the soil biological community cannot be over-emph-

asized. Despite the well-known importance of soil biological processes, the development of monitoring and management guidelines is in its infancy. Soil biological health generally improves when the following management practices are applied:

- ✓ Regularly adding adequate organic matter,
- ✓ Diversifying the type of plants across the landscape and though time,
- ✓ Keeping the ground covered with living plants and residue,
- ✓ Avoiding excessive levels of disturbances including soil mixing or tillage, compaction, pesticides, heavy grazing, and residue burning.

Organic Carbon Management for Building Resilient Soil Production Systems

Mohinder Singh and Naresh Kaushik

Introduction

Soil Organic Carbon (SOC) reservoir is an important component of the global C cycle most vital indicator of soil health, yet it is in a state of crisis at present, particularly in the Indian subcontinent (1-0.3%). Therefore, enhancing and maintaining SOC concentration to above the critical threshold (~1.5% in the 0-20cm depth) is essential to improving soil quality, increasing use efficiency of nutrients and water, minimizing vulnerability to extreme climatic events, decreasing susceptibility to erosion and other degradation processes, and sustaining agronomic production. Conventional intensive agriculture has led to a substantial decline in SOC levels. Adoption of scientifically validated land management practices such as conservation agriculture, agroforestry, organic manuring, integrated nutrient management, and diversified farming systems is essential for enhancing carbon (C) sequestration in agricultural soils. Although cropland soils in India possess significant potential to store soil organic carbon (SOC), the current rates of sequestration remain modest and require rigorous evaluation across diverse soil types, climatic conditions, and production systems. In addition to organic carbon storage, the dynamics of inorganic carbon, including the formation of secondary carbonates and the leaching of bicarbonates under irrigated conditions, must be systematically quantified to obtain a comprehensive assessment of soil C dynamics. Future strategies should emphasize strengthening academic curricula at State Agricultural Universities to incorporate climate change mitigation and carbon sequestration science, establishing a dedicated Climate-Resilient Agriculture Program of National Initiative on Climate Resilient Agriculture (NICRA), and developing institutional frameworks that incentivize farmers and land managers through payments for ecosystem services, particularly for enhancing soil carbon stocks. This article examines the important role of SOC, analyses the failure triggered by its depletion, and explores how organic production technologies can restore this vital resource to build resilient and climate-smart agro-ecosystems.

Soil Organic Carbon: Impact and Factor effecting it

India is currently facing widespread land degradation that threatens the livelihoods of millions. National mapping data from the Ministry of

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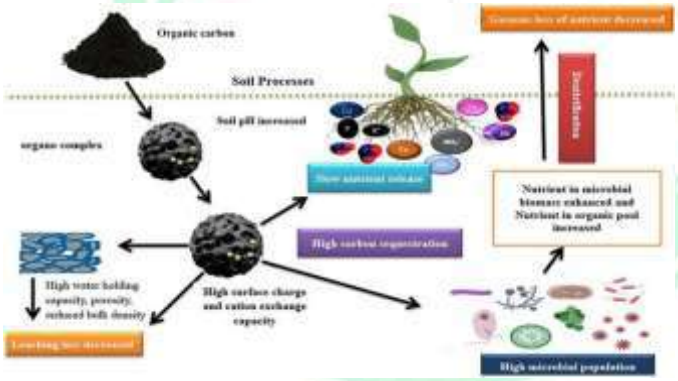
Environment and Forests indicates that approximately 97.8 million hectares nearly 29.8% of India's total geographical area are affected by degradation processes such as water and wind erosion, salinization, waterlogging, and vegetation loss. A primary driver of this degradation is the catastrophic decline in SOC levels. Long-term trends and regional studies, including those by ICRISAT, highlight a substantial drop in SOC across Indian agricultural soils compared to historical levels. Most alarming is data from the National Rainfed Area Authority (NRAA), which shows that SOC levels in India have plummeted from an average of 1.0% to a meagre 0.3% over the past 70 years. This decline is most pronounced in arid regions and areas subjected to intensive "Green Revolution" style cultivation, where the soil's capacity to buffer against drought and erosion has been severely compromised.

SOC impact on Soil physical properties: Soil organic carbon (SOC) dynamics are governed by the balance between carbon inputs and outputs within the soil-plant-atmosphere system. Carbon inputs arise primarily from above- and belowground crop residues, animal manures, composts and other organic amendments, while outputs occur through erosion by wind and water, gaseous losses from microbial and root respiration and leaching processes. Residue decomposition generally follows an exponential decay pattern and is strongly influenced by residue quality, soil and water management practices, soil type, and climatic conditions. Biochemical characteristics of residues particularly the carbon-to-nitrogen (C:N) ratio, and the concentrations of cellulose, lignin, and polyphenols play a critical role in regulating decomposition rates. High C:N residues such as wheat and maize typically decompose more slowly than low C:N residues from legumes. Management practices including residue shredding, incorporation, retention, or removal further influence SOC turnover. Historical intensive tillage and land-use change from native perennial vegetation to cultivated systems have reduced SOC stocks by nearly 50% in many soils. Moreover, SOC accumulation tends to be slower in clayey, compact, and poorly drained soils compared with coarse-textured or sloping soils. Under many cultivated conditions, less than 10% of crop residue carbon may ultimately be stabilized as SOC. It has pronounced effects on soil physical properties, particularly aggregation, compaction resistance, and water retention. Organic matter acts as a binding agent, facilitating macroaggregate formation and reducing susceptibility to slaking and surface sealing. Improved aggregation preserves surface-connected macropores, enhancing water infiltration, precipitation capture, and reducing runoff. Higher SOC levels are also associated with reduced soil compatibility and lower bulk density, as demonstrated in long-term conservation systems incorporating cover crops. Increased SOC raises the critical water content at which compaction occurs, making soils more resilient under mechanical stress. Furthermore, due to its lower density relative to mineral particles and its high water-holding capacity, SOC substantially

improves soil moisture retention. Even small increases in SOC can significantly enhance plant-available water, thereby mitigating the impacts of droughts, intense rainfall events and soil degradation, particularly in surface layers where SOC concentration is highest.

Organic carbon impact on Soil Biochemical Attributes: Variations in soil organic carbon (SOC) concentration are closely linked to changes in soil chemical and biological properties. SOC constitutes nearly 58% of soil organic matter and serves as the primary driver of numerous biochemical processes within the soil system. While the influence of SOC on soil chemical properties has been extensively documented, its role in regulating microbial dynamics and biological processes is equally critical. Changes in SOC levels directly affect microbial biomass, community composition and soil respiration rates. Management practices that enhance SOC, such as no-till and residue retention, often stimulate microbial activity, particularly in surface soil layers where organic inputs accumulate. Strong correlations have been reported between SOC concentration and soil enzyme activities, such as invertase, under long-term conservation tillage systems. Similarly, soil microbial biomass has been shown to co-vary with SOC across diverse agricultural fields. Specific microbial groups respond differently to SOC fractions: bacterial and actinomycete populations are more closely associated with fine particulate organic matter, whereas fungal and mycorrhizal communities are linked with coarse particulate organic matter fractions. These SOC-driven changes in microbial activity regulate nutrient transformations, organic matter turnover, and overall soil resilience. A reciprocal relationship exists between SOC and soil biochemical processes. SOC provides both habitats, through stable aggregate formation, and substrate for microbial communities, while microbial processes govern SOC decomposition and stabilization. Additionally, SOC significantly influences soil chemical properties such as pH buffering capacity and cation exchange capacity (CEC). Higher SOC levels enhance the soil's ability to retain and exchange nutrients, thereby improving fertility. SOC also plays a crucial role in mitigating environmental pollution. Due to its high specific surface area and net negative charge, organic matter effectively adsorbs cations and organic contaminants, including pesticides and herbicides, thereby reducing nonpoint source pollution and improving water quality. Compared with clay minerals, organic matter exhibits a greater capacity to bind pollutants. Overall, SOC is central to regulating chemical reactions, microbial processes and environmental functions that determine soil behaviour and sustainability. Beyond its recognized role in climate change mitigation, SOC is fundamental to maintaining soil health through its influence on physical, chemical, and biological processes. Increasing SOC enhances aggregation, reduces compaction, regulates water and gas exchange, minimizes surface sealing and crusting, moderates shrink–swell behaviour, reduces erosion and stimulates microbial activity and pollut-

ant biodegradation. Improvements in one soil property due to SOC often trigger positive changes in other interrelated properties. For instance, enhanced aggregate stability increases micro-porosity, promotes infiltration and supports microbial processes. A reciprocal relationship exists whereby SOC promotes aggregate formation, and stable aggregates protect SOC from decomposition. The magnitude of these benefits varies with soil texture, clay mineralogy, SOC fractions (labile and stable pools), and climate. In soils with high clay content and specific surface area, incremental increases in SOC may yield comparatively smaller improvements than in silt loam soils.



Source: https://www.researchgate.net/publication/368476209/figure/fig2/AS:11431281242333304@17154 2 9853644

Tillage and Soil Organic Carbon Dynamics: Tillage practices exert a profound influence on soil health and soil organic carbon (SOC) dynamics. Continuous and intensive soil disturbance accelerates the oxidation of soil organic matter (SOM), increases CO_2 emissions, disrupts soil structure, and enhances susceptibility to erosion, subsoil compaction and reduced infiltration capacity (Blanco-Canqui and Lal, 2008). Conventional tillage (CT), which typically involves deep inversion using mouldboard or disk ploughs followed by secondary tillage operations, exposes protected organic matter to rapid decomposition and degrades soil physical integrity. Long-term reliance on CT has been widely recognized as unsustainable, particularly in Mediterranean and semi-arid regions, where it contributes to SOM depletion, nutrient loss, microbial disruption, and hardpan formation (Kassam *et al*., 2009).

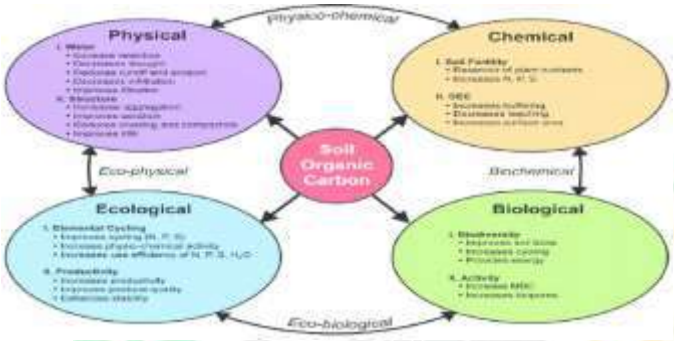
Conservation tillage systems, including no-tillage (NT) and reduced tillage (RT), have been promoted as sustainable alternatives that enhance SOC sequestration, reduce CO_2 emissions, and support low-carbon agriculture. Numerous long-term studies demonstrate that NT improves SOC content, aggregate stability, hydraulic properties, nutrient retention, microbial biomass, and enzyme activities compared with CT. These benefits are amplified when NT is combined with effective residue retention, balanced fertility management, and diversified cropping systems. SOC sequestration rates under NT are often highest during the first 5-10 years following adoption (Pittelkow *et al*., 2015; Govaerts *et al*., 2009, Govaerts *et al*., 2009).Reduced tillage (RT) represents an intermediate approach between NT and CT and has gained attention as a flexible conservation option. RT practices, such as shallow disking, can enhance aggregation and SOC stocks relative to CT, although generally to a lesser extent than NT. Increasingly, research has examined shifts between tillage systems, including transitions from CT to NT or RT, and more recently, tillage

reversal from NT back to tillage due to management constraints. Occasional or strategic tillage in long-term NT systems is sometimes used to alleviate compaction, nutrient stratification, weed pressure, or pest issues (Dang *et al*., 2015). However, the long-term implications of permanent transitions from NT to RT on SOC and soil health remain insufficiently documented.

Crop Diversification and Soil Organic Carbon Dynamics: Cropping systems are another major determinant of soil health and SOC dynamics. Diversification through inclusion of pulses and oilseeds in cereal-based systems has been advocated to improve soil properties and ecosystem. Crop rotation, particularly diversified crop rotations (three or more crops), is a core principle of conservation agriculture. Such rotations enhance SOC accumulation, nutrient cycling, microbial diversity, and enzyme activity compared with monoculture or simple rotations (Congreves *et al*., 2015). Global syntheses suggest that increasing crop rotation complexity can raise SOC by approximately 0.15 ± 0.11 t C ha^{-1} yr^{-1}, a rate comparable to NT adoption. Legumes play a pivotal role in diversified rotations due to their capacity for biological nitrogen fixation, which improves soil fertility and reduces reliance on synthetic fertilizers. Despite clear benefits, the extent to which crop diversification influences the distribution of SOC among particulate and mineral-associated fractions requires further investigation. Integrating conservation tillage with diversified crop rotations offers a synergistic pathway for improving soil health, enhancing SOC sequestration, and promoting sustainable agricultural production (Diop *et al*., 2026).

Residue burning and its effect: Crop residue burning is widely practiced after rice and wheat harvest, yet its implications for soil quality and ecosystem functioning remain a concern, particularly in arid and semi-arid agroecosystems. This study assessed the impact of residue burning on soil physicochemical properties, microbial communities, and CO_2 emissions. Comparative analyses conducted before and after burning revealed measurable alterations in soil characteristics. A consistent shift in soil texture from silty clay loam to clay loam was observed, primarily due to a reduction in silt fraction following burning. Tawfeeq *et al*., (2025) reported that soil organic matter (SOM) declined significantly from 15.63 ± 0.87 to 11.78 ± 0.28 g kg^{-1} ($p \leq 0.05$). Similarly, magnesium concentration decreased markedly from 0.18 ± 0.02 to 0.06 ± 0.02 mmol L^{-1} ($p \leq 0.05$). In contrast, soil pH, electrical conductivity, calcium, potassium, and nitrogen showed no significant changes. Microbial populations, including bacteria, fungi and actinomycetes, exhibited relative resilience, with no statistically significant differences in abundance immediately after burning. However, CO_2 flux measurements indicated an initial surge in CO_2-C release, attributed to rapid microbial decomposition of thermally altered organic substrates, followed by a slower mineralization phase over time. The influence of residue burning on soil health was

closely associated with soil texture, which governs carbon retention, nutrient availability, and microbial habitat. Fine-textured soils such as silty clay loam typically preserve higher SOM and nitrogen due to reduced aeration and slower decomposition, whereas structural changes toward relatively coarser conditions accelerate organic matter loss. Alterations in texture can therefore modify microbial activity and carbon turnover, ultimately affecting soil resilience and fertility.



Source: https://www.researchgate.net/publication/311665037/figure/fig4/AS:439599660048384@1481820134039/mpacts-of-soil-organic-carbon-pool-on-improvements-of-soil-physical-chemical.png

Effect of Different Fertilizer types on Organic Carbon: Soil aggregates play a central role in stabilizing soil organic carbon (SOC) and regulating nutrient cycling, microbial activity, and water movement. Fertilization practices strongly influence how organic carbon is distributed among aggregate size fractions and, consequently, the stability of SOC in soils. Evidence from long-term studies and meta-analyses indicates that organic fertilizers, inorganic fertilizers, their combinations, and straw return all enhance the organic carbon (OC) content of macroaggregates (>2 mm and 0.25-2 mm) and microaggregates (0.053-0.25 mm) compared with unfertilized soils. Among treatments, the combined application of organic and inorganic fertilizers (NPKM) exerts the greatest positive effect, followed by organic manure (M), integrated NPK with straw (NPKS), straw alone (S), and NPK alone. In unfertilized soils, root residues and exudates are the primary carbon inputs. However, root exudates can stimulate microbial decomposition of existing SOC, partly offsetting carbon gains. Fertilization increases crop biomass, root turnover, and residue returns, thereby enhancing carbon inputs. Organic fertilizers directly contribute exogenous carbon and improve soil biological activity, enzyme activity, and nutrient status, creating favourable conditions for SOC accumulation. Compared to straw, organic manure often has a more balanced C/N ratio due to prior decomposition, making it more readily utilizable by soil microbes without competing with crops for nitrogen. Macroaggregates show greater OC enhancement than microaggregates and silt-clay fractions under organic and combined fertilization. Larger aggregates provide better aeration, infiltration, and structural stability, making them sensitive indicators of management-induced changes in SOC. Over time, organic carbon from residues and manures first accumulates in macroaggregates, then gradually migrates into microaggregates and finally into silt and clay fractions as decomposition proceeds. The duration of fertilization also affects OC dynamics. Long-term inputs increase OC content in macroaggregates, whereas silt and clay fractions exhibit a saturation trend after several years. These

finer fractions, protected by mineral associations, reach carbon saturation earlier than larger aggregates. Carbon associated with silt and clay is more stable due to physicochemical protection, while macroaggregate-associated carbon is more dynamic and prone to microbial turnover. Climatic conditions further modulate these effects. Under cooler and drier conditions, organic inputs enhance OC accumulation in macro- and microaggregates due to slower decomposition rates. In contrast, high temperature and moisture accelerate microbial activity and SOC mineralization, particularly in smaller aggregates. Soil texture also governs OC stabilization. Sandy loam soils respond strongly to organic inputs in macroaggregates due to greater pore space for carbon incorporation, whereas clay loam soils, with higher nutrient and water retention, promote aggregation and SOC stabilization across aggregate sizes. Land-use type influences these responses as well. In well-aerated upland soils, organic and integrated fertilization consistently increases OC across aggregate fractions. In contrast, paddy soils under prolonged chemical fertilization may experience reductions in OC in smaller aggregates due to faster aggregate turnover and SOC mineralization.

Conclusions

Even short-term residue removal in long-term no-till systems led to measurable SOC losses, increased compaction, and reduced microbial efficiency. Crop residue retention is therefore critical for maintaining SOC stocks, soil structure, and biological functioning. Long-term monitoring is recommended to quantify absolute SOC change, but current evidence strongly supports residue retention as a cornerstone of sustainable no-till management. These findings demonstrate that residue burning adversely affects key soil properties, particularly SOM and magnesium both essential for maintaining soil fertility and structural stability. Over time, such changes may reduce carbon sequestration potential, disturb nutrient cycling, and compromise soil resilience. Despite the widespread prevalence of residue burning, evidence regarding its long-term impacts in semi-arid regions remains limited and sometimes inconsistent. Overall, both natural factors (climate, texture) and management factors (fertilizer type, duration, and land use) regulate SOC distribution in soil. Organic and integrated nutrient management practices are particularly effective in promoting carbon accumulation in macroaggregates, which later contributes to more stable SOC pools. So, it is the need of time for adopting sustainable residue management practices to preserve soil health and ensure long-term agricultural productivity.

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From Forest Vines to Global Tables: The Story of Black Pepper

M. Kabilan

Introduction

Black pepper is so familiar today that it is easy to forget how extraordinary its journey has been. Sitting quietly on dining tables across the world, it seasons food almost invisibly, added without ceremony to soups, vegetables, meats and marinades. Yet this unassuming spice once commanded the attention of kings, fueled long-distance trade, shaped global exploration and linked forest communities to far-off civilizations. Known for centuries as the King of Spices, black pepper is a powerful reminder that even the smallest agricultural product can leave a deep imprint on human history. The story of black pepper begins not in ports or markets, but in dense tropical forests, where climbing vines wound themselves around tall trees under the shade of rainforest canopies. From these forest origins, pepper traveled across oceans and continents, transforming cuisines, economies and cultures. This article traces that remarkable journey from wild forest vines to carefully cultivated farms, from ancient trade routes to modern global kitchens revealing how black pepper became one of the most influential spices the world has ever known.

Forest Origins: Where Pepper was Born: Black pepper is native to the humid evergreen forests of the Western Ghats, a mountain range running parallel to India's western coast. This region, now recognized as one of the world's biodiversity hotspots, provided the precise ecological conditions pepper needed to thrive: warm temperatures, high humidity, rich organic soils and natural shade. In its wild form, pepper grew as a perennial climber, using forest trees as living supports. The vine produced long spikes of berries that matured slowly under filtered sunlight. These berries, when dried, developed the pungent aroma and sharp heat that define black pepper. Indigenous forest communities were the first to recognize pepper's value. Initially, it was gathered from the wild and used sparingly to flavor food, preserve meat and treat digestive ailments. At this stage, pepper was not yet a global commodity it was a forest treasure, deeply embedded in local food habits and traditional knowledge systems.

Early Domestication: From Wild Vine to Managed Crop: Unlike many crops that were domesticated through large-scale land clearing, black pepper followed a more subtle path. Early cultivators realized that pepper thrived best under forest-like conditions. Instead of removing trees, they retained shade and planted pepper vines alongside existing vegetation. This method of cultivation later recognized as an early form of agroforestry allowed pepper to retain its natural growth habits while benefiting from human care. Farmers selected vines with better yield, stronger aroma and disease

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tolerance, gradually improving quality over generations. By the time organized societies emerged in South India, black pepper had already transitioned from forest produce to cultivated spice. Its value was recognized not only for flavor, but also for its preservative and medicinal properties, making it an important commodity long before global trade networks expanded.

Pepper in Ancient Civilizations: As trade networks developed within the Indian subcontinent, black pepper moved beyond forest regions into towns, cities and royal courts. It became an essential part of regional cuisines, enhancing taste and aiding digestion. Its warming nature made it particularly valuable in tropical climates, where food spoilage and digestive discomfort were common. Traditional medical systems incorporated black pepper as a key ingredient. It was believed to stimulate appetite, improve metabolism, clear respiratory passages and enhance the effectiveness of other herbs. This dual identity as both spice and medicine greatly increased its demand. Pepper soon began to travel beyond India's borders. Traders carried dried pepper berries along land routes to Central Asia and by sea to the Middle East. There, it entered new culinary traditions and gained a reputation as a luxury spice, affordable only to the wealthy.

The Spice that Connected Worlds: Black pepper's journey from regional spice to global commodity accelerated with the expansion of maritime trade. Arab traders played a crucial role in transporting pepper across the Indian Ocean, establishing trade links between South Asia, the Middle East and Europe. In ancient and medieval Europe, black pepper was prized not only for flavor but also for its perceived medicinal and preservative qualities. It was used to mask the taste of preserved foods and symbolized wealth and sophistication. At times, pepper was so valuable that it was used as currency, tribute and dowry. This demand transformed pepper into a driver of global exploration. European powers, eager to bypass intermediaries and access pepper directly, searched for sea routes to India. These voyages reshaped world history, linking continents and laying the foundations for colonial trade systems. Thus, a forest vine from South Asia became a catalyst for global connectivity, altering the course of economics, politics and cultural exchange.

Cultivation Expands but Forest Wisdom Remains : As pepper demand grew, cultivation expanded beyond wild forest edges into managed farms. Yet, even with expansion, the crop retained its dependence on shade and moisture. Farmers continued to grow pepper as a climber, using living trees or supports rather than open-field systems. In regions like Western Ghats, pepper farms often blended seamlessly with forest vegetation. Tall shade trees provided microclimatic stability, protecting vines from excessive heat and wind. Leaf litter enriched the soil, while biodiversity helped regulate pests and diseases. This ecological compatibility distinguished black pepper from many later plantation crops. While productivity could be improved, the crop resisted complete industrialization, remaining closely tied to

natural systems.

From Berry to Spice: Processing and Transformation: The transformation of fresh pepper berries into black pepper is deceptively simple yet critical to quality. Harvested when berries begin to turn from green to yellow, pepper spikes are collected by hand. The berries are then separated and dried. During drying, enzymatic reactions and moisture loss cause the outer skin to darken and wrinkle, forming the familiar black peppercorn. Proper drying preserves aroma, pungency and shelf life. Traditional sun-drying methods are still widely used, reflecting the continuity of age-old practices. This minimal processing preserves pepper's natural compounds, ensuring that its flavor and functional properties remain intact. The simplicity of processing also contributes to pepper's enduring appeal across cultures.

Flavor, Fire and Chemistry: Black pepper's distinctive heat comes primarily from piperine, a natural alkaloid concentrated in the outer layers of the peppercorn. Unlike the sharp burn of chili peppers, pepper's heat is warm, lingering and aromatic. Beyond pungency, black pepper offers complexity. Its flavor profile includes woody, citrusy and slightly floral notes that vary depending on origin, climate and cultivation practices. This complexity makes black pepper uniquely versatile, enhancing almost any dish without overpowering it. Modern science has validated many traditional claims about black pepper. Piperine has been shown to improve nutrient absorption, particularly of compounds like curcumin. Antioxidant and antimicrobial properties further support pepper's reputation as both food and medicine.

Black Pepper in Global Cuisines: Few spices are as universally used as black pepper. From Indian curries and European soups to Asian stir-fries and American grills, pepper transcends culinary boundaries. It adapts to local tastes, pairing equally well with vegetables, meats, seafood and even some desserts. This universality stems from pepper's balance. It adds depth without dominating, warmth without bitterness and aroma without heaviness. As cuisines evolved and globalized, black pepper remained constant, a familiar anchor amid changing flavors. In modern kitchens, pepper is often taken for granted, yet its absence is immediately noticeable. This quiet indispensability speaks to its enduring culinary power.

Economic Importance and Farmer Livelihoods: Despite its small size, black pepper remains a high-value crop. For farmers in hilly and forest-adjacent regions, it offers an important source of income. Pepper vines, once established, can produce for many years, providing long-term returns. Pepper cultivation supports a wide network of livelihoods from nursery operators and farm laborers to traders and exporters. In many regions, it forms the backbone of mixed farming systems, grown alongside coffee, arecanut, coconut and fruit trees. However, pepper farming is not without risk. Yield fluctuations, pest pressures, climate variability and volatile market prices can threaten farmer stability.

These challenges highlight the need for resilient production systems and fair market access.

Colonial Trade and Changing Power: The global pepper trade reached new heights during the colonial period. European powers established control over spice-producing regions, reorganizing production and trade to serve distant markets. While this expanded pepper's global reach, it often disrupted local systems and concentrated profits elsewhere. Over time, producing regions regained greater control, but the legacy of colonial trade still influences market structures and pricing. Understanding this history is essential to appreciating the complex dynamics that continue to shape the spice trade today.

Sustainability and the Future of Pepper: In the modern era, black pepper faces new challenges. Climate change threatens rainfall patterns and temperature stability, directly affecting vine health and yield. Diseases and pests have become more severe in some regions, particularly where biodiversity has declined. Yet pepper also offers solutions. Its compatibility with agroforestry makes it well-suited to sustainable farming models that emphasize soil health, biodiversity and climate resilience. Shade-grown pepper systems can sequester carbon, conserve water and support wildlife while producing valuable crops. Revitalizing pepper cultivation requires combining traditional ecological knowledge with modern science. Improved planting material, better disease management and farmer-centered extension services can help secure the crop's future.

From Local Spice to Global Staple

Today, black pepper is produced and consumed across the world, yet its heart remains in the forests where it first evolved. Even as it travels thousands of kilometers to reach global markets, its essence reflects tropical rains, shaded soils and careful human stewardship. Consumers may sprinkle pepper without a second thought, but each grain carries centuries of history of forest gatherers, traders, sailors, farmers and cooks. Few food items embody such a rich intersection of nature, culture and commerce.

Conclusion

From forest vines climbing ancient trees to global tables set in distant lands, black pepper's story is one of continuity and transformation. It has survived shifts in empires, cuisines and technologies, adapting without losing its identity. Black pepper's true power lies not only in its pungency, but in its ability to connect worlds. It links forests to farms, farmers to consumers and past traditions to modern lifestyles. In an age of rapidly changing food systems, black pepper stands as a reminder that enduring value often grows slowly, nurtured by nature and human care alike. The next time black pepper is added to a meal, it is worth pausing to remember its journey a journey that began in shaded forests and continues, quietly but powerfully, on plates around the world.

Concept of Essentiality and Classification of Mineral Nutrients

Karamveer and Ravinder Kaur

Abstract

Mineral nutrients play a crucial role in the proper growth and development of plants. These nutrients control physiological processes, facilitate metabolic functions, and ensure the successful completion of the life cycle of plants. The concept of essentiality assists in determining which mineral nutrients are absolutely necessary for plant growth and which are required under certain conditions. This article describes the concept of essentiality, the criteria for essential nutrients, and the classification of mineral nutrients based on their requirement, function, and mobility in plants. A proper understanding of these concepts is essential for proper nutrient management.

Introduction

For plants to develop, reproduce, and yield economic produce, they need a steady diet of nutrients. Although carbon, hydrogen, and oxygen are derived from air and water, the other nutrients are taken from the soil in the form of mineral ions. A deficiency or imbalance in these nutrients can prove detrimental to plant health and productivity. To deal with plant nutrients in a scientific manner, it is necessary to understand which elements are required by plants and how they behave in the plant system. The idea of essentiality offers a scientific approach to determining the essential mineral elements, while classification enables an understanding of their functions and applications in agriculture.

Concept of Essentiality of Mineral Nutrient

The concept of essentiality was introduced to differentiate essential elements from nonessential elements. As per this concept, a mineral element can be labelled as essential only if it fulfils certain criteria.

- ✓ Firstly, the plant should not be able to complete its life cycle without the presence of that element.
- ✓ Secondly, the role of that element should be unique and cannot be replaced by any other element in plant metabolism.
- ✓ Thirdly, that element should be directly involved in plant metabolism. It can be a part of essential organic compounds, take part in enzyme systems or control major physiological processes.

Those elements that do not fully satisfy the above criteria but help in improving plant growth or stress tolerance are known as beneficial elements. These include sodium, silicon, and cobalt in some plant species.

Classification of Mineral Nutrients

Classification Based on Quantity Required

Macronutrients: Macronutrients are needed in larger quantities and comprise more than 0.1 percent of the total dry weight of the plant.

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- ✓ The primary macronutrients are nitrogen, phosphorus, and potassium. These elements are primarily responsible for vegetative growth, metabolism and plant vigour.
- ✓ The secondary macronutrients are calcium, magnesium, and sulphur. These elements are necessary for plant growth, chlorophyll synthesis and protein synthesis.

Micronutrients: Micronutrients are required in minute quantities but are as essential as macronutrients for plant growth. Micronutrients include iron, manganese, zinc, copper, boron, molybdenum, chlorine, and nickel. A deficiency of micronutrients can lead to severe physiological disorders in plants.

Classification Based on Functional Role

- ✓ Certain nutrients like nitrogen, phosphorus, and sulphur are a part of organic molecules such as proteins, nucleic acids, and ATP.
- ✓ Elements like potassium, magnesium, zinc, and manganese function primarily as activators of enzymes.
- ✓ Calcium is a part of cell wall and membranes, while magnesium is the central part of the chlorophyll molecule.
- ✓ Iron and copper are important in oxidation and reduction reactions of photosynthesis and respiration.

Classification Based on Mobility in Plants

- ✓ Nutrients such as nitrogen, phosphorus, potassium and magnesium are mobile in plants. The deficiency symptoms of these nutrients are visible on older leaves.
- ✓ Calcium, iron, and boron are less mobile. The deficiency symptoms of these nutrients are visible on younger leaves.

Conclusion

The idea of essentiality offers a scientific basis for comprehending the mineral needs of plants. The categorization of mineral nutrients according to the amount, role, and mobility of the nutrients is beneficial for identifying deficiencies and implementing fertilization practices. Adequate knowledge of essential mineral nutrients is vital for enhancing crop yields, sustaining soil fertility, and developing a sustainable agricultural system.

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Integrated Nutrient Management for Healthy Soils

M. A. Ajabe and N. M. Maske

Abstract

Soil health is the cornerstone of sustainable agriculture and long-term food security. Intensive farming practices and excessive reliance on chemical fertilizers have led to soil degradation, nutrient imbalances and declining productivity. Integrated Nutrient Management (INM) offers a holistic approach to maintaining soil fertility by combining chemical fertilizers, organic manures, crop residues, green manures and biofertilizers in a balanced manner. INM not only ensures the efficient supply of essential nutrients to crops but also improves soil physical, chemical and biological properties. By enhancing soil organic matter, microbial activity and nutrient-use efficiency, INM contributes to improved crop yields, reduced environmental pollution and sustainable resource use. In this article covered the principles, components and benefits of Integrated Nutrient Management and highlights its role in restoring and maintaining healthy soils for sustainable agricultural systems.

Introduction

Soil is a living and dynamic system that supports plant growth by supplying nutrients, water and a favorable physical environment. However, modern agricultural practices focused on high-input chemical fertilizers have caused serious concerns such as nutrient depletion, soil acidity, salinity, loss of organic matter and reduced microbial activity. These problems threaten soil health and long-term agricultural sustainability. Integrated Nutrient Management (INM) has emerged as an effective strategy to address these challenges by promoting balanced nutrient application through the combined use of organic, inorganic and biological nutrient sources. INM aims to optimize crop nutrition while minimizing nutrient losses and environmental impacts. By improving soil structure, nutrient availability and biological activity, INM enhances soil resilience and productivity. In the context of climate change, population growth and declining soil fertility, INM plays a vital role in sustaining agricultural production while conserving soil and environmental resources.



Fig. 1: Components of an integrated nutrient management (INM)

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Impact of Integrated Nutrient Management on Soil Health

Improvement in Soil Organic Matter: The inclusion of organic manures, compost and crop residues increases soil organic matter content. Higher organic matter improves soil structure, aggregation and porosity, leading to better aeration and root penetration. It also enhances water-holding capacity and nutrient retention.

Enhanced Nutrient Availability: INM ensures a continuous and balanced supply of macro- and micronutrients. While chemical fertilizers provide immediate nutrient availability, organic sources release nutrients slowly, reducing losses through leaching and volatilization. This synchronized nutrient release improves nutrient-use efficiency.

Stimulation of Soil Microbial Activity: Organic inputs and biofertilizers promote the growth and activity of beneficial soil microorganisms such as bacteria, fungi and actinomycetes. These microbes play a key role in nutrient cycling, organic matter decomposition and the production of plant growth-promoting substances.

Balanced Soil Chemical Properties: Integrated use of nutrient sources helps maintain soil pH and reduces problems like soil acidity or salinity caused by the continuous use of chemical fertilizers. Organic amendments buffer soil reactions and improve cation exchange capacity.

Improved Soil Physical Properties: The addition of organic materials enhances soil aggregation, reduces bulk density and improves infiltration rates. This leads to better root development and reduces soil erosion and surface runoff.

Reduced Environmental Pollution: INM minimizes excessive fertilizer application, thereby reducing nutrient losses to water bodies and lowering greenhouse gas emissions. Efficient nutrient management helps prevent nitrate leaching and phosphorus runoff, protecting soil and water quality.

Improved Crop Productivity and Sustainability: By ensuring balanced nutrition and healthier soils, INM supports stable crop yields over time. Improved soil health enhances plant resilience to stress conditions such as drought, pests and diseases, contributing to sustainable farming systems.

Contribution to Climate-Resilient Agriculture: Enhanced soil organic carbon through INM increases carbon sequestration potential. Healthy soils with better structure and biological activity are more resilient to climate variability, making INM an important component of climate-smart agriculture.

Conclusion

Integrated Nutrient Management is a practical and sustainable approach for maintaining soil health and ensuring long-term agricultural productivity. By combining organic, inorganic and biological nutrient sources, INM improves soil physical, chemical and biological properties while reducing environmental risks. Healthy soils supported through INM not only enhance crop yields but also strengthen ecosystem services and climate resilience. Adoption of INM practices, supported by soil testing and farmer awareness, is essential for

sustainable agriculture and food security in the future.

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Crop Physiology-Based Strategies for Food Security under Climate Change

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Abstract

Climate change is emerging as one of the most serious threats to global food security. Increasing temperatures, unpredictable rainfall, frequent droughts and floods, and extreme weather events are directly affecting crop growth and productivity. Crop physiology, which focuses on the functional processes of plants, helps us understand how crops respond to these environmental stresses. By applying physiological concepts such as stress tolerance, water use efficiency, photosynthetic efficiency, and nutrient use efficiency, it is possible to develop strategies that support sustainable food production under changing climatic conditions. This article highlights the role of crop physiology-based approaches in achieving food security in the era of climate change.

Introduction

Food security refers to a situation where all people have continuous access to sufficient, safe, and nutritious food required for a healthy life. Climate change seriously threatens food security by influencing crop growth, yield stability, and quality. Variations in temperature, rainfall patterns, atmospheric carbon dioxide (CO_2) concentration, and the increasing occurrence of droughts, heat waves, and floods directly affect important plant physiological processes such as photosynthesis, respiration, transpiration and nutrient uptake. Crop physiology provides valuable insights into how plants respond to such stresses and how these responses can be managed or improved. Using this knowledge, scientists can develop climate-resilient crop varieties, while farmers can adopt improved crop management practices. Therefore, crop physiology plays a vital role in ensuring food security under changing climatic conditions.

Crop Physiology-Based Strategies

Improving Photosynthetic Efficiency: Photosynthesis is the foundation of crop productivity and yield formation. Climate change affects this process through high temperatures, water stress, and altered CO, levels.

Strategies

- ✓ Development of crop varieties with improved photosynthetic efficiency
- ✓ Promotion of C4 and CAM plants in hot and dry regions
- ✓ Improvement of leaf structure and canopy architecture for better light interception
- ✓ Proper crop spacing and row orientation to minimize shading

Impact: Enhanced photosynthesis results in greater biomass production and improved yield, even under stressful environmental conditions.

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Enhancing Water Use Efficiency (WUE): Water scarcity is one of the most serious challenges posed by climate change. Crop physiology helps explain how plants absorb, transport, and utilize water efficiently.

Strategies

- ✓ Development of drought-tolerant varieties with deep and efficient root systems
- ✓ Selection of crops with higher water use efficiency
- ✓ Use of mulching and antitranspirants to reduce water loss
- ✓ Adoption of efficient irrigation methods such as drip and sprinkler systems

Impact: Improved water use efficiency allows crops to produce higher yields with limited water availability, especially in drought-prone areas.

Developing Stress-Tolerant Varieties: Crops are continuously exposed to various environmental stresses that limit productivity.

Types of Stresses

Abiotic stresses: Drought, heat, cold, salinity and flooding

Biotic stresses: Pests, diseases, weeds

Physiological Mechanisms

- ✓ Accumulation of osmoprotectants such as proline and sugars
- ✓ Synthesis of heat shock proteins under high temperatures
- ✓ Better stomatal regulation to control water loss
- ✓ Strong antioxidant defense systems to reduce oxidative damage

Impact: Stress-tolerant crop varieties can withstand extreme conditions and help maintain stable yields under climate uncertainty.

Efficient Nutrient Use: Climate change influences nutrient availability in soil and their uptake by plants. Efficient nutrient use is essential for sustainable crop production.

Strategies

- ✓ Breeding crops with well-developed root systems for improved nutrient absorption
- ✓ Improving nutrient use efficiency (NUE), especially nitrogen use efficiency
- ✓ Balanced fertilizer application based on soil testing Use of organic manures and biofertilizers

Impact: Efficient nutrient use reduces production costs, improves crop yield and minimizes environmental pollution.

Climate-Smart Cropping Practices: Crop physiology also supports the adoption of better crop management practices suited to changing climates.

Strategies

- ✓ Adjustment of sowing dates according to weather patterns
- ✓ Crop diversification and intercropping systems
- ✓ Use of short-duration varieties to escape stress periods
- ✓ Adoption of conservation agriculture practices such as minimum tillage and residue retention

Impact: These practices reduce production risks and enhance food security under variable and unpredictable climatic conditions.

Conclusion

Climate change presents a major challenge to global food security, particularly in developing countries. Crop physiology offers a scientific under-standing of how plants respond to environ-mental stresses and how these responses can be improved. By enhancing photosynthetic efficiency, water and nutrient use efficiency, and stress tolerance, crop physiology-based strategies support the development of climate-resilient crops and sustainable agricultural systems. The adoption of these approaches by farmers, researchers and policy-makers is essential to ensure stable food production and food security for present and future generations.

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Cape Gooseberry (*Physalis peruviana* L.): An Emerging High-Valued Fruit Crop

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Abstract

Cape gooseberry (*Physalis peruviana* L.), a member of the family Solanaceae, is an underutilized fruit crop with significant nutritional, medicinal, and economic potential. Native to South America, the crop has adapted well to diverse agro-climatic conditions and is gaining attention as a high-value fruit in developing and developed countries. This article reviews the origin, botany, cultivation practices, nutritional composition, health benefits, and economic importance of cape gooseberry, highlighting its potential for commercial cultivation and agricultural diversification.

Introduction

Cape gooseberry *Physalis peruviana* L. is an annual growing fruit crop belonging to the family Solanaceae. The plant of cape gooseberry is herbaceous or soft wooded plant usually reaches 2-3 feet height. Cape goose-berry is extensively grown in tropical and subtropical region of the world. The latitude ranges are about 450S and 600N, it can be growing at high elevation up to 500-3000m from asl 1600-9800 ft. The fruit is small with 1-3.5 cm in diameter yellow orange berry fruit enclosed by the large accrescent epicalyx and resemble tomato in shape with sweeter taste, better aroma and higher pectin content. It is also commonly called Poha or Poha berry in Hawaii, Golden berry in South Africa and Rashbhari, Makoi, Tepari, Husk cherry, Peruvian ground cherry in India. The name of cape gooseberry is most probably derived from the name of "Cape of Good Hope" of South Africa where it was commercially grown. The ripe fruits are eaten as fresh fruit and used in making excellent quality of jelly, sauces and particularly jam for which it is called as "Jam fruit of India" The fruits are also attractive sweet when dipped in chocolate or other glazes or pricked and rolled in sugar. The fruits contain 1.8% protein, 0.2% fat and 11.5% carbo-hydrates. It is also content 10 mg of calcium, 60 mg of phosphorus and 18 mg of iron, thiamine 0.1 mg and 1.70 mg niacin and high level of vitamin A, B, C. It contains 2380 IU of vitamin A and 49 mg of vitamin C, and produce 55 calories of heat per 100 g of fruit (Khan and Gower, 1955).





Origin and Distribution: The species belongs to genus physalis are commercially grown in temperate and tropical region of the world. These are perennial in temperate region and annual in tropical and sub-

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tropical region. Cape gooseberry comprises of three species and they are originated from tropical Asia and South America. *Physalis peruviana* is originated from South America and are native of Peru and Northern part of chilli, rest other species such as ixocarpa and pubescence are originated from tropical Asia and Indian. Portugeese and Spanish voyagers introduced this crop in various part of the world. Cape gooseberry name are derived from the name of Cape of Good Hope of South America where it is commercially grown. Presently this species peruviana is commercially widely grown in tropical and subtropical region of the world. Australia, Indonesia, Sri Lanka, India, Myanmar, Malaysia, Pacific Island, Bangladesh, Southern China, Vietnam, Cambodia, Southern Thailand, South African countries, Algeria and Western African countries, Portugal, Italy Greece. In the North, cape gooseberries can grow at an elevation up to 4,000 feet, and in the South, up to 6,000 feet. Regions of India cultivating the fruit commercially are West Bengal, north India, and eastern India. The perennial Cape gooseberry can grow wherever tomatoes grow In India's southern hill countries.

Botanical Description

Scientific name: *Physalis peruviana* L.

Family: Solanaceae

Chromosome number: 2n = 48

The plant grows 0.6-1.5 m tall with a shallow root system. Flowers are yellow with dark purple spots at the base. The fruit is a berry, round to oval, enclosed in a papery calyx that enlarges during fruit development and protects it from insects and birds.

Climate and Soil Requirements

Cape gooseberry performs best in:

Climate: Mild subtropical to temperate climate

Temperature: 18-25 °C

Rainfall: 800-1,500 mm annually

Well-drained sandy loam to loamy soils with a pH of 5.5-7.0 are ideal. The crop is moderately tolerant to drought but sensitive to waterlogging.

Propagation and Cultivation Practices: Seed propagation is broadly adopted in the propagation of cape gooseberry for annual crop, but the perennial crop which can be thrive upto 4 years may be propagated by vegetative means. The seeds of cape gooseberry are very small so it is very difficult to sown. It is sown in the seed beds for raising seedlings after that transplant in main field. Seed bed should be raised up to height of 8-10 cm, wide 1.5 m and long 4 m. 4-6 kg of seed is sufficient for 1 hectare land transplantation. For small area seeds can be grow in seed pans for easy handling. Seeds after sowing it should be covered with leaf mould and capiously watered. In the case of vegetative propagation shoot cutting and layring are commonly practiced with varying success. One year old plant should be selected for vegetative propagation; cuttings should be at least 20-25cm long is selected from the mature but succulent shoots during the rainy season when the atmospheric temperature and humidity remain comparatively high. Layring are more effective as well as cuttings.

Spacing: 60 × 60 cm or 75 × 60 cm

Manures and Fertilizers

FYM: 10-15 t ha^{-1}

NPK: 100:60:60 kg ha^{-1} (split application recommended)

Irrigation: Irrigation at 7-10-day intervals is ideal, especially during flowering and fruiting stages.

Yield: Average yield ranges from 10-15 t ha^{-1}, depending on variety, management practices, and environmental conditions.

Nutritional Composition

Cape gooseberry is rich in:

- ✓ Vitamin C (20-40 mg/100 g)
- ✓ Vitamin A and carotenoids
- ✓ Polyphenols and flavonoids
- ✓ Minerals such as iron, phosphorus and potassium

The fruit also contains bioactive compounds like withanolides, which exhibit antioxidant and anti-inflammatory properties.

Medicinal and Health Benefits: Scientific studies indicate that cape gooseberry possesses:

- ✓ Antioxidant activity
- ✓ Anti-diabetic and hypolipidemic effects
- ✓ Immunomodulatory properties
- ✓ Anti-cancer potential

Traditionally, it has been used to treat liver disorders, asthma, and inflammatory conditions.

Post-Harvest Management and Processing: The papery husk provides natural protection, extending shelf life up to 2-3 weeks under ambient conditions. Fruits can be processed into:

- ✓ Jams and jellies
- ✓ Dried fruits
- ✓ Juices and concentrates
- ✓ Nutraceutical products

Economic Importance and Future Prospects: Cape gooseberry offers high returns due to its export demand and low production cost. Its suitability for organic farming and minimal pest incidence further enhances profitability. With proper varietal improvement, post-harvest technology, and market linkages, cape gooseberry can play a vital role in income generation and agricultural diversification.

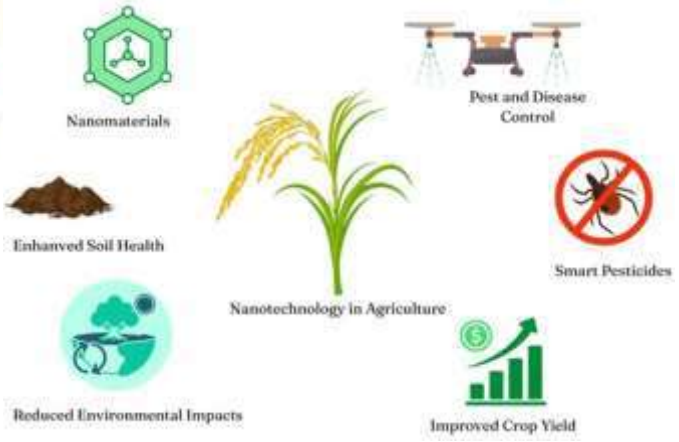
Conclusion

Cape gooseberry is a promising fruit crop with immense potential in sustainable agriculture. Its nutritional richness, medicinal value and adaptability to varied agro-climatic conditions make it an ideal candidate for commercial cultivation. Increased research efforts and farmer awareness can significantly enhance its role in global horticulture.

Nanotechnology: A Tiny Revolution Transforming Modern Agriculture

Simran, Rupam Nehta, Garima, Ibajanai Kurbah and Sanjeev Kumar

Nanotechnology is an innovative way to help make advancements in agriculture and to create many new opportunities in order to help meet today's global problems. Some of these include solving problems related to nutritional security, sustainability and environmental conservation (Kumar *et al*., 2023). Historically, agriculture has been and continues to be an important part of the global economy; it supports the production of the raw materials that are used in the food industry and the feed industry (Gupta *et al*., 2022). Nanotechnology in agriculture enables precise and enhance nutrient delivery, pesticides, and other inputs, improving crop productivity and resource-utilization efficiency. It supports sustainable agriculture by enhancing soil quality, reducing environmental impacts, and increasing yield and crop quality. It has many features that help it to be incorporated into many different realms of science, to include agricultural nanotechnology, an interdisciplinary area that uses nanotechnology-based products within the realm of agriculture, to produce greater crop yields and environmental sustainability. Examples of how nanotechnology has changed the future of agricultural inputs and thus agricultural systems are through targeted, precise delivery of nutrients and protective agents delivered by nanocarriers. Nanocarriers allow the proper amount of nutrients and protective agents to be applied at the proper time and delivered to the proper location on the plant, thus increasing the production and quality of crops while minimizing losses, reducing environmental contamination, and maximizing safety for consumers. Research in agricultural nanotechnology will continue to increase and positively influence the way in which agricultural systems will be developed in the future as well as improve sustainable intensification as well as improve global food and nutritional security.



Nanotechnology applications in modern agriculture

Utilization of nanomaterials in crop species: To improve plant growth and performance, a variety of nanomaterials have been used in various crop species

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Multi-walled carbon nanotubes (MWCNTs) are given through seed priming in crops such as wheat, maize, groundnuts, soyabean, barley and garlic because it enhances germination, growth of seedlings, increased biomass accumulation and water absorption potential of seeds. Zinc oxide nanoparticles are commonly applied as foliar sprays and combined with growth media. In crops like wheat, coffee and cluster bean, ZnO NPs improve growth, biomass accumulation, net photosynthetic rate and increase grain yield (Rossi, 2019). CuO nanoparticle play dual functionwhenapplied on tomato plants as foliar spray, it helps the plant to effectively control late blight disease. Whereas in Spinach, it received CuONPs when mixed with soil, they improve photosynthesis and increase biomass production. Seeds are primed with iron sulfide (FeS_2) for chickpea, pea, carrot, sesame seeds and mustard because it helps to increase germination and crop yield. Several crops are treated with silver nanoparticles (AgNPs), such as cowpea by foliar spraying, wheat by combining with pot soilwhich help to enhance growth and biomass by stimulating root nodulation and soil bacterial diversity (Iqbal 2019). Iron oxide (Fe/Sio_2) nanoparticles is applied as fertilizers to maize and groundnuts to enhance plant growth and biomass accumulation. TiO_2 nanoparticles is used as a foliar spray in case of spinach and as a seed-priming treatment because it help to improve its chlorophyll, nitrogen and protein content where as in case of rice crop it is applied as foliar spray to overcome Cd toxicity, improve growth by stimulating antioxidant potential and inhibiting cd translocation. SiO_2 nanoparticles, applied alone or in combination with TiO_2 and isused in rice for alleviated heavy metal toxicity stress. They improve growth by decreasing metal accumulation and restricting its transport within the plants.Aluminium oxide (Al_2O_3) nanoparticles in tomato plants control root rot in tomato. Furthermore, it is also involved in fruit protection in case of plum fruits sprayed with ZnO, CuO, and Ag nanoparticles help the plant to suppress grey mold symptoms and soil borne diseases (Shang *et al.,* 2019). Overall, nanotechnology provides a potent and novel approach to promote crop development, increase yields, strengthen disease resistance, and lessen the effects of environmental challenges. The application of nanoparticles in agriculture has enormous potential to increase farming's productivity, sustainability, and resilience in the future.

Utilization of Nanotechnology in Agriculture

Nanotechnology -enable crop growth: The Green Revolution significantly boosted grain yield through high yielding varieties and fertilizers, but excessive chemical inputs have now degraded soil health and polluted water bodies. Overuse of nitrogen fertilizers contributes to groundwater contamination and eutrophication. Nano fertilizers offer a sustainable alternative, improve nutrient use efficiency by ensuring slow and controlled nutrient release. Their tiny size facilitates faster nutrient uptake, promoting better plant growth compared to traditional fertilizers.

Nanotechnology based plant protection: Over 90 per cent of applied pesticides are lostto the environment and fail to reach target pests, resulting in poor pest control and environmental contamination. Nanotechnology offers a sustainable solution by improving herbicides, fungicides, bactericides, and insecticides through enhanced bioavailability, targeted delivery and controlled release. Nanoencapsulation protects active ingredients from degradation and ensures their release at minimal effective doses in the root zone. This reduces pesticide quantity, lowers production costs, and minimizes soil residue buildup. Metal oxide nanoparticles such as Zinc oxide have also exhibited strong disease resistance against *Alternaria*, *Fusarium*, *Mucor*, and *Rhizopus* species.

Nanotechnology-based crop improvement: The union of nanotechnology with genetic engineering has led to the creation of sophisticated molecular carriers that enable more precise gene delivery. Traditional gene delivery methods face limitations such as host specificity, membrane barriers, and inefficient nuclear migration, which nanoparticles can effectively overcome. By binding genetic material to nanoparticles like gold, magnetite, carbon, or calcium phosphate, gene transfer becomes more targeted and less damaging to cells. Nanomaterials also reduce off-target effects and allow direct delivery into organelles such as chloroplasts and mitochondria. (SiO_2) have recently been developed to safely transport DNA segments to specific species (Gupta *et al.*, 2023).

Constraints of nanotechnology in agriculture: Despite its promising applications in agriculture, nanotechnology still faces major challenges that must be addressed before it can become transformative. Large-scale production of uniform nanoscale materials is expensive, technically demanding, and requires specialized infrastructure. Concerns havebeen raised about the persistence of engineered nanoparticles in the environment and their potential movement into the food chain, which may threaten ecosystem stability and human health. Additionally, inconsistent global regulations and fears of toxicity during manufacturing, transport, and handling hinder widespread adoption. Therefore, strong research efforts and robust regulatory frame-works are essential to ensure the safe and sustainable application of nanotechnology in agriculture (Pandey *et al.*, 2023). Evaluating the long -term behaviour movement and environmental impact of nanoparticles ensure the safe use of nanoparticles in agriculture, long-term field studies are needed to understand their fate, transport, and ecological impacts beyond laboratory conditions. Future research must focus on biodegradable nanomaterials, stronger regulations, transparent risk assessments, and stakeholder confidence. Evaluating the scalability, socioeconomic impacts, and adoption barriers of nano-based products is equally essential. With responsible collaboration among scientists, farmers, industry, and policymakers, nanotechnology can sustainably transform agriculture and strengthen global food security.

Conclusion

Nanotechnology offers the means to address major obstacles in contemporary agriculture through means of increasing efficiency with respect to the use of inputs, developing targeted delivery systems for nutrients, and providing protection from insects, diseases, etc. Nanotechnology can contribute to increase crop yield and crop quality while supporting sustainable and value-added agricultural systems. Unfortunately, a general lack of an established regulatory framework has limited widespread acceptance. Therefore, robust safety assessments, long-term field trials, and comprehensive regulatory coverage will be needed before there is widespread acceptance of nanotechnology-based products in agriculture.

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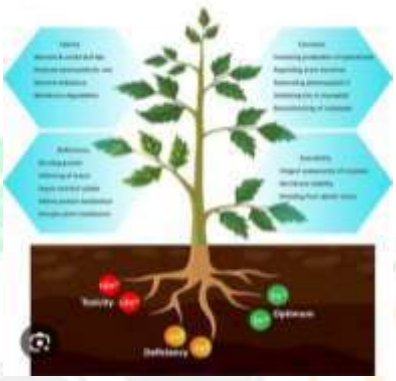
Nutrient Mobility and Its Relation to Deficiency Symptoms

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Abstract

This article talk about how nutrients move inside plant body and how this movement decide deficiency symptoms. Many times people get confuse that why yellowing start in some leaves first and some leaves later. This article try to explain this concept in very simple way and grammar is also not very perfect so that it look like student written work.

Introduction



Plants need many nutrients for proper growth and development. But all nutrients do not move same way inside plant. Some nutrients can move easily from old leaves to new leaves, while some nutrients stay fixed where they are absorbed. Because of this difference, deficiency symptoms also appear in different parts of plant. If we understand nutrient mobility, then deficiency identification become easy. This magazine explain this topic in simple language for students.

Nutrient Mobility: Based on movement inside plant, nutrients are divided into two groups: mobile nutrients and immobile nutrients. Mobile nutrients are those nutrients which can move from older leaves to younger leaves when plant face nutrient shortage. Because of this, deficiency symptoms of mobile nutrients appear first on old leaves.

Examples of mobile nutrients are Nitrogen, Phosphorus, Potassium and Magnesium. When these nutrients become low, plant transfer them from old leaves to young leaves to support growth. So old leaves start showing yellowing or stress symptoms.

Immobile nutrients are nutrients which cannot move easily once they are fixed in plant tissues. So when plant face deficiency of immobile nutrients, symptoms appear first on young leaves. Examples include Calcium, Iron, Boron and Sulphur. In such case young leaves become pale, deformed or show necrotic spots.

Relation with Deficiency Symptoms: When nutrient is mobile, deficiency symptoms show first on older leaves. For example nitrogen deficiency cause yellowing of lower leaves. Magnesium deficiency cause interveinal chlorosis in old leaves. When nutrient is immobile, deficiency symptoms appear on young leaves. Calcium deficiency cause tip burn and deformation of young leaves. Iron deficiency cause yellowing of youngest leaves while veins remain green.

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Why this Happens: Plant always try to protect new growing parts. New leaves are important for photosynthesis and growth. So if nutrient is mobile, plant move it from old leaves to new leaves. But if nutrient is immobile, plant cannot move it and young leaves suffer first.



Importance for Farmers and Students: Knowledge of nutrient mobility is very important for correct deficiency diagnosis. Many farmers make mistake in fertilizer application because they do not know about nutrient mobility. Students also get many exam questions related to mobile and immobile nutrients, so this topic is important from academic point of view.

Conclusion

Nutrient mobility play important role in appearance of deficiency symptoms in plants. Mobile nutrients show deficiency on older leaves while immobile nutrients show deficiency on young leaves. Understanding this basic concept help in easy identification of nutrient problems and better crop management.

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Contribution of Crop Physiology to Sustainable and Precision Agriculture

Shivam Gairola and Ravinder Kaur

Abstract

Crop physiology is study of how plants grow and how they react with environment. It helps farmers and scientist to understand plant needs for water, nutrients and light. In present time agriculture face many problems like climate change, low water and soil degradation. Crop physiology gives basic knowledge to improve crop production with less harm to nature. By understanding process like photosynthesis, transpiration and nutrient uptake, better crop management can be done. This article explains role of crop physiology in sustainable and precision.

Introduction

Now agriculture is not only about increasing yield, it is also about saving environment for future. Sustainable agriculture means producing food without damaging soil and water. Precision agriculture focusses on giving right input at right time and right place. Crop physiology connects plant science with field practices. It explains how crop respond to water, fertilizer, temperature and light. This knowledge help farmers to reduce wastage of inputs and increase efficiency. Therefore, crop physiology is very important for modern agriculture system.

Role of Crop Physiology in Sustainable Agriculture

Water Use Efficiency: Crop physiology explains how water is absorbed by roots and lost through transpiration. By knowing this process irrigation can be planned properly. Some crop has physiological characters like deep roots and less water loss. These characters help in saving water and support sustainable agriculture.

Nutrient Use Efficiency: Plants need nutrients like nitrogen, phosphorus and potassium for growth. Crop physiology helps us to understand how these nutrients are taken and used by plant. If fertilizer is applied according to plant need, wastage is reduced. This also reduce soil and water pollution and keep soil healthy.

Stress Tolerance: Crops face stress like drought, heat and salinity. Crop physiology helps to study how plants react under stress condition. Some physiological traits like chlorophyll content and photosynthesis rate show stress level in plant. Using this knowledge stress tolerant varieties can be developed for sustainable farming.

Role of Crop Physiology in Precision Agriculture

Site Specific Management: In a field all areas are not same. Crop physiology helps to understand plant response in different soil and moisture condition. This support site specific irrigation and fertilizer application.

Use of Sensors: Precision agriculture uses sensors to

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measure plant condition like canopy temperature and leaf colour. These are related with plant physiology. With this information stress and nutrient deficiency can be detected early.

Input Optimization: Knowledge of crop growth stages and physiological requirement help in applying inputs at correct time. This reduces cost and improve crop performance.

Conclusion

Crop physiology plays important role in sustainable and precision agriculture. It helps in better use of water and nutrients and improve stress tolerance in crops. By combining crop physiology with modern technology, farming can become more efficient and environment friendly. Therefore, crop physiology is necessary for future agriculture and food security.

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Physiological Basis of Nutrient Use Efficiency

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Abstract

This article try to explain how plants use nutrients in better or poor way. Nutrient use efficiency is very important in agriculture because many times plants do not use all nutrients which we give through fertilizer. Inside plant body many physiological activities happen which decide whether nutrient will be used or get wasted. This magazine explain those basic physiological points in simple language so that it can be easy to understand.

Introduction

In present agriculture, farmers mostly believe that more fertilizer means more yield. But in reality, plants do not always respond same way. Sometimes plants absorb nutrients properly and sometimes they do not even when soil is rich. This happen because of internal plant physiology. Nutrient use efficiency means the ability of plant to absorb nutrients, move them inside body and use them for growth and development. If we understand these physiological processes, fertilizer use can be reduced and soil health can be maintained. This article try to explain these ideas without using very hard scientific terms.

Nutrient Uptake by Roots: Roots are the main part of plant which take nutrients from soil. Root hairs help to increase surface area and improve absorption. But nutrient uptake is not same all time. It depend on soil moisture, soil temperature and condition of roots. When roots grow deeper and spread more, plant can explore more soil and get more nutrients. If roots are damaged or weak, nutrient use efficiency decrease.

Transport of Nutrients in Plant: After absorption, nutrients move inside plant through xylem and phloem. This movement depend a lot on water flow. If plant is facing water stress, nutrient movement become slow. Many nutrients move along with water, so without proper water supply plant cannot use nutrients even if soil contain enough amount.

Enzymes and Metabolic Activities: Inside plant body, enzymes help in converting absorbed nutrients into useful forms. If enzyme activity is low, nutrients cannot be used properly. Photosynthesis and respiration are also important processes which decide nutrient utilization. When photosynthesis rate is high, nutrient use efficiency also increase because nutrients are used in making plant tissues.

Nutrient Interactions: Nutrients do not work alone. Sometimes one nutrient affect uptake of another nutrient. For example, excess phosphorus can reduce zinc absorption. Too much nitrogen can cause fast growth but plant tissues become weak. This imbalance reduce nutrient use efficiency because plant cannot maintain proper nutrient balance.

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Genetic Factors: Different crop varieties show different nutrient use efficiency. Some varieties absorb nutrients fast, some store them better and some use nutrients more efficiently even in low supply. Plant breeders select such varieties so that farmers can get good yield with less fertilizer input.

Environmental Effects: Environmental factors also affect nutrient use efficiency. Low temperature reduce root activity and nutrient uptake. High temperature increase water loss and reduce nutrient movement. Soil pH decide availability of nutrients in soil. If pH is not suitable, nutrients remain locked and plant cannot use them.

Conclusion

Nutrient use efficiency is not only related to fertilizer application. It mainly depend on physiological processes inside plant. From root absorption to nutrient utilization, every step play important role. By understanding these physiological bases, better crop management and variety selection can be done. Improving nutrient use efficiency help in reducing cost, protecting environment and achieving sustainable agriculture.

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Visual Diagnosis of Nutrient Deficincy Symptoms in Crops

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Abstract

Healthy plant growth depends on the proper availability of nutrients in the soil. When plants do not receive enough essential nutrients, they begin to show visible signs known as nutrient deficiency symptoms. Visual diagnosis is a simple and quick method used to identify these problems by observing changes in plant colour and structure.

Introduction

Plants need different nutrients for their normal growth and development. These nutrients are absorbed from the soil in required amounts. If any nutrient is lacking or unavailable, the plant cannot grow properly and starts showing visible symptoms. These symptoms may appear on leaves, stems, roots, or fruits. Visual diagnosis means identifying nutrient deficiencies by carefully observing these visible symptoms in the field. It is one of the most comm-only used methods because it is simple, economical, and does not require laboratory equipment.

Types of Nutrient Deficiency Symptoms

Based on the quantity required by plants, nutrients are classified into two main groups: **Macronutrients:** These are needed in large amounts: Primary nutrients: Nitrogen (N), Phosphorus (P), Potassium (K) Secondary nutrients: Calcium (Ca), Magnesium (Mg) and Sulphur (S)

Micronutrients: These are needed in very small amounts but are equally important: Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl), and Nickel (Ni) Types of Nutrient Deficiency Symptoms Nitrogen deficiency: Older leaves turn pale yellow, plant growth becomes slow, and crops appear weak. Phosphorus deficiency: Leaves become dark green or purple, root growth is poor, and crop maturity is delayed. Potassium deficiency: Yellowing and burning of leaf edges occur, stems become weak, and disease resistance decreases. Calcium deficiency: Young leaves become distorted, growing points die, and disorders like blossom end rot appear. Magnesium deficiency: Yellowing occurs between veins of older leaves while veins remain green. Iron deficiency: Young leaves show interveinal chlorosis, giving the plant a pale yellow appearance. Zinc deficiency: Leaves remain small, internodes shorten, and specific disorders like Khaira disease in rice are seen.

Impacts and Effects of Nutrient Deficiencies

Nutrient deficiencies negatively affect crop production in many ways: Reduced yield and poor crop quality Slow and uneven plant growth Delay in

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flowering and fruit formation. Higher chances of pest and disease attack Economic loss to farmers Long-term imbalance in soil fertility.

Conclusion

Visual diagnosis of nutrient deficiency symptoms plays a vital role in crop management. It helps in the early detection of nutrient problems and allows timely corrective measures such as fertilizer application. Although visual diagnosis is very useful, it should be supported by soil and plant testing for accurate results. Balanced nutrient management ensures healthy crops, better yield, and sustainable agricultural practices.

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Impact of Climate Change on Vegetable Production

Krishna, Rohit, Vikash Kumar and Deepika

Introduction

The term "climate change" refers to variations in the average of several climatic factors, including temperature, precipitation, relative humidity and the composition of atmospheric gases. The changes in climate may include fluctuations in temperature, increase in soil salinity, waterlogging, high atmospheric CO_2 concentration and UV radiation. Globally averaged surface temperature is expected to rise between 1.1°C up to 6.4°C by the last decade of the 21st century (Minaxi *et al.,* 2011). Agriculture is a climate dependent activity. So, it is going to be effected by climate change largely.

Effect of climate change on agriculture

Climate change and agriculture are interrelated processes, both of which take place on a global scale. A significant change in climate on a global scale will impact agriculture and consequently affect the world's food supply. More erratic rainfall patterns and unpredictable high temperature spells will consequently reduce crop productivity. Changes in rainfall patterns will affect soil surface temperatures and moisture availability. This will influence crop establishment crops stand maturation period and the total agricultural production. Current variation in crop productivity and yields among different regions, are likely to become greater as the effects of climate change are felt by farmers.

Effect of climate change on vegetable production

Vegetables are generally sensitive to environmental extremes, and thus high temperatures and limited soil moisture are the major causes of low yields as they greatly affect several physiological and biochemical processes like reduced photosynthetic activity, altered metabolism and enzymatic activity, thermal injury to the tissues, reduced pollination and fruit set etc. The consequences of the climate change badly hit the vegetable production. The failure of the monsoons results in water shortages, resulting in below-average crop yields. The effects of elevated temperature and unpredictable and irregular precipitation can disrupt the normal growth and development of plants which ultimately affect crop productivity Crop yields in Asia are expected to decline by 2.5-10% from 2020 onwards and by 5-30% after 2050, with worst declines in South and Central Asia (Cruz *et al.,* 2007). In this article, the impact of global climate change on vegetable crop growth and yield is discussed. Some of the important environmental stresses which affect vegetable production have been reviewed below.

Temperature

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High temperature: Temperature are the most important climatic factor which directly affect the vegetable production and slitly change in temperature effect productivity and yield of vegetable. Extreme temperature above 40°C causes desiccation whereas temperature below 0°C witness chilling and freezing injury in many vegetables. A constantly high temperature causes an array of morpho-anatomical changes in plant which affect the seed germination, plant growth, flower shedding, pollen viability, gametic fertilization, fruit setting, fruit size, fruit weight, fruit quality etc. High temperature causes injuries resulting in reduction of the productivity. High temperature in tomato cause a set of failure; this includes bud drop, abnormal flower development, poor pollen production, dehiscence and viability ovule abortion, poor carbohydrate availability due to reduced viability and other reproductive abnormalities. Degradation of lycopene starts at 27°C and it is completely destroyed at 40°C (Ayyogari *et al.*, 2014). Germination of cucumber and melon seeds are greatly suppressed at 42 and 45°C respectively, whereas germination will not occur at 42°C in watermelon, summer squash, winter squash and pumpkin seeds (Kurtar, 2010). Warm humid climate increase the vegetative growth and result, in poor production of female flowers in cucurbitaceous vegetables which causes low yield. In okra, high temperatures cause poor germination of seed during spring summer season

Low temperature: Vegetables suffer chilling injury with temperature ranges from 0°C-10°C and freezing injury below 0°C which cause significantly damage to crops. Freeze injury leads to rupture of plant cell wall and destruction of cytoplasmic constituents as ice crystals are formed from cytoplasmic water. Exposure to chilling temperature in temperate climate may lead to a severe reduction of yield or complete crop failure due to either direct damage or delayed maturation. Even a small drop in temperature, causing no visible damage to chilling sensitive plants, may cause up to 50% reduction in their productivity (Kopanh, 1969). The germination is adversely affected when the soil temperature is below 10°C. Low night temperatures (14°C or less) reduced the number of pollen grains per flower and impaired their germination ability, and affected fruit set and fruit shape in sweet pepper. Low temperature combined with low irradiance caused puffiness and blotchy ripening in tomato as well as a deterioration of taste due to decline in sugar content while citric acid content was unchanged (Rylski *et al.*, 1994).

Flooding: Waterlogging is a serious problem which affects crop growth and yield in low lying rainfed areas. Most of the vegetables are highly sensitive to flooding, especially those who are shallow rooted. The main cause of damage under waterlogging is oxygen deprivation which affect nutrient and water uptake so the plants show wilting even when surrounded by excess of water. In sensitive crop plants, flooding causes leaf chlorosis and reduces shoot and root growth, dry matter accumulation and total plant yield. The degree of damage increased with the duration of water logging and damage was

more severe in younger plants compared to the older plants. Pepper (*Capsicum annum* L.) is sensitive to prolonged flooding. Continuous flooding of pepper plants for 4 weeks resulted in poor growth, yellowing of leaves, blackening of the root tips, and a distinct swelling at the junction of the shoot and the roots (Hasnain and Sheik, 1976) caused by decreased O_2 supply. Onion is also sensitive to flooding during bulb development with yield loss up to 30-40%.

Drought: Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Vegetables, being succulent product, generally consist of greater than 90% water (AVRDC, 1990). Thus, water greatly influences the yield and quality of vegetables; drought conditions drastically reduce vegetable productivity. Drought stress causes an increase of solute concentration in the environment (soil), leading to an osmotic flow of water out of plant cells. This leads to an increased water loss in plant cells and inhibition of several physiological and bio-chemical processes such as photosynthesis, respiration etc., thereby reduces productivity of most vegetables. The water stress results in significant decrease in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress have less fruit yield and quality. Potato is highly sensitive to drought; a moderate level of water stress can also cause reductions in tuber yield (Jefferies and Mackerron, 1993). Root and bulb crops like potato, carrot and onion crop yields depend on the production and translocation of carbohydrates from the leaf to the root or bulb (storage organ). Occurrence of drought stress during enlargement of storage organs reduces yield and quality, Fifty percent reduction in fresh fruit yield of okra has been reported at 6.7 dS m^{-1} (Minhas and Gupta, 1993) More than 50% yield reduction was reported in tomato because of water stress during reproductive stage.

Salinity: Salinity is a serious problem that reduces growth and productivity of vegetable crops in many salt-affected areas. Salt stress causes loss of turgor, reduction in growth, wilting, leaf abscission, decreased photosynthesis and respiration, loss of cellular integrity, tissue necrosis and finally death of the plant. Onions are susceptible to saline soils, while cucumber, eggplant, pepper, and tomato are moderately sensitive to saline soils. Salinity causes a significant reduction in germination percentage, germination rate, and root and shoots length and fresh root and shoot weight in cabbage. Salinity reduces dry matter production, leaf area, relative growth rate and net assimilation rate in chilli. High salt concentration causes a reduction in fresh and dry weight of all cucurbits. Salinity tends to reduce the tuber yield in potato.

Effect of carbon dioxide

CO_2 has the potential to affect major physio-logical processes namely photosynthesis, respiration and transpiration. Carbon dioxide concentration is increasing and will continue to rise even more rapid-

ly for the next 50-100 years unless current patterns of fossil fuel consumption change, concentration of greenhouse gases like CO_2 and CH_4 is increasing in the atmosphere day by day. They are not only responsible for global warming but also cause their own direct effect on growth and development of plants. The high atmospheric CO_2 content inhibits tomato fruit ripening. This inhibition is due to the suppression of the expression of ripening associated genes, which is probably related to the stress effect exerted by high CO_2 (Rothan *et al.,* 1997)

Impact of climate change on pollinating agents and pollination behaviour

Climate change will be the most important cause of biodiversity loss over the next 100 years, which causes changes in species distributions, phenology and ecological interactions. For example, many vegetable crops like cole crops, onion and root crops are pollinated by insects as changes in insect species distribution will affect the pollination. Changes in temperature and precipitation patterns can disrupt the synchronization between flowering plants and their pollinators. For example, if a species of flower blooms earlier due to warmer temperatures but its pollinator emerges later, it can lead to mismatches, reducing the reproductive success of both parties. Extreme weather events, such as hurricanes, droughts, and heavy rainfall, can also directly impact pollinator populations by destroying habitats, reducing food availability, and increasing mortality rates. Pollinators contribute to the pollination of many crops, including fruits, vegetables, nuts, and oilseeds. Declines in pollinator populations or disruptions in pollination services can have negative impacts on agricultural productivity and food security. Farmers may need to adapt their practices to mitigate the effects of climate change on pollinators, such as implementing habitat restoration measures or diversifying crop pollination strate

Climate change impacts on vegetable pests and diseases

Insects are particularly sensitive to temperature because they are stenotherms (cold-blooded). Climate changes will make some environments more favorable to pests and diseases. Higher temperatures cause faster disease cycles in air borne pathogens and increase their survival due to reduction in frost. Warmer temperatures also seem to favor the incidence of the late blight caused by (*Phytophthora capsici*) in pepper Warmer tempera-tures also seem to favor the incidence of the late blight caused by (*Phytophthora capsici*) in pepper. In general, insects respond to higher temperature with increased rates of development and with less time between generations. Increase in temperature in the range of 1°C to 5°C would increase insect survival due to low winter mortality, increased population build-up, early infestations and resultant crop damage by insect-pests under global warming scenario. Increased temperatures will accelerate the development of cabbage maggot, onion maggot, European corn borer, Colorado potato beetle. Many researcher revealed that increase in temperature during winter endorse higher population of insects vectors such as

aphid, jassids, white fly, etc. which act as vectors for several viral strains attack potato and sugar beet plants. Viroid multiplication at temperatures above 25°C is inhibited at lower temperatures. Thus, increasing temperatures may also favor the incidence of viroids in major vegetable crops such as tomatoes and pepper. Increasing temperatures up to 30°C enhanced the development and fertility of Aphis gossypii on cucumber.

Conclusion

Climate change exerts profound effects on vegetable production by altering key environmental parameters such as temperature, water availability, salinity, and atmospheric CO_2 levels. Both high and low temperatures can impair germination, growth, reproduction, and fruit quality, while water stress either drought or waterlogging reduces yield and crop viability. Salinity further limits growth, and elevated CO_2 can disrupt physiological processes and fruit ripening. Indirect effects, such as altered pollinator activity and enhanced pest and disease pressures, compound these challenges. Collectively, these impacts threaten food security and vegetable productivity, particularly in climate-sensitive regionns. Mitigation and adaptation strategies, including improved irrigation, resilient crop varieties, and integrated pest management, are essential to sustain vegetable production under the predicted climate change scenarios.

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Engineered Biochar: A Smart Carrier for Nutrients in Crops

Rohit, Neeraj and Pooja Pahal

Crop cultivation consumes large amounts of fertilizer to meet rising demand but much of this fertilizer is lost to leaching and volatilization. Biochar the carbon-rich byproduct of biomass pyrolysis has emerged as a sustainable soil amendment because of its high porosity and stable carbon content. However, raw biochar alone supplies few nutrients. This has led to "engineered biochar", biochar that is modified or combined with fertilizers to act as a slow-release nutrient carrier. Engineered biochar can synchronize nutrient delivery with plant needs while sequestering carbon for decades. In many crops, such biochar-based fertilizers have markedly improved yields and efficiency.

Why Engineer Biochar?

Unmodified biochar improves soil structure, water retention and cation-exchange capacity, thus indirectly aids crops. But by itself it contains relatively low amount of plant-available nutrients. In a long-term trial without added fertilizer, yields eventually leveled off because biochar did not provide enough nutrients as biochar's main benefit was retaining and recycling what little fertilizer remained in soil. To overcome this, researchers load or modify biochar so it carries nutrients. Nutrient-enriched biochars are tailored to release nutrients in a controlled manner. In other words, engineered biochar turns into a "smart fertilizer" or slow-release matrix, combining the advantages of organic soil amendment with more efficient nutrient delivery. Most new biochar-based fertilizers are designed for slow release and such fertilizers consistently increase crop yields and reduce the leaching and volatilization of nutrients.

How Biochar is Engineered?

Physical activation: Ball-milling, steam or CO_2 treatments enlarge biochar's surface area and open pores. Nanoparticles or activated carbons can make more sites for holding nutrients or microbes.

Chemical modification: Treating biochar with acids, alkalis or salts introduces functional groups (-COOH, -OH) that bind nutrients. Impregnation with metal oxides (e.g. MgO, CaO, FeO) creates strong adsorption sites.



Nutrient loading (enrichment): Biochar can be coated or mixed with conventional fertilizers or organic wastes. Urea, superphosphate or NPK mixes are physically attached to biochar granules, often using a binder (starch, resin, clay). Biochars can also be directly mixed with manure, compost or sludge so

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that the final material contains high N, P or K.

Biological priming: Some engineered biochars are inoculated with beneficial microbes (PGPR, mycorrhizae) or vermicompost. These microbes solubilize or mobilize nutrients.

Nutrient Delivery Mechanisms

Adsorption and complexation: Nutrients can bind to charged or functional sites on biochar. Metal-modified biochars (MgO, CaO) form insoluble nutrient complexes (e.g. Mg-P, Ca-P) that gradually dissolve instead of running off immediately. Similarly, cationic fertilizers (NH_4^+, K^+) adsorb to negatively charged biochar surfaces.

Slow diffusion/desorption: Nutrients impregnated in biochar pores or coatings take time to diffuse out. Lab experiments show phosphorus diffuses out of biochar clay composites with pseudo second order kinetics, much slower than from a soluble fertilizer. Urea coated by biochar showed a prolonged release pattern in soil.

Reduced leaching and volatilization: By binding nutrients, engineered biochars sharply cut losses. Biochar-coated urea has been shown to reduce nitrate leaching and N_2O emissions, meaning more N stays plant-available.

Enhanced nutrient uptake: By improving soil pH and structure, biochar makes nutrients more accessible. The porous biochar matrix also provides habitat for microbes that mineralize organic nutrients. For example, nitrogen-enriched biochars boost nitrification (producing NO_3^-) by stimulating ammonia-oxidizing bacteria. This synergistic effect means plants often absorb more nutrients when biochar is present.

Agronomic Benefits for Crops

Applied properly, engineered biochars can substantially improve growth, quality and soil health. Key findings from recent studies include:

Higher yields and biomass: Numerous experiments report significant yield boosts in crops. In a pot trial, MgO biochar loaded with P more than doubled bok choy yield compared to standard superphosphate fertilizer. One study found that adding biochar to urea reduced soil N losses and caused maize biomass to triple. In a long-term experiment, biochar-based fertilization delivered higher yields than fertilized controls due to its cumulative soil benefits.

Improved quality and safety: Biochar fertilizers often enhance nutrient content and reduce unwanted compounds. Many studies note improved vitamin, mineral or protein content in vegetables after biochar amendment. Slower nutrient release also means plants are less stressed, yielding better-tasting and longer-lasting produce.

Stronger root systems: Several reports show deeper and more extensive roots in crops grown with biochar fertilizers. This is attributed to better soil aeration and gradual nutrient supply. For example, banana-peel biochar-based fertilizer significantly enhanced root and shoot growth in cucumber, broccoli and okra. Stronger roots can further improve water and nutrient uptake.

Higher nutrient use efficiency (NUE/PUE): By matching release to demand and cutting losses,

engineered biochars raise the percentage of applied nutrients that end up in the crop. Studies often find higher NUE or PUE with biochar.

Environmental and Economic Impact

Carbon sequestration: Biochar is extremely stable in soil (persists decades to centuries), so every ton added locks carbon that would otherwise return to the atmosphere. In life-cycle analyses, crop systems with biochar had much lower net carbon emissions or negative emission. This "negative emission" effect can be counted as an economic benefit (carbon credit) in modern accounting.

Reduced GHG and N footprint: Stabilizing nitrogen in biochar means less N_2O (a potent greenhouse gas) and nitrate runoff. Biochar-based N fertilizer drastically reduces N leaching. Less fertilizer runoff also means less eutrophication of waterways. Overall, switching to biochar amendments tends to lower the environmental damage cost.

Soil health enhancement: Biochar improves soil structure, porosity and organic matter over the long term. Many studies report higher soil carbon, water retention and microbial activity after biochar use.

Lower fertilizer inputs: Because engineered biochars boost nutrient efficiency, farmers can often apply less chemical fertilizer. Several reports show that partial substitution of NPK with biochar maintains or increases yields while reducing chemical use. This cuts costs and reduces dependency on synthetic inputs.

Economic benefits: When carbon value is included, biochar use can improve farm economics. Even ignoring carbon credits, reduced fertilizer bills and higher yields often pay back the investment over time.

Conclusion

Engineered biochar, whether coated with urea, doped with minerals or combined into composite slow-release granules, represents a frontier in smart fertilization. In cropping systems, early results are encouraging. Carefully designed biochar fertilizers have elevated yields, improved crop quality, and cut nutrient losses. At the same time, biochar locks away carbon and builds soil health for future crops. By tailoring biochar's structure and chemistry, we can create fertilizers that slow-release N, P, K in sync with plant needs. In doing so, biochar moves from a mere soil additive to a carrier of nutrients, making crop production more productive and sustainable.

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Disease Suppressive Soils: Mechanisms and Importance in Sustainable Plant Disease Management

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Introduction

Soil-borne plant pathogens such as fungi, bacteria, and nematodes are responsible for many serious crop diseases. These pathogens survive in the soil for long periods and infect plants through roots or other underground parts. Common examples include wilt, root rot, damping-off, and collar rot diseases. Traditionally, chemical fungicides and soil fumigants have been used to control these diseases. However, excessive use of chemicals can lead to environmental pollution, development of resistant pathogens, and harm to beneficial soil organisms. In recent years, attention has shifted toward sustainable disease management practices. One such approach is the use of disease suppressive soils. These soils have the natural ability to reduce or prevent plant diseases even when pathogens and susceptible host plants are present. The suppression of disease occurs due to the interaction between soil microorganisms, soil properties and plant roots.

Concept of Disease Suppressive Soil

Disease suppressive soil can be defined as a soil in which the activity of plant pathogens is reduced or inhibited by natural biological, chemical, or physical factors present in the soil. In such soils, pathogens either fail to establish themselves or their growth and infection ability are significantly reduced. The suppressive nature of soil is mainly due to the presence of beneficial microorganisms such as bacteria, fungi, and actinomycetes. These micro-organisms compete with pathogens for nutrients and space or produce substances that inhibit pathogen growth.

Types of Disease Suppressive Soils

Disease suppressive soils are generally classified into two types:

General Suppressive Soil: In this type of soil, a large number of diverse microorganisms collectively suppress the growth of pathogens. The suppression is not specific to a single pathogen but affects many

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different pathogens. This suppression occurs due to intense microbial competition for nutrients and ecological niches.

Specific Suppressive Soil: In specific suppressive soils, certain microorganisms play a key role in controlling a particular pathogen. For example, some beneficial bacteria or fungi may specifically inhibit the growth of a particular soil-borne pathogen. The suppressive effect can often be transferred to other soils by adding small amounts of suppressive soil containing these microorganisms.

Mechanisms of Disease Suppression

Several biological and ecological mechanisms contribute to disease suppression in soils.

Competition for Nutrients and Space: Beneficial soil microorganisms compete with plant pathogens for nutrients and space around the root zone (rhizosphere). When beneficial microbes dominate, pathogens cannot establish themselves effectively, reducing disease development.

Antibiosis: Some soil microorganisms produce antibiotic substances that inhibit or kill plant pathogens. These antibiotics suppress the growth and reproduction of harmful microorganisms in the soil.

Parasitism and Predation: Certain beneficial fungi and bacteria directly attack and parasitize plant pathogens. For example, some fungi can grow on pathogen structures and destroy them, thereby reducing their population in the soil.

Induced Systemic Resistance (ISR): Beneficial microorganisms in the rhizosphere can stimulate the plant's natural defense mechanisms. This process is known as induced systemic resistance. As a result, plants become more resistant to infection by pathogens.

Improvement of Soil Health: Healthy soils with good organic matter content, proper aeration, and balanced nutrients promote the growth of beneficial microorganisms. These microbes help maintain a balanced microbial community that suppresses pathogens.

Importance in Sustainable Agriculture

Disease suppressive soils play a significant role in sustainable agriculture. Their importance can be summarized as follows:

Environmentally Friendly Disease Control: Disease suppression occurs naturally without the need for chemical pesticides, reducing environmental pollution.

Improved Soil Health: Suppressive soils contain diverse microbial communities that enhance soil fertility, nutrient cycling, and plant growth.

Reduced Dependence on Chemicals: Using suppressive soils helps reduce the use of fungicides and soil fumigants, lowering production costs and minimizing health risks.

Long-Term Disease Management: Unlike chemical control, which provides temporary relief, disease suppressive soils provide long-term protection by maintaining a stable microbial balance.

Support for Organic Farming: Suppressive soils are especially beneficial in organic and sustainable farming systems where chemical inputs are limited.

Methods to Enhance Disease Suppressiveness

Farmers and researchers can enhance the suppressive capacity of soil through several practices:

- ✓ Addition of organic matter and compost
- ✓ Application of bio-control agents such as beneficial fungi and bacteria
- ✓ Crop rotation with non-host crops
- ✓ Maintaining proper soil fertility and pH
- ✓ Reducing excessive use of chemical pesticides

These practices promote beneficial microorganisms and improve soil biological activity.

Conclusion

Disease suppressive soils represent a natural and sustainable approach to plant disease management. The suppressive effect results from complex interactions among soil microorganisms, soil properties, and plant roots. By understanding the mechanisms involved in disease suppression, scientists and farmers can develop effective strategies to enhance soil health and reduce plant diseases. Promoting disease suppressive soils through organic amendments, crop rotation, and biological control can contribute significantly to sustainable agriculture and environmentally safe crop production.

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The Hidden Gold of the Fungal Kingdom: Spent Mushroom Substrate as a Regenerative Resource

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Within the controlled environments of mushroom farms, a significant issue of surplus is emerging. For each kilogram of fresh, edible mushrooms produced, approximately five kilograms of a soil-like by-product remain. This material, referred to as Spent Mushroom Substrate (SMS), has traditionally been regarded as an agricultural challenge, often treated as waste to be discarded, incinerated, or deposited in landfills. Recent developments indicate that this so-called waste may represent a significant resource within the circular bioeconomy. Rather than being depleted, Spent Mushroom Substrate contains active biological components, enzymes, and organic matter, which may provide effective solutions to several critical challenges in contemporary agriculture.

What is Spent Mushroom Substrate?

Spent Mushroo, Substrate (SMS) refers to the organic materis left over after the harvesting of mushrooms. The initial substrate may consist of various components such as straw, corn cobs, poultry waste, gypsum or sawdust, depending on the type of mushroom (typically *Agaricus bisporus* or species of Pleurotus).

Upon harvesting, not all utilized by the mushrooms. The leftover substrate is altered by the fungal mycelium the root-like structure of the fungus.

This 'spent' substance is abundant in:

Organic Matter: Elevated concentrations of lingo-cellulose and humic substances.

Nutrients: Nitrogen, Phosphorous, Potassium (NPK), along with crucial micronutrients like calcium and magnesium.

Extracellular Enzymes: Robust compounds such as laccase and cellulose that have the ability to dismantle resilient organic bonds.

Microbial Life: A thriving community of advent-ageous bacteria and leftover fungal mycelium.

Applications in Regenerative Agriculture

Soil Improvement and Nutrient Enrichment: A prominent application of SMS is its role as a soil enhancer and organic fertilizer. Its substantial organic matter promotes soil structure, aeration, and moisture retention, particularly in compromised or compacted soils. Research has indicated that applying SMS can lead to increased crop production, bolster root growth and lessen erosion. In contrast to chemical fertilizers, SMS offers a gradual release of nutrients, fostering enduring soil fertility instead of mere short-term nutrient surges. This slow-release characteristic reduces nutrient runoff and ground-water pollution, rendering it especially beneficial in sustainable agricultural practices**.**

Composting and Organic Mixtures: SMS is often

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combined with a variety of organic waste, such as kitchen scraps or yard debris, during composting. Its semi-decomposed condition accelerates the composting process and enhances the quality of the final product. The resulting compost is abundant in humus and advantageous microorganisms, making it ideal for organic farming and horticultural applications.

Disease Resistance and Plant Vitality: Studies show that SMS can inhibit soil-borne plant diseases such as Pythium, Fusarium, and Rhizoctonia. This property is attributed to the competitive microbial populations and antifungal compounds generated by the residual mycelium. Consequently, SMS aids in diminishing pesticide reliance and bolsters integrated pest management practices.

Environmental Cleanup and Ecosystem Recovery

Bioremediation and Mycoremediation: Fungi are well-known for their capacity to decompose complex pollutants, including hydrocarbons, agricultural chemicals, and heavy metals. SMS retains enzymatic activity that can break down environmental toxins. It has been effectively utilized in bioremediation initiatives targeting:

- ✓ Oil-contaminated soils
- ✓ Residues from agricultural pesticides
- ✓ Effluents from industrial dyes
- ✓ Immobilization of heavy metals

By functioning as both a biological agent and a structural framework, SMS serves as an efficient and cost-effective remediation resource, particularly in developing areas.

Land Rehabilitation and Mine Restoration: Degraded areas, such as post-mining locations, frequently experience poor soil quality and minimal organic content. SMS has been applied to reintroduce organic material, encourage microbial settlement, and promote vegetative cover. These efforts underline SMS's importance in restoring ecosystem functionality and expediting natural succession processes.

Energy Generation and the Bioeconomy

Bioenergy and Anaerobic Digestion: Spent mushroom substrate can serve as a feedstock for anaerobic digestion, resulting in biogas production. While its lignocellulosic properties may restrict digestibility, pre-treatment techniques (mechanical, thermal or biological) can greatly enhance methane output. Merging mushroom cultivation with biogas systems fosters synergistic waste-to-energy cycles.

Biochar and Carbon Storage: The pyrolysis of SMS generates biochar, a stable, carbon-rich material utilized for soil enhancement and carbon storage. Biochar obtained from SMS boosts nutrient conservation and microbial activity while securing carbon in soils for centuries. This positions SMS as an essential component in climate change mitigation strategies.

Economic and Community Consequences

Value Generation for Mushroom Cultivators: Viewing SMS as a co-product rather than a disposal item unlocks additional revenue opportunities for mushroom producers. The markets for organic soil enhancements, compost mixtures and bio-based materials present financial benefits while lessening

disposal expenses.

Rural Progress and Circular Economies: The reuse of spent mushroom substrate (SMS) bolsters local circular economies by intertwining agriculture, energy generation and ecological service. Small-holders, cooperatives and rural communities reap benefits from localized resource cycles that diminish reliance on outside inputs.

Challenges and Limitations

In spite of its potential, various hurdles restrict the broad implementation of SMS-oriented solutions:

- ✓ Inconsistency in composition, necessitating uniformity.
- ✓ Logistics expenses arising from bulkiness and moisture levels.
- ✓ Possible salt or heavy metal buildup depending on the resource materials
- ✓ Regulatory hindrances concerning waste designation and land utilization.

Confronting these obstacles demands unified research, policy backing and collaboration across sectors.

Future Outlook: Unlocking the Full Potential of SMS

Breakthroughs in biotechnology, system architecture and sustainable agriculture are broadening the prospective application of spent mushroom substrate. New studies are investigating SMS as a resource of biodegradable packaging, enzyme harvesting and even building materials. As societies shifts towards, low-waste, bio-based economics, SMS emerges as a testament to how fungal ingenuity can inform sustainable design.

Embracing SMS as “hidden treasure” calls for a change in thinking from linear consumption to regenerative management. By harmonizing human systems with fungal functions, we advance nearer to resilient ecosystems and sustainable food networks.

Conclusion

Spent mushorrm substrate illustrates the overlooked potential in biological byproducts. Rather than waste, it stands as a multifunctional regenerative asset capable of rejuvenating soils, restoring environments, generating renewable energy and nurturing circular economics. As the fungal realm continues to spark innovation, SMS presents a concrete route towards ecological restoration and sustaibale advancement.

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Ripe Taar (Asian Palmyra Palm Fruit): A Potential Solution to Malnutrition

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Abstract

The Asian palmyra palm (*Borassus flabellifer*), popularly known as toddy palm, sugar palm, or ice apple, is a slow-growing but highly valuable tree native to South and Southeast Asia. It is traditionally referred to as a "celestial tree" due to its wide range of uses, including food, medicine, and materials. Although the raw translucent kernels (ice apple) are widely consumed as a seasonal summer fruit, the ripe palmyra pulp remains underutilized despite its high nutritional value. The ripe pulp is rich in dietary fibre, vitamins (A, B-complex, and C), minerals (iron, calcium, potassium, and phosphorus), and bioactive compounds such as flavonoids and phenolics. Proper utilization of ripe pulp can help reduce nutritional deficiencies and malnutrition at low cost, while also preventing significant post-harvest wastage. This article highlights the nutritional profile, traditional food products, extraction methods, preservation techniques, and economic importance of ripe palmyra pulp, emphasizing its potential contribution to rural development and food security.

Introduction

The Asian palmyra palm (*Borassus flabellifer*) is a robust tree widely distributed in India, Sri Lanka, Bangladesh, Myanmar, Thailand, and other parts of Southeast Asia. It is commonly known as toddy palm, sugar palm, or ice apple. In traditional communities, it is respected as a "celestial tree" (Karpaga Vruksham) because nearly every part of the plant is useful for food, medicine, household products, and livelihood support. Despite its wide traditional importance, the ripe palmyra fruit pulp remains underutilized in many regions. Large quantities of ripe fruits are wasted annually due to lack of processing facilities and low awareness of its nutritional and commercial value. The ripe pulp can serve as a low-cost and nutrient-dense food source, particularly beneficial in combating malnutrition and micronutrient deficiencies.

Culinary and Commercial Uses of Palmyra Palm

The palmyra palm supports rural livelihoods through multiple edible and commercial products.

Fruit (Ice Apple/Nungu): The tender seeds, commonly known as ice apple or nungu, are translucent and jelly-like. They are widely consumed during summer as a natural coolant. The ripe pulp is also used in traditional preparations such as *taler bora*.

Sap (Neera/Toddy): Sweet sap tapped from the inflorescence is consumed fresh as neera or fermented into toddy, an alcoholic beverage. The sap

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is also a raw material for processed sweeteners.

Palm Sugar and Jaggery: Fresh sap can be boiled to prepare palm jaggery (karuppatti), a nutrient-rich sweetener traditionally considered healthier due to its lower glycemic index compared to refined sugar.

Palmyra Sprouts: Germinated seeds produce edible tubers known as palmyra sprouts. These are boiled or roasted and consumed as a snack.

Materials and Traditional Uses: Leaves are used for thatching, weaving mats, baskets, fans, and eco-friendly household products. Historically, palmyra leaves were also used as manuscripts for writing and preserving literature.

Medicinal Benefits

In traditional medicinal systems such as Ayurveda and Siddha, palmyra palm is used for various health benefits.

Digestive health: The fruit pulp is used to treat gastritis, heartburn, and constipation due to its mild laxative effect.

Skin care: The pulp is applied topically to soothe prickly heat, boils, and sunburn.

Nutritional support: The fruit and sap provide vitamins and minerals that help improve general health and immunity.

Nutritional Profile of Ripe Palmyra Pulp

The ripe yellow-orange pulp is nutritionally richer than the tender translucent kernels. It contains dietary fibre, vitamins, minerals, and antioxidant compounds.

Key Nutrients (per 100 g)

Dietary fibre: Up to 3.0% (both soluble and insoluble fibre)

Vitamin C: Approximately 16.9 mg

Vitamin A: Supports immunity and skin health

Minerals: Potassium (21.5 mg), phosphorus (15.0 mg), and iron (1.2 mg)

Bioactive compounds: Flavonoids and phenolic compounds with antioxidant and anti-inflammatory properties

Ripe palmyra pulp has strong potential as a low-cost food supplement for populations suffering from malnutrition, anaemia, and micronutrient deficiency.

Traditional and Low-Cost Uses of Ripe Palmyra Pulp

Ripe palmyra pulp can be processed into multiple nutritious food products.

Taler Bora (Fritters): Pulp mixed with rice flour, coconut, and jaggery, fried into small balls.

Taler Kheer (Pudding): Pulp cooked with milk and sugar to prepare a creamy dessert.

Pannattu (Fruit Leather): Sun-dried pulp preserved as fruit leather, retaining fibre and phytochemicals.

Jams and spreads: Pulp blended with other fruits (such as orange) to reduce bitterness and improve taste.

Method of Extraction and Preservation

Ripe palmyra pulp extraction requires effort due to its fibrous nature, but it is manageable using traditional techniques.

Extraction of Pulp

✓ Select a fully ripe fruit (soft and aromatic).

- ✓ Remove the crown and peel the black outer skin.
- ✓ Separate the 2-3 large seeds covered in yellow fibre.
- ✓ Soak the seeds in water (about 1 cup) for 4-5 hours.
- ✓ Rub the seeds against a grater or bamboo basket to release pulp.
- ✓ Strain through a sieve or cotton cloth to remove fibres.

Reducing Bitterness

Ripe pulp has slight bitterness. To reduce this: Pour pulp into a cotton cloth and hang it for 4-5 hours to drain bitter liquid.

Preservation Methods

Freezing: Best long-term method; pulp can be stored for several months to one year.

Cooking: Simmer pulp with sugar and salt for 10–20 minutes; refrigerate up to 1.5 weeks.

Drying (Pannattu): Sun-dry pulp into fruit leather; store for several months.

Role in Rural Economy and Malnutrition Reduction

Utilization of ripe palmyra pulp provides strong economic opportunities for rural development. In many regions, over 60% of annual fruit yield is wasted due to poor processing and commercialization. In Sri Lanka alone, approximately 10,000 tons of ripe palmyra fruit is wasted annually. Processing the pulp into value-added products such as jams, jellies, cordials, and fruit leather can reduce post-harvest losses and increase farmer income. This also supports employment in dryland regions where other crops often fail. Furthermore, palmyra-based products have export potential as natural "superfoods" and eco-friendly alternatives.

Conclusion

Ripe palmyra fruit pulp is an underutilized nutritional resource with high potential to address malnutrition, micronutrient deficiency, and rural poverty. Its rich fibre, vitamins, minerals, and bioactive compounds make it suitable for low-cost nutritious foods. Promoting processing, preservation, and commercialization of ripe palmyra pulp can significantly reduce wastage and improve food security and livelihoods.

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Physiological Approaches to Sustainable Agriculture in India

Adarsh Raj and Ravinder Kaur

Abstract

Sustainable agriculture is essential for ensuring food security, environmental protection, and economic stability in India. Crop physiology plays a vital role in achieving sustainability by improving plant efficiency in utilizing water, nutrients, and light while reducing stress-related yield losses. Physiological approaches such as improved photosynthetic efficiency, stress tolerance mechanisms, nutrient-use efficiency, and water-use optimization contribute significantly to sustainable crop production. In the Indian context, where agriculture faces challenges like climate change, soil degradation, and water scarcity, understanding plant physiological processes is crucial. This article discusses key physiological approaches that support sustainable agriculture in India and highlights their impacts on crop productivity and environmental conservation.

Introduction

India's agriculture is the backbone of the national economy and supports the livelihood of a large population. However, modern agriculture faces serious challenges such as declining soil fertility, water scarcity, climate variability, and the overuse of chemical inputs. Sustainable agriculture aims to meet present food demands without compromising the ability of future generations to produce food. Crop physiology, which deals with the study of plant functions and processes, provides scientific solutions to improve crop performance under both normal and stress conditions. Physiological approaches help enhance resource-use efficiency, increase stress tolerance, and maintain ecological balance. Therefore, applying physiological principles is essential for achieving sustainable agriculture in India.

Physiological Approaches and their Impacts

Improved Photosynthetic Efficiency: Photosynthesis is the primary physiological process responsible for biomass production and yield. Enhancing photosynthetic efficiency through better canopy architecture, an improved leaf area index, and efficient carbon assimilation increases crop productivity without increasing input use. Selection of crop varieties with higher photosynthetic rates contributes to sustainable yield improvement.

Water-Use Efficiency: Water scarcity is a major concern in Indian agriculture. Physiological traits such as stomatal regulation, deep root systems, and osmotic adjustment help plants utilize water efficiently. Crops with improved water-use efficiency require less irrigation and perform better under drought conditions, promoting sustainable water manage-ment.

Nutrient-Use Efficiency: Efficient uptake, transport

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and utilization of nutrients are vital for sustainable farming. Physiological mechanisms such as enhanced root growth, mycorrhizal associations, and efficient nutrient metabolism reduce dependency on chemical fertilizers. This minimizes soil and water pollution and lowers production costs.

Stress Tolerance Mechanisms: Plants face various abiotic stresses such as drought, salinity, heat, and cold. Physiological responses such as antioxidant enzyme activity, accumulation of compatible solutes, and hormonal regulation help plants survive stress conditions. Stress-tolerant crops ensure stable yields under changing climatic conditions.

Growth Regulation and Hormonal Balance: Plant growth regulators such as auxins, gibberellins, cytokinins, abscisic acid, and ethylene play a crucial role in growth and development. Proper hormonal balance improves flowering, fruit set, and stress adaptation, contributing to sustainable crop production.

Source-Sink Relationship: Efficient translocation of photosynthates from the source (leaves) to the sink (grains, fruits) is essential for yield improvement. Optimizing source-sink relationships through physiological management enhances productivity without excessive resource input.

Conclusion

Physiological approaches offer effective and eco-friendly solutions for achieving sustainable agriculture in India. By improving photosynthesis, water- and nutrient-use efficiency, and stress tolerance, crop physiology helps maintain productivity while conserving natural resources. Integration of physiological principles with modern agricultural practices can reduce environmental degradation and ensure long-term agricultural sustainability. Therefore, strengthening research and awareness of crop physiological approaches is essential for sustainable agricultural development in India.

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Root Water Uptake Mechanism under Variable Soil Moisture Conditions

Ravinder Kaur and Utkarsh Kumar

Abstract

The root water dynamics is a crucial factor in the life process and the growth of the plant .Water uptake by plant roots varies significantly with moisture conditions present in the soil.Under variable moisture conditions, plants must adjust their hydraulic conductivity and root architecture. This article details the pathways of water movement-apoplastic, symplastic, and transmembrane-and how the expression of aquaporins and root "hydrotropism" allow plants to survive fluctuating water availability. Generally the soil moisture is good but it also depends on several physical, topological and chemical factors of soil with respect to the plant and its channel through which it channels the water.

Introduction

The root water uptake mechanism is a passive thing in terms of general functioning. The mechanism works on the potential gradient, the water moves from high potential to low potential. Several other factors can affect this situation like the water holding capacity of the soil, the plant physiology and the climatic factors also.The process of Root water uptake (RWU) is more than a simple straw-like suction; it is a sophisticated, adaptive mechanism that bridges the gap between soil physics and plant physiology. Plants adapt their water uptake mechanisms in response to decreasing soil moisture. While low-resistance pathways dominate in optimal conditions, plants employ several strategies to bridge the gap as soil resistance increases in drying soil.

Hydraulic Signaling: Plants use chemical messengers such as Abscisic Acid (ABA), to balance water loss and uptake.

Structural Plasticity: Root anatomy is modified to maintain contact with receding water films in the soil.

Osmotic Adjustment: Solutes accumulate within root cells to maintain the necessary suction pressure for water extraction from drying pores.

Types, impacts and classification

The efficiency of root water uptake is determined by a combination of physical soil properties and biological responses. These can be classified based on the energy expenditure and the environmental pressures the plant faces.

Classification of Uptake Mechanisms

Passive Uptake (Transpiration-Driven): The most common form, where water is pulled into the roots by the tension created by leaf transpiration. This follows the Lp (hydraulic conductivity) of the root system.

Active Uptake (Osmotic-Driven): Occurs mainly

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when transpiration is low (e.g., at night). The plant accumulates minerals in the xylem, lowering the water potential and forcing water into the root, often resulting in "guttation" (water droplets on leaf edges).

Impacts of Variable Soil Moisture

Hydraulic Conductivity Loss: As soil dries, the connectivity between soil pores and the root surface breaks. This creates a high-resistance "buffer zone" that slows uptake even if the plant has high internal suction.

Root System Architecture (RSA) Plasticity: Plants respond to moisture variability by altering their growth. Under mild stress, plants often allocate more.

Embolism and Cavitation: Under extreme moisture stress, air bubbles can form in the xylem (embolism), blocking the "hydraulic highway." Plants must then invest energy to repair these vessels or grow new ones once moisture returns.

Conclusion

Root water mechanism is a kinetic interface between biology and physics.The changes and exceptions are a matter of discussion but under variable soil moisture, plants transition from high-efficiency passive uptake to survival-based physiological regulation. The ability of a plant to navigate these fluctuations-through aquaporin gating, osmotic adjustment, and architectural changes-determines its resilience in the face of environmental stress. As global weather patterns become increasingly erratic, a deep understanding of these hydraulic mechanisms remains the cornerstone of modern agronomy and climate science.

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Plant Ideotype Concept and Its Application in Crop Improvement: A Rice-Focused Research Perspective

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Abstract

The plant ideotype concept provides a systematic and physiology-driven framework for crop improvement by emphasizing the design of plant types with optimized morphological physiological and phenological traits for specific environments. This article critically examines the theoretical foundation of ideotype breeding and its practical application in crop improvement with particular emphasis on rice (*Oryza sativa* L.) as a model crop. It synthesizes research evidence demonstrating how traits such as erect leaf architecture reduced plant height improved source-sink balance and enhanced root system architecture have contributed to substantial yield gains and improved resource-use efficiency. Empirical data from field experiments, multi-environment trials and crop simulation models highlight yield increases of 20-40 percent in rice ideotypes alongside improvements in radiation use efficiency harvest index and yield stability. The integration of ideotype concepts with modern breeding tools including genomics high-throughput phenomics and climate-resilient breeding strategies is also discussed. The article underscores the importance of environment-specific ideotype design to address genotype-by-environment interactions under changing climatic conditions. Overall, the plant ideotype concept emerges as a robust and forward-looking strategy for achieving sustainable and resilient crop productivity.

Introduction

Increasing global food demand, shrinking natural resources and climate variability have intensified the need for more efficient and resilient crop varieties. Traditional plant breeding approaches largely based on empirical selection for high yield have achieved remarkable gains but are increasingly constrained by physiological and environmental limits. In this context the plant ideotype concept offers a rational and predictive approach to crop improvement (Donald, 1968). Rice (*Oryza sativa* L.) as a staple food for more than half of the world's population, provides one of the most successful examples of ideotype-based breeding. Physiological limitations such as mutual shading lodging, and inefficient assimilate partitioning in traditional tall

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varieties prompted the design of rice ideotypes with improved canopy architecture, reduced plant height and higher harvest index. Advances in crop physiology modelling and molecular genetics have further strengthened the application of ideotype concepts in rice improvement making it a model crop for understanding the practical value of ideotype-based breeding strategies.

Concept of Plant Ideotype

2.1 Definition and Origin: A plant ideotype can be defined as an idealized plant model possessing a set of morphological and physiological traits that collectively contribute to higher yield and improved adaptability under a given agroecological condition. The term was formally introduced by Donald in 1968 who emphasized that breeding should focus on designing plant types rather than merely selecting superior individuals from existing populations.

Ideotype Versus Yield-Based Selection: Yield is a complex trait influenced by numerous interacting genetic and environmental factors. Selection solely based on yield may obscure underlying physiological limitations. Ideotype breeding shifts the focus toward component traits such as canopy architecture, leaf orientation, tillering behaviour root structure and harvest index which are more heritable and can be manipulated with greater precision.

Key Traits of Plant Ideotypes

Canopy Architecture: An efficient canopy structure is a defining feature of most crop ideotypes. Traits such as erect leaves optimal leaf area index reduced mutual shading, and improved light penetration enhance photosynthetic efficiency at the whole-canopy level. This concept has been particularly successful in cereals such as rice and wheat.

Source-Sink Relationships: Ideotypes are characterized by balanced source and sink capacities. Enhanced photosynthetic source strength must be matched with sufficient sink size, including grain number and size to avoid assimilate limitation. Improved partitioning of assimilates toward economic yield is a major objective in ideotype design.

Root System Architecture: Root traits are increasingly recognized as critical components of ideotypes especially under water-and nutrient-limited conditions. Deep well-branched root systems improve access to soil moisture and nutrients, contributing to stress tolerance and yield stability.

Phenology and Growth Duration: Optimized phenological development allows ideotypes to escape or tolerate environmental stresses. Traits such as early Vigor synchronized flowering, and appropriate maturity duration are tailored to specific agroclimatic zones.

Application of Plant Ideotype Concept in Rice Improvement

Rice Ideotype Development and Yield Gains: Rice ideotype breeding has played a central role in global yield improvement. The introduction of semi-dwarf rice varieties during the Green Revolution was based on an ideotype characterized by short stature erect leaves and high harvest index (Khush, 2001). Field experiments demonstrated that erect-leaf rice ideo-

types improved light distribution within the canopy leading to higher canopy photosynthesis and grain yield. Yield increases of 20-40 percent over traditional varieties were reported under irrigated conditions, primarily due to reduced lodging and improved assimilate partitioning (Yoshida 1981).

Physiological and Morphological Trait Contributions: Research has quantified the contribution of key ideotype traits in rice. Increases in harvest index from approximately 0.30 in traditional varieties to 0.45-0.50 in improved ideotypes have been strongly associated with yield enhancement (Evans, 1993). Studies on leaf angle distribution indicate that erect leaves can increase radiation use efficiency by 10-15 percent, particularly under high nitrogen input systems. Root ideotype research has further shown that deeper and more compact root systems improve drought tolerance and nutrient uptake efficiency.

Multi-Environment Validation: Multi-location trials across Asia have shown that rice ideotypes maintain higher yield stability across diverse environments, although genotype-by-environment interactions remain significant (Peng *et al.,* 2008). These studies highlight the importance of developing environment-specific rice ideotypes rather than a single universal plant type.

Integration with Modern Breeding Tools

Molecular Breeding and Genomics: Advances in genomics have enabled the identification of genes and quantitative trait loci associated with ideotype traits. Marker-assisted selection and genomic selection allow breeders to combine multiple ideotype traits efficiently accelerating the breeding process.

High-Throughput Phenomics: Phenomics platforms provide precise measurement of ideotype traits such as canopy temperature leaf angle and biomass accumulation. These tools bridge the gap between genotype and phenotype improving the accuracy of ideotype-based selection.

Climate-Resilient Ideotypes: Climate change has expanded the ideotype concept to include resilience traits such as heat tolerance drought resistance and efficient radiation and water use. Designing ideotypes for future climates is a major research priority in crop improvement.

Research Evidence and Data Supporting the Ideotype Concept

Empirical Evidence from Major Crops: Substantial experimental evidence supports the effectiveness of ideotype-based breeding in enhancing crop productivity. In rice the development of semi-dwarf ideotypes with erect leaves and higher harvest index led to yield increases of 20-40 percent under irrigated conditions. Field experiments demonstrated that erect-leaf rice ideotypes intercepted light more uniformly across the canopy resulting in higher canopy photosynthesis and improved nitrogen use efficiency. In wheat ideotype breeding focusing on reduced plant height stronger stems and increased grain number per spike contributed to yield gains exceeding one percent per year in several breeding programs. Data from multi-location trials showed that semi-dwarf ideotypes produced higher yields primarily due to improved assimilate partitioning

and lodging resistance. Maize ideotypes with upright leaves and compact architecture allowed higher planting densities, leading to yield increases of 15-30 percent in high-input systems. These gains were associated with enhanced radiation interception and reduced inter-plant competition.

Quantitative Trait Contributions: Physiological studies have quantified the contribution of ideotype traits to yield. For example, increases in harvest index from 0.30 to 0.45 in cereals have been associated with significant improvements in grain yield without proportional increases in total biomass. Similarly, root ideotype studies have shown that deeper rooting depth can improve water extraction by 20-25 percent under drought conditions, resulting in higher yield stability.

Integration of Modelling and Simulation Data: Crop simulation models have been widely used to evaluate ideotype performance under varying environments. Modelling studies indicate that optimizing leaf angle distribution and phenology can increase radiation use efficiency by 10-20 percent. Simulations under future climate scenarios further suggest that ideotypes combining heat tolerance, early Vigor and efficient water use can outperform conventional varieties by up to 25 percent in stress-prone regions.

Ideotype Validation through Phenomics and Genomics: High-throughput phenotyping data have validated ideotype trait selection by linking canopy temperature depression normalized difference vegetation index and biomass accumulation with yield performance. Genomic studies have identified quantitative trait loci associated with ideotype traits such as plant height tiller number and root depth, enabling more precise selection and pyramiding of desirable characteristics.

Limitations and Challenges

Despite strong research support, ideotype breeding faces challenges related to genotype by environment interactions and trait trade-offs. Ideotypes optimized for high-input environments may perform poorly under resource-limited conditions necessitating environment-specific designs. Additionally, the complexity of integrating multiple traits requires careful balancing to avoid negative correlations.

Conclusion

The plant ideotype concept represents a paradigm shift in crop improvement moving from empirical yield-based selection toward a rational trait-oriented and physiology-driven breeding strategy. Evidence from rice improvement clearly demonstrates that deliberate modification of key traits such as canopy architecture plant stature source-sink balance, and root system architecture can significantly enhance radiation use efficiency harvest index and yield stability. The success of semi-dwarf, erect-leaf rice ideotypes highlights the practical value of ideotype-based breeding in overcoming physiological limitations inherent in traditional plant types. Furthermore, the integration of ideotype concepts with modern tools such as genomics high-throughput phenomics and crop simulation model-

ling has strengthened the precision and predictability of breeding outcomes. Despite challenges related to genotype-by-environment interactions and trait trade-offs, the development of environment-specific and climate-resilient ideotypes offers a promising pathway for sustaining productivity under increasing climatic uncertainty. Overall ideotype-based breeding provides a robust framework for designing future crop varieties that combine high yield potential with resource-use efficiency and adaptability thereby contributing to long-term agricultural sustainability and global food security.

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Diffusion as a Fundamental Process in Plant Metabolism

Ayush Kumar and Ravinder Kaur

Abstract

Diffusion, the passive movement of molecules along a concentration gradient, is a foundational physical process underpinning all major plant metabolic functions. This article moves beyond a basic definition to explore diffusion as a dynamically managed principle central to metabolic efficiency, spatial organization, and adaptive responses. We highlight innovative insights into how plants architect their intracellular and tissue landscapes through metabolic channeling, cytosolic streaming, and specialized diffusion barriers to optimize the fluxes of CO_2, photosynthates, ions, and signaling molecules. Furthermore, we discuss trending applications of this knowledge in improving water-use efficiency, designing nanoparticle delivery systems in agri-tech, and overcoming transport bottlenecks in synthetic biology. Understanding and manipulating diffusive pathways is thus presented as a critical frontier for developing resilient and productive crops in a changing climate.

Introduction

In the dynamic world of plant physiology, complex processes like photosynthesis, respiration, and nutrient assimilation capture the imagination. Yet, underlying these sophisticated metabolic pathways is a silent, passive, and indispensable physical process: diffusion. This article revisits diffusion not as a simple textbook concept, but as a fundamental and trending driver of metabolic efficiency, spatial organization, and adaptive responses in plants. Recent advances in bioimaging and computational modeling are revealing how plants architect their intracellular and tissue landscapes to optimize diffusive flows, making the understanding of this basic process more innovative and critical than ever for applications in sustainable agriculture and bioengineering.

The Silent Conductor of Metabolic Pathways

At its core, diffusion is the net movement of molecules or atoms from a region of higher chemical potential (concentration) to a region of lower chemical potential. In plant metabolism, this process is paramount for:

Gas Exchange: The entry of CO_2 into leaf mesophyll cells and the exit of O_2 and water vapor (transpiration) are governed by diffusion across concentration gradients through stomatal pores and intercellular air spaces.

Metabolite Partitioning: The movement of sugars from photosynthetic source tissues (leaves) to sink tissues (roots, fruits) begins with diffusion from sites of production in the chloroplast stroma to the phloem loading zones.

Intracellular Transport: The distribution of small metabolites, ions, and signaling molecules within the

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cytosol and across organelle membranes often relies on diffusion over short distances.

Innovative Insights: Beyond Simple Gradients

Spatial Organization of Metabolism (Metabolic Channeling): Plants minimize diffusion distances by organizing enzyme complexes in close proximity. Se- quential enzymes of the Calvin cycle may associate in metabolons, ensuring rapid transfer of intermediates and enhancing metabolic efficiency.

Cytosolic Streaming as a Diffusive Enhancer: Cytoplasmic streaming (cyclosis) enhances intra- cellular mixing, effectively reducing diffusion limitations in large plant cells.

Diffusion Barriers and Compartmentalization: The Casparian strip in root endodermal cell walls restricts apoplastic flow, forcing selective membrane transport. Leaf air-space architecture optimizes CO_2 diffusion while limiting water loss.

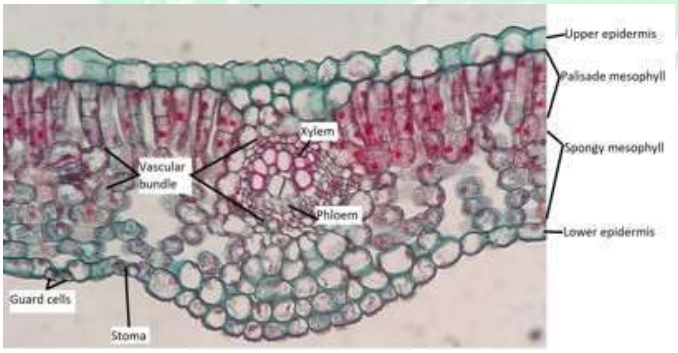


Figure 1: Internal cross-section of a plant leaf illustrating diffusion pathways. The micrograph shows upper and lower epidermis, palisade and spongy mesophyll tissues, vascular bundle (xylem and phloem), and stomata facilitating diffusion of CO_2 and O_2 (Source: BioLibreTexts Biology, CC BY license)

Trending Applications: From Theory to Techn- ology

Improving Water-Use Efficiency (WUE): Optimi- zing internal diffusion pathways enhances photo- synthesis per unit water loss.

Table 1: Key Diffusive Fluxes in Plant Metabolism and their Metabolic Roles

Molecule	Direction of Net Flux	Primary Site and Role	Approx. Distance
CO_2	Atmosphere → Chloro- plast	Photosynthesis (leaf mesophyll)	10–500 μm
O_2	Organelles → Atmo- sphere	Respiration, photores- piration	10–500 μm
Sucrose	Parenchyma → Sieve element	Carbon transport (phloem)	< 50 μm
Ions (K^+, NO_3^-)	Soil → Root cortex	Nutrition, turgor	< 100 μm
ABA	Guard cell → Neigh- bours	Stress signaling	Cellular scale (μm)

Source of data: Compiled from physiological literature. μm = micrometer.

Conclusion

Diffusion is not merely a passive physical phenomenon but a central organizing principle around which plant anatomy and metabolism are structured. Modern plant science highlights diffusion as both a constraint and an opportunity for enhancing metabolic efficiency. As agriculture moves toward sustainability under climate stress, optimizing diffusive pathways offers promis- ing avenues for improving crop resilience and productivity.

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The Chemistry of Soil pH and Acidity

B. Subhash

Abstract

Soil pH is a key chemical variable that controls proton activity, Aluminium hydrolysis, nutrient equilibria, and microbial transformations in agroecosystems. Variations in active, exchangeable, and residual acidity control cation exchange dynamics, phosphorus fixation, base saturation, and Aluminium toxicity thresholds. Recent research (2024-25) have identified synergistic liming-organic amendment techniques for restoring buffering capacity and enhancing nutrient bioavailability in acid soils. Understanding hydrogen ion activity and soil buffering processes is critical for improving fertilizer efficiency, maintaining crop output, and increasing soil resilience in intensified agricultural systems.

Introduction

Soil pH is a fundamental chemical property that determines whether the soil solution is acidic or alkaline and it has a significant impact on agricultural production and sustainability. On a scale of 0-14, hydrogen ion (H^+) activity determines the solubility and availability of important nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients like iron, zinc, and manganese. Most crops thrive in slightly acidic to neutral soils (pH 6.0-7.0), where nutrient availability is highest. Outside of this range, nutrient shortages, toxicities, and lower yields may result. Soil pH also affects microbial activity and nutrient cycle processes such organic matter decomposition, nitrogen transformation, and phosphorus mineralization. In acidic environments, microbial competition for nitrogen may rise, limiting crop nutrient uptake and influencing fertilizer effectiveness. Furthermore, soil acidity influences fertilizer efficiency; for example, in highly acidic soils, phosphorus may become fixed in insoluble forms. Overall, soil pH controls chemical, biological, and ecological soil processes, influencing nutrient management, crop yield, and long-term soil health. Understanding soil pH is critical for designing sustainable and effective agriculture management strategies.

Soil pH: Chemical Definition and Meaning

Soil pH is a fundamental chemical property that quantifies the acidity or alkalinity of soil solutions, regulating chemical reactions, nutrient conversions, and plant-soil interactions. Chemically, soil pH is defined as the negative logarithm of hydrogen ion activity (H^+) in the soil solution:

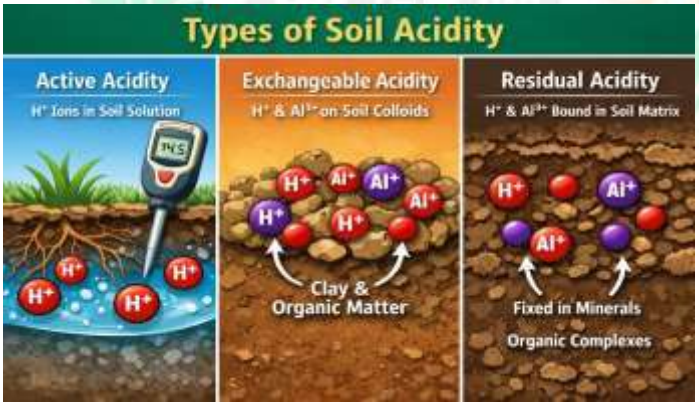
$$pH = -\log[H^+]$$

It represents proton activity rather than total hydrogen ion concentration. Because the pH scale is logarithmic, a one-unit decrease in pH corresponds

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to a ten-fold increase in H^+ activity. On the standard scale, pH values less than 7 indicate acidic circumstances, 7 is neutral, and pH values greater than 7 are alkaline. These categories help to describe how soil chemical processes and plant responses alter over acidity gradients. Soil acidity is not primarily based on free H^+ ions. Exchangeable aluminum (Al^{3+}) is a major contributor to acidity in humid tropical and subtropical soils. When the pH dips below 5.5, aluminum becomes more soluble and hydrolyzes, releasing more H^+ ions and increasing acidity. Soil pH measures both active acidity (free H^+ in solution) and potential acidity (related with exchangeable aluminum), which impact nutrient availability, buffering capacity, and biological activity.

Types of Soil Acidity



Active acidity: The pH directly measures the proportion of hydrogen ions (H^+) present in soil solutions. It determines the immediate chemical environment in which plant roots exist. Continuous proton inputs from nitrification and acid deposition cause a significant increase in active acidity.

Exchangeable acidity: Exchangable acidity referes to H^+ and Al^{3+} Adsorb on soil colloids (clays and organic materials). Aluminium, especially in heavily Worn soils, contributes significantly to this form by hydrolyzing and releasing H^+ into the soil solution. In acid soils, active and exchangeable acidity have major influence on nutrient availability and toxicity thresholds.

Remaining acidity: Soil mineral structures and organic complexes store H^+ and Al^{3+}, which contribute to residual acidity. Although soil pH meters do not detect it right away, this pool serves as a long-term acidity reservoir, gradually buffering changes and necessitating increased liming inputs for neutralization.

Sources of soil acidity

Rainfall and leaching in humid locations, base cation leaching (Ca^{2+}, Mg^{2+}). Soil acidity is mostly caused by the presence of K^+ and Na^+. Heavy rainfall displaces base cations, leaving H^+ and Al^{3+} dominant on exchange sites, leading to lower pH values.

Nitrogen Fertilizer Use: Ammonium-nitrogen fertilizers (e.g., ammonium sulphate, urea) generate acidity via nitrification, in which ammonium is converted into nitrate, releasing hydrogen ions. Long-term high N inputs increase acidification, especially in highland and intensively cultivated soils.

Organic Matter Decomposition: Microbial mineralization of organic wastes produces organic acids (such as fulvic and humic acids), which can contribute to soil acidity. The rate and extent of acid generation are determined by residue quality and

microbial activity.

Aluminium Hydrolysis: At pH values below ~5.5, Al^{3+} becomes soluble. Aluminium is a key component in highly acidic soils, which are prevalent in tropical and subtropical agriculture due to hydrolysis reactions that increase H^+ levels.

Soil Buffering Capacity: Soil buffering refers to the soil's resistance to pH changes. It is determined by cation exchange capacity (CEC), clay concentration, and organic matter. Soils with a high CEC have a greater buffering capacity and require more additions to adjust pH. This explains why sandy or low-organic soils acidify more quickly and respond better to liming.

Effect of Soil pH on Nutrient Availability

Nutrient availability in most crop systems peaks around neutral pH (≈6.0-7.0). At a low pH:

- ✓ Base cations (Ca^{2+} and Mg^{2+}) become less accessible.
- ✓ High quantities of Aluminium and manganese can be harmful.
- ✓ Phosphorus is fixed in unavailable forms.

According to several global assessments, pH fluctuations outside of optimum ranges limit macronutrient uptake and impair fertilizer efficiency.

Measurement of Soil pH

Reliable assessment utilizes both laboratory and field techniques:

- ✓ Measure active acidity in soil-water or soil-$CaCl_2$ solutions using a glass-electrode potentiometric method.
- ✓ Portable pH metres and indicator strips enable quick examination for management decisions.
- ✓ Exchangeable acidity is usually determined via KCl extraction.

Liming: Chemical Neutralization of Acidity

Liming remains the principal corrective strategy:

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$$

Calcium carbonate $CaCO_3$ (lime) neutralizes H^+ and raises pH. Recent studies also demonstrate the benefits of combining lime with organic amendments to enhance soil chemical properties and phosphorus availability.

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Role of Biotechnology in Host Plant Resistance

Nidhi Kumari, Chanchal Shakyawal, Rishabh Shukla, Yogendra and Vrushali Patil

Role of Biotechnology in Resistance

Biotechnology plays a crucial role in Host Plant Resistance (HPR) by by enabling precise identification, transfer and enhancement of resistance traits in crops. Unlike conventional breeding, which depends on natural variation and long selection cycles, modern biotechnological tools accelerate the development of resistant varieties with higher accuracy and efficiency. It involves developing crop varieties that can resist insect pests, diseases, and stresses using modern molecular tools. It enables the identification, modification and introduction of resistance genes into plants.

Key Roles Include

- ✓ Development of transgenic crops (e.g., Bt cotton, Bt maize) that produce insecticidal proteins
- ✓ Use of RNA interference (RNAi/HIGS) to silence essential pest genes
- ✓ Genome editing (CRISPR/Cas) to enhance or create resistance without foreign DNA
- ✓ Gene stacking/pyramiding for durable and broad-spectrum resistance
- ✓ Omics and marker-assisted selection for precise and faster breeding

Transgenic Insecticidal Traits

Transgenic insecticidal traits are genetically engineered characteristics that make plants capable of defending themselves against insect pests. The most successful and widely used example is the incorporation of Bt (*Bacillus thuringiensis*) genes into crops such as:

- ✓ Bt cotton
- ✓ Bt maize
- ✓ Bt brinjal (in some countries like Bangladesh)
- ✓ Bt soybean (limited regions)

Bt genes code for cry or vip proteins, which are insecticidal crystal proteins.

Major Benefits

- ✓ High effectiveness against major pests like bollworms, borers, and rootworms.
- ✓ Reduced pesticide use (up to 40-80% reductions in many regions).
- ✓ Improved yield stability due to lower pest pressure.
- ✓ Environmentally friendly (less spray, less contamination).
- ✓ Target specificity → minimal non-target effects.

Mechanism of Bt Toxins (Cry Proteins)

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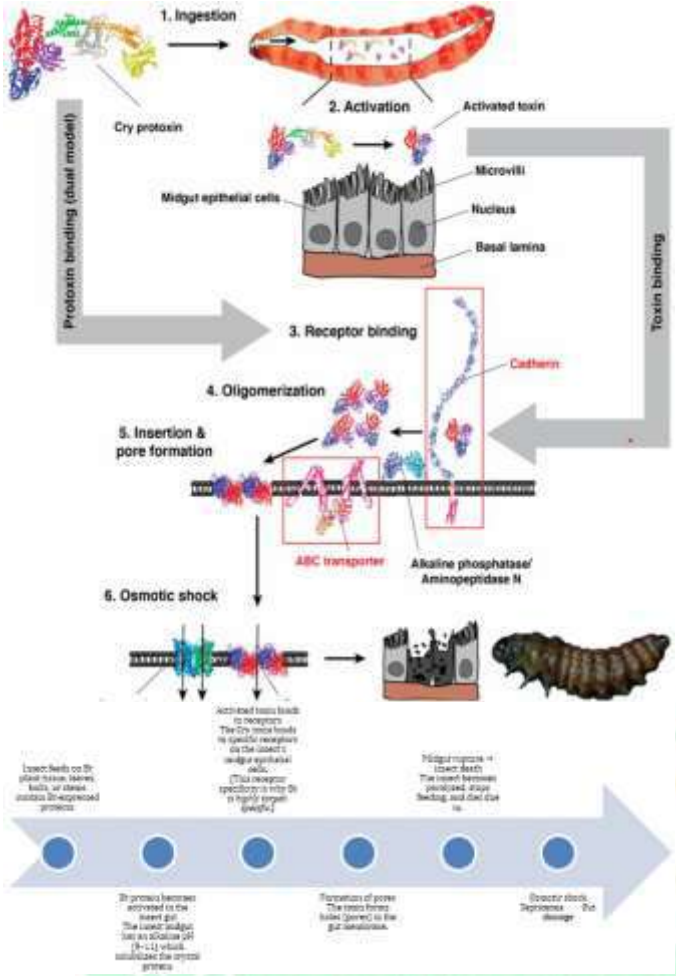


Fig. 1: Mechanism of Bt Toxins

RNA Interference (RNAi): RNAi is a natural biological process where double-stranded RNA (dsRNA) triggers the degradation of a specific messenger RNA (mRNA), blocking gene expression.

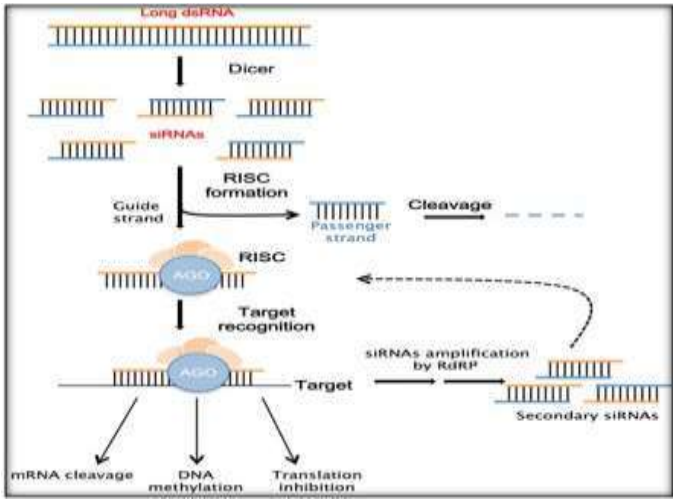


Fig. 2: RNA Interference

Host-Induced Gene Silencing (HIGS)

HIGS is a biotechnology application of RNAi where plants are engineered to produce double-stranded RNA (dsRNA) that targets and silences essential genes in pests or pathogens. When insects, fungi, nematodes, or viruses attack the plant, they absorb the dsRNA and their vital genes get switched off, reducing infection or killing them.

- ✓ Plant is engineered to produce dsRNA against an essential insect pest gene.
- ✓ Insect feeds on the plant and ingests the dsRNA.
- ✓ Inside the insect, Dicer enzyme cuts dsRNA into siRNA.
- ✓ siRNA joins the RISC complex.
- ✓ RISC uses siRNA as a guide to find the matching pest mRNA.
- ✓ Target mRNA is cut and destroyed → protein is not formed.
- ✓ Essential pest gene stops working → insect stops feeding, growth is inhibited, or the pest dies.

Example

Zhu *et al*. (2012) reported that transgenic tobacco plants expressing dsRNA targeting the ecdysone receptor (EcR) gene of Helicoverpa armigera significantly reduced EcR mRNA levels in larvae, causing molting defects and larval death, thereby enhancing plant resistance.

HIGS-based transgenic wheat targeting aphid genes significantly reduced aphid survival, reproduction, and population density, with RNAi effects persisting across multiple generations (Liu *et al*., 2020).

Host-induced gene silencing (HIGS) in transgenic rice targeting essential genes of rice stem borer and brown planthopper resulted in effective gene silencing, developmental defects, and high pest mortality, leading to strong insect resistance in rice (Liu *et al*., 2020).

Genome Editing (CRISPR/Cas) in Host Plant Resistance (HPR)

CRISPR/Cas gene editing is used to enhance plant resistance against insect pests by precisely modifying specific plant genes.

- ✓ First, a gene that affects insect susceptibility or plant defense is selected, and a guide RNA (gRNA) matching that gene is designed.
- ✓ The Cas9 enzyme and gRNA are then delivered into plant cells, where Cas9 cuts the DNA at the target site.
- ✓ During the repair process, mutations are introduced that disrupt the gene, reducing the plant's susceptibility to insects.
- ✓ Edited cells are regenerated into whole plants, which are screened to confirm successful gene editing and then tested for improved insect resistance, resulting in plants that naturally defend themselves without introducing foreign DNA.

Example

Kuai *et al*. (2024) used CRISPR/Cas9 to knock out susceptibility-related genes in rice, resulting in reduced brown planthopper feeding and survival.

Zhang *et al*. (2018) edited SlJAZ2 in tomato, a negative regulator of the jasmonic acid pathway, leading to enhanced resistance against chewing insects such as *Helicoverpa armigera*.

Lu *et al*. (2018) CRISPR-Cas9 deletion of the CYP71A1 gene in rice enhanced resistance against brown planthopper and stem borer by altering plant metabolite balance.

Gene Stacking (Gene Pyramiding)

Gene stacking involves combining multiple resistance genes within a single plant to achieve broad-spectrum and durable resistance against insect pests. Instead of relying on a single gene, which pests can overcome over time, gene stacking targets different mechanisms of defense simultaneously, making it harder for insects to adapt.

For example, in cotton, Bt genes like Cry1Ac and Cry2Ab have been stacked to control bollworm species. Plants expressing both genes show higher resistance and reduced larval survival than plants with a single Bt gene, delaying the development of insect resistance. Similarly, stacking genes for defensive proteins (like proteinase inhibitors) with secondary metabolite pathway genes can enhance resistance to chewing pests in crops like tomato and rice.

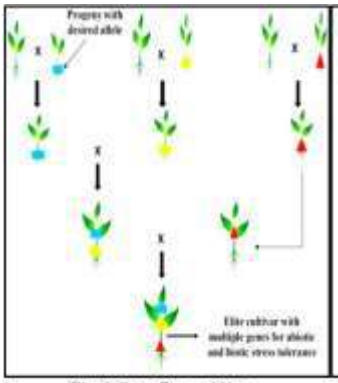


Fig. 3 Gene Pyramiding

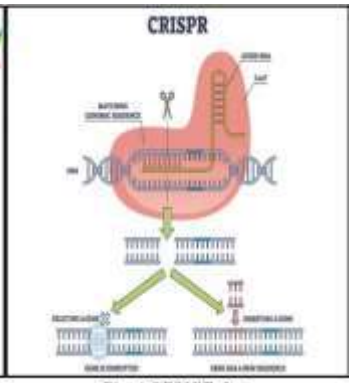


Fig. 4 CRISPR Cas

Bt Cotton: *Cry1Ac* + *Cry2Ab* + *Vip3A* → resistance against bollworms

Bt Maize: *Cry1Ab* + *Cry1F* → resistance against stem borers & fall armyworm

Rice (Experimental): Bt genes stacked for resistance to yellow stem borer

Soybean: Bt trait combinations for lepidopteran pests

Marker-Assisted Selection (MAS)

Marker-Assisted Selection (MAS) is a modern plant breeding technique that uses molecular markers specific DNA sequences associated with desirable traits to select plants carrying genes of interest, such as resistance to pests and diseases. Instead of relying solely on visible traits (phenotypes), which can be influenced by the environment, MAS allows breeders to identify resistant plants at the DNA level.

- ✓ First, genes or quantitative trait loci (QTLs) that confer resistance to a specific pest or pathogen are identified in a donor plant.
- ✓ DNA markers closely linked to the resistance genes are developed. Common markers include RFLPs, SSRs, SNPs, and CAPS.
- ✓ Breeding populations (offspring) are screened for the presence of these markers using molecular techniques.
- ✓ Only plants carrying the resistance gene(s) are selected for further breeding, ensuring high accuracy.
- ✓ MAS can be used to pyramid multiple resistance genes, improving the durability of host plant resistance.

Examples

- ✓ Introgression of Bph14 and Bph15 through MAS to enhance the resistance in Minghui 63 and its derived hybrids against BPH (Hu *et al*., 2012).
- ✓ Genes from wild tomato species, such as *Solanum peruvianum*, have been incorporated via MAS to develop varieties resistant to whitefly (*Bemisia tabaci*) and tomato leaf miner (*Tuta absoluta*), reducing crop losses.
- ✓ Pyramiding of two brown plant hopper resistance genes Bph3 and Bph27 (t), into elite rice cultivars showed significantly enhanced resistance against BPH (Liu *et al*., 2016).

Omics in HPR

Omics refers to advanced biological approaches used to study plant resistance at different levels:

Genomics: Study of resistance genes (R-genes, QTLs)

Transcriptomics: Identifies genes activated during insect attack

Proteomics: Studies defense proteins produced against insects

Metabolomics: Analyzes toxic or deterrent metabolites

Genomics

Genomics is the study of the entire genome of a plant to identify genes and genomic regions responsible for resistance against insect pests. By using genomic tools such as QTL mapping, genome-wide association studies (GWAS) and whole genome

genome sequencing, researchers can pinpoint resistance genes and use them in breeding or genetic improvement programs.

Examples

Rice: Genomic studies identified QTLs (e.g., *Bph* genes) for resistance against brown planthopper.

Maize: QTLs associated with resistance to stem borer and fall armyworm.

Cotton: Identification of genes involved in bollworm resistance.

Transcriptomics

Transcriptomics is the study of all RNA transcripts (gene expression) in a plant during insect attack to understand how defense genes are activated or suppressed. It helps identify key defense-related pathways such as jasmonic acid, salicylic acid, and secondary metabolite biosynthesis involved in insect resistance.

Examples

Tomato: Transcriptome analysis showed activation of proteinase inhibitor genes against *Helicoverpa armigera*.

Rice: Increased expression of JA-regulated defense genes during planthopper infestation.

Proteomics

Proteomics is the study of the entire set of proteins produced by a plant during insect attack to understand actual defense responses at the functional level. It helps identify defense-related proteins such as protease inhibitors, lectins, pathogenesis-related (PR) proteins, and enzymes involved in secondary metabolite synthesis.

Examples

Legumes: Detection of protease inhibitors and lectins toxic to insect gut enzymes.

Maize: Identification of defense-related enzymes active against caterpillars.

Metabolomics

Metabolomics is the study of all small metabolites produced by plants during insect attack, helping to understand the chemical basis of plant defense. It identifies defensive compounds such as phenolics, alkaloids, terpenoids, and flavonoids that deter insect feeding, reduce growth, or cause toxicity.

Application: Metabolomics detects toxic or antifeedant metabolites produced during pest attack.

Examples

Cotton: Gossypol accumulation deters bollworms.

Maize: Benzoxazinoids (DIMBOA) provide resistance to stem borers and aphids.

Brassica crops: Glucosinolates deter insect pests.

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Precision Agriculture and Smart Farming Technologies

Suraj Kumar, Rheecha, Neeraj Kumar, Aman Raj and Amay Govind Tikhile

Abstract

Precision agriculture and smart farming technologies are revolutionizing modern agriculture by moving away from traditional, experience-based approaches and toward data-driven decision-making. Farmers may apply inputs precisely where and when they are needed and monitor crop and soil conditions in real time with the use of technologies like GPS, GIS, remote sensing, drones, IoT sensors, artificial intelligence, and automation. This “right input, right place, right time” strategy lowers expenses and its impact on the environment while increasing produ-ction. Applications like targeted pest and disease control, variable rate fertilization, and precision irrigation increase the sustainability and efficiency of resource utilization. Despite its advantages, adoption is hampered by issues like high starting costs, the need for technical expertise, and poor rural connectivity, especially in developing nations. Precision agriculture presents a viable route toward resilient, climate-smart and sustainable farming systems in the future, given the stresses of climate change and the rising demand for food.

Introduction

The way we raise food needs to change in a world where the population is growing continuously and farms are facing increasing strain from climate change. To sustainably fulfill the world's food demands, traditional farming methods that rely on physical labor, intuition, and generalized practices are no longer sufficient. Precision agriculture and smart farming technologies are innovative methods that use state-of-the-art science and data-driven to to increase farming's productivity, efficiency, and sustainability (Krishnababu *et al.*, 2024). The goal of precision agriculture (PA) is to make educated judgments based on actual field data rather than relying just on intuition. By combining technology, sensors, analytics, and automation into a single, intelligent system, smart farming expands on this and helps farmers at every stage of crop production (Raj *et al.*, 2025).

Precision Agriculture: Data based Farming

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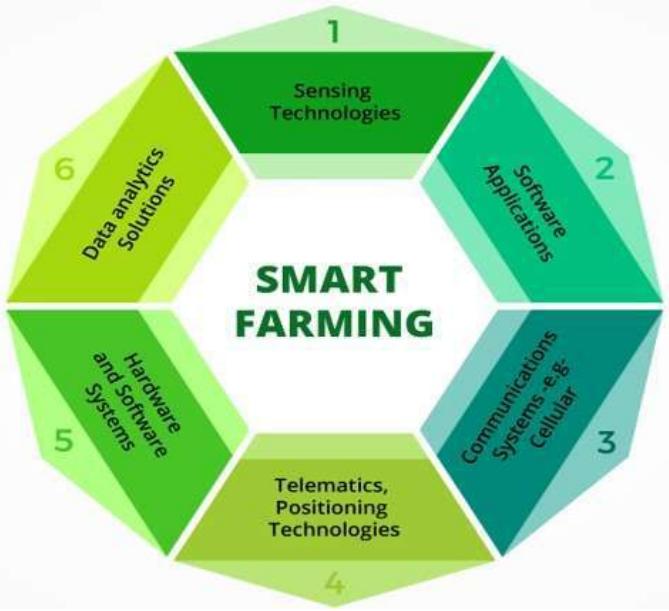
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Fundamentally, precision agriculture applies inputs (water, fertilizer, and pesticides) only where necessary by using technology to comprehend the diversity within an agricultural field. Information on crop growth, soil health, moisture levels, and pest pressure is gathered by sensors, satellite imagery, and tools like drones. After that, this data is examined to help make accurate judgments that reduce expenses and waste while enhancing crop production (Raj *et al.*, 2025). In order to establish a linked agricultural ecosystem, smart farming integrates Internet of Things (IoT) devices, wireless networks, cloud computing, and advanced analytics (like artificial intelligence). Together, they assist farmers in maximizing every aspect of agricultural production, from harvest planning to irrigation timing (Soussi *et al.*, 2024).

Traditional Farms to Smart Farms- Technologies involved

GPS and GIS: Without satellite-based location technologies like GPS, precision agriculture would not be possible. Soil sampling, variable rate application, and yield mapping are all made possible by the high-level mapping of farms using GPS and Geographic Information Systems (GIS). By transforming fields into data layers, this technology makes patterns evident that are otherwise unseen (Raj *et al.*, 2025).

Drones and Remote Sensing: Drones, or unmanned aerial vehicles, or UAVs, are some of the most innovative farming equipment available today. Drones with multispectral, thermal or high-resolution cameras may quickly scan large areas, spotting issues like water stress, disease develop-ment, or food deficits before human eyes can (Shirwal *et al.*, 2025). Real-time crop monitoring, pest detection, and resource optimization are made possible by combining drones with AI and machine learning, according to researchers. This efficiently transforms unprocessed aerial photos into useful farming data (Agrawal and Arafat, 2024).



Smart Sensors and IoT Devices: Data on moisture, temperature, humidity, and nutrient levels are gathered via sensors positioned in the ground, on machinery, or in the atmosphere. These sensors are connected by IoT networks, which transmit real-time data to dashboards or mobile apps that farmers may view from a distance. In addition to saving time and cutting waste, this technology enables automated watering, early pest alarms, and improved input management (Soussi *et al.*, 2024).

Data analytics and artificial intelligence: Strong analysis is required due to the proliferation of data

from sensors, satellites, and drones. AI and machine learning are useful in this situation. AI can make significantly more informed decisions than humans can by analyzing soil health, predicting weather impacts, detecting diseases early, and understanding patterns from massive datasets (Gupta and Pal, 2025).

Benefits of Precision farming to the planet in general and farmers in particular

Smart farming and precision agriculture provide real advantages on the ground, not simply in theory:

Higher Yield and Productivity: Farmers may greatly increase yields and lower crop losses by detecting crop stress early and applying inputs properly.

Lower Input Costs: Using insecticides, water, and fertilizers wisely reduces wasteful spending. Because inputs are only used where necessary, they have a smaller financial and environmental impact (Panotra *et al.*, 2025).

Sustainability of the Environment: Reduced fertilizer and chemical runoff into soil and water bodies results from less over-application. Additionally, precision irrigation saves precious water resources (Krishnababu *et al.*, 2024).

Better Decision-Making: Farmers may make well-informed judgments rather than educated guesses when they have access to data and analytics that provide insights into weather forecasts, planting trends, and field variability.

Challenges for precision agriculture

Despite many benefits, precision agriculture also has hurdles:

High Initial Costs: The cost of advanced equipment, drones, sensors, and software can be a significant deterrent for small and marginal farmers, particularly in developing countries (Krishnababu *et al.*, 2024).

Gap in Technical Knowledge: Training is necessary for the efficient use of smart technologies. Farmers may find it difficult to use these tools effectively without appropriate assistance and training (Krishnababu *et al.*, 2024).

Problems with Connectivity: Reliable internet connectivity is still lacking in many rural regions, which makes remote monitoring and real-time data transfer difficult.

Data Security and Privacy Issues: Large-scale field and agricultural data collection raises concerns about data ownership and privacy, which require strict regulation.

Precision Agriculture in India: Opportunities and Barriers

Precision agriculture is becoming more popular in India due to government programs, agri-tech businesses, and easier access to drones and sensors. However, the country's agriculture is still primarily driven by smallholders. Drones and IoT sensors have been used in experimental projects to improve crop management in states such as Andhra Pradesh and Karnataka. Adoption is nevertheless hampered by issues including expensive equipment, a dearth of local technical assistance, and restricted internet access in remote areas.

Adoption could be accelerated by subsidies, policy assistance, and focused training initiatives (Krishnababu *et al.*, 2024).

The Future of Farming is Smart

Smart farming and precision agriculture are more than just fads; they are influencing how food is produced worldwide in the future. Future developments in robotics, cloud computing, artificial intelligence, and sensor networks will make farms even more intelligent and sustainable. Consider a time in the future when:

- ✓ AI predicts disease epidemics in advance.
- ✓ Crops are tended by robots on their own.
- ✓ Every fertilizer unit and water drop is applied with surgical accuracy.
- ✓ To run their entire farm, small farmers in rural villages utilize smartphone apps.
- ✓ Precision agriculture is setting the pace for this future, which is closer than we realize.

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Carbon Sequestration: Nature's Secret Weapon against Climate Change

Uddhav Kumar, Prabhat Kumar, Naik Kunal Machindra, Aman Raj and Manish Kumar Jha

Abstract

Carbon sequestration is an essential natural and technological approach for reducing atmospheric carbon dioxide (CO_2) levels and mitigating climate change. This article explains how carbon can be captured and stored in vegetation, soils, oceans and geological formations, emphasizing the importance of sustainable land-management practices in enhancing carbon storage. It highlights major anthropogenic and natural sources of CO_2. Special attention is given to soil-based sequestration through crop residue management, conservation agriculture, agroforestry and the application of biochar, which not only increases soil organic carbon but also improves soil fertility, water retention and agricultural productivity. The role of forests as long-term carbon sinks is also discussed. Additionally, the article outlines key challenges such as deforestation, residue burning, intensive tillage, and imbalanced fertilizer use that limit sequestration potential. Overall, carbon sequestration is presented as a practical, eco-friendly strategy that supports climate change mitigation, sustainable agriculture and ecosystem health, offering long-term environmental and socio-economic benefits.

Introduction

Carbon sequestration involves capturing and storing atmospheric carbon dioxide (CO_2), a primary greenhouse gas fuelling global warming and climate change. Human activities like fossil fuel combustion and deforestation have rapidly increased CO_2 levels, making it essential to boost natural sinks such as biomass. One effective strategy is to enhance CO_2 uptake by trees and plants via photosynthesis, locking the gas away in their tissues.

Izaurralde *et al.* (2007) defined carbon sequestration as the impleme-ntation of a land management practice that increased net primary productivity, reduced the rate of heterotrophic respir-ation, or both and led to an increase in ecosystem C storage. Planting trees, reducing the intensity of tillage on cropland, or restoring grasslands on degraded lands will all lead to an increase in C storage in plants, soils, or both.

Carbon sequestration is the placement of

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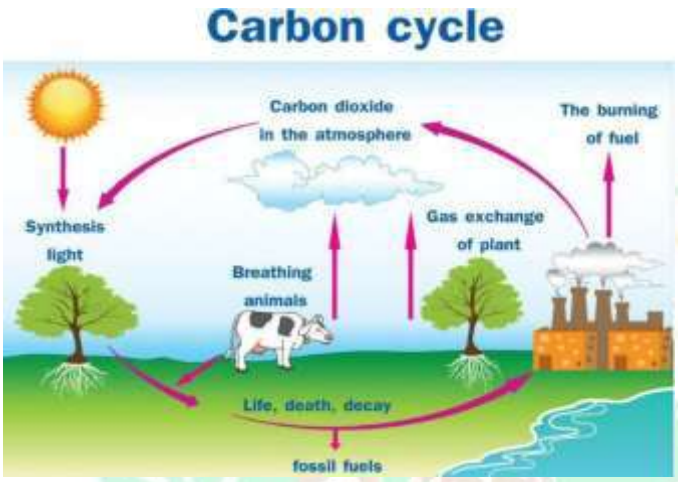
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CO_2 into a depository in such a way that it remains safely and is not released back to the atmosphere. Sequestration means something that is locked away for safekeeping. The trapping of a chemical in the atmosphere or environment and its isolation in a natural or artificial storage area. CO_2 emission rates depend on world economic activity, the energy efficiency of a particular process, and the carbon content of the source of CO_2 emissions (Newell *et al.* 2006).



Carbon emission in India: India has become the world's third-largest emitter of greenhouse gases (GHGs), after China and the United States. India emitted about 3.9 billion metric tons of GHGs, accounting for roughly 7% of the global total. Of this, around 2.8 billion metric tons per year is carbon dioxide (CO_2) from energy and industrial sources. However, India's per capita carbon emissions are about 2.0 metric tons per year, which is significantly lower than the global average and far below that of developed countries.

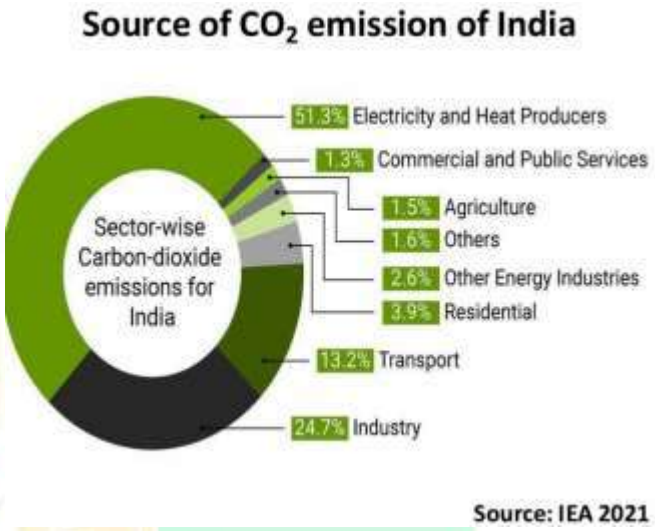
Source of CO_2 Emission

Man-made sources

- ✓ Industries
- ✓ Transportation
- ✓ Land use change
- ✓ Soil cultivation
- ✓ Biomass burning

Natural sources

- ✓ Volcanoes
- ✓ Wild Fires
- ✓ Decomposition
- ✓ Respiration



Type of carbon sequestration

Geological Sequestration: Geologic Sequestration (GS) is the process of injecting carbon dioxide (CO_2), captured from an industrial (e.g., steel and cement production) or energy-related source (e.g., a power plant or natural gas processing facility), into deep subsurface rock formations for long-term storage. This is part of a process frequently referred to as "carbon capture and storage" or CCS.

Terrestrial Sequestration: Terrestrial sequestration is a set of land management practices that maximizes the amount of carbon that remains stored in the soil and plant material for the long term. Benefits of terrestrial storage may include improved soil and

water quality, reduced erosion, reduced evaporative water loss, reduced pest problems, and overall ecosystem improvement.

Ocean sequestration: Ocean sequestration is the natural process by which the world's oceans absorb and store carbon dioxide (CO_2) from the atmosphere through physical dissolution in seawater, biological processes such as photosynthesis by phytoplankton, and storage in coastal ecosystems like mangroves and seagrasses, thereby reducing atmospheric CO_2 levels and helping to mitigate climate change. The ocean absorbs over 25% of the annual release of anthropogenic CO_2

Biochar in Carbon Sequestration

According to Lehmann *et al.* (2006), the term "biochar" is a relatively recent development and evolved in conjunction with issues such as soil management and carbon sequestration. Pyrolysis produces bio-char, a carbon-rich, fine-grained, porous substance and solid byproduct, similar in its appearance to charcoal. Biochar returned to soil produces a range of environmental benefits, such as enhanced soil carbon sequestration and soil fertility improvement. The application of biochar to soil is proposed as a novel approach to establish a significant, long-term sink for atmospheric carbon dioxide in terrestrial ecosystems. 50% of the carbon in biomass is returned to the soil as biochar, increasing soil fertility and crop yield, while sequestering carbon.

Carbon Sequestration in Soil

The carbon that remains as plant tissue is then consumed by animals or added to the soil as litter when the plant dies and decomposes. The primary way that carbon is stored in the soil is as soil organic matter. Soil organic matter is the complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi and bacteria) and carbon associated with soil minerals.

Crop Residue Management in Carbon Sequestration

Crop residue is a principal source of C, which constitutes about 40% of the total biomass on a dry-weight basis. Crop residue includes any biomass left in the field after grain and other economic components have been harvested. Crop residue retention and nutrient application increase SOC and are considered an effective measure of C sequestration. Gradual decomposition of surface residue improves soil organic matter status, biological activity and diversity and contributes to overall improvement in soil quality.

Role of Forest in Carbon Sequestration

As forests grow, they store carbon in woody tissues and soil organic matter.

- ✓ The net rate of carbon uptake is greatest when forests are young, and slows with time.
- ✓ When forests are cut, the carbon they contain may be quickly returned to the atmosphere if the woody tissue is burned or converted to products, such as paper, that are short-lived.
- ✓ If the wood is used for construction or furniture, then those products retain carbon during their

lifetimes and act as carbon sinks.

Benefits of carbon sequestration

Improved Soil Structure: When organic carbon increases in soil, it binds soil particles together into stable aggregates. This creates better pore spaces for air and water movement. Well-structured soil is loose, crumbly, and easier for roots to grow through.

Removing CO_2 from the Atmosphere: Plants absorb CO_2 through photosynthesis and transfer some of that carbon into the soil through roots and plant residues. This stored carbon remains in the soil for years or even centuries, reducing the amount of greenhouse gases in the atmosphere.

Better Water Use and Storage: Soils rich in organic carbon act like a sponge. They absorb and retain more water during rainfall and release it slowly to plants during dry periods. This improves drought resistance and reduces water stress in crops.

Less Erosion: Healthy, carbon-rich soils have stronger structure and better ground cover from vegetation. This prevents soil particles from being washed away by rain or blown away by wind, protecting valuable topsoil.

Increased Soil Fertility: Soil organic carbon improves nutrient availability by enhancing microbial activity. It helps store essential nutrients like nitrogen, phosphorus, and potassium, making them more available to plants.

Improved Biodiversity: Carbon-rich soils support a wide variety of organisms such as earthworms, fungi, bacteria, and insects. These organisms improve nutrient cycling, soil aeration, and overall soil health.

Healthier Ecology: By improving soil health, carbon sequestration supports stable ecosystems, reduces land degradation, and enhances natural cycles such as water and nutrient cycling.

Improved Agricultural Performance: Better soil structure, moisture retention and nutrient availability lead to higher crop yields, improved crop quality, and greater resilience to climate extremes. Farmers benefit from increased productivity and reduced input costs.

Challenges in Soil Carbon Sequestration

Soil carbon sequestration plays an important role in climate mitigation and sustainable agriculture, but several human activities reduce its effectiveness. The following are major challenges:

Deforestation: Cutting down forests reduces the amount of plant biomass that captures CO_2 through photosynthesis. It also disturbs the soil, releasing stored carbon back into the atmosphere and lowering future carbon storage potential.

Residue Burning: Burning crop residues destroys organic matter that could otherwise decompose and add carbon to the soil. It also releases large amounts of CO_2 and other greenhouse gases into the atmosphere.

Conventional Tillage: Frequent ploughing exposes soil organic matter to oxygen, accelerating its decomposition and releasing stored carbon as CO_2. It also breaks soil aggregates, reducing soil structure and stability.

Imbalanced Use of Fertilizer: Excessive or improper use of chemical fertilizers can harm soil

microorganisms that help store carbon. Overuse of nitrogen fertilizers can also increase emissions of nitrous oxide (N_2O), a potent greenhouse gas.

Reduced Inputs of Organic Matter: When farmers remove crop residues or fail to add compost, manure, or cover crops, the soil receives less organic material. This decreases soil carbon levels over time and weakens soil health.

Conclusions

Soil carbon sequestration is an effective and practical strategy for removing atmospheric carbon dioxide (CO_2) compared to many other mitigation approaches because it can be directly implemented through improved land-management practices. Approaches such as Conservation Agriculture (CA), agroforestry, and the application of biochar significantly enhance carbon storage in soils while simultaneously improving soil health. These practices increase soil organic matter (SOM), strengthen soil organic carbon (SOC) levels, enhance microbial activity, reduce soil bulk density, and improve nutrient availability. In addition, a wide range of sustainable agricultural techniques including no-till farming, crop residue management, integrated nutrient management (INM), and mulching can further promote carbon accumulation in plants and soils, making agriculture an important tool in climate change mitigation and long-term soil sustainability.

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Integrated Farming System: Modern Approach Concept for Doubling Farmers' Income

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Abstract

An innovative and sustainable agricultural strategy, the Integrated Farming System (IFS) aims to increase farm production, profitability, and resilience, especially for small and marginal farmers. IFS encourages effective resource recycling and reduces reliance on outside inputs by combining crops, livestock, fisheries, agroforestry, and related businesses into a single farm unit. Around 90-95 percent of nutritional requirements are self-supplied through resource recycling, which curtails the cost of cultivation and increases profit margins and employment. The system's fundamental idea is to turn trash or byproducts from one business into useful inputs for another, which lowers production costs and enhances soil health. IFS offers varied and year-round income prospects, lowering financial risk and improving livelihood stability in the face of declining landholdings, climate variability, and shifting market pricing. Comparing integrated models to monocropping systems, empirical research shows that the former greatly increases net farm returns. With the help of organizations like ICAR and extension systems like Krishi Vigyan Kendras, IFS offers a practical route to sustainable farming and the country's objective of doubling farmers' incomes while maintaining environmental preservation and long-term rural development.

Introduction

India's agricultural sector is changing dramatically. Farm revenues are still erratic and frequently insufficient, even though they continue to directly or indirectly support about half of the population. Farming has become more dangerous due to small landholdings, erratic weather patterns, and shifting market values. It is no longer economically viable to rely just on monocropping in such situations. An agricultural strategy that guarantees resilience, profitability, and production all at once is urgently needed. The Integrated Farming System (IFS), which integrates several farm businesses into a single, effective entity intended to increase revenue while

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avoiding risk, emerges as a practical and scientific answer.

Integrated Farming System

A diversified agricultural production system known as an Integrated Farming System (IFS) combines and manages a variety of farm industries, including crops, livestock, fisheries, agroforestry, and related activities, on a single farm. IFS's core tenet is that "the waste of one enterprise becomes the input of another," encouraging effective resource recycling and reducing external inputs. IFS establishes biological connections among elements to improve total farm productivity and sustainability, in contrast to conventional farming, where each activity operates in isolation. IFS increases farm revenue, reinforces ecological balance, and promotes nutrient recycling, according to studies conducted by the Indian Council of Agricultural Research (ICAR) (Behera, 2013).

IFS is Necessary in the Present Agricultural Scenario

Over 85% of all farming households in India are small and marginal farmers, who dominate the country's agricultural system. These farmers struggle to make enough money from crop production alone since they have limited acreage. The fragmentation of landholdings has considerably decreased per capita farm revenue, according to agricultural statistics provided by the Government of India.

Furthermore, as a result of increased weather variability brought on by climate change, crop yield is directly impacted by droughts, floods, and erratic rainfall patterns. According to research, climate stress increases farmer vulnerability and lowers agricultural productivity (Praveen and Sharma, 2020). In order to overcome these obstacles, IFS diversifies farm businesses such that revenue from other sources can offset losses in one area.

Major Components of an Integrated Farming System

Crop Component: The majority of IFS models continue to be based on the crop enterprise. Depending on the agroclimatic conditions in their area, farmers grow fruits, vegetables, pulses, grains, and oilseeds. Crop variety lowers the accumulation of pests and diseases while increasing productivity per unit area. Crop residues are effectively used rather than burned or wasted when combined with livestock or fisheries. Diversified cropping has been shown to promote soil health and revenue stability (Tiwari *et al.*, 2023).

Livestock Component: Stabilizing farm income depends heavily on livestock integration. Goats and poultry offer short production cycles with rapid financial rewards, while dairy animals generate daily income through milk sales. More significantly, animal waste can be used to prepare organic manure and produce biogas. This decreases production costs and lessens reliance on artificial fertilizers. Dairy integration with crop systems can boost net farm returns by 30-50%, according to studies.

The Fisheries Component: Another source of revenue is fish aquaculture, especially in agricultural ponds. Grain and fish can be produced simultaneous-

ly on the same field thanks to integrated rice-fish systems. In rice fields, fish alleviate pest pressure by feeding on weeds and insects, while their excrement increases the water's minerals. Overall productivity and profitability are increased by this synergy.

Agroforestry Component: Growing trees alongside crops or livestock systems is known as agroforestry. By producing timber, fuelwood, fodder, and fruits, trees contribute to long-term economic stability. Additionally, they improve microclimate conditions, decrease soil erosion and increase carbon sequestration. Agroforestry improves environmental sustainability and land production, according to scientific studies (Nair, 2011).

Resource Recycling: Internal nutrition recycling is IFS's defining feature. Cattle manure feeds biogas plants, crop residues feed cattle, and biogas slurry improves soil fertility. Fish ponds can benefit from the usage of poultry droppings to promote the growth of plankton, which is utilized as fish food. This circular strategy encourages ecological sustainability and lessens reliance on outside inputs. Research shows that recycling nutrients greatly increases soil organic carbon and lowers fertilizer expenses.

IFS-Doubling Farmers' Income

IFS boosts revenue in several ways. First, it ensures a steady flow of income throughout the year: milk every day, vegetables every week, crops every season, and fruits every year. This steady flow of cash enhances financial stability. Second, by producing compost, feed, and manure internally, it lowers input costs. Third, diversification reduces risk by preventing farmers from being fully reliant on the market price of a single commodity. Empirical research indicates that integrated models can increase net returns by 40-100% compared with monocropping systems (Behera *et al*., 2025).



Benefits of integrated farming



Institutions involved and Policy Support

Organizations like the Indian Council of Agricultural Research (ICAR), which carries out model demonstrations throughout agroclimatic zones, have aided in the promotion of IFS in India. To promote integrated models, Krishi Vigyan Kendras (KVKs) offer farmer training and on-field demonstrations. The National Bank for Agriculture and Rural Development (NABARD), which provides livelihood initiatives and rural lending schemes, frequently facilitates financial support for diverse farm firms. These organizations are essential to expanding the use of IFS across the country.

Challenges in Adoption

Widespread adoption is hampered by several issues despite its shown advantages. Small farms may find it challenging to make the initial investment in fish ponds, cattle buildings, or biogas units. Additionally, technological expertise and planning abilities are necessary for managing several businesses. In remote locations, market access for a variety of produce might sometimes be a barrier. Training, financing availability, and institutional assistance are therefore still crucial.

Conclusion

A paradigm change from single-enterprise agriculture to diversified, sustainable, and profit-driven farming is represented by the Integrated Farming System. IFS improves economic resilience while establishing ecological balance through the integration of agriculture, livestock, fisheries, and agroforestry. It enhances soil health, lowers hazards, and guarantees consistent revenue. IFS stands out as a financially feasible and scientifically supported method of doubling farmers' income in the face of declining landholdings and climate unpredictability. In the end, it turns farmers into independent agricultural entrepreneurs rather than just producers.

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Natural Farming: A Pathway to Sustainable Agriculture

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Abstract

Natural farming is an eco-friendly agriculture approach that emphasizes limiting external inputs while collaborating with natural processes. This approach, which was made popular by Masanobu Fukuoka and was inspired by traditional agricultural wisdom, avoids the use of chemical pesticides, synthetic fertilizers, and excessive soil disturbance. Rather, it encourages natural soil enrichment methods, mulching, and biodiversity. The concept, tenets, financial and environmental advantages, difficulties, and prospects of natural farming are all covered in this article. Natural farming is emerging as a sustainable alternative that promotes environmental health, farmer income, and long-term food security as worries about climate change, soil degradation, and food safety grow worldwide.

Introduction

Agriculture has traditionally been essential for human progress and survival. However, contemporary industrial farming has resulted in major environmental challenges such as decreased soil fertility, water contamination, biodiversity loss, and increasing greenhouse gas emissions. Farmers have also faced financial challenges as a result of their reliance on chemical fertilizers and pesticides. In response to these mounting concerns, natural farming has gained acceptance as a long-term solution aimed at restoring harmony between agriculture and the environment. Natural farming is based on the belief that nature is inherently balanced and capable of maintaining soil fertility without the use of artificial chemical inputs. It emphasizes agriculture practices that benefit rather than harm natural ecosystems.

Historical Background and Philosophy

Masanobu Fukuoka, a Japanese farmer and thinker, played an important role in shaping the notion of natural farming. In his well-known book, The One-Straw Revolution, he developed the concept of "do-nothing" farming. This word does not imply inaction, but rather the cessation of unneeded agricultural interventions such as plowing, chemical fertilization, and pesticide application. Fukuoka felt that close study of nature enables farmers to connect their practices with natural systems. His strategy emphasized minimal interference, soil cover, crop diversity, and dependence on natural cycles to sustain productivity. In India, similar principles have been promoted through projects such as Zero Budget Natural Farming (ZBNF), which encourages farmers

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to use locally accessible resources to reduce expenses and boost soil life.

Fundamental Principles of Natural Farming

Natural farming operates on several essential principles:

Removal of Chemical Inputs: Instead of synthetic fertilizers and insecticides, farmers make natural solutions out of cow dung, urine, compost, and plant extracts. These materials boost soil microorganisms and make plants more resistant to pests and diseases.

Minimal soil disturbance: Frequent plowing disrupts soil structure and damages beneficial organisms. Natural farming recommends reducing or avoiding tillage to preserve soil fertility and organic matter

Soil Cover through Mulching: Mulching involves covering the soil surface with organic materials such as straw or crop residues. This technique conserves moisture, suppresses weeds, stabilizes soil temperature and promotes microbial growth.

Crop Diversity: Planting a variety of crops together enhances biodiversity, reduces pest problems naturally, and improves nutrient cycling within the soil.

Environmental Benefits

One of the most significant advantages of natural farming is its good environmental impact.

Soil Health Restoration: Continuous chemical use frequently lowers soil fertility over time. Natural farming enhances soil structure by increasing organic matter and promoting microbial biodiversity. Healthy soil holds more water and nutrients, resulting in long-term productivity.

Water Conservation: Mulching and improved soil structure minimize evaporation while increasing water retention. As a result, irrigation demands are greatly reduced.

Biodiversity Protection: Natural farming promotes a diverse range of beneficial insects, earthworms, birds, and microbes. This biodiversity results in a balanced ecosystem that organically suppresses pests.

Climate Change Mitigation: Healthy soils operate as carbon sinks, absorbing and storing atmospheric CO_2. Furthermore, avoiding synthetic fertilizers minimizes greenhouse gas emissions from their manufacturing and use.

Economic Benefits: Farmers' financial stability can be enhanced by natural farming. Seeds, fertilizers, and insecticides are frequently expensive in modern agriculture. These costs cause many farmers to incur debt. Because farmers make fertilizers and insect repellents from locally accessible materials, natural farming lowers input costs. During the transition period, yields may initially decrease, but production can be stabilized by long-term soil regeneration. Additionally, there is an increasing desire for organic and chemical-free produce. Products from natural farming can frequently command higher market prices, boosting farmers' profits.

Prospects for the Future

Global interest in sustainable agricultural techniques, such as natural farming, has grown as environmental consciousness has grown.

Agroecological methods are being promoted by governments and groups in an effort to guarantee long-term food. The efficacy of natural farming can be increased without sacrificing ecological principles by combining traditional agricultural knowledge with contemporary scientific instruments, such as soil testing and climate forecasting. Natural farming is more than simply a method; it is a change of viewpoint that acknowledges nature as a collaborator in food production rather than just a resource to be exploited.

Conclusion

An effective and sustainable substitute for chemical-intensive agriculture is natural farming. It contributes to long-term ecological balance and food security by restoring soil health, preserving water, safeguarding biodiversity, and lowering farming expenses. Natural farming is a viable route toward resilient and ecologically conscious agriculture, despite obstacles to its widespread adoption. Adopting nature-based farming methods could be essential to ensuring the welfare of present and future generations in a period where environmental sustainability is vital.

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Cultivation Practices of Broccoli under Protected Cultivation: A Gateway to Quality and Profitability in Meghalaya

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Introduction

In India, broccoli farming is emerging as a significant boom for the rural economy, offering high returns per unit area. A quintessential cool-season crop, it thrives in the spring and late winter seasons. Beyond its economic appeal, broccoli is a powerhouse of nutrition, rich in iron, calcium, and vitamins. It contains approximately 3.3% protein and is exceptionally high in Vitamin A and Vitamin C. Furthermore, it provides substantial amounts of riboflavin, niacin, thiamine, and a high concentration of health-promoting carotenoids and glucosinolates like sulforaphane. Primarily used fresh in salads or lightly steamed, broccoli is marketed fresh, frozen, or as a value-added salad component. To overcome climatic constraints and ensure year-round, high-quality production, protected cultivation presents a transformative approach, especially for regions like Meghalaya with variable weather patterns.

Status of Broccoli Cultivation in Meghalaya

A decade or two ago, broccoli was virtually absent from the agricultural tapestry of Meghalaya, particularly in the Ri-Bhoi District. Today, its cultivation is growing steadily, albeit still limited to specific niches and driven by trial-and-error in open fields. Farmers have begun establishing foundational knowledge, primarily through the support of local Krishi Vigyan Kendras (KVKs) and the experiences shared by progressive early adopters. However, open-field cultivation faces challenges like unseasonal rains, pest invasions, and temperature fluctuations, which affect yield and quality. This underscores the critical need to transition towards scientific protected cultivation practices to stabilize and enhance production.

The Current Scenario: Broccoli Cultivation Area in Ri-Bhoi

Providing a single, precise figure for broccoli cultivation is challenging due to the dynamic and rapidly evolving nature of this high-value crop. However, a reliable estimate can be constructed from official data and ground observations.

Estimated Area under Broccoli: As of the latest assessments (2023-24), the area under broccoli cultivation in Ri-Bhoi District is estimated to be between 200 to 300 hectares.

Source of Data & Context: This estimate is derived from:

Cluster Reports: Broccoli cultivation is not widespread uniformly but is concentrated in specific clusters known for temperate vegetables, primarily in Umsning, Jirang, Mawpun, and Umling blocks.

Government & KVK Initiatives: The area has seen a compound annual growth rate of 15-20% over the

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last 5 years, driven by missions like the Mission Organic Value Chain Development for North Eastern Region (MOVCD-NER) and support from the Krishi Vigyan Kendra (KVK), Ri-Bhoi.

Dynamic Nature: The area fluctuates seasonally (mainly a *Rabi*/winter crop) and year-to-year based on market prices from the previous season.

Key Point: Broccoli cultivation, while significant and growing, still occupies a niche segment compared to traditional leafy vegetables and staples in the district.

Total Vegetable Cultivation Area in Ri-Bhoi District

Ri-Bhoi is one of the prime vegetable bowls of Meghalaya, supplying a large portion of the state's and region's demand.

Total Vegetable Area: According to the Meghalaya State Horticulture Department and Agricultural Census data, the total area under vegetable cultivation in Ri-Bhoi District is approximately 10,000 to 12,000 hectares.

Major Crops Included: This area encompasses a diverse mix:

Potato: A major staple and cash crop.

Tomato & Brinjal (Eggplant): Widely cultivated across seasons.

Cole Crops: Cabbage and Cauliflower are the dominant crops in this group and have historically occupied the area now seeing broccoli adoption.

Leafy Vegetables: Including local greens, spinach, etc.

Other Vegetables: Beans, peas, carrots, radishes, and cucurbits (cucumber, pumpkin).

Controlled Environment Condition Requirements

Broccoli under protected structures (polyhouses, net houses, and low tunnels) requires precise environmental management:

Temperature: Optimal range is 18-22°C. Temperatures above 25°C induce premature bolting (flowering), while frost can damage curds. Protected structures help buffer against external extremes.

Relative Humidity: Maintained at 60-70%. Higher humidity promotes fungal diseases (like downy mildew), necessitating good ventilation.

Light: Requires full sunlight. Polyhouse films with high light transmission (UV-stabilized) are essential. In Meghalaya's often cloudy weather, ensuring maximum light penetration is key.

Soil/Growing Media: Well-drained, sandy loam soil with a pH of 6.0-6.8. Soilless media (coco peat, vermiculite, compost mixes) in raised beds or containers are ideal for disease-free nursery and precision farming.

Cultivation and Management Practices

Variety Selection: Choose hybrids suited for protected conditions - 'Green Magic', 'Fiesta', 'Monotop' - known for uniform maturity, compact heads, and disease tolerance.

Nursery Raising: Sow seeds in protrays (98 cells) using sterilized soilless media. This ensures healthy, disease-free, and uniform seedlings ready for transplanting in 25-28 days.

Transplanting & Spacing: Transplant seedlings at

the 4-5 true leaf stage onto raised beds inside the structure. Adopt a spacing of 45 cm x 45 cm for optimal air circulation and light access.

Irrigation: Implement drip irrigation with fertigation. This ensures water and nutrient use efficiency, keeps foliage dry (reducing disease risk), and maintains optimal soil moisture.

Nutrient Management: Adopt a fertigation schedule. A general recommendation includes a balanced NPK mixture along with Calcium and Boron. Boron is critical (foliar spray of 0.2% Borax) to prevent hollow stem disorder.

Climate Management: Use side venting and roof ventilation in polyhouses for cooling and humidity control. Shade nets may be used during periods of intense sun.

Plant Production Problems

Despite the controlled environment, challenges persist:

Pests: Aphids, whiteflies, and cabbage caterpillars can infiltrate. Management includes installing insect-proof nets (40-50 mesh), using yellow sticky traps, and releasing biocontrol agents like Trichogramma wasps.

Diseases: Damping-off, downy mildew, and black rot are concerns. Prevention relies on sterilized media, strict sanitation, avoiding overhead irrigation, and ensuring good ventilation. Fungicidal sprays (like copper-based) may be used as a last resort.

Physiological Disorders

Buttoning: Caused by transplanting old seedlings or nutrient stress.

Hollow Stem: Induced by Boron deficiency and rapid growth.

Purpling of Heads: Often due to low temperature stress or phosphorus imbalance.

Economy and Marketing

Protected cultivation involves a higher initial investment for structure, drip system, and quality inputs. However, it offers compelling advantages:

Premium Yield: Harvests can be 20-30% higher than open fields, with superior quality (tighter, cleaner heads).

Year-Round & Off-Season Production: Enables supply during lean periods (monsoon, peak summer) when market prices are at their peak.

Reduced Pesticide Residue: Controlled conditions lead to cleaner produce, meeting the growing demand for safe, high-quality vegetables from hotels, supermarkets, and export channels.

Market Linkages: Produce from protected cultivation can be branded (e.g., Polyhouse Fresh Broccoli) and directly linked to high-value markets in Shillong, Guwahati, and beyond through existing FPOs facilitated by KVKs and the Meghalaya Basin Management Agency (MBMA).

Conclusion

Protected cultivation of broccoli represents a sustainable and profitable frontier for Meghalaya's agriculture. It mitigates the risks of open-field farming, enhances yield and quality, and aligns with market demands for safe, consistent produce. While knowledge dissemination and initial capital remain hurdles, coordinated efforts from KVKs, state

horticulture departments, and financial institutions can empower farmers. By adopting this science-intensive practice, Meghalaya can secure its position as a reliable producer of this nutritional superfood, turning the green crowns of broccoli into crowns of economic prosperity for its farming community.

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Role of Green Manure Crop in Sustainable Agriculture

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Abstract

Green manuring is an eco-friendly agricultural practice of growing, cutting, and ploughing under fresh green plant biomass (often legumes like sunhemp or dhaincha) into the soil to significantly enhance its organic matter, nutrient content (especially nitrogen), structure, and fertility. It acts as a sustainable, cost-effective, and natural alternative to chemical fertilizers. Soil health and fertility are fundamental pillars of sustainable agriculture, ensuring long-term productivity and environmental integrity. Green manuring, a practice rooted in agro ecological principles, has gained recognition as an effective and sustainable strategy to enhance soil quality. The concept of green manuring, its benefits and its role in promoting sustainable agriculture. It involves planting specific cover crops, often legumes or nitrogen-fixing plants, in between cash crops or during fallow periods. These cover crops are then incorporated into the soil, enriching it with organic matter and vital nutrients. The symbiotic relationship between certain cover crops and soil microorganisms allows for the fixation of atmospheric nitrogen, reducing the need for synthetic fertilizers and mitigating the environmental impact of excess nitrogen use. The advantages of green manuring extend beyond soil fertility. This practice enhances soil structure, water retention, and reduces erosion, all of which contribute to improved soil health. The addition of organic matter boosts microbial diversity, leading to increased nutrient cycling and a reduction in soil borne diseases. It also plays a pivotal role in carbon sequestration, contributing to climate change mitigation by storing carbon in the soil. This abstract emphasizes the importance of green manuring as a sustainable solution for enhancing soil health and fertility. Its ability to reduce the reliance on chemical inputs, conserve water, and sequester carbon makes it an invaluable practice for modern agriculture. To maximize the potential of green manuring, farmers must tailor their cover crop choices to their specific agro ecological context and integrate it into their crop rotation systems. Further research and knowledge sharing are essential to support the adoption and optimization of green manuring for a sustainable and resilient agricultural future.

Introduction

Green manure refers to crops grown to be incorporated into the soil, enhancing its organic matter. These crops are usually fast-growing and include species such as legumes. Leguminous plants are popular as they add nitrogen to the soil through nitrogen fixation. Other plants used as green manure can include grasses and clovers.

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These crops are grown for a specific period and then ploughed under, rather than being harvested for sale or consumption. This method enriches the soil with nutrients and organic matter, which helps improve its quality and structure. Green Manuring Green manuring/ In situ green manuring involves raising of crops specifically to be incorporated into the soil where it was raised. Green manure crops are typically legumes, grasses, or other plants that are rich in nutrients and organic matter. Green manuring improves physical, chemical and biological properties and helps in maintaining soil fertility, structure, and overall soil health, reducing the need for synthetic fertilizers and promoting sustainable agriculture.

In Situ Green manuring Advantages

- ✓ Crops are grown and incorporated into the soil in the same location
- ✓ No transportation or storage required
- ✓ Reduced labour and costs
- ✓ Immediate soil improvement Ex: Sunhemp, Cowpea, Dhaincha
- ✓ Enhances soil fertility and structure
- ✓ Supports beneficial microorganisms
- ✓ Increases nutrient availability
- ✓ Reduces soil erosion
- ✓ Promotes ecosystem services

Benefits

Soil fertility improvement: Green manure adds organic matter, nutrients and beneficial micro-organisms to the soil.

Soil structure improvement: Green manure helps improve soil porosity, aeration, and water-holding capacity.

Erosion control: Green manure crops help hold soil in place, reducing erosion and soil loss.

Weed suppression: Green manure crops can outcompete weeds, reducing the need for herbicides.

Pest and disease management: Some green manure crops repel pests and diseases, reducing the need for pesticides.

Characteristic of Green Manuring Crops

- ✓ It is Capable of establishing and growing quickly.
- ✓ Tolerant to adverse climatic conditions such as drought, water logging, high and low temperatures etc. and tolerant to pests and diseases.
- ✓ It should possess adequate Rhizobium nodulation potential and must be effective nitrogen fixer.
- ✓ It should be capable of growing very fast and capable of accumulating sufficient fixed N in 4-6 weeks.
- ✓ Easy to incorporate and quickly decomposable.

Classification of green manuring

In-situ green manuring: In this system the short duration legume crops are grown and buried in the same site when they attain the age of 60-80 days after sowing. This system of on-site nutrient resource generation is most prevalent in northern and southern parts of India where rice is the major crop in the existing cropping systems. E.g., Sun hemp, Dhaicha, Shervi, Urd, Mung, Cowpea, Berseem, etc

Green leaf manuring: Green leaves and tender plant parts of the plants are collected from shrubs and trees

growing on bunds, degraded lands or nearby forest and they are turned down or mixed into the soil 15-30 days before sowing of the Crops depending on the tenderness of the foliage or plant parts. E.g., Glyricidia, Pongamia, Neem, Gulmohur, Peltophorum, Calotropis, Avise, Subabul, Wild Indigo, Mahua, etc.

Advantage of green manuring

Increased Organic Matter: Green manure, typically composed of plant residues, adds organic matter to the soil. As these residues decompose, they provide a continuous source of organic material that enriches the soil. This organic matter stimulates the activity of beneficial soil microorganisms, fostering nutrient cycling and soil health.

Improved Soil Structure: Green manures play a crucial role in improving soil structure. The root systems of green manure crops help break up compacted soil, creating channels for air and water movement. This enhances soil aeration, drainage, and tilth, ultimately improving the water-holding capacity (WHC) of the soil. The enhanced structure also reduces runoff and erosion caused by heavy rainfall, leading to better soil conservation.

Nutrient Cycling: Green manure crops have the ability to access nutrients from deeper soil layers and accumulate them in their biomass. When the green manure is incorporated into the upper soil layer, these nutrients become available for subsequent crops. This nutrient cycling process reduces the risk of nutrient leaching and makes essential elements more accessible to plants.

Nitrogen Fixation: Many green manure crops, particularly leguminous ones, have the unique ability to fix atmospheric nitrogen through symbiotic relationships with nitrogen-fixing bacteria in their root nodules. This biological nitrogen fixation process converts atmospheric N_2 into ammonium (NH_4^+), which enriches the soil with readily available nitrogen. This added nitrogen can be used by succeeding crops, reducing the need for synthetic nitrogen fertilizers and promoting sustainable nutrient management.

Increased Nutrient Availability: Green manuring can increase the availability of certain plant nutrients, such as phosphorus (P_2O_5), calcium (Ca), magnesium (Mg), and iron (Fe). The organic matter provided by green manures serves as a nutrient reservoir, gradually releasing these essential elements for plant uptake.

Function of Green Manuring

- ✓ Green manures such as clover and vetch contain nitrogen fixing symbiotic bacteria in root nodules that fix atmospheric nitrogen in a form that plants can use. This performs the vital function of fertilization. If desired, animal manures may also be added.
- ✓ Depending on the species of cover crop grown, the amount of nitrogen released into the soil lies between 40 and 200 pounds per acre. With green manure use, the amount of nitrogen that is available to the succeeding crop is usually in the range of 40-60% of the total amount of nitrogen that is contained within the green manure crop.

- ✓ Green manure acts mainly as soil-acidifying matter to decrease the alkalinity/pH of alkali soil by generating humic acid and acetic acid.
- ✓ Incorporation of cover crops into the soil allows the nutrients held within the green manure to be released and made available to the succeeding crops. This results immediately from an increase in abundance of soil microorganisms from the degradation of plant material that aid in the decomposition of this fresh material.
- ✓ Nitrogen fixation: The main benefit of using a legume as a green manure is that legumes fix nitrogen from the atmosphere and convert it into a form that is available to other plants. Legumes from a symbiotic association with soil bacteria called rhizobium. These bacteria colonize the root hairs of the legumes and multiply causing swellings, which become nodules.

The bacteria benefit from the relationship by obtaining carbohydrates (plant sugars) from the legume. The growing legume benefits from the nitrogen that is captured from the air and converted into ammonium legume benefits from the nitrogen that is captured from the air and converted into ammonium within the nodules.

Limitations and Challenges

- ✓ While green manure offers many benefits, there are challenges. One significant limitation is the time required to grow and incorporate the green manure crops, which might not fit all farming schedules. This can be a problem for farmers who need quick soil fertility solutions.
- ✓ Climate can also limit the effectiveness of green manure. For instance, in very cold regions, certain green manure crops may not thrive, impacting their effectiveness in nutrient release and soil improvement.
- ✓ Using green manure also requires knowledge of crop rotation and soil management. Inappropriate use can lead to poor results or even harm soil health if not managed correctly. The cost of seeds and labor for planting and incorporating green manure can also be prohibitive for some farmers.
- ✓ Farmers and gardeners must weigh these limitations when considering green manure for their practices. Proper planning and understanding of local conditions are crucial for maximizing the benefits of green manure.

Conclusion

Green manuring is a promising and sustainable approach to enhance soil health and fertility in agriculture. This eco-friendly practice reduces reliance on synthetic fertilizers, enriching the soil with organic matter and nutrients, leading to increased crop yields and improved quality. It also fosters diverse microorganisms, aiding nutrient availability and disease control while preventing soil erosion and improving water retention. Additionally, it contributes to carbon sequestration, helping combat climate change. Successful adoption requires regional and crop-specific considerations and support systems. Green manuring is crucial for sustainable agriculture and addressing global environmental challenges, promoting a healthier planet

for future generations. Scientific research and practical experience have shown that incorporating green manure crops into agricultural systems can lead to improved soil productivity, structure, and erosion control while reducing the reliance on synthetic fertilizers and herbicides, making it a sustainable choice for farmers.

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How Plant Cell Parts Specialize to Control Metabolism

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Abstract

Plant metabolism has tons of different reactions that help plants grow and stay alive. These reactions are managed well because plant cells have different parts that each do their own thing. Each part has a certain setup that helps specific reactions happen. For example, chloroplasts handle photosynthesis, mitochondria control energy, vacuoles keep things balanced, and the endoplasmic reticulum and Golgi apparatus deal with proteins and fats. Peroxisomes help with breaking down stuff and removing toxins. All these parts working together keeps plant cells running smoothly.

Introduction

Plants are pretty complex and constantly doing all sorts of reactions to keep everything going. These reactions are plant metabolism, which includes photosynthesis, breathing, creating molecules and turning energy into different forms. Plant cells are unique because they have different parts that each have their own job. This division of labor makes things run better, stops different reactions from messing with each other, and lets the plant fine-tune what it's doing.

How Metabolism is controlled in Plant Cells

Metabolic regulation is how plants control and organize their reactions. This is done by tweaking enzymes, controlling what's available, managing energy, and keeping things separate in different parts of the cell. Each part keeps its own internal conditions just right such as pH, allowing reactions to proceed as planned. This helps plants react to things around them like light, temperature, and how much food they can get.

Chloroplasts: Photosynthesis

Chloroplasts are where photosynthesis happens in green plants. The light reactions make ATP and NADPH. The Calvin cycle then fixes carbon dioxide into carbs. Chloroplasts also create fats, amino acids, and pigments, which makes them important for basic metabolism.

Mitochondria: Energy

Mitochondria control cell respiration. They break down carbs, fats, and proteins to produce ATP. They work with chloroplasts closely and help with photorespiration by handling the carbon and energy balance in plant cells.

Vacuoles: Storage

The central vacuole stores ions, sugars, acids, pigments, and other compounds. It balances cell pH, osmotic pressure, and removes toxic stuff, which keeps the cell stable.

Endoplasmic Reticulum and Golgi Apparatus

The rough endoplasmic reticulum makes proteins, and the smooth endoplasmic reticulum

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handles fats. The Golgi apparatus then changes, packages, and sends these molecules where they need to go. It also helps make cell wall stuff like pectin and hemicellulose.

Peroxisomes: Breaking Down

Peroxisomes have enzymes that do oxidative reactions. They break down fatty acids and hydrogen peroxide, and help with photorespiration, which protects cells from damage.

Conclusion

Plant cells specialize in different functions which helps with metabolic regulation. Each part has its own conditions that helps with reactions, which helps it coordinate. Chloroplasts, mitochondria, vacuoles, endoplasmic reticulum, Golgi apparatus, and peroxisomes make up a network that lets plants adapt to environment change.

Water Use Efficiency in Crops under Climate Stress

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Abstract

Climate change has intensified water scarcity through increased temperature, erratic rainfall, and frequent drought events, posing a serious threat to global agriculture. Improving Water Use Efficiency (WUE) the capacity of crops to produce biomass or yield per unit of water consumed has become a central strategy for achieving sustainable crop production under climate stress. This article discusses the concept of WUE, its physiological and molecular basis, the influence of climate stresses such as drought and heat, crop-specific responses, and recent advances in agronomic, breeding, and technological approaches to enhance WUE. Understanding and improving WUE is critical for ensuring food security in water-limited environments.

Introduction

Water is the most limiting factor for agricultural productivity worldwide. Agriculture consumes nearly 70% of global freshwater resources, yet climate change is reducing water availability through prolonged droughts, heat waves, and altered precipitation patterns. In countries like India, where farming is predominantly rainfed, climate-induced water stress has become a major constraint to crop yield stability. Under these conditions, Water Use Efficiency (WUE) has emerged as a vital indicator of crop performance. Rather than focusing only on water supply, WUE emphasizes how effectively crops use available water to produce yield. Improving WUE is therefore a cornerstone of climate-smart and sustainable agriculture.

Concept and Types of Water Use Efficiency

Water Use Efficiency can be expressed at different biological and agronomic levels:

Leaf-Level (Intrinsic WUE): Defined as the ratio of photosynthetic carbon assimilation (A) to transpiration (T) or stomatal conductance. It reflects physiological efficiency at the leaf scale.

Whole-Plant or Crop-Level WUE: WUE = Biomass or grain yield\Evapotranspiration (ET) This form is most relevant for agronomy and field management.

Agronomic WUE: It refers to yield per unit of irrigation water applied, often used in irrigation studies and water productivity analysis.Each level provides different insights, but crop-level WUE is most useful for addressing climate stress in farming systems.

Climate Stress and Its Influence on WUE

Drought Stress: Drought is the most significant climate stress affecting WUE. Under mild drought:

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- ✓ Stomatal closure reduces transpiration faster than photosynthesis.
- ✓ This often results in a temporary increase in WUE.

However, under severe or prolonged drought:

- ✓ Photosynthesis declines sharply.
- ✓ Leaf senescence accelerates.
- ✓ Yield loss outweighs any gains in WUE.

Recent meta-analyses show that drought can increase WUE by 5-20% at the physiological level, but grain yield often decreases, highlighting a trade-off between efficiency and productivity.

Heat Stress: High temperatures increase:

- ✓ Evaporative demand
- ✓ Soil moisture loss
- ✓ Plant respiration rates

Although elevated CO_2 may improve intrinsic WUE by reducing stomatal conductance, extreme heat reduces photosynthetic efficiency and enzyme stability, leading to lower effective WUE at the crop level.

Combined Heat and Drought Stress: In real field conditions, drought and heat often occur together. Their combined effect is more damaging than individual stresses, severely impairing Photosynthesis, reproductive development, and yield, particularly in cereals such as rice, wheat, and maize.

Physiological and Morphological Basis of WUE

Stomatal Regulation: Stomata play a central role in WUE by balancing CO_2 uptake and water loss. Genotypes with:

- ✓ Rapid stomatal response
- ✓ Optimized stomatal density tend to show improved WUE under water stress.

Root System Architecture: Deep and well-branched root systems enhance:

- ✓ Access to subsoil moisture
- ✓ Drought avoidance capacity

Root traits such as root depth, length density, and hydraulic conductance are now key targets in breeding for improved WUE.

Photosynthetic Efficiency: Higher photosynthetic capacity under limited water availability improves biomass accumulation per unit of water used. Maintenance of chlorophyll content and Rubisco activity under stress contributes to better WUE.

Crop-Specific Responses

Different crops show variable WUE responses due to genetic and physiological differences:

Rice: Traditionally water-intensive, but aerobic rice and alternate wetting and drying (AWD) systems significantly improve WUE.

Wheat: Moderate drought often increases WUE, but terminal heat stress reduces grain filling.

Maize and sorghum: C_4 crops generally exhibit higher WUE than C_3 crops.

Millets: Naturally high WUE and drought tolerance make them ideal for climate-resilient agriculture.

Agronomic and Technological Strategies to Improve WUE

Efficient Irrigation Management

- ✓ Drip and sprinkler irrigation
- ✓ Deficit irrigation strategies
- ✓ Sensor-based & AI-driven irrigation scheduling

These methods reduce water losses and improve crop water productivity.

Soil and Crop Management

- ✓ Mulching and residue retention reduce evaporation
- ✓ Conservation tillage improves soil moisture retention
- ✓ Optimized planting density enhances water capture efficiency

Crop Improvement and Breeding: Modern breeding focuses on:

- ✓ Drought-tolerant and water-efficient genotypes
- ✓ Marker-assisted selection for root and stomatal traits
- ✓ Gene editing tools (CRISPR-Cas) to improve WUE-related genes

Emerging Research and Future Perspectives: Recent advances include:

- ✓ Remote sensing and UAV-based WUE assessment
- ✓ Crop simulation and machine-learning models
- ✓ Integration of physiological traits with genomic selection

Future research aims to break the trade-off between high WUE and high yield, ensuring productivity without excessive water use.

Conclusion

Water Use Efficiency is a critical parameter for sustaining crop production under climate stress. While climate change poses serious challenges through drought and heat stress, improvements in crop physiology, breeding, and water management offer promising solutions. Enhancing WUE must be approached holistically integrating plant traits, agronomic practices, and modern technologies. Strengthening WUE will be essential for achieving food security, resource conservation, and climate-resilient agriculture in the coming decades.

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Gene Editing Technologies in Fruit Crops

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Introduction

Fruit crops have a major role in food nutritional security as well as in food production systems. Due to the growing population and differences in preferences of dietary preferences among the people, a sustained increase in fruits and even nut crops is required (Hwalla *et al*., 2016). Many fruit and nut crop varieties with improved yield, quality, colour, and size attributes have been developed through conventional breeding methods. Even though the conventional breeding method is slow but its outcomes are ambiguous in these perennial crops due to its lengthy juvenile stages, heterozygous character and lack of connections between seedling and adult plant. Hence, conventional breeding techniques are insufficient and ineffective for producing variations quickly to meet the shifting consumer needs. Genome editing is an emerging genomics based technology that enable precise and targeted alterations in gene. The genetic improvement of the crops could be revolutionized by gene editing, which can greatly speed up the varietal development.

Genome Editing: Genome editing technologies, which recently made it possible to make genetic modifications at certain loci, are those that allow for precise DNA editing. Due to the genetic alterations brought by hybridizations and mutagenesis which utilize radiation and chemical agents that resulting in genetic variations that is improved with the advent of contemporary breeding practices followed in crops (Goulet *et al*., 2017). The mutations or modifications which have been brought through gene editing are similar to those which happens through natural or conventional breeding, but genome editing is more specific when compared to natural breeding (Tzftra *et al*., 2012). There are different genome editing tools available but only three are widely followed in fruit crops namely:

- ✓ CRISPR/Cas 9
- ✓ Transcription activator-like effector nucleases (TALENs)
- ✓ Zinc finger nucleases (ZFNs).

CRISPR/Cas 9-based genome editing: The CRISP R/Cas9 system stands out as the most efficient and easy-to-use option among the three genome-editing technologies. Its enhanced targeting precision, versatility, and straightforward operation have made it a widely adopted tool for genome modification (Doudna *et al*., 2014). CRISPR/Cas 9 technique is based on a Cas 9 protein that recognizes the protospacer neighbouring motif, a very short and common sequence (3-8 nt in length). This nuclease is directed to a more precise target, which is a complementary sequence to PAM, by the help of a guide RNA (gRNA). This gRNA has a nucleotide

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length of 20 bp. Recent advancements in the CRISPR-Cas 9 system enable accurate and target-specific alteration of genomic regions and regulation of gene expression. It can be used in a range of cells and organisms and is an inexpensive method. Target genes regulating the desired target gene or locus are identified for CRISPR-Cas9-based genome editing, and guide RNAs (sgRNAs) are made to precisely direct the Cas9 endonuclease to the target gene or locus. sgRNAs are created by utilizing bioinformatic tools, while taking into account potential off-targets in the genome. The co-expression of sgRNAs and Cas9endonuclease in the transformed plants is made possible by the cloning of the sgRNA and Cas9 coding sequences into expression vectors. The transformed cells or plants are recognized using the selection or reporter markers, which are also a part of the genome editing vector. Verification of the alterations caused by genome editing is possible by sequencing the target gene in transformed plants. The CRISPR-Cas9 cassette can be deleted from sexually reproduced plants through segregation in the following generation to produce genome-edited plants free of transgenes.

Potential applications of CRISPR/Cas 9 based genome editing in fruit crops: With the advancement in genomics and molecular biology, genome editing has been applied to several crops, including the perennial crops like fruits (Kamburova *et al*., 2017). The first genome editing was described in sweet orange in 2014 using the CRISPR/Cas 9 technique. This strategy can be used to enhance traits including fruit quality, yield, shelf life and resistance to biotic and abiotic stress by changing the target genes in specific biochemical and signalling pathways. List of genome editing studies in fruit crops are given in the Table 1.

Table 1: Genome editing studies in different fruit crops

Fruit crops	Gene targeted	Genome editing tools	Function of gene
Sweet orange	*CsPDS* gene	CRISPR/Cas 9 sgRNA	Biosynthesis of carotenoid
Apple and Fig	*uidA* gene	ZFNs under heat shock promoter	Reporter gene
Grape	*MLO-7* in grape	CRISPR/Cas 9	*MLO* – susceptible gene for powdery mildew
Kiwifruit	*AcPDS*	CRISPR/Cas 9	Biosynthesis of carotenoid
Banana	Five MaGA20ox2	CRISPR/Cas9 each gene's second exon is targeted by two sgRNAs	Biosynthesis of gibberellin
Walnut	*JrPDS*	CRISPR/Cas9 *JrPDS*is targeted by five sgRNAs	Biosynthesis of carotenoid
Pomegranate	*PgUGT84A23* and *PgUGT84A24*	CRISPR/Cas9/two sgRNAs	UDP-dependent glycosyl transferase enzyme biosynthesis
Grape	*VvPDS*	CRISPR/Cas9 Four sgRNAs with different GC content	Biosynthesis of carotenoid

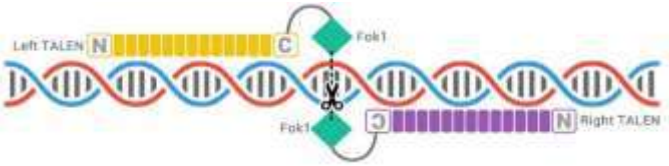
Fruit quality and shelf life: Genome editing was used to increase the amount of lycopene in tomatoes by encouraging lycopene synthesis while preventing its conversion to α- and β-carotene. Five genes were simultaneously knocked down using CRISPR/Cas 9 namely stay-green 1 (*SGR 1*), lycopeneε-cyclase (*LCY-E*), beta-lycopene cyclase (*Blc*), lycopene β-cyclase 1(*LCY-B1*) and *LCY-B2* and this led to increased lycopene content by 5-folds. By using CRISPR-Cas9 to delete the gene in suspension cells, it has been demonstrated that the L-idonate dehydrogenase (*IdnDH*) gene regulates tartaric acid (TA) biosynthesis in grapevine (Wang *et al*., 2019). Shelf life is a crucial aspect of fruit quality after the harvest of ripe fruits. Ethylene is essential for the ripening and softening of fruit, according to studies on the shelf-life of fleshy fruits, like tomatoes (Wang

et al., 2019). Gene expression can be suppressed by either removing the gene or altering the methylation status of the DNA. By employing CRISPR-Cas9 gene editing to eliminate the Banana fruits' shelf life was increased by 40 days compared to the wild type when the *MaACO1* (aminocyclopropane-1-carboxy-late oxidase 1) gene, which codes for the enzyme that converts ACC to ethylene, was expressed (Hu *et al*., 2021).

Transcription activator-like effector nucleases (TALENs): The TALENs-based biotechnology provides several major improvements over the existing biotechnology used in many genetically modified organisms (GMOs), which include:

- ✓ Gene modification/replacement that is site specific, and can be done without introducing any foreign DNA.
- ✓ No presence of a selection marker, such as the Kanamycin resistance gene.
- ✓ If a foreign gene must be introduced, it is inserted to a predefined genomic location.

Application of TALENs based biotechnology in Apple: The TALENs based biotechnology is applicable to apple. The two major genes that have been recently identified were targeted for this technique. One is *Ma* gene which controls fruit acidity level (Xu *et al.,* 2011) and the other is the *Co* gene, which controls columnar growth habit (Bai *et al.,* 2012). The initial objective of this technique was to test how well the TAL-ENs we designed would target the selected genes in apple cells. But the long-term goal is to use a series of custom TALENs to modify or replace a set of genes in popular apple varieties so that desirable traits, such as minimal pruning, self-thinning, resistance to major insects and diseases, high keeping quality and others, will be expressed.



Zinc Finger Nucleases (ZFNs): Transgenic apple and fig lines carrying a zinc-finger nuclease (ZFNs) under the control of a heat-shock promoter were developed. The editing of a mutated uidA gene, following the expression of the ZFN genes by heat shock, was confirmed by GUS staining and sequencing of the PCR product. Finally, whole plants with a repaired *uid*A gene due to deletion of a stop codon were regenerated. The ZFN-mediated gene modifications were stable and passed onto regene-rants from ZFN-treated tissue cultures. This is the first demonstration of efficient and precise genome editing, using ZFN at a specific genomic locus, in two different perennial fruit trees, apple and fig. It is concluded that targeting a gene in apple or fig with a ZFN introduced by transient or stable transformation should allow knockout of a gene of interest. Using this technology for genome editing enables marker gene-independent and antibiotic selection-free genome engineering with high precision in fruit trees, advancing both basic science and non-transgenic breeding programs (Peer *et al*., 2015).

Conclusion

Genome editing opens up significant possibi-

lities for enhancing fruit and nut crops, particularly those that are difficult to improve through conventional breeding. It allows precise, efficient, and faster genetic modifications, helping speed up the development of improved varieties something increasingly important due to rising global food needs and climate-related challenges. As the technology advances, it will enable the modification of many different genes to create fruit and nut crops with better productivity, quality, and stress tolerance. One major benefit is that genome editing can add new or improved traits directly into well-liked cultivars without affecting their existing beneficial features. Wild ancestors of cultivated crops, which often possess traits such as resistance to various stresses or superior fruit attributes, serve as important sources of useful genes for editing. Crops developed through genome editing can be released as new varieties for commercial use or utilized as pre-breeding materials in further improvement programmes. Overall, genome editing makes it possible to produce high-quality fruit and nut crops more quickly and with fewer off-target risks.

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Biochar Application in Agriculture: A Sustainable Approach for Soil Health and Crop Productivity

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Abstract

Biochar is a carbon-rich material produced through the pyrolysis of organic biomass under limited oxygen conditions. In recent years, biochar has emerged as a promising soil amendment due to it's potential to improve soil fertility, enhance crop productivity, and mitigate climate change. It's unique physicochemical properties contribute to improved soil structure, nutrient availability, microbial activity, and long-term carbon sequestration. This article reviews the role of biochar in agriculture, focusing on its effects on soil physical, chemical, and biological properties, crop growth, nutrient use efficiency, and environmental sustainability.

Introduction

Modern agriculture is under pressure due to soil degradation, nutrient loss, and climate change. Long-term intensive farming and heavy use of chemical fertilizers have reduced soil fertility, lowered organic matter, and increased environmental pollution, threatening the sustainability of farming systems. Biochar, a stable carbon-rich material made from biomass, has emerged as an eco-friendly soil amendment. Its porous structure helps improve soil structure, water retention, nutrient availability, and microbial activity, while also storing carbon in the soil for long periods. As a result, biochar is increasingly seen as a sustainable option to restore soil health, reduce dependence on chemical fertilizers, and support stable crop production while protecting the environment.

Production and Characteristics of Biochar: Biochar is made by heating organic materials such as crop residues, wood waste, or animal manure at high temperatures (about 300-700 °C) under little or no oxygen, a process known as pyrolysis. The quality and properties of biochar depend on the type of raw material used and the temperature at which it is produced. In general, biochar contains a high amount of stable carbon, has an alkaline nature, and possesses a porous structure. It also has a good capacity to hold nutrients, which makes it useful as a soil amendment for improving soil fertility and quality.

Effect of Biochar on Soil Physical Properties: The application of biochar has a positive effect on soil physical properties such as bulk density, porosity, and soil structure. When biochar is added to soil, it helps to reduce soil bulk density, making the soil lighter and easier to work with. Its porous structure creates more pore spaces in the soil, which improves air movement and allows better circulation of oxygen

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around plant roots. Biochar also improves the water-holding capacity of soil by storing moisture in its pores and releasing it slowly to plants. This benefit is especially important in sandy, dry, and degraded soils where water drains quickly. In addition, biochar reduces soil compaction, which helps plant roots penetrate deeper and spread more easily. Improved root growth leads to better nutrient uptake and stronger crop establishment. Overall, biochar-amended soils create a healthier root environment, resulting in improved plant growth and higher crop productivity.

Effect of Biochar on Soil Chemical Properties: Biochar improves soil chemical properties by increasing soil pH in acidic soils, which reduces aluminum toxicity and improves nutrient availability. It also enhances the soil's cation exchange capacity, helping retain essential nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium. In addition, biochar reduces nutrient leaching and improves fertilizer use efficiency, leading to better soil fertility and crop growth.

Effect of Biochar on Soil Biological Properties: Biochar has a positive effect on soil biological properties by creating a good living environment for soil microorganisms. When biochar is added to soil, it increases microbial population and enzyme activity, which are important for soil fertility. It's porousstructure provides shelter and space for microbes to grow and multiply. Biochar also supports beneficial microbial processes such as biological nitrogen fixation and phosphorus solubilization, helping to make nutrients more available to plants. Increased microbial activity improves nutrient cycling in the soil and strengthens overall soil health. As a result, biochar-amended soils become more productive and better able to support healthy crop growth.

Influence of Biochar on Crop Growth and Yield: Biochar application improves crop growth and yield by enhancing soil moisture retention, nutrient availability and root development. These improvements create better soil conditions for plant growth and result in higher productivity. Biochar has shown beneficial effects on a wide range of crops, including cereals, pulses, oilseeds, and horticultural crops. However, the response of crops to biochar varies depending on soil type, biochar properties, application rate, and crop species. Therefore, proper management is essential to achieve maximum benefits.

Role of Biochar in Climate Change Mitigation: Biochar helps mitigate climate change by storing stable carbon in soil for long periods, which reduces carbon dioxide release into the atmosphere. Its application in agricultural soils also lowers greenhouse gas emissions, particularly nitrous oxide and methane. By converting biomass into biochar and adding it to soil, carbon is retained in a stable form, making biochar an effective and eco-friendly tool for climate change mitigation.

Biochar Application Methods and Rates: Biochar can be applied to soil using different methods such as broadcasting and mixing it into the soil, compost-

ing it with organic manures, or applying it along with biofertilizers. The recommended application rate usually ranges from 2 to 10 tonnes per hectare, depending on soil condition, crop needs, and the quality of biochar used. Applying biochar together with chemical fertilizers or organic amendments improves its effectiveness and helps prevent temporary nutrient immobilization. This combined application ensures better nutrient avail-ability to crops and improves overall soil fertility.

Limitations and Future Prospects: The use of biochar faces limitations such as variable crop response under different soil types, high production costs, and lack of standardized quality guidelines. Limited awareness and availability also restrict its adoption by small and marginal farmers. Future research should focus on long-term field studies under various agro-climatic conditions, crop-specific recommendations, and integration of biochar with existing nutrient management practices. Develop-ment of low-cost biochar production technologies using local biomass will help promote its wider use in agriculture.

Conclusion

Biochar is an effective soil amendment that improves soil fertility, crop productivity, and enviro-nmental sustainability. It enhances soil physical, chemical, and biological properties, creating a healthier soil environment for better crop growth. When combined with organic manures and inorganic fertilizers, biochar improves nutrient use efficiency, reduces losses, increases soil organic carbon, and supports climate change mitigation, making it valuable for sustainable agriculture and long-term food security

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Physiological Determinants of Yield and Yield Stability in Major Crops

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Abstract

Yield and yield stability are critical targets in crop improvement programs aimed at ensuring food security under changing climatic and resource-constrained environments. Crop yield is the cumulative outcome of multiple physiological processes, including photosynthesis, assimilate partitioning, root system development, phenological adaptation, nutrient use efficiency, and stress tolerance mechanisms. Yield stability, defined as the ability of a genotype to maintain consistent productivity across variable environments, depends on the robustness and plasticity of these physiological traits. Advances in crop physiology have highlighted the importance of radiation use efficiency, harvest index stability, root system architecture, and metabolic resilience in sustaining yields under abiotic stresses such as drought, heat, and nutrient limitations. Emerging tools such as high-throughput phenotyping, crop growth modeling, and physiological trait-based breeding are enabling more precise identification and utilization of yield-determining traits. This article reviews the major physiological determinants of yield and yield stability in major crops, emphasizing recent trends and innovations that can contribute to sustainable and climate-resilient agricultural production.

Introduction

Achieving high and stable crop yields under increasingly variable climatic conditions remains a central challenge in global agriculture. Yield is a complex trait governed by the interaction of genetic potential, environmental factors and crop management practices, all of which operate through plant physiological processes. Yield stability, defined as the ability of a crop to maintain productivity across diverse environments, has gained renewed importance under climate change induced stresses such as heat, drought, salinity, and nutrient imbalances. Understanding the physiological determinants that regulate yield formation and stabilization in major crops is therefore critical for developing resilient cropping systems. Plant physiological traits such as photosynthetic efficiency, assimilate partitioning, canopy architecture, root system dynamics, and stress tolerance mechanisms directly influence biomass production and its conversion into economic yield. Recent advances in crop physiology, phenotyping tools, and systems modeling have provided new insights into how these traits can be optimized through breeding and agronomic interventions. This article synthesizes current knowledge on the key physiological determinants of yield and yield stability in major field crops, highlighting emerging trends and opportunities for sustainable productivity enhancement.

Concept of Yield Formation in Crops

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Crop yield is the final outcome of a sequence of physiological processes operating throughout the crop life cycle. These include light interception, carbon assimilation, nutrient uptake, biomass accumulation and partitioning of assimilates to harvestable organs. Yield can be expressed as:

Yield = Total Biomass × Harvest Index

Where harvest index (HI) represents the proportion of total above-ground biomass allocated to the economic yield. Improvements in either biomass production or HI can enhance yield, but long-term yield stability depends on maintaining these processes under fluctuating environmental conditions.

Photosynthesis and Radiation Use Efficiency: Photosynthesis is the primary physiological driver of biomass accumulation. Yield improvements in major cereals such as wheat (Triticum aestivum L.) and rice (Oryza sativa L.) over past decades have been partly attributed to enhanced radiation use efficiency (RUE) rather than increases in leaf-level photosynthetic rate alone.

Key determinants include

- ✓ Leaf area index (LAI) and canopy duration
- ✓ Chlorophyll content and stay-green traits
- ✓ Efficient light distribution within the canopy

Improved canopy photosynthesis through optimized leaf angle, delayed senescence, and enhanced CO_2 assimilation contributes to both yield and yield stability, particularly under stress environments.

Assimilate Partitioning and Sink Strength: While biomass production sets the yield ceiling, effective assimilate partitioning determines realized yield. Sink strength, defined as the capacity of organs such as grains, tubers, or pods to accumulate assimilates, plays a decisive role.

Physiological traits influencing partitioning include:

- ✓ Grain number and grain filling rate in cereals
- ✓ Pod and seed set efficiency in legumes
- ✓ Tuber initiation and bulking duration in potato

A stable harvest index under variable environments is a hallmark of high-yielding and climate-resilient cultivars.

Root System Architecture and Water Relations: Roots serve as the interface between the plant and soil resources. Root system architecture (RSA) strongly influences water and nutrient uptake efficiency, particularly under drought and low-fertility conditions.

Important physiological attributes include:

- ✓ Root depth and density
- ✓ Root hydraulic conductivity
- ✓ Root-to-shoot signaling under water stress

Crops with deeper and more plastic root systems often exhibit superior yield stability across rainfed environments.

Phenology and Thermal Time Utilization: Crop phenology determines the duration of vegetative and reproductive phases and their synchronization with environmental conditions. Thermal time (growing degree days, GDD) governs developmental transitions such as flowering and maturity.

Optimized phenology ensures:

- ✓ Avoidance of terminal heat or drought stress
- ✓ Efficient utilization of available resources
- ✓ Stable grain filling duration

Phenological plasticity is increasingly recognized as a key trait for yield stability under climate variability.

Stress Physiology and Yield Stability: Abiotic stresses disrupt physiological processes, leading to yield reductions. Yield stability depends on the crop's ability to maintain physiological homeostasis under stress.

Major physiological mechanisms include:

- ✓ Osmotic adjustment and membrane stability
- ✓ Antioxidant defense systems
- ✓ Maintenance of photosynthesis under stress

Recent breeding efforts focus on combining high yield potential with stress-adaptive physiological traits rather than stress tolerance alone.

Nutrient Use Efficiency and Metabolic Regulation : Efficient nutrient uptake and utilization are critical for sustaining yield under limited input conditions. Physiological nutrient use efficiency (PNUE) reflects the biomass or yield produced per unit nutrient absorbed.

Key determinants:

- ✓ Root nutrient acquisition capacity
- ✓ Internal nutrient remobilization
- ✓ Enzyme efficiency in metabolic pathways

Improved nitrogen use efficiency (NUE) in cereals is a major research trend for enhancing yield stability while reducing environmental footprints.

Emerging Trends and Innovations: Recent advances influencing crop yield physiology include:

- ✓ High-throughput phenotyping for physiological traits
- ✓ Crop growth modeling integrating physiology and climate data
- ✓ Ideotype breeding targeting physiological efficiency
- ✓ Use of plant growth regulators and biostimulants

These approaches allow precise identification and manipulation of physiological traits associated with stable yields.

Key Physiological Determinants of Yield and Yield Stability in Major Crops

- ✓ Role in yield formation
- ✓ Contribution to yield stability
- ✓ Physiological trait
- ✓ Photosynthetic efficiency
- ✓ Biomass production
- ✓ Maintains productivity under stress
- ✓ Harvest index
- ✓ Biomass partitioning
- ✓ Stable economic yield
- ✓ Root architecture
- ✓ Water and nutrient uptake
- ✓ Drought and nutrient stress tolerance
- ✓ Phenological duration
- ✓ Resource use efficiency
- ✓ Stress avoidance
- ✓ Stress tolerance mechanisms
- ✓ Cellular protection
- ✓ Reduced yield variability

Units: Biomass (g m^{-2}), Yield (kg ha^{-1}), Root depth

(cm)

Source: Compiled from published physiological studies.

Conclusion

Yield and yield stability in major crops are fundamentally governed by an integrated network of physiological processes operating from germination to maturity. Photosynthetic efficiency, assimilate partitioning, root system architecture, phenological adaptation, and stress tolerance mechanisms collectively determine both the magnitude and consistency of crop productivity. In the face of climate change and resource limitations, future yield gains must rely not only on genetic improvement but also on a deeper physiological understanding of crop environment interactions. Innovative approaches such as physiological trait-based breeding, precision agronomy, and systems modeling offer promising pathways to enhance yield stability without compromising sustainability. Strengthening the physiological foundation of crop improvement programs will be essential for ensuring global food security in an increasingly uncertain agro-ecological landscape.

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Soil Carbon Sequestration: A Step towards Sustainability

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Abstract

Carbon sequestration is a key strategy for mitigating climate change by reducing atmospheric carbon dioxide (CO_2) concentrations. Among available approaches, soil carbon sequestration is particularly effective due to the high carbon storage potential of agricultural and degraded soils. Globally, soils store more carbon than the atmosphere and vegetation combined, and this capacity is strongly influenced by land-use and management practices. Sustainable agricultural practices can enhance soil carbon stocks while improving soil health, productivity, and food security. Soil-based carbon sequestration is therefore a cost-effective and practical approach for long-term climate change mitigation and environmental sustainability.

Introduction

Carbon sequestration plays a critical role in regulating climate and maintaining soil and eco-system health. Through photosynthesis, atmospheric carbon is captured by plants and stored in biomass and soils, while respiration and decomposition release part of it back into the atmosphere. When carbon storage exceeds carbon release, ecosystems act as carbon sinks, helping to reduce atmospheric greenhouse gas concentrations. However, human activities such as deforestation, intensive land use, soil disturbance, and fossil fuel combustion have disrupted this balance, leading to increased carbon emissions. Since the late 19th century, global temperatures have risen significantly, largely due to the accumulation of greenhouse gases in the atmosphere. The continued rise in carbon dioxide, methane, and nitrous oxide concentrations has intensified climate change, causing ecosystem degradation and extreme events such as frequent wildfires. Enhancing carbon sequestration in soils and vegetation is therefore a key strategy for mitigating climate change. Improved land management practices that increase soil organic carbon can not only reduce greenhouse gas emissions but also improve soil fertility, biodiversity, and long-term ecosystem sustainability.

Carbon sequestration approaches

Natural or biological or terrestrial carbon sequestration: Natural or terrestrial carbon sequestration is the process of storing carbon in forests, soils, grasslands, and wetlands. Plants absorb carbon dioxide (CO_2) during photosynthesis and store it in their biomass, while some of this carbon enters the soil through plant residues and microbial activity, where it can be stored for long periods. Practices such as afforestation, forest restoration, wetland protection, reduced tillage, cover cropping and agro-

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forestry help increase carbon storage and reduce CO_2 emissions. However, stored carbon is sensitive to disturbances like climate change, wildfires, and land-use changes. Large-scale restoration can increase carbon sequestration but may affect agricultural production, so a balance is needed between food security and environmental protection.

Geological carbon sequestration: Geological carbon sequestration involves storing large amounts of carbon dioxide (CO_2) deep underground in suitable geological formations. Carbon dioxide is captured from industrial sources such as power plants and cement industries using different capture technologies before it is released into the atmosphere. The captured CO_2 is then compressed, transported, and injected into underground reservoirs like depleted oil and gas fields, saline aquifers, and deep rock formations, where it can be stored for long periods. For safe and effective storage, factors such as reservoir capacity, structural stability, leakage risks, and long-term monitoring must be carefully considered.

Oceanic carbon sequestration: Oceanic carbon sequestration occurs when oceans absorb carbon dioxide (CO_2) from the atmosphere and store it as dissolved carbon compounds. The oceans act as the largest natural carbon sink, absorbing about 2 gigatons of carbon each year. While this process helps reduce atmospheric CO_2, it also causes ocean acidification, which can damage marine organisms and ecosystems. The long-term impacts of increased CO_2 absorption on ocean life and food webs are still under scientific study.

Principles and mechanisms of carbon sequestration

Carbon sequestration includes methods to capture and store atmospheric carbon dioxide (CO_2) in different reservoirs. These methods are important for sustainable energy and environmental planning and are mainly classified into two types: abiotic (technological and geological) and biotic (plant- and soil-based) sequestration.

Abiotic carbon sequestration: Non-biological carbon capture: Abiotic carbon sequestration uses physical, chemical, and engineering methods to capture and store CO_2 without living organisms. Oceanic and geological storage offer large capacity, and recent advances have improved CO_2 capture, transport, and injection technologies.

- ✓ Deep sea carbon injection or oceanic injection: Deep-sea carbon injection means storing captured carbon dioxide (CO_2) deep in the ocean so it doesn't quickly return to the atmosphere. At great depths, the CO_2 stays more stable and can be stored for a long time. The ocean can hold large amounts of CO_2, but this method may disturb deep-sea life and ocean balance, so its environmental safety and long-term effects need careful study.
- ✓ Subsurface carbon storage or geological injection- Subsurface carbon storage is basically about taking carbon dioxide (CO_2) from factories and power plants and safely locking it deep underground. The gas is captured, compressed,

and then injected into places like old oil and gas fields, coal seams, or deep salty water layers called saline aquifers. Once underground, the CO_2 gets trapped by the rocks and water and can even turn into solid minerals over time. In some cases, injecting CO_2 also helps push out remaining oil from old wells, making this method useful for both reducing pollution and getting extra energy.

- ✓ Chemical scrubbing and carbon mineralization store carbon dioxide (CO_2) by turning it into stable solid minerals. First, CO_2 is captured from industrial gases using chemical solvents such as amines or carbonates. Then, the captured CO_2 reacts with minerals to form solid carbonates like calcium or magnesium carbonate, which can store carbon permanently. Certain rocks rich in magnesium and calcium are suitable for this process. However, the reactions happen slowly, and speeding them up requires extra energy, high temperature or pressure, making the process costly.

Biotic carbon sequestration: biological carbon capture: Biotic carbon sequestration is the process of capturing carbon dioxide (CO_2) from the atmosphere using living organisms such as plants and microorganisms. It involves actively managing vegetation, soils, and biological processes to increase carbon storage rather than only reducing emissions. Improving the efficient use of resources like water and energy also helps maintain and enhance the carbon stored in terrestrial ecosystems.

- ✓ Marine carbon storage: Oceanic carbon sequestration: Marine carbon sequestration happens when phytoplankton absorb CO_2 during photosynthesis, and part of this carbon sinks to the ocean floor for long-term storage. Iron availability affects phytoplankton growth, so iron fertilization has been studied to increase carbon uptake. However, its environmental impacts are uncertain, making ocean fertilization controversial.
- ✓ Terrestrial carbon capture: Soil, forest and wetlands carbon sequestration: Terrestrial carbon sequestration is the process of capturing carbon dioxide (CO_2) from the atmosphere and storing it in soils, forests, and wetlands. A large share of human-produced CO_2 is absorbed by these land ecosystems, making them important natural carbon sinks. Plants take in CO_2 through photosynthesis and store it in biomass and soil organic matter.This type of carbon capture not only helps reduce atmospheric CO_2 but also improves soil fertility, water quality, ecosystem health.
- ✓ Soil carbon sequestration: Soil carbon sequestration is the process of storing more carbon in the soil by improving land management in farms, forests, and grazing areas. It mainly increases soil organic carbon and, to a lesser extent, soil inorganic carbon. This can be achieved by restoring degraded soils and adopting practices such as adding crop residues and organic manures, using biochar, growing cover crops,

reducing tillage, practicing agroforestry, and applying nutrients in a balanced way. These methods not only capture carbon but also improve soil fertility, structure, and crop productivity.

- ✓ Forest ecosystem: Carbon sinks: Forests store large amounts of carbon in trees, wood, and soil, making them important carbon sinks. Rising CO_2 can increase forest growth, but this effect is limited by nutrients and water. Planting and restoring forests can help capture more carbon, but large-scale plantations may reduce water availability and harm biodiversity. So, forest carbon storage works best when managed carefully, balancing climate benefits with enviro-nmental impacts.
- ✓ Wetlands: Carbon reservoirs: Wetlands store very large amounts of carbon, mainly in their soils, often far more than in their vegetation. When wetlands are drained for farming or forestry, this stored carbon is released as CO_2. Restoring wetlands can gradually turn them back into effective carbon sinks, although recovery takes time.
- ✓ Biofuels: Biofuels are plant-based fuels that help reduce CO_2 by storing carbon in soil and using atmospheric CO_2 for growth. Crops like poplar and switchgrass are effective, but large-scale plantations may compete with food and water resources.

Advantages and disadvantages of carbon sequestration

Advantages

- ✓ Captures CO_2 naturally through plants and soils.
- ✓ Improves soil structure, fertility, and water retention.
- ✓ Reduces erosion and nutrient loss.
- ✓ Restores degraded lands and enhances wildlife habitats.
- ✓ Cost-effective and strengthens ecosystem services. Can store massive amounts of CO_2, potentially more than all fossil fuel carbon.
- ✓ Reduces atmospheric CO_2 beyond natural limits.
- ✓ Can be combined with energy production (e.g., enhanced oil recovery).

Disadvantages

- ✓ Limited total capacity (50-100 Pg C over 25-50 years).
- ✓ Carbon can be released back if land is plowed, deforested, or mismanaged.
- ✓ Expensive and technologically complex.
- ✓ Risk of CO_2 leakage.
- ✓ Expensive and technologically complex.
- ✓ Risk of CO_2 leakage.

Conclusion

Natural sinks like forests, soils, and oceans absorb about 60% of human-made CO_2, but this is not enough for future emissions. Managed eco-systems can store more carbon through restoration, smart land use, and Resource Management Practices (RMPs). Biotic sequestration relies on plants, soils, and wetlands, while abiotic methods include injecting CO_2 into oceans, underground rocks, or converting it into stable minerals.

Abiotic methods have high storage potential but are costly and need careful monitoring. Policies, regulations, and carbon credit systems are important for both types. Reducing emissions through clean energy and alternative fuels like bioethanol, biodiesel, and biogas is equally crucial.Carbon sequestration improves soil health, crop growth, and food security. Climate, soil type, and management practices influence carbon storage, while conservation tillage, crop rotation, and legumes help increase soil organic carbon. Overall, combining emission reduction with sequestration supports sustainable agriculture and climate mitigation.

Interrelationship between Water Relation and Mineral Nutrition in Plants

Poorti Jha and Ravinder Kaur

Abstract

Water and minerals are the two most essential requirements for plant growth. They are tightly coupled up as water acts as the solvent and transport medium for nutrition uptake, while nutrients regulate water balance via osmotic potential. Plant roots can absorb these nutrients only when they are in dissolved form. Thus, without adequate water, even nutrient-rich soils may fail to support healthy plant growth. At night, mineral free water usually exerted a large effect on uptake, including the complete suppression of guttation.

Introduction

Mineral nutrition plays a fundamental role in plant growth, development, and productivity. Plants require a balanced supply of essential mineral elements to complete their life cycle and maintain physiological processes. They interact in complex and dynamic ways within the plant system and soil environment. Synergistic interactions enhance the availability or efficiency of certain nutrients, while antagonistic interactions may inhibit absorption or create deficiencies, even when nutrients are present in adequate amounts in the soil. The amount of water that could be taken up by leaves and their turgor pressure were related to the osmotic pressure of the sap and calculation of turgor pressure.

Concept of Water Relation in Plants

Water is the most abundant and essential component of plant cells, constituting about 70-95% of the fresh weight. It has many chemical and physical properties that make it particularly suitable medium in which life can occur.

Different life processes in plant include water as a chemical compound. Water present in soil enters the plant body by process of absorption and then moves in the upward direction by the process of ascent sap.

Importance of Water in Plants

- ✓ Acts as a solvent for mineral nutrients and metabolites
- ✓ Maintains cell turgidity and structural support
- ✓ Serves as a raw material in photosynthesis
- ✓ Regulates temperature through transpiration
- ✓ Facilitates transport of substances via xylem and phloem

Diffusion and Osmosis

Water transport in plants occurs through:

Diffusion: To diffuse means to spread in all directions. During this process the movement of particle is from the region of higher concentration to region of lower concentrations.

- ✓ Movement of water from soil into plant body is mainly by this process.
- ✓ The loss of large quantity of water, in vapour

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form is mostly done by diffusion only.

Osmosis: Diffusion of water with inorganic elements dissolved in it through a semipermeable membrane from a region of higher concentration to lower concentrations. Due to presence of semipermeable membrane it is considered as one of the special type of diffusion.

- ✓ Entry of water into plant cell from soil depends on osmosis.
- ✓ Transport of water from one living cell to another and from one region to another, in the plant body is possible due to osmosis.
- ✓ Different movements exhibited by different organs in plant are due to osmosis.
- ✓ During process of growth by cell divison, elongation of newly formed cells is possible due to supply of water by the process of diffusion.

Concept of Mineral Nutrition in Plants

Mineral nutrients are inorganic elements obtained from the soil that are essential for the completion of a plant's life cycle.

- ✓ The plant cannot complete its life cycle without it.
- ✓ Its function is specific and they can't be replaced by another element.
- ✓ It is directly involved in plant metabolism.

Concept was established through criteria proposed by Arnon and Stout.

Classification of Essential Elements

Based on the quantity required by plants, mineral nutrients are classified into:

Macronutrients

Nutrition which are required in large amounts are termed as micronutrients. They are further divided into two types of nutrients.

Primary macronutrients: Nitrogen (N), Phosphorus (P), Potassium (K)

Secondary macronutrients: Calcium (Ca), Magnesium (Mg), Sulfur (S)

Micronutrients

Nutrients which are required in small quantities but are equally essential for the growth and well being of the plant are termed as micronutrient. Here are some types of micronutrients

Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl) and Nickel (Ni).

Functions of Mineral Nutrients

Mineral nutrients perform various roles in plants:

- ✓ Hepls in structural development of the plant. (nitrogen in proteins)
- ✓ Helps in enzyme activation (e.g., magnesium, zinc)
- ✓ Osmotic regulation (e.g., potassium)

Mechanism of Mineral Uptake

Mineral nutrients are absorbed from the soil in ionic form through roots by:

Passive absorption: Along concentration gradient which can be done without the use of ATP. And less energy is being used in this process.

Active absorption: Against concentration gradient using energy (ATP) and a good amount of energy is being used in this process

Importance of Mineral Nutrition

Understanding mineral nutrition helps in:

- ✓ Improving crop yield which further helps in increasing income.
- ✓ Designing balanced fertilizer programs.
- ✓ Managing soil fertility and reducing wastage of money, time and labour.
- ✓ Preventing environmental pollution due to over-fertilization and also helps as money management as no extra fertilizer is being purchased.

Conclusion

Mineral nutrition is fundamental to plant growth, development, and productivity. Essential mineral elements, whether required in large or small quantities, perform specific and irreplaceable roles in structural formation, energy transfer, enzyme activation and regulation of physiological processes. The proper absorption, transport, and utilization of these nutrients determine the overall health and performance of plants. A balanced supply of mineral nutrients is crucial, as both deficiency and excess can disrupt metabolic activities and reduce crop yield. Understanding the concept of mineral nutrition not only enhances our knowledge of plant physiology but also supports efficient fertilizer management, improved soil fertility practices, and sustainable agricultural production. Ultimately, effective mineral nutrition management is key to ensuring food security and maintaining environmental balance.

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Role of Root Morphology in Nutrient Acquisition

Pankaj Vishwakarma and Ravinder Kaur

Abstract

The shape of a plant's roots matters a lot for how well it gets nutrients from the soil. Things like how long the roots are, how much surface area they have, how thick they are, and how they branch out really change how well plants can suck up important stuff like nitrogen, phosphorus, and potassium. Different root shapes let plants live in different kinds of soil and get what they need, even when there's not much available. It's getting more and more important to understand how root shape and getting nutrients are related so we can use less fertilizer and grow crops in a more sustainable way. This article talks about why root shapes are so important for plant food and how they can help farms produce more.

Introduction

Roots are super important, but they're hidden underground. They hold the plant in place and grab water and nutrients from the soil. The shape of the roots really matters for how well they do this job. With soil running out of nutrients and the weather changing, it's becoming super important to understand how root shapes work so we can grow crops in a sustainable way. This article is about how different root shapes help plants get food and how we can use that knowledge to grow better crops.

Understanding Root Shape: Root shape means things like how long the roots are, how thick they are, how much surface area they have, and how they branch out. These things decide how well a plant can check out the soil and grab nutrients. Different plants have different root systems, like taproots or fibrous roots, that are good for different soils and environments. When roots are shaped well, plants can get nutrients even from bad soil.

Root Length and Area: How long the roots are and how much surface area they have is related to how many nutrients they can grab. Longer roots can go deeper into the soil, and more surface area means they can touch more soil particles. Nitrogen is usually deeper down, so longer roots are great for getting it. Phosphorus doesn't move around much in the soil, so more surface area helps plants grab it. Thin roots with lots of surface area are really good at getting nutrients.

Root Thickness and Food: How thick the roots are changes how well they move nutrients around and grab them. Thin roots have more surface area compared to their size, so they're better at grabbing things like phosphorus and zinc that don't move around much. Thick roots give the plant more support and help move water and nutrients over long distances. Having a mix of thick and thin roots is the best way to get nutrients.

What Root Hairs Do: Root hairs are tiny little hairs

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on the roots that make the surface area bigger. They're really important for getting phosphorus, iron, and manganese. Root hairs help plants grab more nutrients by touching more of the soil and releasing stuff that helps loosen up the nutrients. Plants with lots of root hairs are good at getting nutrients even when the soil isn't very fertile.

Root Design and Branching: Root design is how the roots are arranged in the soil. Roots that branch out a lot can check out more of the soil. Roots that are shallow and branch out are good at grabbing nutrients from the topsoil. Plants with deep roots are good at getting water and nutrients from farther down. This helps plants live even when there's not much water or nutrients.

Table 1: Influence of Root Morphological Traits on Nutrient Uptake

Root Trait	Nutrient	Affected Function
Root length	Nitrogen (N)	Access to deep soil nutrients
Root hairs	Phosphorus (P)	Increased surface area
Thin roots	Zinc (Zn)	Efficient absorption
Root branching	Potassium (K)	Greater soil exploration

Innovative and Trending Approaches: Plant breeders and scientists are trying to make crops with better roots. They're using fancy stuff like root mapping and changing genes to find and improve root features. Crops that can handle bad weather and have good roots are becoming popular as a way to manage nutrients in a sustainable way.

Conclusion

Root shape is super important for how plants get food because it changes how well they can check out the soil and grab important nutrients. Things like how long the roots are, how much surface area they have, how thick they are, and how they branch out all change how well they get nutrients. Understanding and improving root shapes can help us use less fertilizer and grow crops in a more sustainable way. So, we should pay more attention to root shape when we're trying to grow better crops.

Cellular Mechanisms of Stress Perception and Signal Transduction

Tokato H. Awomi and Ravinder Kaur

Introduction

Cells are always hit with stress, like when it gets too hot or cold, or when they get hurt by bad stuff inside, or when there's too much or too little water, or when germs attack. To live, grow, and get used to new stuff, cells must be able to sense these stress signals and turn them into actions. This job involves a whole group of things working together, like special receivers, helpers that pass messages, enzymes, and special proteins, all to keep the cell balanced. Learning about this is getting popular because it matters to farms, medicine, and how we make things with living stuff.

How Cells Sense Stress

Sensing stress starts at the cell's outer skin or inside tiny rooms within it. There are receivers, like proteins on the surface, channels for stuff to go in and out, and sensor enzymes that find changes in the cell's world. For example, if the cell skin gets too soft or hard because of heat, channels that react to touch can turn on. If there are bad chemicals around, receivers that grab onto things can spot them. These sensors turn the outside problems into signals that start a chain reaction inside.

Helpers that Pass Messages: Helpers that pass messages, like calcium, bad oxygen bits, a chemical called cAMP, and another one called IP_3, are a big deal for making signals stronger. When stress is sensed, the amount of calcium inside changes super fast. It tells other proteins that grab calcium to get to work. Bad oxygen bits can hurt, but in small amounts, they help turn on stress-fighting genes.

How Signals Travel

Signals travel through a bunch of steps where enzymes called kinases and phosphatases add or take away phosphate. MAPK chains are studied a lot and help with stress. They make sure the right signal goes to the right place so cells can react the right way to different stresses. The activated enzymes then tell special proteins to turn on genes that fight stress.

What it's Good for and What's New

New stuff in biology has made us know more about how cells send stress signals. People are trying to change these signals to make crops that can handle stress, fight illness better, and make treatments for stress problems in people. Using computers and system biology has made it faster to find the key players in these signal chains.

Conclusion

How cells sense stress and send signals is a team project that keeps creatures alive when things get tough. From sensing the stress to turning on genes and getting used to the change, every move is watched carefully to keep the cell safe. Studying this more can help with big world problems like health, farming, and keeping the planet okay.

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The Universal Currency of Life: Water Potential as the Master Regulator of Cellular Dynamics

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Abstract

Water potential (Ψw), a thermodynamic measure of water's energy state, is the definitive parameter governing water movement and cellular hydration across biological systems. This article repositions Ψw from a classic osmotic concept to a central, dynamic regulator in contemporary cell physiology. We dissect its components solute potential (Ψs), pressure potential (Ψp), matric potential (Ψm), and gravitational potential (Ψg) and illustrate their interplay in maintaining turgor, driving growth, and facilitating transport. Highlighting innovative trends, we explore how Ψw functions as a hydraulic signal, influencing mechanosensing, gene expression, and developmental patterning. Cutting-edge applications in phenotyping for climate resilience, precision agriculture, synthetic biology for water-use efficiency, and modeling ecosystem hydraulic failure are detailed. By integrating biophysics with cell signaling, this review underscores Ψw's pivotal role as a universal currency for understanding and manipulating cellular homeostasis, offering critical insights for tackling global challenges in food security and environmental sustainability.

Introduction

Water is the fundamental solvent of life, constituting 70-95% of active cellular mass. Yet, the movement and availability of this crucial molecule are not governed by its concentration alone, but by its energy state a concept encapsulated by water potential (Ψw). In cell physiology, water potential is the ultimate arbitrator of hydration, turgor, and growth. This article explores the innovative resurgence of water potential studies, driven by advanced biophysical tools and its critical applications in understanding climate resilience, crop engineering, and medical therapeutics. We position Ψw not as a classic botanical parameter, but as a universal, trending metric for cellular homeostasis across biological kingdoms.

Deconstructing Water Potential: The Equation of Life: Water potential is defined as the potential energy of water per unit volume relative to pure water at standard temperature and pressure. It is expressed in megapascals (MPa) and is described by the central equation:

$$\Psi w = \Psi s + \Psi p + \Psi g + \Psi m$$

Where:

Ψw = Total water potential (MPa)

Ψs = Solute potential (Osmotic potential): Always negative. Decreased by dissolved solutes.

Ψp = Pressure potential: Usually positive (turgor pressure) in walled cells; can be negative in xylem or animal tissues.

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Ψg = Gravitational potential: Significant in tall trees, often negligible at cellular scale.

Ψm = Matric potential: Negative due to adhesion to surfaces (e.g., soil, cell walls).

In most cellular contexts, Ψw ≈ Ψs + Ψp. Water always moves from a region of higher (less negative) Ψw to a region of lower (more negative) Ψw.

Table 1: Typical Water Potential Components in Different Cell Types

Cell Type / System	Ψs (MPa)	Ψp (MPa)	Ψw (MPa)	Physiological Implication
Turgid Plant Cell	0.8	+0.6	-0.2	High turgor drives cell expansion
Flaccid Plant Cell	0.8	0.0	-0.8	Wilting; no growth drive
Animal Cell (Blood)	-0.7	~0.0	-0.7	Maintained for osmotic balance with plasma
Xylem Sap (Midday)	-2.0	-1.0	-3.0	Negative Ψp indicates tension
Desert Soil (Dry)	Below -5.0	0.0	Below -5.0	Water inaccessible to most plants

Source: Compiled from standard biophysical texts and contemporary research data.

Innovative Insights: Beyond Osmosis to Cellular Signaling and Mechanics

Modern research has expanded the role of Ψw from a passive driver of osmosis to an active signaling entity and biomechanical regulator.

The Hydraulic Dashboard: Real-time micro-tensiometers and pressure probes now allow for the monitoring of cellular Ψw dynamics. These "hydraulic signatures" are unique to stress conditions (e.g., drought, salinity) and are being used as phenotyping traits for selecting resilient crops.

Turgor as a Developmental Cue: In plants, Ψp is not just for rigidity. Oscillations in Ψp are integral to cytoskeletal reorganization and the polarized trafficking of auxin transporters, directly linking water status to morphogenesis.

Apoplastic Sensing: The cell wall-Ψm interface is a hotspot for sensing. Changes in apoplastic Ψw are detected by mechanosensitive ion channels (e.g., MSLs, Piezos) and receptor-like kinases, triggering downstream calcium waves and abscisic acid (ABA) synthesis.

Medical Applications: In mammalian physiology, Ψw gradients govern edema and fluid balance in tissues. Tumor microenvironments often exhibit altered Ψw, affecting drug delivery efficacy. Research into cryopreservation relies heavily on precise manipulation of Ψs to prevent ice-crystal damage to cells.

Trending Applications: From Labs to the Field

The concept is pivotal in cutting-edge biotechnological and ecological applications.

Synthetic Biology & Water-Use Efficiency (WUE) : Engineers are designing synthetic osmolytes (e.g., modified betaines) and promoting suberin deposition in root endodermis to manipulate tissue-specific Ψs, creating crops that "manage" their internal water economy.

Hydraulic Failure Modeling: Climate models now incorporate plant Ψw thresholds (e.g., P50, the Ψw at which 50% xylem conductivity is lost) to predict forest mortality under drought and heatwaves, a critical aspect of carbon cycle projections.

Precision Agriculture: Soil Ψw sensors linked to automated irrigation systems deliver water only when soil Ψw drops below a crop-specific threshold,

optimizing yield and conserving water.

Food Security & Post-Harvest Physiology: The Ψw of seeds and stored grains determines their longevity and susceptibility to pathogen attack. Managing atmospheric Ψw in storage silos is a key non-chemical preservation strategy.

Conclusion

Water potential is far more than a cornerstone of elementary biology. It is a dynamic, integrative biophysical variable that sits at the nexus of cellular mechanics, signaling, and organism-environment interaction. The renewed focus on quantifying and manipulating Ψw, powered by interdisciplinary tools from biophysics, genomics, and data science, is providing unprecedented insights into how living systems manage their most precious resource. As we face global challenges of water scarcity and climate instability, a deep understanding of water potential is not just academically fascinating it is imperative for innovating sustainable solutions in agriculture, ecology, and medicine. Mastering the currency of water potential is, unequivocally, mastering a fundamental language of life itself.

Mechanisms of Water Absorption in Crop Plants under Field Conditions

Divyanshu Joshi and Ravinder Kaur

Abstract

Water is the most important requirement for crop plants. Plants cannot survive, grow, or produce yield without water. Crop plants absorb water from the soil mainly through their roots. This absorbed water is used for photosynthesis, transport of nutrients, cell enlargement, and regulation of plant temperature. Under natural field conditions, water absorption depends on many factors such as soil moisture, soil type, climate, and root system of the plant. This article explains the mechanisms of water absorption in crop plants using simple and easy language so that the concept can be clearly understood by students.

Introduction

Water plays a very vital role in the growth and development of crop plants. About 80 to 90 percent of the plant body is composed of water. It is essential for seed germination, cell division, cell elongation, absorption of nutrients, and photo-synthesis. In field conditions, crops are exposed to natural environmental factors such as rainfall, temperature, wind, sunlight, and soil conditions. These factors directly affect the availability of water in the soil. Roots absorb water from the soil and transport it to different parts of the plant through xylem tissues. If water absorption is not proper, plants show symptoms like wilting, yellowing of leaves, stunted growth, and reduced yield. Therefore, understanding the mechanism of water absorption is very important for better crop management. In agricultural fields, water is supplied to crops mainly through rainfall and irrigation. However, not all the water present in soil is available to plants. Some water is lost through evaporation and deep percolation. Therefore, plants must efficiently absorb available soil water for their survival. Crop physiology helps us understand how plants absorb water under such field conditions.

Mechanisms of Water Absorption in Crop Plants

Water absorption mainly occurs through the root system, especially through root hairs. Root hairs are thin, elongated structures present near the tip of young roots. They increase the surface area of roots and help in better contact with soil particles. Because of this large surface area, roots are able to absorb more water from the soil solution.

Active Absorption of Water: Active absorption of water takes place due to the metabolic activity of living root cells. In this process, energy is required, which is obtained from respiration. Root cells actively absorb mineral ions such as nitrates, phosph-ates and potassium from the soil. This increases the concentration of solutes inside the root cells.

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As a result, water enters the root cells from the soil by osmosis. Active absorption is important when transpiration rate is low, such as during night time or under cloudy conditions. This mechanism helps plants absorb water even when external conditions are not favorable. Active absorption is mainly controlled by the root itself. If the roots are healthy and actively respiring, water absorption will be better. Damage to roots due to pests, diseases, or waterlogging reduces active absorption of water.

Passive Absorption of Water: Passive absorption of water does not require energy from root cells. It mainly depends on transpiration pull created by the leaves. When water evaporates from the surface of leaves during transpiration, a suction force is created in the xylem vessels. This force pulls water upward from roots to leaves. Under field conditions, passive absorption is the most common mechanism of water absorption, especially during daytime when temperature and sunlight are high.

Environmental factors such as temperature, wind speed, humidity, and light intensity strongly affect passive absorption. High temperature and wind increase transpiration and thus increase water absorption. High humidity reduces transpiration and lowers water uptake.

Osmosis: Osmosis is an important process involved in water absorption. It is defined as the movement of water from a region of higher water potential to a region of lower water potential through a semi-permeable membrane. Root hair cells contain cell sap with higher concentration of solutes compared to soil water. Therefore, water enters the root hairs by osmosis and then moves from cell to cell until it reaches the xylem tissue.

Root Pressure: Root pressure is a positive pressure developed in the roots due to continuous absorption of mineral salts. This pressure helps in pushing water upward through the xylem vessels. Root pressure is more noticeable during night or early morning when transpiration rate is low. It is commonly observed in crops grown in well-watered soils such as rice, sugarcane, and wheat.

Factors Affecting Water Absorption under Field Conditions

Several factors influence water absorption by crop plants under field conditions. Soil factors such as texture, structure, moisture content, aeration, and temperature affect water availability. Sandy soils allow quick drainage, while clay soils hold more water. Root factors like depth, number of root hairs, and root length increase water absorption. Environmental factors such as temperature, humidity, wind, and light also affect transpiration and water uptake.

Conclusion

Water absorption is one of the most important physiological processes in crop plants. Under field conditions, plants absorb water mainly through active and passive mechanisms involving osmosis, transpiration pull, and root pressure. Proper soil moisture, healthy root system, and favorable environmental conditions are necessary for efficient water absorption. Understanding these mechanisms helps farmers in better irrigation management and

improves crop growth and yield. Efficient use of water resources is essential for sustainable agriculture.

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Millets: Enhancing Food Systems Resilience and Nutritional Quality

Sunita Choudhary and Rajesh Choudhary

Abstract

Millets are ancient, climate-resilient cereals whose genetic diversity and physiological traits enable superior tolerance to drought, heat, low rainfall, and poor soil fertility compared with many major cereals, positioning them as strategic crops for sustainable food systems under climate change. This synthesis aims to consolidate evidence on how millets contribute to climate security, nutritional security, and sustainable farming, and to highlight research and management approaches that enhance these benefits. Drawing on reported field observations and crop/ecophysiological characteristics, alongside genetic studies including genome-wide association studies (GWAS) and agronomic evidence on integrated nutrient management, the analysis underscores both productivity and health-related advantages.

Introduction

Millets are naturally adapted to harsh environmental conditions, such as drought, low rainfall, high temperatures, and poor soil fertility, making them exceptionally climate-resilient crops. Their genetic diversity and physiological traits enable millets to withstand abiotic stresses better than many major cereals, positioning them as crucial crops in changing climate scenarios. For instance, proso millet's ability to perform well under drought and intense heat while maintaining stable yields with efficient water use highlights its role as a sustaining food resource in arid regions and drought-prone areas. Additionally, millets require minimal external inputs and thrive with low water and nutrient demands, which reduces vulnerability to climate variability and supports sustainable farming systems.

Millets, often referred to as ancient grains, play a significant role in addressing modern challenges related to nutritional security and climate resilience, making them vital for sustainable food systems in the face of global changes. These grains offer opportunities for crop diversification, adaptation to low-input and marginal environments, and resilience against climate extremes. Their short life cycles and minimal water and nutrient requirements fit well within sustainable agricultural frameworks. This positions millets as key crops not only for today's food security but also for future-proofing agriculture against ongoing environmental changes. As ancient grains, millets provide dual benefits: nutrition and climate resilience, which are critical for addressing modern food security challenges. Their genetic diversity, adaptability, and nutritional superiority

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make them indispensable allies in building sustainable, resilient and nutritious food systems worldwide. Therefore, encouraging research, utilisation, and conservation of millets is essential for meeting the nutritional and climate challenges of the 21st century.

Millets are nutritionally superior to many major cereals, including rice and wheat, and play a significant role in ensuring nutritional security, especially in arid and semi-arid regions. They are rich sources of essential nutrients, such as dietary fibre, calcium, iron, zinc, B-complex vitamins, and protein. Finger millet, in particular, is noted for its exceptionally high calcium content, nearly three times that of milk on a weight basis, which makes it valuable in combating osteoporosis and addressing child malnutrition. In addition to calcium, finger millet also contains vital amino acids that are often deficient in starchy diets, contributing to a more balanced nutritional profile. Millets, such as barnyard, finger, foxtail, kodo, and proso millets, provide substantial protein and micronutrients, such as iron and zinc, which are crucial to addressing hidden hunger a condition marked by widespread micronutrient deficiencies, particularly in developping countries. Regular consumption of millets can help reduce anaemia and other deficiency-related disorders by supplying these important minerals. Millets have a low glycaemic index, indicating that they release glucose slowly into the bloodstream. This characteristic makes them suitable for individuals with diabetes, as well as for weight management and reducing lifestyle disorders linked to blood sugar spikes. Processing methods, such as fermentation, can improve nutrient bioavailability and reduce anti-nutritional factors, further enhancing their nutritional quality. Thus, millets' low glycaemic index, combined with their rich nutrient content, supports their role in addressing chronic health issues and promoting dietary health. Advances in genetic research aim to improve millet varieties for enhanced nutrient quality and climate resilience, ensuring better productivity and nutrition under changing environmental conditions. Nutrient management technologies that integrate organic nutrient sources with chemical fertilisers have been shown to improve millet yield and grain quality, supporting sustainable agriculture and long-term nutritional security.

Role of Millets in Nutritional and Climate Security

Millets are known for their resilience under adverse climatic conditions, such as drought, heat, and poor soils, which are increasingly prevalent owing to climate change. Their strong abiotic and biotic stress tolerance allows them to thrive in arid and semi-arid ecologies, where major cereals struggle, thus helping to sustain food production in vulnerable regions. Research employing genome-wide association studies (GWAS) in major and minor millets has identified genes linked to stress tolerance, yield, nutrient use efficiency, and nutritional quality traits, underscoring their potential to secure food and nutrition under changing climatic scenarios. Field studies on crops such as proso millet

have shown that they maintain stable yields and efficient water use, even in drought-prone Mediterranean climates, showcasing adaptation that ensures agroecosystem resilience and resource sustainability. Nutritionally, millets are powerhouse grains rich in micronutrients, essential amino acids, dietary fibre, and antioxidants that often surpass major cereals, such as rice and wheat, in terms of health benefits. Their nutrient density contributes to diversified diets, addressing malnutrition and micronutrient deficiencies that are widely prevalent in many regions. Their inclusion as staple foods promotes better dietary outcomes while supporting ecological sustainability.

Millets: Ancient Grains for Modern Challenges

Despite their historical importance as staple foods for civilisations, millet and other small-seeded cereals were sidelined during the Green Revolution. However, current climatic threats and nutritional crises have renewed interest in these ancient grains as solutions for sustainable nutrition and food security. "Kabog millet", an ancient ecotype of proso millet grown in the Philippines, exemplifies how ancient grains, once neglected, can be reintroduced to diversify diets and remedy food insecurity. Studies have revealed that its rich nutritional profile encourages the redesign of local diets for more balanced nutrition and supports biodiversity through the conservation of neglected plant varieties. This repositioning of ancient millets aligns with global efforts to transform food systems amid climate change and biodiversity loss.

Millets and Climate Security

Millets are inherently climate-resilient crops because of their physiological and genetic traits, making them particularly well-suited to withstand drought and heat stress under changing climate conditions. As C_4 plants, millets exhibit high water use efficiency, requiring significantly less water approximately 60-70% less than rice and can thrive in low-rainfall regions receiving as little as 300-400 mm annually. This drought tolerance is attributed to effective water and energy management within their physiological systems, enabling them to maintain growth and yield stability during prolonged dry spells. For instance, proso millet has demonstrated stable yields and water use efficiency under rainfed, drought-prone Mediterranean conditions, making it an advantageous crop for areas anticipating increased drought severity with climate change. Regarding heat resilience, millets tolerate higher temperatures better than many staple cereals, and can maintain stable production when other crops often fail under heat stress. The ability to sustain productivity is linked to complex genetic traits governing stress tolerance, photosynthetic efficiency and nutrient use, which are being explored through genome-wide association studies to further enhance millet varieties for climate resilience. Heat tolerance mechanisms include the maintenance of membrane stability, efficient antioxidant defences and metabolic adjustments that prevent damage under elevated temperatures, supporting crop survival and yield stability in warming climates.

Millets and Sustainable Farming Systems

Millets play a significant role in promoting sustainable farming systems, particularly because of their adaptability to arid and semi-arid regions and their capacity to thrive under low-input conditions. They contribute to ecological sustainability by supporting integrated nutrient management practices that enhance soil organic carbon and nutrient buffering. The use of organic inputs, such as farmyard manure, biocompost, biofertilizers, and legumes, in millet cropping systems not only improves soil fertility but also enhances grain quality and yield stability, facilitating long-term ecological and economic sustainability in rainfed ecosystems. In the broader context of sustainable agriculture, millet cultivation aligns with key principles such as reducing reliance on synthetic fertilisers, promoting biodiversity, and managing abiotic stresses, such as drought, thus addressing climate resilience in vulnerable regions. Sustainable farming models emphasise the use of bioresources, including organic amendments, biopesticides, and biofertilizers, which can be effectively integrated into millet-based farming to improve nutrient cycling, pest management and soil health, fostering more circular and resilient agricultural systems. Millets contribute to sustainable intensification in dryland farming systems by offering a climate-resilient crop option that mitigates issues, such as land degradation and malnutrition, commonly encountered in marginal areas. Their cultivation supports multifunctional benefits, such as conserving water resources, maint-aining soil structure, and providing stable yields under erratic climatic conditions, thus enhancing food and nutritional security for smallholder farmers. The integration of millets into farming systems also complements sustainable agri-food approaches that prioritise local governance, food sovereignty, and social justice by promoting crops adapted to local environments and cultural practices. By diversifying cropping systems and reducing dependence on conventional staples, millets can aid in building resilient agroecosystems that are ecologically sound and economically viable, thereby contributing to sustainable livelihoods and equitable food systems.

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Role of Crop Rotation in Pest and Disease Management

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Abstract

Crop rotation is an important agronomic practice that involves growing different crops in a planned sequence on the same field over successive seasons. This practice plays a significant role in maintaining soil fertility and managing pests and diseases in agricultural systems. Continuous monocropping often leads to the buildup of pests, pathogens, and weeds, which ultimately reduces crop productivity. Crop rotation helps break the life cycles of many pests and disease-causing organisms by interrupting their host availability. It also enhances soil health, improves nutrient utilization, and supports sustainable crop production. Properly designed crop rotation systems can reduce reliance on chemical pesticides and contribute to environmentally friendly agriculture. Therefore, crop rotation is considered an essential component of integrated pest and disease management strategies in modern agriculture.

Introduction

Agricultural sustainability depends on the effective management of pests, diseases, and soil fertility. One of the oldest and most effective agronomic practices used to achieve this goal is crop rotation. Crop rotation refers to the practice of growing different types of crops in a sequential order on the same piece of land over a period of time. Continuous cultivation of the same crop in the same field, known as monoculture, often results in the buildup of pests and pathogens that specifically attack that crop. Over time, this leads to increased disease incidence and higher pest populations. Crop rotation disrupts the life cycle of these organisms by introducing non-host crops into the cropping sequence, thereby reducing pest and disease pressure.

In addition to pest and disease control, crop rotation contributes to improved soil structure, better nutrient availability, and enhanced biological activity in the soil. As a result, it plays a vital role in sustainable agriculture and integrated crop management systems.

Concept and Principles of Crop Rotation

Crop rotation involves the systematic planting of different crops belonging to different botanical families in a specific sequence. The main principle behind crop rotation is that pests and pathogens are often host-specific. When a different crop is grown in the following season, the pests or pathogens that depend on the previous crop fail to survive or reproduce.

Important principles of crop rotation include:

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- ✓ Alternating deep-rooted and shallow-rooted crops
- ✓ Including leguminous crops in the rotation
- ✓ Avoiding repeated cultivation of crops belonging to the same family
- ✓ Maintaining a balanced cropping system

These principles help maintain soil fertility and reduce pest and disease buildup.

Role of Crop Rotation in Pest Management

Breaking Pest Life Cycles: Many insect pests depend on a specific host crop for survival. When that crop is replaced with a non-host crop, the pest population declines due to lack of food and suitable habitat. For example:

- ✓ Rotating maize with legumes reduces maize stem borer infestation.
- ✓ Rotating cotton with cereals helps reduce bollworm populations.

Reducing Soil-Borne Pests: Certain pests such as nematodes and grubs survive in soil and attack specific crops. Crop rotation with resistant or non-host crops can significantly reduce their population. Example:

- ✓ Rotating cereals with legumes helps control root-knot nematodes.

Reducing Dependence on Chemical Pesticides: By naturally suppressing pest populations, crop rotation reduces the need for chemical pesticides, which helps protect the environment and beneficial organisms.

Role of Crop Rotation in Disease Management

Control of Soil-Borne Diseases: Many plant diseases are caused by pathogens that survive in soil for several years. Crop rotation interrupts their life cycle and prevents the spread of disease. Examples include:

- ✓ Fusarium wilt
- ✓ Root rot
- ✓ Damping-off

Growing non-host crops prevents the pathogens from multiplying.

Reduction of Pathogen Population: Without a suitable host plant, disease-causing organisms gradually decline in the soil, resulting in lower disease incidence in subsequent crops.

Improvement of Plant Health: Healthy soils with diverse microbial populations can suppress harmful pathogens. Crop rotation enhances soil microbial diversity and reduces disease occurrence.

Additional Benefits of Crop Rotation

Improvement of Soil Fertility: Leguminous crops such as pulses fix atmospheric nitrogen, enriching soil fertility and reducing fertilizer requirements.

Better Weed Management: Different crops require different cultivation practices, which helps break weed life cycles and reduce weed infestation.

Enhanced Soil Structure: Crop rotation improves soil structure, increases organic matter content, and enhances water-holding capacity.

Examples of Crop Rotation Systems

Some common crop rotation systems include:

- ✓ Wheat - Chickpea
- ✓ Rice - Mustard
- ✓ Maize - Soybean
- ✓ Sorghum - Pigeon pea

These systems help maintain soil fertility and minimize pest and disease problems.

Conclusion

Crop rotation is a simple yet highly effective agronomic practice for managing pests and diseases in agricultural systems. By disrupting pest life cycles and reducing pathogen buildup, crop rotation helps maintain crop health and productivity. It also improves soil fertility, enhances biodiversity, and promotes sustainable agriculture. Incorporating crop rotation into farming systems can significantly reduce dependence on chemical pesticides and contribute to environmentally friendly crop production. Therefore, crop rotation should be widely adopted as an integral component of integrated pest and disease management strategies.

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Drought Management Methods in Dryland Farming

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Abstract

Dryland farming plays a crucial role in global food production, particularly in arid and semi-arid regions where rainfall is scarce and erratic. Drought is one of the major constraints affecting crop productivity, soil health, and farmer livelihoods in these areas. Effective drought management strategies are essential to ensure sustainable agricultural production and food security. This paper discusses the causes and impacts of drought in dryland agriculture and highlights various management strategies including soil moisture conservation, crop selection, water harvesting, cropping systems, and technological interventions. Adoption of integrated drought management practices can improve resilience, enhance resource use efficiency, and stabilize crop yields under moisture stress conditions.

Introduction

Dryland agriculture refers to crop production under conditions of limited moisture availability, usually in regions receiving less than 750 mm of annual rainfall. These areas are characterized by erratic rainfall, high evaporation rates, and poor soil fertility. Drought is defined as a prolonged period of deficient precipitation resulting in water scarcity that adversely affects crop growth and agricultural productivity. Globally, drylands cover nearly 41% of the earth's land surface and support the livelihoods of billions of people dependent on agriculture. In India, rainfed agriculture accounts for a significant portion of crop production and contributes substantially to food security. However, irregular rainfall and frequent droughts pose serious challenges to sustainable farming systems. Effective drought management requires integrated approaches involving soil and water conservation, crop management, technological interventions, and policy support. The objective of this paper is to review major drought management strategies that can improve the resilience of dryland farming systems.

Rainfed agriculture provides a large share of food grains, fodder, and oilseeds, but irregular rainfall distribution can severely affect production and rural livelihoods.

Drought Management Method in Dryland Farming

Soil Moisture Conservation

Soil moisture conservation is the most important strategy to mitigate drought effects. Techniques include:

Mulching: Applying crop residues or organic materials on the soil surface reduces evaporation and improves soil moisture retention. Mulching can

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significantly reduce water loss from the soil surface.

Conservation Tillage: Minimum tillage or zero tillage practices reduce soil disturbance, improve soil structure, and enhance water infiltration.

Contour Farming: Ploughing along contour lines helps reduce runoff and soil erosion while conserving moisture in the root zone.

Water Harvesting Techniques

Water harvesting is essential for dryland agriculture where rainfall is limited.

In-situ Water Harvesting: Practices such as:

- ✓ Contour bunding
- ✓ Tied ridges
- ✓ Compartmental bunding

These methods help store rainwater in the soil profile and increase moisture availability for crops.

Ex-situ Water Harvesting: Collection of rainwater in farm ponds, tanks, or reservoirs for supplementary irrigation during dry spells.

Crop and Variety Selection: Choosing drought-tolerant crops and varieties is an effective strategy in dryland areas. Drought-resistant crop varieties require less water and can withstand moisture stress conditions.

Crop Diversification: Crop diversification reduces risk in dryland farming systems. Farmers may grow multiple crops to minimize losses during drought.

For example:

- ✓ Intercropping systems (sorghum + pigeon pea)
- ✓ Mixed cropping
- ✓ Crop rotation

Such systems improve soil fertility and enhance overall farm productivity.

Efficient Nutrient Management: Balanced fertilizer application helps crops withstand drought stress. Key practices include:

- ✓ Integrated Nutrient Management (INM)
- ✓ Application of organic manure
- ✓ Use of biofertilizers

Organic matter improves soil structure and water-holding capacity.

Weed Management: Weeds compete with crops for soil moisture and nutrients. Effective weed control ensures that available moisture is utilized by crops rather than weeds. Methods include:

- ✓ Mechanical weeding
- ✓ Herbicide application
- ✓ Mulching

Agroforestry and Shelterbelts: Agroforestry systems combine trees with crops to improve microclimate and reduce evaporation losses.

Role of Climate-Smart Agriculture

Climate-smart agriculture focuses on increasing productivity while adapting to climate change. Practices include:

- ✓ Precision agriculture
- ✓ Efficient irrigation technologies
- ✓ Improved crop varieties
- ✓ Integrated soil-water management

Such strategies improve resilience and sustainability of dryland farming systems.

Conclusion

Drought is one of the most serious constraints affecting dryland agriculture. Sustainable drought

management requires integrated strategies including soil moisture conservation, rainwater harvesting, crop diversification, improved varieties, and efficient nutrient management. Adoption of climate-smart agricultural practices and technological innovations can significantly enhance the resilience of dryland farming systems. Strengthening research, extension services, and farmer awareness is essential to ensure sustainable crop production and food security in drought-prone regions.

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Role of Organic Farming in Sustainable Agriculture

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Abstract

Organic farming is an environmentally sustainable agricultural system that relies on ecological processes, biodiversity, and natural cycles to maintain soil fertility and crop productivity. It excludes the use of synthetic fertilizers, pesticides, and genetically modified organisms. Sustainable agriculture aims to meet the food and fiber needs of the present generation without compromising the ability of future generations to meet their own needs. Organic farming contributes significantly to sustainable agriculture by improving soil health, conserving biodiversity, reducing environmental pollution, and enhancing long-term agricultural productivity. The adoption of organic farming practices such as crop rotation, green manuring, composting, and biological pest control promotes ecological balance and resource conservation. Additionally, organic farming supports rural livelihoods and provides safe and nutritious food to consumers. Despite its numerous advantages, challenges such as lower yields during the transition period, certification issues, and limited market access remain obstacles to its widespread adoption. This paper discusses the concept, principles, practices, benefits, and challenges of organic farming and highlights its crucial role in achieving sustainable agricultural development.

Introduction

Agriculture plays a vital role in ensuring food security and supporting livelihoods across the world. However, the rapid intensification of agriculture during the Green Revolution led to heavy dependence on chemical fertilizers, pesticides, and high-yielding varieties. Although these technologies significantly increased food production, they also resulted in several environmental problems such as soil degradation, water pollution, declining bio-diversity and increased greenhouse gas emissions. In recent years, there has been growing concern about the sustainability of conventional agricultural systems. Sustainable agriculture aims to maintain productivity while conserving natural resources and protecting the environment. Organic farming has emerged as an alternative farming system that promotes ecological balance and sustainable production. Organic farming focuses on maintaining soil health, promoting biodiversity, and minimizing environmental impacts by avoiding synthetic inputs. It relies on natural processes and locally available resources to sustain agricultural productivity. Therefore, organic farming is considered an important component of sustainable agriculture.

Concept of Organic Farming

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Organic farming is a holistic agricultural production system that emphasizes the use of natural inputs and biological processes to maintain soil fertility and crop productivity. According to the Food and Agriculture Organization (FAO), organic farming is a production management system that promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. Organic farming encourages practices such as crop rotation, composting, green manuring, biological pest control, and the use of organic fertilizers. These practices improve soil fertility, enhance nutrient cycling, and reduce dependence on external chemical inputs.

Principles of Organic Farming

Organic farming is based on four fundamental principles proposed by the International Federation of Organic Agriculture Movements (IFOAM):

Principle of Health: Organic agriculture should sustain and enhance the health of soil, plants, animals, humans, and the environment.

Principle of Ecology: Organic farming should be based on living ecological systems and cycles, working with them rather than dominating them.

Principle of Fairness: Organic agriculture should build relationships that ensure fairness with respect to the common environment and life opportunities.

Principle of Care: Organic farming should be managed responsibly to protect the health and well-being of present and future generations.

Organic Farming Practices

Organic farming involves several environmentally friendly practices that promote sustainable agricultural production.

Crop Rotation: Crop rotation helps maintain soil fertility, reduce pest and disease incidence, and improve soil structure.

Green Manuring: Green manure crops such as sunhemp and dhaincha are grown and incorporated into the soil to improve organic matter content and nutrient availability.

Composting and Vermicomposting: Composting converts organic waste into nutrient-rich manure, while vermicomposting uses earthworms to accelerate the decomposition process.

Biological Pest Control: Natural predators, parasitoids, and microbial biopesticides are used to control pests and diseases without harmful chemicals.

Use of Biofertilizers: Biofertilizers such as Rhizobium, Azotobacter, and phosphate-solubilizing bacteria enhance nutrient availability and promote plant growth.

Role of Organic Farming in Sustainable Agriculture

Soil Health Improvement: Organic farming improves soil fertility by increasing organic matter content and microbial activity. The application of compost, farmyard manure, and green manure enhances soil structure and nutrient availability.

Environmental Protection: Organic farming reduces environmental pollution by eliminating synthetic pesticides and fertilizers. It prevents contamination of soil, water, and air.

Biodiversity Conservation: Organic farming promotes biodiversity by supporting beneficial insects, soil microorganisms, birds, and wildlife. Diverse cropping systems such as intercropping and mixed farming enhance ecological balance.

Climate Change Mitigation: Organic farming helps mitigate climate change by reducing greenhouse gas emissions and increasing carbon sequestration in soils.

Sustainable Resource Management: Organic farming promotes efficient use of natural resources such as water, soil, and energy through sustainable practices like mulching and rainwater harvesting.

Production of Safe Food: Organic foods are free from harmful chemical residues and are considered safer and healthier for consumers.

Economic Sustainability: Organic farming reduces dependence on costly chemical inputs and allows farmers to utilize locally available organic resources, improving profitability in the long term.

Challenges in Organic Farming

Despite its advantages, organic farming faces several constraints:

- ✓ Lower yields during the initial transition period
- ✓ Limited availability of organic inputs
- ✓ Lack of technical knowledge among farmers
- ✓ Certification and marketing challenges
- ✓ Higher labor requirements

Proper training, research support and government policies are necessary to overcome these challenges.

Government Initiatives Promoting Organic Farming in India

The Government of India has launched several programs to promote organic farming, including:

- ✓ Paramparagat Krishi Vikas Yojana (PKVY)
- ✓ National Programme for Organic Production (NPOP)
- ✓ Mission Organic Value Chain Development for North Eastern Region (MOVCDNER)
- ✓ Rashtriya Krishi Vikas Yojana (RKVY)

These initiatives provide financial assistance, training, and certification support to encourage farmers to adopt organic farming.

Conclusion

Organic farming plays a crucial role in promoting sustainable agriculture by maintaining soil fertility, conserving biodiversity, and protecting the environment. It offers a viable alternative to chemical-intensive farming systems and contributes to long-term agricultural sustainability. Although certain challenges exist, increasing awareness, government support, and technological innovations can enhance the adoption of organic farming. Therefore, integrating organic farming practices with modern scientific knowledge can help achieve sustainable agricultural development and ensure food security for future generations.

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Climate-Smart Agriculture

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Abstract

Escalating climate variability is disrupting traditional, intuition-based farming by shifting seasons, intensifying unseasonal events (e.g., March hail), and prolonging dry spells, with acute yield losses when heat coincides with sensitive phenological stages such as flowering in rice and maize, producing empty husks rather than filled grains. This narrative synthesis aims to outline a climate-smart agriculture (CSA) toolkit that sustains food security and farm profitability under increasingly blurred seasonal patterns. Drawing on described agronomic, technological, and policy measures, the approach integrates crop genetic adaptation, precision resource management, and risk-transfer mechanisms alongside farmer-led knowledge exchange. Key strategies include deployment of drought-resilient varieties characterized by earlier maturity (10-15 days), deeper rooting to access subsoil moisture, and diversification toward hardy "super-grains" such as pearl millet (bajra) and ragi that perform under low water and marginal soils.

Introduction

For generations, a farmer's best friend has been their intuition, the ability to read the clouds or feel the moisture in the soil. However, today, the "old ways" are being challenged by a climate that no longer follows the rules. Climate-smart agriculture (CSA) is not just a technical term; it is a toolkit for resilience. It is about ensuring that as the world gets hotter and the rains get weirder, our plates stay full and our farmers remain profitable.

The New Normal: Understanding Climate Variability

We used to talk about "global warming" as a distant threat. Now, we talk about variability. For example, unseasonal hail in March can destroy a wheat crop, or a "dry spell" that lasts three weeks longer than usual. This unpredictability affects crops where it hurts the most: their biological clock. When temperatures spike during the flowering stage, plants such as rice or maize get "stressed," leading to empty husks instead of full grains. It is not just about surviving the heat; it is about navigating a landscape in which the seasons themselves have become blurred.

Seeds of Hope: Drought-Resilient Crop Varieties

If the environment is changing, the seeds must also change. Scientists and traditional seed savers are now focusing on drought-resilient varieties. These are not just "tough" plants; they are also biologically efficient.

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Early Finishers: Some new varieties of pulses and cereals mature 10-15 days earlier, allowing them to be harvested before the peak summer heat sets in. Deep-Rooted Champions: Breeding focus has shifted to plants with deeper root systems that can tap into moisture stored deep in the subsoil.

The Return of Millets: We are witnessing a massive comeback for "super-grains," such as pearl millet (Bajra) and ragi. These crops are ultimate survivors; they need very little water and can thrive in soils where other crops would fail.

Every Drop Counts: Water-Saving Irrigation: In many parts of the world, water has been treated as an inexhaustible resource. Climate-smart farming, however, views water as liquid gold. The shift is moving away from "flood irrigation" (where fields are simply drowned in water) toward precision irrigation. The use of drip systems or subsurface pipes ensures that water goes exactly where it is needed: to the roots. By using solar-powered soil sensors, a farmer can check their smartphone to see if a field actually needs water or if it is just the surface that looks dry. It is about being surgical rather than wasteful.

Farming as a Solution: Carbon Sequestration: Agriculture is often blamed for carbon emissions; however, it is one of our best tools for cleaning the atmosphere. This is known as carbon farming. By practising "no-till" farming, in which we avoid churning up the earth, we keep the carbon stored in the soil instead of releasing it into the air. When farmers plant "cover crops," such as clover or beans, during the off-season, they are not only protecting the soil from erosion but literally breathing carbon back into the earth. Healthy, carbon-rich soil acts like a sponge, holding more water and requiring less chemical fertiliser. This is a win for the planet and for the farmer's wallet.

The Safety Net: Schemes and Adaptation

No farmer should have to face a changing climate alone. Governments are increasingly intervening with adaptation strategies that blend technology with financial security.

Weather-Based Insurance: Digital tools now allow for "parametric insurance," in which a farmer automatically receives a payout if satellite data indicate a certain level of rainfall deficiency or heat no long claims processes are required.

Custom Hiring Centers: Not every small farmer can afford a laser land leveller or a drone. Government-backed centres are emerging to "rent" such high-tech equipment to local communities.

Knowledge Sharing: Through "Climate-Smart Villages," farmers are becoming teachers, sharing techniques that have worked in their specific microclimate, ensuring that the transition is led by people with dirt under their fingernails.

Bridging the Gap: Innovation or Tradition?

One of the most powerful realizations in 2026 is that Climate-Smart Agriculture doesn't always mean "expensive" or "high-tech." For many farmers, the choice is between adopting cutting-edge laboratory solutions and reviving ancient time-tested wisdom. In reality, the most successful farms perfo-

rm both tasks.

The Power of "Or": A farmer might choose a genetically mapped, drought-tolerant seed variety or opt for "Landrace" seeds traditional varieties that have naturally adapted to their specific local soil over centuries.

Low-tech vs. high-tech: Resilience can look like a million-dollar satellite-guided tractor, or it can look like a simple "zai pit" a traditional African technique of digging small holes to catch runoff and concentrate compost. Both are "smart" because they save crops.

The Human Cost of Inaction vs. The Reward of Adaptation

The adoption of climate-smart practices is often driven by necessity. When a family farm faces three consecutive years of crop failure, the conversation shifts from "Should we change?" to "How fast can we change?"

Financial Stability: Adapting is not just about saving the planet; it is about saving the bank account. Farmers using water-saving drip irrigation often see their pumping costs drop by 30% to 40%, turning a razor-thin margin into a liveable profit.

Mental Well-being: There is profound human relief in knowing that one's livelihood is not entirely at the mercy of a single rain cloud. Using resilient seeds provides a "buffer" a sense of security that allows the next generation to see farming as a viable career rather than a gamble.

Looking Ahead: A Collective Responsibility

The story of farming in a changing climate is still being written. It is a narrative of human ingenuity facing environmental volatility.

For the Farmer: It is about the courage to try a new row-spacing technique or to plant a crop they have never grown before, such as quinoa or dragon fruit, which might handle the heat better than the staples of their father's time.

For the Consumer: It is about choosing to buy from those who practice carbon sequestration and understanding that the price of food includes the cost of protecting the Earth, which is where it grew.

Summary

The text frames climate-smart agriculture (CSA) as a practical resilience toolkit responding to a "new normal" of climate variability unseasonal hail, prolonged dry spells, and blurred seasons that disrupts crop phenology, particularly heat spikes during flowering that cause stress and yield losses (e.g., empty husks in rice and maize). It describes adaptation through drought-resilient crop choices and breeding, including early-maturing pulse and cereal varieties (10-15 days sooner), deeper-rooted plants that access subsoil moisture, and a resurgence of hardy millets such as pearl millet (bajra) and ragi that thrive with minimal water on marginal soils. Water is treated as a limiting resource, motivating a shift from flood irrigation to precision delivery via drip and subsurface systems, supported by solar-powered soil sensors and smartphone-based decisions to irrigate only when needed. The piece also positions agriculture as part of the climate solution through carbon farming: no-till practices

retain soil carbon, while cover crops (e.g., clover, beans) reduce erosion and increase soil carbon, improving water-holding capacity and lowering fertilizer dependence benefiting both emissions goals and farm profitability. Recognizing that farmers cannot adapt alone, it highlights policy and institutional safety nets such as parametric, weather-based insurance triggered by satellite indicators of rainfall deficits or heat, custom hiring centers that rent equipment (e.g., laser land levellers, drones) to smallholders, and "Climate-Smart Villages" that promote peer-to-peer learning tailored to microclimates. A central nuance is that CSA in 2026 spans both innovation and tradition, from genetically mapped drought-tolerant seeds to locally adapted landraces, and from satellite-guided machinery to low-tech methods like zai pits that capture runoff and concentrate compost. Finally, it emphasizes the human stakes adaptation accelerating after repeated crop failures with documented economic gains (30-40% reductions in pumping costs from drip irrigation) and improved mental well-being from reduced livelihood uncertainty, while calling for shared responsibility: farmers experimenting with new techniques and heat-tolerant crops (e.g., quinoa, dragon fruit) and consumers supporting producers who sequester carbon and recognizing environmental stewardship as part of food's true cost.

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Soil Health Management: Strategies for Sustainable Agriculture

Sunita Choudhary and Rajesh Choudhary

Abstract

Soil health underpins farm productivity yet is frequently managed as inert "dirt," a misconception that accelerates exhaustion of soils, particularly in harsh semi-arid environments where moisture scarcity and heat stress intensify degradation. This work aims to synthesise actionable, science-based soil health management principles that sustain yields while rebuilding soil function and resilience under a changing climate. Using a practice-oriented integrative framework, the text consolidates key diagnostic, amendment, nutrient, microbial, and remediation interventions and links each to mechanistic soil processes and on-farm outcomes. Regular soil testing is presented as the primary diagnostic tool to quantify pH, electrical conductivity (as an indicator of salt build-up), and nutrient availability (notably N, P, and K), enabling targeted fertiliser applications that reduce economic losses from unnecessary inputs and mitigate risks of acidification, salinisation, and runoff associated with over-fertilisation and under-watering.

Introduction

We often treat the ground beneath our feet as just dirt an empty canvas where we drop seeds and expect miracles. However, soil is a living, breathing ecosystem. It is the very foundation of our food system, and right now, it is exhausted. When we continuously push the land without giving anything back, especially in harsh, semi-arid climates where moisture is already scarce and heat stress is high, the soil loses its vitality. Managing soil health is not just another task on a farmer's endless to-do list; it is the ultimate investment in the longevity and productivity of a farm.

Importance of Soil Testing

Imagine walking into a doctor's clinic with a fever and the doctor handing you a random handful of pills without checking your pulse or running a blood test. This is analogous to dumping fertilisers onto a field without first testing the soil. Soil testing eliminates the guesswork in farming. It provides a clear snapshot of what is happening underground, revealing the pH levels, electrical conductivity (which indicates salt buildup), and the exact availability of essential nutrients, such as nitrogen, phosphorus, and potassium. By understanding exactly what the soil lacks, farmers can apply the correct nutrients in the correct amounts. This not only saves hard-earned money from being wasted on unnecessary chemicals but also prevents the soil from becoming overly acidic or saline, a common

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issue when land is over-fertilized and under-watered.

Role of Organic Matter in Soil Fertility

If soil is considered a living body, organic matter is its beating heart. Organic matter, derived from decomposed plant residues, farmyard manure, and compost, transforms lifeless dust into rich, crumbly earth. In regions where the sun beats down relentlessly and water is a precious commodity, organic matter acts like a giant underground sponge. It drastically improves the soil's water-holding capacity, ensuring that every drop of irrigation counts and that roots stay hydrated for longer. Beyond moisture, it provides a slow, steady release of nutrients and creates the perfect airy structure for roots to penetrate deeply. Without organic carbon, the soil compacts, hardens in the sun, and is simply blown away by the wind.

Integrated Nutrient Management (INM): For decades, the farming debate has been polarised: chemical fertilisers versus strict organic farming. However, the most practical and productive path forward is integrated nutrient management (INM). Consider INM as a balanced diet for the soil. Chemical fertilisers are similar to a shot of espresso they provide an immediate and vital nutrient boost when the crop needs it most. However, one can not survive on espresso alone. INM blends targeted chemical inputs with organic sources, such as green manure, compost and crop residues. This combination ensures that the crop receives the immediate nutrients it needs for high yields today, while the organic inputs rebuild the soil's structure and fertility for tomorrow. It is about feeding the plant and soil simultaneously.

Biofertilizers and Microbial Solutions: Beneath the surface, there is an invisible workforce of billions of microbes toiling away. Modern agriculture has long ignored them; however, today, we are harnessing their power through biofertilizers. These are essentially living formulations of beneficial bacteria and fungi that are introduced to seeds or soil. Nitrogen Fixers: Microbes, such as Rhizobium (crucial for legumes) or Azotobacter, act as tiny fertiliser factories, pulling nitrogen directly from the air and feeding it to plant roots.

Phosphate Solubilisers: Soils often contain ample phosphorus, but it is locked in a chemical form that plants can not absorb. Phosphate solubilising bacteria (PSB) dissolve these bonds, serving the nutrient up on a silver platter.

Mycorrhizae: These beneficial fungi attach to roots and act as microscopic extensions, reaching far into tiny soil pores to scavenge for water and minerals that plants can not reach on their own.

Restoring Degraded Soils

The degradation of millions of hectares of agricultural land, plagued by severe erosion, heavy crusting, and rising salinity and alkalinity, is a painful reality. However, soil is incredibly forgiving if given the chance to heal. Restoring degraded land requires patience and the right physiological approach. For soils suffering from high alkalinity, integrating amendments such as gypsum alongside heavy organic matter can help flush out toxic sodium

Planting hardy, deep-rooted cover crops like Dhaincha (Sesbania) and ploughing them back into the earth as green manure can break up hardpans and revitalise exhausted fields. This is a shift from merely extracting from the land to actively nurturing it back to health.

Core Principles of Soil Health Management

To secure food systems against a changing climate, we must start from the ground up. Here is a summary of the essential pillars of soil health, breaking down complex science into actionable, everyday farming practices.

Soil Diagnostics (The "Why" of Soil Testing): The problem: Blindly applying fertilisers leads to nutrient imbalances, wasted money, and chemical runoff.

Solution: Regular soil testing provides a precise "health card" for the field.

Key Takeaway: Testing reveals the exact pH, electrical conductivity, and macro/micronutrient deficiencies, allowing for targeted surgical applications of fertiliser rather than wasteful broadcasting.

Organic Matter (The Soil's Lifeline): Heat stress and continuous cropping strip the soil of its natural structure, turning it into dust.

The Solution: Adding compost, farmyard manure, and crop residues

Key Takeaway: Organic carbon is the ultimate buffer. It improves the physical structure of the soil and drastically increases its water-holding capacity (crucial for drought resistance), creating a hospitable environment for beneficial microbes.

Integrated Nutrient Management (The Balanced Diet)

The Problem: Sole reliance on chemical fertilisers degrades the soil over time, whereas sole reliance on organic methods may not meet immediate high-yield crop demands.

Solution: A hybrid approach (INM): Key Takeaway: By combining chemical inputs for immediate plant uptake with organic manures for long-term soil conditioning, we feed both the current crop and future soil. It maximises yield while minimising ecological damage.

Soil Microbiology (The Invisible Workforce): The problem: Nutrients, such as phosphorus, are often chemically bound in the soil, making them unavailable to plant roots.

The Solution: Introducing biofertilizers (living microbial formulations)

Microbes, such as Rhizobium, fix atmospheric nitrogen, whereas phosphate-solubilizing bacteria and mycorrhizal fungi break down complex soil minerals and extend the reach of the root system, acting as natural, free-working fertiliser factories.

Land Remediation (Healing Degraded Earth)

The problem: High salinity, alkalinity, and hardpan formation render once-productive land barren. The Solution: Strategic interventions, such as green manuring and chemical amendments.

Key Takeaway: Incorporating deep-rooted cover crops, such as Dhaincha (Sesbania), breaks up compacted soil, whereas amendments, such as gypsum, help flush out toxic salts. Degraded soil is not a lost cause; it simply requires a shift from

extraction to active rehabilitation.

Summary

This study frames soil not as inert "dirt" but as a living ecosystem whose exhaustion especially under semi-arid conditions marked by moisture scarcity and heat stress threatens long-term farm productivity, making soil health management a central investment rather than an optional task. It emphasizes soil testing as the foundational diagnostic tool that replaces fertilizer guesswork with field-specific evidence on pH, electrical conductivity (as an indicator of salinity buildup), and nutrient availability (notably nitrogen, phosphorus, and potassium), enabling precise nutrient application that reduces costs, avoids over-fertilization, and prevents downstream problems such as acidification, salinization and chemical runoff. The work positions organic matter (from decomposed residues, farmyard manure, and compost) as critical to fertility and resilience by improving soil structure, enhancing aeration and root penetration, buffering against compaction and wind erosion, and acting as a "sponge" that markedly increases water-holding capacity and supports slow nutrient release benefits that are particularly decisive in hot, water-limited environments.

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Speed Breeding: A Revolutionary Tool for Rapid Crop Improvement

Nikhil Priyadarshi, K. N. Shah, D. K. Rana, Sweta Kumari and Abhay Singh

Abstract

Escalating global food demand necessitates innovative strategies to accelerate crop improvement. Conventional breeding approaches require nearly a decade to release a new cultivar, thereby constraining the rate of genetic gain. Speed breeding addresses this limitation through the strategic manipulation of photoperiod and temperature under controlled environments to hasten flowering and seed development. This approach enables multiple generations per annum, markedly shortening breeding cycles and expediting the development of homozygous lines. When integrated with genomic selection, gene editing and advanced phenotyping platforms, speed breeding enhances precision, efficiency and trait pyramiding within contemporary breeding programmes. Despite challenges relating to energy consumption and infrastructural investment, ongoing technological advancements are improving its scalability and sustainability. Speed breeding thus represents a transformative advancement in plant science, offering a pragmatic pathway for developing climate-resilient and high-yielding cultivars to strengthen global food security.

Introduction

The global population is projected to approach 10 billion by 2050, necessitating a 50-70 per cent increase in food production to ensure nutritional security (Hickey *et al.*, 2019). However, conventional plant breeding remains inherently time-intensive; the development of a new cultivar typically spans eight to ten years owing to extended generation intervals (Shreya *et al.*, 2022). To overcome this constraint, speed breeding has emerged as a transformative technological intervention. Inspired in part by early research conducted to cultivate wheat under continuous illumination in controlled environments, speed breeding manipulates environmental parameters to induce rapid flowering and seed set (Potts *et al.*, 2023).

By integrating extended photoperiods with optimised temperature regimes, breeders can achieve four to six generations annually in crops such as wheat, barley and chickpea, compared with only one or two generations under conventional field conditions (Watson *et al.*, 2018). This acceleration fundamentally redefines the tempo of genetic advancement.

The Science behind Speed Breeding

Photoperiod and Temperature Manipulation: The foundational principle of speed breeding lies in the deliberate regulation of photoperiod, the duration of daily light exposure, alongside temperature optimisation. Plants are typically grown under extended illumination regimes, often comprising twenty-two hours of light followed by two hours of darkness, to stimulate sustained photosynthetic

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activity and promote earlier floral initiation (Shinde *et al.,* 2023). Empirical evidence demonstrates that a twenty-two-hour photoperiod significantly reduces days to flowering in wheat genotypes when compared with conventional twelve-hour regimes (Dubcovsky *et al.,* 2006). Temperature regimes are likewise finely calibrated to maximise growth efficiency while maintaining plant vigour, thereby ensuring that accelerated development does not compromise reproductive success.



Figure 1: Controlled growth chamber setup showing extended LED photoperiod systems

Methodologies

Speed breeding may be implemented through several operational models, depending on infrastructural capacity and financial resources (Shinde *et al.,* 2023):

Speed Breeding I (Controlled Growth Chambers) : Utilises fully enclosed chambers offering precise regulation of humidity (approximately 70%), temperature (22°C/17°C day-night cycles) and light spectra through advanced light-emitting diode systems.

Speed Breeding II (Glasshouses): Employs glasshouses supplemented with high-pressure sodium vapour lamps or light-emitting diodes to extend photoperiod duration, representing a comparatively cost-effective alternative to growth chambers.

Speed Breeding III (Low-Cost Systems): Incorporates insulated rooms equipped with standard air-conditioning units and modular light systems, thereby facilitating adoption in resource-limited settings and expanding accessibility in developing regions.

Applications in Modern Agriculture

Accelerating Generation Turnover: The primary application of speed breeding lies in rapid generation advancement. By markedly shortening generation cycles, homozygous lines can be developed in a fraction of the time required under pedigree breeding systems. Notably, six generations of wheat and barley have been successfully produced within a single year under controlled speed breeding conditions (Watson *et al.,* 2018). This rapid turnover substantially enhances selection efficiency and accelerates varietal release.

Integration with Genomic Tools: The true potential of speed breeding is realised when integrated with contemporary genomic technologies. It aligns seamlessly with single seed descent and marker-assisted selection, facilitating accelerated fixation of desirable alleles. Recent developments have further combined speed breeding with gene editing technologies such as clustered regularly interspaced short palindromic repeats and associated protein systems, enabling rapid segregation of editing constructs and the development of edited, transgene-free lines within compressed timeframes (Potts *et al.,* 2023). This synergy supports effective trait pyramid-

ing, whereby multiple desirable attributes including disease resistance and drought tolerance are consolidated within elite cultivars (Samantara *et al.*, 2022). Such integrative approaches represent the frontier of precision plant breeding.

Challenges and Future Prospects

Despite its considerable promise, speed breeding presents notable challenges. Infrastructure establishment and sustained energy requirements, particularly under prolonged lighting regimes, may impose financial constraints (Wanga *et al.*, 2021). Moreover, concerns surrounding phenotypic plasticity persist, as plants cultivated under accelerated cycling conditions may express morphological variations distinct from field-grown counterparts, potentially complicating yield-based selection decisions (Shinde *et al.*, 2023). Nevertheless, advancements in energy-efficient lighting systems and the integration of renewable energy sources are progressively mitigating these limitations. Emerging research is exploring the convergence of speed breeding with artificial intelligence-driven predictive modelling and high-throughput phenotyping platforms to optimise parental selection and streamline breeding pipelines (Rai, 2022). Such interdisciplinary integration may redefine the architecture of future breeding programmes.

Conclusion

Speed breeding constitutes a paradigm shift in agricultural science by effectively decoupling plant improvement from seasonal constraints. By reducing breeding cycles from nearly a decade to only a few years, it offers a scientifically robust and operationally pragmatic response to global food security challenges. When harmonised with genomic selection and gene editing technologies, speed breeding will play an indispensable role in developing climate-resilient, high-yielding cultivars capable of sustaining an expanding global population.

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Jeevamrut: Elixir of Life for Plants

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Abstract

Jeevamruth is a liquid organic formulation used in natural farming to enhance soil microbial activity and improve crop growth. It is prepared from desi cow dung, cow urine, jaggery, pulse flour, water, and a small amount of soil. Based on two years of practical use in an organic field, it has shown positive results in soil health and crop performance. This article presents its preparation, composition, roles, and limitations from both practical experience and available knowledge.

Introduction

Jeevamruth (Jeevamrutha) is a traditional Indian bio inoculant widely employed to enhance soil fertility through the stimulation of beneficial microbial activity. Unlike synthetic fertilizers, Jeevamruth functions as a microbially enriched fermented formulation that improves soil biological health and nutrient availability. The preparation of Jeevamruth involves the fermentation of indigenous cow dung and cow urine, supplemented with jaggery, pulse flour, a small quantity of healthy local soil, and water. These substrates act as carbon and nitrogen sources, promoting the rapid proliferation of native soil microorganisms. The resulting microbial population plays a significant role in nutrient transformation processes, particularly nitrogen fixation and phosphorus solubilization. Jeevamruth is deeply embedded in indigenous Indian agricultural practices including concepts derived from Vedic agriculture. Its application aligns with sustainable farming principles by restoring soil biological balance, enhancing soil structure, and reducing dependence on chemical fertilizers.



Drenching of jeevamrut in organic field

This bio-input is a central component of Zero Budget Natural Farming (ZBNF), an agroecological approach popularized by Subhash Palekar, which emphasizes minimal external inputs and farmer self-reliance. The term Jeevamruth is derived from the Sanskrit words “Jeevan” (life) and “Amrit” (life-sustaining or medicinal nectar), symbolizing its role in sustaining soil life.

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From an agronomic perspective, Jeevamruth serves as an effective alternative to chemical fertilizers due to its natural composition and microbial richness. Its use has been associated with improved nutrient cycling, enhanced microbial biomass, and increased soil fertility. Owing to its organic origin, Jeevamruth is compatible with organic and natural farming systems, offering a cost-effective and sustainable strategy for maintaining soil productivity and long-term agricultural resilience.



Ingredients required for preparation of jeevamrut

Cow dung based organic manures host a wide range of useful microorganisms, mainly bacteria, fungi, yeast, and actinomycetes. Cow urine contains essential amino acids that help increase the nitrogen content of organic formulations and also enhance plant resistance against various diseases. Jaggery serves as a source of potassium, an important plant nutrient, and helps improve tolerance to drought conditions. Pulse flour provides amino acids that support the growth and activity of beneficial microbes, while chickpea flour is rich in protein and low in fat. Forest soil acts as a natural bio-inoculant containing NPK, nitrogen-fixing organisms, phosphate solubilizing bacteria and other beneficial microbes. Since these microorganisms occur naturally, they remain active for a longer duration in organic preparations.

Ingredints: pH and their roles

Ingredient	pH (Approx.)	Roles
Water	6.5-7.5	Mixing medium for fermentation
Cow dung	7.0-8.5	Main source of microbes
Cow urine	8.0-9.0	Provide nitrogen and minerals
Jaggery	5.0-6.0	Energy (carbon) for microbes
Pulse flour	6.0-6.5	Protein and nitrogen source
Soil	6.5-7.5	Adds native microorganisms

Flow chart of jeevamrut preparation

10 kg fresh desi cow dung

10 liters desi cow urine

2 kg jaggery

2 kg pulse flour

Handful of local soil

200 liters water

▼

Take a clean drum and add water

▼

Add all ingredients to the drum

▼

Mix thoroughly

▼

Ferment for 5-7 days (Stir twice daily)

▼

Jeevamruth ready for application

Application and dose of uses

Soil: Dilute 1:10 with water and apply near roots every 15 days.

Seed Treatment: Soak seeds in 1:10 solution for 30 minutes before sowing.

Foliar Spray: Spray 1:20 diluted solution on foliage

every 15-20 days.

Compost: Mix with compost to boost microbial activity and decomposition.

Drip Irrigation: Filter and apply about 200 L acre^{-1} through drip to supply nutrients and beneficial microbes.

Uses and Benefits of Jeevamrut

- ✓ Improves soil fertility by enhancing beneficial microbial activity.
- ✓ Supplies essential nutrients for better crop growth and yield.
- ✓ Strengthens plant resistance to pests and diseases.
- ✓ Low-cost and farmer-friendly alternative to chemical fertilizers.
- ✓ Eco-friendly, reducing chemical use and environmental impact.
- ✓ Safe and flexible in use; excess application does not harm soil.
- ✓ Local soil adds native microbes well suited to regional conditions.

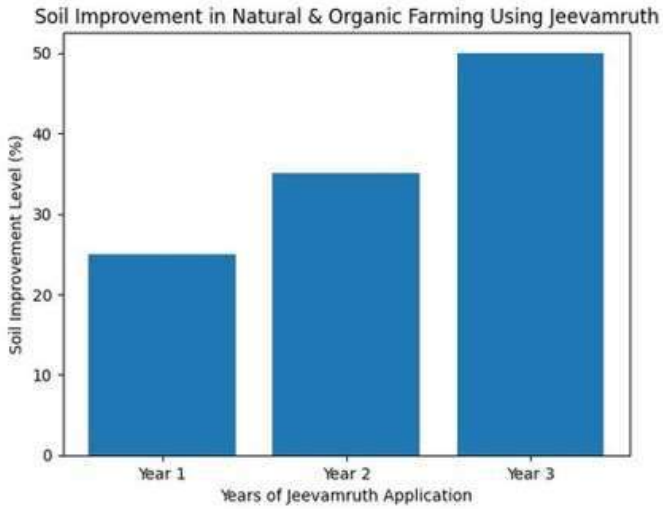


Limitations of Jeevamrut

- ✓ Not a full nutrient source - it mainly boosts soil microbes, but supplies little plant nutrition.
- ✓ Needs regular preparation - has to be made again every few days.
- ✓ Depends on desi cow inputs- dung and urine from local cows may not be easily available.
- ✓ Short storage time - cannot be kept for long after making.
- ✓ More labor required - takes effort to prepare and apply.
- ✓ Slower visible effects - works gradually compared to chemical fertilizers.

Conclusion

Jeevamruth is a simple, low-cost organic input that improves soil life and supports healthy crop growth. From my two years of use in organic farming, it has shown positive effects on soil condition and crop performance. Although it requires regular preparation and is not a complete fertilizer, it is an effective tool for reducing chemical use and promoting sustainable agriculture.



Distant Hybridization in Citrus and Grapes

Suhasini Chikkalaki

Introduction

Hybridization is a defined as crossing or inter-breeding between two genetically dissimilar parents. Hybridization between individuals from different species belonging the same genus (interspecific hybridization) or two different genera of same family (intergeneric hybridization) is termed as wide/distant hybridization and such crosses are known as distant crosses or wide crosses (Liu *et al.*, 2014). This because individuals used for hybridization in such cases are taxonomically more distantly related than different variety from the same species. Wide Hybridization involves many limitation both in developmental processes and also after development of a line or hybrid. However, there are several problems associated with wide hybridization such as occurrence of self and cross incompatibility which lead to poor recovery of viable seeds or hybrids. These barriers are broadly categorized into three major barriers *viz*., temporal and spatial isolation of species (difference in climatic and ecological region of cultivated and wild species), Pre fertilization barriers (due to presence of pollen germination inhibition factors) and Post fertilization barriers (due to breakdown of embryo). However, success can be achieved after overcoming incompatibility barriers. The techniques such as mentor pollination, use of bridge species, embryo rescue and protoplast fusion have played significant role in recovering of hybrids.

Techniques to overcome barriers in wide hybridization: There are several problems associated with wide hybridization such as occurrence of self and cross incompatibility which lead to poor recovery of viable seeds or hybrids. But there are many techniques to overcome these problems leading to successful cross. Techniques like embryo rescue, somatic hybridization, reciprocal crosses, manipulation of ploidy, use of PGRs and bridge crosses are standardized in order to overcome the temporal and spatial isolation species, pre and post fertilization barriers associated with wide hybridization.

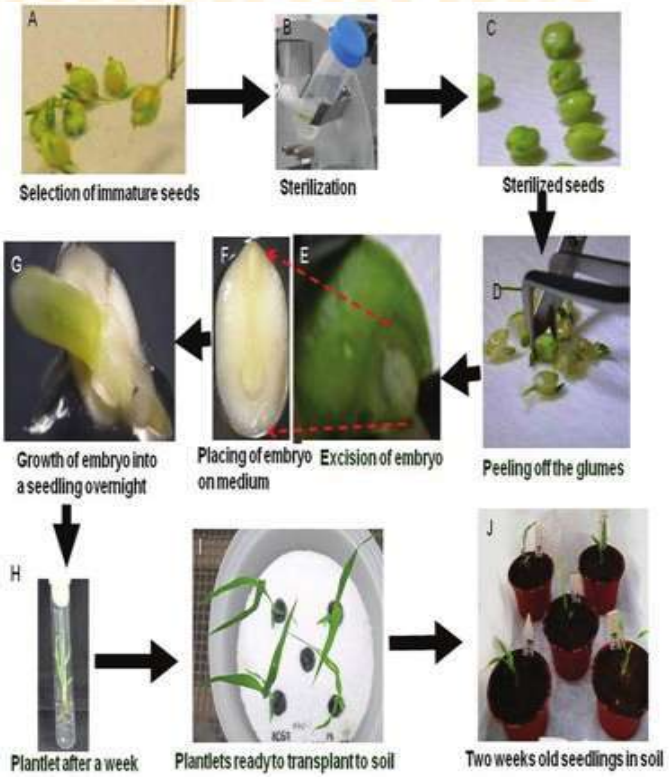


Fig. 1: Embryo rescue: E.g. Citrus and Grapes

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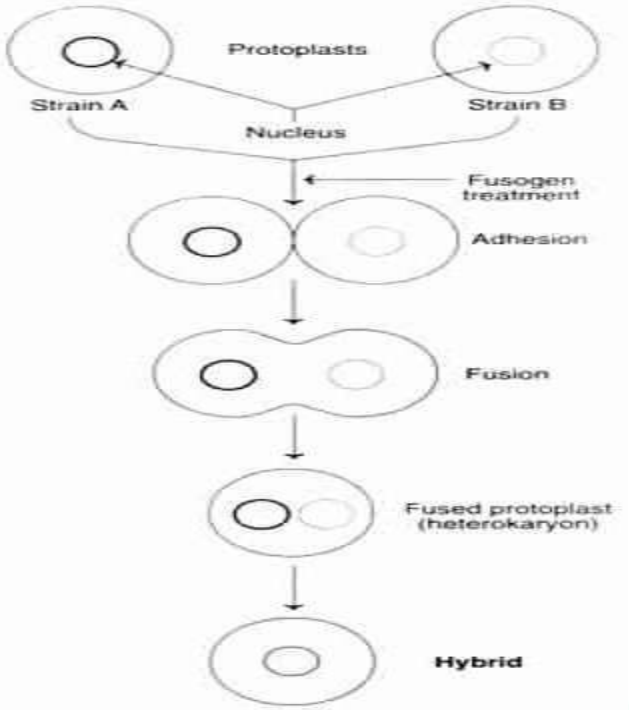


Fig. 2: Somatic embryogenesis: E.g. *C. sinensis* L. Osb. cv. Trovita + *Poncirus trifoliate, Poncirus trifoliata* L. Raf. + *Fortunella hindsii*

Reciprocal crosses: Reciprocal cross may be attempted when one parental combination fails. E.g. Muscat Hamburg × Jingyou; Jingyou × Muscat Hamburg (Sun *et al*., 2011)

Manipulation of ploidy: Diploidization of solitary genomes to make them paired will be helpful to make the cross fertile. E.g. Kyoho grape bred in Japan is tetraploid, which can reach 13 g berry^{-1} and above compared to typical wine grape berry weight is 1-2 g (Wang *et al*., 2001).

Bridge crosses: When two parents are incompatible, a third parent that is compatible with both the parents can be used for bridge crosses and thus it becomes possible to perform cross between the original parents. E.g.: *C. sinensis* × *Severinia disticha*, a somatic hybrid can be used as a bridge species between Citrus and related genera.

Use of growth regulators: Pollen tube growth can be accelerated by using growth hormones like IAA, NAA, 2, 4-D and Gibberellic acid.

Wide/distant hybridization in citrus and grapes

Flowering and anthesis in citrus: Cymes, are produced on current season growth, the flowers are white in colour in most of the species except lemon and citron where they are purplish on the outside. Maximum anthesis is between 11.00 a.m. to 12.00 noon, the dehiscence of anthers takes place there 45 minutes before anthesis or within 45 minutes after anthesis and the receptivity of stigma starts either 15 minutes to 2 hours before anthesis. Flowering and anthesis in grapes: Petals and sepals are (five in number) fused and during anthesis the petals detach from the base forming a cap like structure called 'calyptra' Calyx 4-5 (3-7) sepals, connate and corolla 4-5 (3-7, 0) petals, distinct (connate) or apically coherent, androecium 4-5 (3-7) stamens, distinct or anthers connate; opposite petals and gynoecium 2. Anthesis - 6 -8 weeks after the commencement of shoot and peak anthesis is between 7 -8 am in North India and between 8-9 am in South India.

Hybridization technique in citrus and grapes



Fig. 3: A) a large unopened bud, (B) emasculation, (C) pollination of the emasculated flower, (D) cotton pad wrapping around the twig, (E) bagged twig, (F) general view of the seed parent after crossing

Genetic source: resistant/tolerance for abiotic and biotic stress in citrus and grapes

Citrus

Salt	Rangpur lime, Marmalade orange, Cleopatra mandrin and Nasnaran
Drought	Rangpur lime, Marmalade orange, Rough lemon, and Sour orange
Yield	Rangpur lime, Rough lemon, Cleopatra mandrin, Sour orange, and Karna katta
Quality	Sour orange, Carrizo citrange, Troyer citrange, Sweet orange and Nasnaran
Root rot	Marmalade orange, Carrizo citrange, Troyer citrange and Rangpur lime
Nematode	Marmalade orange, sweet lime, Carrizo citrange, Troyer citrange, Karna katta, Nasnaran and Survernia disticha
Tristeza	Marmalade orange, Rangpur lime, Rough lemon, Cleopatra mandrin, Trifoliate orange, Carrizo citrange, Troyer citrange, Nasnaran and Sweet orange
Exocortis	Rough lemon, Cleopatra mandrin, Sweet orange, Sour orange and Grape fruit
Gummosis	Trifoliate orange, Sour orange , Rangpur lime, Cleopatra mandrin and Grape fruit
Greening	Poncirus, Gajanimma, Florida rough and Karna katta

Grapes: Muscadinia is a rich source of resistance to disease and pests and also possesses a unique and delightful flavour and aroma. The crosses between *Vitis* and *Muscadinia* which differ in chromosome number are made with difficulty, but most of the resulting hybrids remain sterile, crossing within *Muscadinia* has given outstanding self-fertile cultivars like Tarheel, South land, Magron, Regale and Triumph. Some of the outstanding contributions of interspecific hybridization are cold and mildew resistant: Amur hybrid, Delaware and some importantrootstock of grape i.e. 1613, telki 5 A, Harmony. Species like *V. berlandieri, V. ripoeria, V. candicans, V. longii, V. champini* tolerate excessive salt in the soil and thus *can* be used in the improvement programmes oriented to breed salt resistant types, Dog Ridge and Salt Creek impart nematode and salt resistance to the grafts and *V. berlanderii, V. arizonica, V. tiliefolia* highly suitable for inducing drought tolerance.

Achievements

Citrus

Rootstock hybrids of citrus developed in India

Institute	Rootstock hybrid	Parentage	Traits
IIHR, Bangalore	CRH- 12	Rangpur lime × Trifoliate orange	Highly resistant to phytophthora and nematode, moderately tolerant to salinity and tolerant to drought
	CRH- 57	Rough lemon × Trifoliate orange	Highly resistant to phytophthora and nematode, tolerant to salinity and drought
	CRH- 47	Cleopatra mandrin × Trifoliate orange	moderately tolerant to salinity
NRCC, Nagpur	NRCC 1 to NRCC 10		

Interspecific polyembryonic hybrid of lemon developed by IIHR: Rasraj: Resistant to bacterial canker, the hybrid drives genes by Nepali round lemon parent and other characters from acid lime. The fruit is yellow coloured, weighs 55 g, 70 % of juice and 12 seeds. The acidity is 6 % and TSS is around 8 °B.

Intergeneric hybrids in citrus

***Citrofortunella*:** These plants are hardier and more compact than most citrus plants, often referred to as cold hardy citrus. They produce small acidic fruit and make good ornamental plants.

Hybrids	Parents
Calamondin	Tangerine × Kumquat
Citrangequat	Citrange × Kumquat
Limequat (*Citrofortunella floridana*)	Keylime × Kumquat
Orangequat (*Citrofortunella nippon*)	Satsuma mandrin × Kumquat
Procimequat	Limequat × Kumquat

Citrocirus: Citrocirus also according to the Swingle system, is a hybrid genus, containing hybrids between members of the *Citrus* and the closely related *poncirus.*

Trifoliate orange: A cold hardy that is commonly used as a citrus rootstock.

Citranget	*Citrus sinensis* × *Poncirus trifoliata* Troyer, Rusk and Carrizo
Citrumelo	*Citrus paradisi* × *Poncirus trifoliata*

Grapes: Inter varietal hybridization (IARI)

Hybrid	**Parentage**
Hybrid 62-37	Hur × Pusa seedless
H 62-65	Hur × Pusa seedless
H 62-20	Hur × Black Hamburg
H 62-67	Hur × Bharat early
H 63-10	Bhokri × Pearl of Casaba
H 63-32	Bhokri × Pearl of Casaba
Pusa Navrang	Madeleine Angevine × Rubi Red
Pusa Urvashi	Hur × Beauty seedless

The promising hybrids developed at IIHR, Bangalore

Hybrid	**Parentage**
Arkawati	Black Champa × Thompson seedless
Arka Kanchan	Anab - e Shahi × Queen of vineyards
Arka Shyam	Bangalore blue × Black Champa
Arka Hans	Bangalore blue × Anab – e Shahi
Arka Chitra	Angur Kalan × Anab – e Shahi
Arka Krishna	Black Champa × Thompson seedless
Arka Majestic	Angur Kalan × Black Champa
Arka Neelamani	Black Champa × Thompson seedless
Arka Soma	Anab - e Shahi × Queen of vineyards
Arka Trishna	Bangalore blue × Convert large black
Arka Shweta seedless	Anab - e Shahi × Thompson seedless

Panchagavya, Beejamrit and Jeevamrit: Role in Sustainable Agriculture

Ankit Yadav, K. N. Shah, D. K. Rana, Pragya Pancholi and Abhay Singh

Abstract

The excessive reliance on chemical fertilizers and pesticides in modern agriculture has resulted in soil degradation, declining microbial diversity, environmental pollution, and increased production costs. Indigenous liquid organic formulations such as Panchagavya, Beejamrit, and Jeevamrit have gained scientific importance due to their ability to enhance soil biological activity, nutrient cycling, and plant physiological processes. These formulations, prepared from cow-based products and locally available organic materials, act primarily as biostimulants rather than direct nutrient fertilizers. Numerous experimental studies have demonstrated their positive effects on seed germination, crop growth, yield, quality, soil health, and stress tolerance across a wide range of crops. This article critically reviews the composition, nutrient content, agronomic uses, and sustainability potential of Panchagavya, Beejamrit, and Jeevamrit based on authentic scientific evidence.

Introduction

The Green Revolution substantially increased agricultural productivity but simultaneously intensified the use of synthetic fertilizers and pesticides, leading to soil structural deterioration, nutrient imbalance, loss of soil organic carbon, and disruption of beneficial soil microorganisms (Somdutt *et al.*, 2023). Continuous agrochemical use has also resulted in groundwater contamination, reduced input-use efficiency, and higher cultivation costs, particularly affecting small and marginal farmers (Lakhani, 2024). These challenges have emphasized the need for sustainable and environmentally safe alternatives that restore soil health while maintaining crop productivity (Kaushal *et al.*, 2024). Traditional Indian farming systems have long recognized the importance of cow-based organic inputs in sustaining soil fertility and crop vigor (Palekar, 2006). Panchagavya, Beejamrit, and Jeevamrit are prominent indigenous liquid organic formulations widely used in organic farming and Zero Budget Natural Farming systems (Somdutt *et al.*, 2023). Unlike chemical fertilizers, these formulations enhance crop performance mainly through stimulation of soil microbial activity, nutrient mobilization, and improvement of plant physiological efficiency (Sreenivasa *et al.*, 2010; Patel *et al.*, 2024).

Concept of Liquid Organic Manures

Liquid organic manures are fermented biological inputs designed to enhance soil biological processes rather than supply nutrients in inorganic forms (Sreenivasa *et al.*, 2010). These formulations provide readily available carbon and energy sources

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that stimulate rapid multiplication of beneficial microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, fungi, and actinomycetes **(**Somdutt *et al.,* 2023). Increased microbial activity results in higher soil enzyme activities, including dehydrogenase, phosphatase, and urease, which accelerate organic matter decomposition and nutrient mineralization (Lakhani, 2024). In natural farming systems, Panchagavya, Beejamrit, and Jeevamrit play complementary roles (Palekar, 2006). Beejamrit is mainly used for seed and planting material treatment, Jeevamrit functions as a soil microbial inoculant and nutrient mobilizer, and Panchagavya acts as a plant growth promoter and immunity enhancer when applied as foliar spray or soil drench (Somdutt *et al.,* 2023).

Panchagavya: Panchagavya is a fermented liquid organic formulation prepared from five cow-derived products, namely fresh cow dung, cow urine, milk, curd, and ghee, which together provide a rich consortium of beneficial microorganisms, enzymes, and organic metabolites (Devakumar *et al.,* 2008; Somdutt *et al.,* 2023). Cow dung acts as a primary source of bacteria, fungi, and actinomycetes, while cow urine contributes nitrogenous compounds, minerals, enzymes, and antimicrobial substances that support microbial proliferation and plant health (Lakhani, 2024). Milk and curd supply proteins, amino acids, and lactic acid bacteria that enhance fermentation efficiency, whereas ghee functions as a lipid source that stabilizes bioactive compounds formed during fermentation (Devakumar *et al.,* 2008). In many farming systems, jaggery, ripe banana, sugarcane juice, or tender coconut water are added to increase carbohydrate availability and accelerate microbial multiplication (Palekar, 2006). Pancha-gavya contains low concentrations of macro-nutrients, with reported nitrogen levels generally ranging from 0.03-0.06%, phosphorus 0.01-0.02%, and potassium 0.02-0.04% (Devakumar *et al.,* 2008; Somdutt *et al.,* 2023). However, it is comparatively rich in micronutrients such as iron, zinc, copper, manganese, calcium, and magnesium, which are essential for enzymatic activation, chlorophyll synthesis, and physiological regulation in plants (Singh *et al.,* 2022). Fermentation also results in the formation of water-soluble vitamins, amino acids, organic acids, enzymes, and plant growth regulators such as indole-3-acetic acid, gibberellic acid, and cytokinins, which enhance nutrient assimilation and metabolic efficiency (Devakumar *et al*., 2008). Panchagavya is widely used as a foliar spray and soil drench in vegetable, fruit, and horticultural crops to improve vegetative growth, flowering, yield, and quality **(**Singh *et al.,* 2022). Foliar application enhances nutrient absorption through leaf surfaces and improves photosynthetic efficiency, while soil application stimulates rhizospheric microbial activity and nutrient mobilization (Somdutt *et al*., 2023). Regular application has been reported to enhance resistance to pests and diseases, reduce dependence on synthetic growth regulators and pesticides and lower cultivation costs, making Panc-hagavya an important input in organic and natural

farming systems (Palekar, 2006; Lakhani, 2024).

Beejamrit: Beejamrit is a liquid organic formulation prepared using fresh cow dung, cow urine, lime, and a small quantity of native soil collected from healthy crop rhizospheres (Palekar, 2006). Cow dung and cow urine act as reservoirs of beneficial micro-organisms that rapidly colonize the seed surface and early rhizosphere after application (Kumar *et al.*, 2022). Lime helps regulate pH and creates unfavorable conditions for pathogenic fungi and bacteria, while native soil introduces locally adapted microbial strains that enhance compatibility with field soil conditions (Somdutt *et al*., 2023; Lakhani, 2024). Beejamrit contains very low concentrations of macronutrients and is not primarily intended to serve as a nutrient source for crops (Kumar *et al.,* 2022). Nitrogen, phosphorus, and potassium are present only in trace amounts sufficient to support early microbial activity on seed surfaces during germination (Somdutt *et al*., 2023). Calcium supplied through lime contributes mainly to seed sanitation and pathogen suppression rather than direct plant nutrition (Lakhani, 2024). Thus, the nutritional role of Beejamrit is indirect and primarily mediated through improved microbial colonization and root initiation. Beejamrit is primarily used for seed treatment, seedling root dip, and planting material treatment prior to sowing or transplanting (Palekar, 2006). Seed treatment with Beejamrit has been shown to improve germination percentage, seedling vigor, root development, and uniform crop establishment across cereals, pulses, and vegetables (Kumar *et al.,* 2022). Its use reduces reliance on chemical seed dressers and fungicides, contributing to environmentally safe crop production and improved early crop performancee (Somdutt *et al*., 2023).

Jeevamrit: Jeevamrit is fermented liquid organic manure prepared from cow dung, cow urine, jaggery, pulse flour, and a small quantity of native soil (Palekar, 2006). Cow dung and cow urine provide a diverse microbial consortium, while jaggery serves as a readily available carbon source that accelerates microbial multiplication during fermentation (Somdutt *et al.,* 2023). Pulse flour supplies nitrogen and amino acids that enhance microbial growth and enzymatic activity, and native soil introduces site-specific microorganisms adapted to local soil environments (Lakhani, 2024; Kaushal *et al.,* 2024). Compared to other liquid organic formulations, Jeevamrit contains moderate levels of plant-available nutrients, with reported nitrogen content of approximately 0.06-0.12%, phosphorus 0.02-0.04%, and potassium 0.05-0.10% (Somdutt *et al.,* 2023; Lakhani, 2024). It also supplies essential micro-nutrients such as iron, zinc, manganese, copper, and boron, which support enzymatic reactions and plant physiological processes (Kaushal *et al.,* 2024). The presence of soluble carbon compounds enhances microbial biomass and soil enzyme activity, leading to increased mineralization of native soil nutrients and improved nutrient use efficiency (Patel *et al*., 2024). Jeevamrit is commonly applied as a soil drench or through irrigation water to stimulate soil microbial activity and nutrient cycling throughout

the crop growth period (Lakhani, 2024). Repeated application improves soil structure, aggregation, moisture retention, and long-term fertility (Kaushal *et al.,* 2024). Numerous studies have reported enhanced crop growth, yield, and quality following Jeevamrit application, and recent evidence indicates its effectiveness in mitigating abiotic stresses such as drought and salinity by improving antioxidant enzyme activity and plant water relations (Patel *et al.*, 2024).

Conclusion

Panchagavya, Beejamrit, and Jeevamrit are scientifically validated indigenous liquid organic formulations that improve soil biological activity, nutrient use efficiency, crop productivity, and sustainability. Their agronomic value lies primarily in stimulation of microbial processes and enhancement of plant physiological functions rather than direct nutrient suppl. Integration of these formulations into farming systems can reduce dependence on chemical inputs, lower production costs, and minimize environmental pollution. Standardization of preparation methods, long-term field evaluation, and wider dissemination through extension programs will further strengthen their role in sustainable and climate-resilient agriculture.

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Breeding for Disease Resistance in Vegetable Crops

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Abstract

Vegetable crops play a vital role in human nutrition, providing essential vitamins, minerals, and dietary fiber. However, the productivity and quality of vegetable crops are severely constrained by various diseases caused by fungi, bacteria, viruses, and nematodes. Chemical control of diseases is often costly, environmentally unsafe, and may lead to the development of resistant pathogen strains. Breeding for disease resistance offers a sustainable, economical, and eco-friendly approach to managing plant diseases in vegetable crops. This paper discusses the importance of disease resistance breeding, types of disease resistance, sources of resistance, methods used in breeding programs, and modern approaches such as molecular breeding. The role of resistant varieties in sustainable vegetable production is emphasized.

Introduction

Vegetable cultivation is an important component of agriculture due to its high economic value and nutritional significance. Vegetables are rich sources of vitamins, minerals, antioxidants, and dietary fiber, contributing significantly to food and nutritional security. However, vegetable crops are highly susceptible to a wide range of diseases that can cause severe yield losses and reduce market quality. Plant diseases such as early blight and late blight in tomato, downy mildew in cucurbits, club root in cole crops, bacterial wilt in solanaceous vegetables, and viral diseases like mosaic and leaf curl cause significant economic losses worldwide. Traditionally, farmers rely heavily on chemical pesticides to manage these diseases. Excessive use of chemicals leads to environmental pollution, health hazards, and increased production costs. Breeding for disease resistance is considered one of the most effective and sustainable strategies for disease management. Resistant varieties reduce dependency on chemicals, ensure stable yields and are compatible with integrated disease management practices. Therefore, the development of disease-resistant vegetable varieties has become a major objective in vegetable breeding programs.

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Importance of Disease Resistance Breeding

Disease resistance breeding offers several advantages in vegetable production:

- ✓ Reduces yield losses caused by pathogens
- ✓ Minimizes the use of chemical pesticides
- ✓ Lowers production costs for farmers
- ✓ Enhances environmental and human health safety
- ✓ Provides long-term and economical disease control
- ✓ Supports sustainable and organic farming systems

Resistant varieties are especially beneficial for small and marginal farmers who may not afford expensive chemical inputs.

Types of Disease Resistance

Disease resistance in vegetable crops can be classified based on genetic control and response to pathogens.

Vertical Resistance: Vertical resistance is governed by one or a few major genes and provides high-level resistance against specific races of a pathogen. It is often complete but may break down when new pathogen races emerge.

Horizontal Resistance: Horizontal resistance is controlled by many minor genes and provides partial but durable resistance against a wide range of pathogen races. It is more stable and long-lasting.

True Resistance: True resistance prevents or restricts the establishment and multiplication of the pathogen within the host plant.

Tolerance: Tolerant plants can withstand infection and produce reasonable yields despite the presence of disease.

Sources of Disease Resistance

The success of disease resistance breeding depends on the availability of suitable resistance sources.

- ✓ Cultivated varieties and landraces
- ✓ Wild relatives of vegetable crops
- ✓ Indigenous germplasm collections
- ✓ Mutant lines
- ✓ Introduced germplasm from other regions

Wild species have been widely used as resistance sources, such as *Solanum pimpine-llifolium* for disease resistance in tomato and *Cucumis hardwickii* in cucurbits.

Breeding Methods for Disease Resistance

Selection: Resistant plants are selected from segregating populations under natural or artificial disease pressure.

Hybridization: Crossing resistant and susceptible parents to transfer resistance genes into high-yielding varieties.

Backcross Breeding: Used to introduce resistance genes into elite cultivars while retaining desirable agronomic traits

Recurrent Selection: Useful for improving horizontal resistance controlled by polygenes.

Mutation Breeding: Induced mutations are used to create new resistance sources when natural resistance is unavailable.

Screening Techniques for Disease Resistance

Effective screening is essential for identify-

Table 1: Examples of Disease-Resistant Vegetable Varieties

S.No.	Varieties and Hybrids	Special features	S.No.	Varieties and Hybrids	Special features
Tomato			**Brinjal**		
1.	Arka Abha Arka Alik Arka Shreshta	Resistant to bacterial wilt	1.	Pusa purple Long Pusa Anupam Arka Nidhi Arka Keshav Neelima	Resistant to bacterial wilt
2.	Arka Abhijit	Highly resistant to bacterial wilt	2.	Pusa Bhairav	Resistant to phomopsis fruit rot
3.	Arka Ashish	Tolerant to bacterial wilt	3.	Hisar Samrat	Tolerant to shoot and fruit borer and resistant to BW
4.	Kashi Vishesh Hisar Anmol	Resistant to TLCV	4.	VRM - 1	resistant to leaf spot and verticillum wilt
Chilli			**Potato**		
1.	Pusa Sadabahar	Resistant to CMV, TMV and leaf curl viruses	1.	Kufri Himalini Kufri Shaillja Kufri Jawakar	Moderate resistant to late blight
2.	Punjab Lal	Resistant to TMV	2.	Kufri Girdhari Kufri Himsona	Highly resistant to late blight
3.	Arka Lohit Arka Harita	Tolerant to powdery mildew	3.	Kufri Sindhuri Kufri Jeevan Kufri Lalima	Moderately resistant to early blight

These varieties have significantly contributed to increased productivity and reduced pesticide use.

ing resistant genotypes.

- ✓ Field screening under natural infection
- ✓ Artificial inoculation techniques
- ✓ Greenhouse and controlled environment screening
- ✓ Use of disease scoring scales
- ✓ Reliable screening ensures accurate selection of resistant lines.

Modern Approaches in Disease Resistance Breeding

Marker-Assisted Selection (MAS): Molecular markers linked to resistance genes are used to select resistant plants at early growth stages.

Transgenic Approaches: Introduction of resistance genes from unrelated organisms, especially for viral resistance.

Genomic and Molecular Breeding: Advanced tools such as QTL mapping and genomic selection improve breeding efficiency and accuracy.

Conclusion

Breeding for disease resistance in vegetable crops is a crucial component of sustainable agriculture. It provides an effective, economical, and environmentally safe approach to disease management. The integration of conventional breeding methods with modern molecular tools has enhanced the efficiency of resistance breeding programs. Continued exploration of diverse germplasm, wild relatives, and advanced biotechnological approaches will further strengthen the development of durable disease-resistant vegetable varieties. Such efforts are essential to ensure food security, environmental protection, and improved livelihoods for farmers.

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Root System Architecture: Engineering the Hidden Half for Optimal Water Capture

Kanchan Panwar and Ravinder Kaur

Abstract

Root System Architecture (RSA) the spatial configuration of roots in soil is a primary determinant of a plant's ability to acquire water, especially under suboptimal conditions. This article explores RSA not merely as a static structure but as a dynamic, plastic, and intelligent foraging system. We detail how specific architectural traits, such as root angle, depth, branching density, and the proliferation of root hairs, directly influence water uptake efficiency by exploring deeper soil layers and maximizing soil contact. Emphasizing cutting-edge research, we discuss the genetic and molecular drivers of RSA, the role of hydrotropism and rhizosphere interactions, and the application of phenotyping technologies like X-ray computed tomography (CT). Furthermore, we highlight the strategic manipulation of RSA through breeding and biotechnology as a trending, sustainable solution to enhance crop resilience and water-use efficiency (WUE) in the face of climate change-driven droughts.

Introduction

Beneath the soil surface lies a complex, dynamic organ system whose architecture is critical for survival: the root system. Root System Architecture (RSA) defines the three-dimensional arrangement of roots, encompassing traits like depth, spread, angle, and branching intensity. In an era of increasing water scarcity, understanding and optimizing RSA is paramount for developing resilient crops. An ideal RSA for water uptake is not a one-size-fits-all model but a context-specific design that efficiently explores soil volumes to access stored water. This article delves into the functional roles of key RSA traits, the innovative technologies used to study them, and the promising strategies to harness RSA plasticity for sustainable agriculture.

Key RSA Traits and Their Hydraulic Functions

RSA is a composite of several measurable traits, each contributing uniquely to soil exploration and water extraction.

The Dynamics of RSA: Plasticity and Hydrotropism

RSA is not genetically predetermined but displays remarkable phenotypic plasticity in response to soil water gradients.

Hydrotropism: Unlike gravitropism, hydrotropism is the directed growth of roots towards moisture. This response, mediated by abscisic acid (ABA) signaling and auxin redistribution in the root cap, allows roots to actively seek out wetter soil patches, significantly improving foraging efficiency.

Adaptive Plasticity: Under drought stress, plants

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often exhibit:

Increased Root: Shoot Ratio: Prioritizing carbon allocation to root growth.

Root Proliferation in Wet Layers: If a wet layer is detected, lateral roots proliferate specifically in that zone.

Reduced Surface Rooting: To conserve resources and avoid the dry topsoil.

Innovative Phenotyping: Seeing into the Soil

Advances in phenotyping are revolutionizing RSA research, moving from destructive sampling to non-invasive, dynamic imaging.

X-ray Computed Tomography (CT): Provides high-resolution 3D images of roots in situ, allowing quantification of architectural traits over time without disturbing the soil matrix.

Rhizotrons and Minirhizotrons: Transparent soil or tubes with camera systems enable direct, repeated visual monitoring of root growth dynamics.

Ground-Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT): Larger-scale geophysical techniques for mapping coarse root systems (e.g., trees) in the field.

Engineering RSA for the Future: Breeding and Biotech Trends

The goal is to develop crops with "designer" root systems tailored to specific environments.

Genome-Wide Association Studies (GWAS): Identifying quantitative trait loci (QTLs) and genes associated with desirable RSA traits like root depth and angle in crops like rice (DRO1 gene) and wheat.

CRISPR-Cas9 Gene Editing: Directly modifying key regulators of root development (e.g., auxin response factors, PIN genes for auxin transport) to engineer specific architectural changes.

Synergy with Arbuscular Mycorrhizal Fungi (AMF): Breeding plants that foster symbiosis with AMF, which effectively extend the root absorption network (hyphal length) into finer soil pores, accessing water unavailable to roots alone.

Hydraulic Redesign: Beyond architecture, breeding for root anatomical traits like smaller xylem vessel diameter to reduce vulnerability to cavitation during severe soil drying, ensuring continuous water transport from an optimally designed RSA.

Conclusion

Root System Architecture is a master trait in the plant's strategy for survival and productivity under water-limited conditions. It represents a sophisticated, responsive interface between plant and soil. The integration of advanced phenotyping, molecular genetics, and traditional breeding is unlocking our ability to understand and mold the hidden half of plants. By selectively engineering RSA favoring deeper, steeper, and smarter root systems we can develop a new generation of crops that are inherently more efficient at capturing water. This approach offers a sustainable, less input-intensive pathway to bolstering global food security against the escalating challenges of drought and climate variability. Investing in the roots is investing in the resilience of our future harvests.

Recent Advances in Crop Physiology and their Applications in Indian Agriculture

Ranjana Danu and Ravinder Kaur

Abstract

Crop physiology deals with the study of growth, development and functioning of crop plants. In recent years, many advances have been made in crop physiology to improve crop productivity and stress tolerance. These advances mainly focus on photosynthesis efficiency, water and nutrient use efficiency and stress management. In Indian agriculture, where farmers face problems like climate change, drought and poor soil fertility, these advances are very useful. This article highlights some important recent advances in crop physiology and their applications in Indian agricultural system.

Introduction

Indian agriculture is the backbone of Indian economy, but it is facing many challenges such as climate variability, population pressure and limited natural resources. To meet the increasing food demand, improving crop yield in sustainable manner is very important. Crop physiology helps in understanding how crops respond to environmental conditions and management practices. Recent advances in crop physiology provide new approaches to enhance crop growth, development and productivity. These advancements are helpful in improving the performance of crops under both normal and stress conditions.

Recent Advances in Crop Physiology and their Applications

Advances in Photosynthesis Research: One of the major advancements in crop physiology is related to improving photosynthetic efficiency. Scientists are working on reducing photorespiration losses and increasing carbon fixation. Improvement in leaf architecture and chlorophyll content helps plants to capture more sunlight. In Indian crops like rice and wheat, improved photosynthesis results in better biomass production and grain yield.

Stress Physiology and Climate Resilient Crops: Understanding plant response to abiotic stresses such as drought, heat and salinity is an important advancement. Physiological traits like osmotic adjustment, antioxidant activity and stomatal regulation are used to develop stress tolerant varieties. In India, development of drought tolerant varieties of crops like millets and pulses has helped farmers in rainfed areas.

Improvement in Water Use Efficiency: Recent research focuses on improving water use efficiency through better root system and stomatal control. Physiological techniques such as deficit irrigation and use of antitranspirants are based on crop physiological principles. These practices are very

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helpful in water scarce regions of India where irrigation facilities are limited.

Nutrient Use Efficiency: Advances in crop physiology have improved understanding of nutrient uptake and utilization by plants. Improved nutrient use efficiency helps in reducing fertilizer requirement and production cost. Balanced fertilization based on crop physiological needs also reduces environmental pollution. This approach is now being promoted in Indian agriculture.

Role of Plant Growth Regulators: Use of plant growth regulators is another important advancement. Hormones like auxins, gibberellins and cytokinins are used to regulate flowering, fruit set and growth. In horticultural crops, application of growth regulators has shown positive results in improving yield and quality.

Impact on Indian Agriculture: Recent advances in crop physiology help farmers to manage crops more efficiently under changing climate conditions. These advancements improve crop yield, reduce risk of crop failure and enhance resource use efficiency. Adoption of physiological based practices supports sustainable agriculture and improves farmer income.

Conclusion

Recent advances in crop physiology have contributed significantly to the improvement of crop production in India. Better understanding of physiological processes such as photosynthesis, water use efficiency and stress tolerance helps in developing improved crop varieties and management practices. These advances are essential for ensuring food security and sustainable agriculture in future. Therefore, crop physiology plays a very important role in modern Indian agriculture.

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Role of Crop Physiology in Climate-Resilient Agriculture

Rishu Raj and Ravinder Kaur

Abstract

Climate change poses a serious threat to global and Indian agriculture by increasing the frequency of droughts, floods, heat stress, and unpredictable weather patterns. Climate-resilient agriculture focuses on enhancing the capacity of crops to withstand and adapt to climatic stresses while maintaining productivity. Crop physiology plays a crucial role in climate resilience by explaining how plants respond to environmental stresses at morphological, biochemical, and molecular levels. Physiological traits such as efficient photosynthesis, improved water-use efficiency, stress tolerance mechanisms, and hormonal regulation help crops adapt to changing climatic conditions. This article discusses the role of crop physiology in developing climate- resilient agriculture and highlights its importance in ensuring sustainable food production.

Introduction

Agriculture is highly dependent on climatic conditions, making it one of the most vulnerable sectors to climate change. Rising temperatures, irregular rainfall, drought, salinity, and heat waves negatively affect crop growth and yield. Climate-resilient agriculture aims to reduce the adverse impacts of climate change by improving crop adaptability and yield stability. Crop physiology, the study of plant functional processes, provides scientific insights into how plants respond to environmental stresses. Understanding physiological processes helps in developing climate-resilient crop varieties and management practices. Therefore, crop physiology plays a vital role in strengthening agricultural resilience under changing climatic conditions.

Role of Crop Physiology in Climate-Resilient Agriculture

Enhanced Photosynthetic Efficiency under Stress : Photosynthesis is highly sensitive to climatic stresses such as heat and drought. Physiological adaptations like improved chlorophyll stability, efficient carbon fixation and better canopy architecture help plants maintain photosynthesis under stress conditions. Crops with higher photosynthetic efficiency show better growth and yield stability during climate extremes.

Water-Use Efficiency and Drought Adaptation: Water scarcity is one of the most critical impacts of climate change. Physiological traits such as stomatal regulation, deep and extensive root systems, and osmotic adjustment enable plants to conserve water and tolerate drought. Improved water-use efficiency helps crops survive under limited water availability.

Temperature Stress Tolerance: High and low temperature stresses affect enzymatic activity, respirati-

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on and membrane stability. Physiological mechanisms such as heat shock protein synthesis, membrane lipid modification, and enhanced antioxidant activity protect plants from temperature-induced damage. These mechanisms help crops adapt to rising temperatures and cold stress conditions.

Nutrient Uptake under Climate Stress: Climate change alters soil nutrient dynamics and availability. Physiological traits such as efficient root architecture, nutrient transport systems, and beneficial symbiotic associations enhance nutrient uptake under stress conditions. Improved nutrient-use efficiency ensures better crop performance even in degraded soils.

Role of Antioxidants and Stress Metabolites: Under climatic stress, plants generate reactive oxygen species (ROS), which can cause cellular damage. Crop physiology explains the role of antioxidant enzymes such as catalase, peroxidase and superoxide dismutase in protecting plants from oxidative stress. Accumulation of compatible solutes like proline and glycine betaine further enhances stress tolerance.

Hormonal Regulation in Stress Adaptation: Plant hormones such as abscisic acid, ethylene, auxins, and cytokinins regulate plant responses to environmental stress. Abscisic acid plays a key role in drought tolerance by inducing stomatal closure, while other hormones help in growth regulation and recovery after stress. Proper hormonal balance is essential for climate-resilient crop production.

Conclusion

Crop physiology plays a central role in developing climate-resilient agriculture by enhancing plant adaptation to climatic stresses such as drought, heat, and nutrient imbalance. Physiological traits related to photosynthesis, water- and nutrient-use efficiency, stress tolerance, and hormonal regulation ensure stable crop yields under changing environmental conditions. Integrating crop physiological knowledge with breeding programs and sustainable management practices can significantly improve agricultural resilience and food security. Therefore, strengthening research and application of crop physiology is essential for achieving climate-resilient agriculture.

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Role of Aquaporins in Regulating Osmotic Water Movement

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Introduction

Aquaporins are special proteins in membranes that make channels. These channels help water move quickly and selectively across cell walls. Before these were found, folks thought water just diffused across cell walls. But that didn't explain how fast water moves in places like kidneys, plant roots, and blood cells. The discovery of aquaporins changed how we see water movement and even won a Nobel Prize in 2003. Now, we know aquaporins are key to water balance in animals, plants, and tiny organisms. They matter a lot in bodies, sickness, and even tech.

How Osmosis Works?

Osmosis is when water moves across a membrane from where there's more water to where there's less. This happens because of stuff dissolved in the water. Think of it like water trying to even things out. This is measured by osmotic pressure (Pascal, Pa) and concentration (moles per liter, mol L^{-1}). In living things, ions, sugars, and other stuff create these differences. Keeping this balance is needed for cells to stay the right size and shape. Aquaporins make it easier for water to move across the membrane without letting other stuff through.

What Aquaporins look like and how they're sorted

Aquaporins are part of a big family of membrane proteins. Each aquaporin makes a pore, and four of these usually team up to make a working group in the membrane. They're picky about what goes through, only letting water molecules pass one at a time. Based on what they let through, aquaporins are either just for water or for water and other small stuff like glycerol and urea.

How they move water selectively

The aquaporin channel has a tiny opening lined with amino acids that act like a filter. Two important parts, called NPA motifs, make the opening even smaller. This forces water molecules to line up and stops protons (H^+) from leaking through, which keeps the cell's electrical balance. The channel's size is measured in nanometers (nm). The way water molecules line up makes sure things are both quick and selective.

What they do in Animals

In animals, aquaporins are super important for kidneys. They control how water is reabsorbed and how concentrated urine is. For example, Aquaporin-2 is controlled by a hormone and manages water flow in kidney ducts. They also help with fluid in the brain, gland stuff, lung moisture, and skin hydration. If something's wrong with aquaporin genes, it can cause problems like diabetes insipidus, brain swelling, and gland issues.

What they do in Plants and how they adapt

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In plants, aquaporins live in the cell membrane and in vacuoles. They manage water going into roots, water leaving leaves, and cell pressure. Plant aquaporins react to things like drought, salt, and heat. Because of this, they're a hot topic in farming research for climate-ready crops that use water well.

Cool New Research

These days, research is looking at aquaporin-based membranes for cleaning water. Fake membranes with aquaporin proteins let water through really well, cutting down on energy compared to normal filters. In medicine, aquaporins are being looked at as targets for meds that reduce swelling in tumors and get drugs where they need to go. People are trying to use aquaporins to manage water in cells for industry and farming.

How we measure this stuff

Water flow is usually measured as osmotic permeability coefficient (Pf) in meters per second (m/s). Solute concentration is measured in mol L^{-1} and pressure is measured in Pascal (Pa). Symbols and shortcuts follow the rules of chemistry and biochemistry groups. Everything here uses metric and SI units.

Conclusion

Aquaporins are key players in how water moves across cell membranes. Their structure lets water move quickly while keeping everything else in check. From kidneys and brains to plant survival and water filters, aquaporins are a big deal in biology and tech. As we get better at making biomimetic stuff and messing with genes, aquaporins should be even more important for solving problems related to water, health, and the environment.

Cellular Basis of Growth and Development in Crops

Dimpal Bisht and Ravinder Kaur

Abstract

Growth and development in crop plants is a continuous and complex process which takes place at cellular level. The increase in size, weight and complexity of crops is mainly due to cell division, cell enlargement and cell differentiation. These cellular activities are controlled by genetic factors, plant hormones and environmental conditions. Understanding the cellular basis of growth is very important for improving crop productivity and better crop management. This article explains the basic cellular processes responsible for growth and development in crops in a simple and systematic manner.

Introduction

Crop growth and development are the fundamental processes that determine final yield and productivity. Growth refers to irreversible increase in size and dry matter, while development includes changes in form and function of plant during its life cycle. At the base of all these processes lies the activity of plant cells. Every organ such as root, stem, leaf and flower originates from cells. Therefore, knowledge of cellular basis of growth and development is essential in crop physiology. In agricultural crops, proper understanding of these cellular mechanisms helps farmers and scientists to manipulate growth for better yield under different field conditions.

Types / Impacts / Classification of Cellular Processes

Cell Division: Cell division is the primary step in growth and occurs mainly in meristematic tissues of plants. It takes place by mitosis, resulting in formation of new cells. Apical meristems present at root and shoot tips are responsible for increase in length of crops, whereas lateral meristems increase thickness. Rapid cell division is observed in young tissues of crops like rice, wheat and maize. Any disturbance in cell division directly affects plant growth.

Cell Enlargement: After cell division, cells increase in size by absorbing water and developing large vacuoles. Cell enlargement contributes maximum to increase in plant size. This process depends on turgor pressure, elasticity of cell wall and availability of water. Auxins play an important role in cell elongation. Proper water supply and nutrient availability enhances this process in crop plants.

Cell Differentiation: Cell differentiation is the process by which newly formed cells become structurally and functionally specialized. Through differentiation, cells form tissues like xylem, phloem, cortex and epidermis. Differentiation is essential for proper functioning of plant organs.

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In crops, differentiation of vascular tissues helps in efficient transport of water and nutrients.

Dedifferentiation and Redifferentiation: In some cases, mature cells regain the capacity to divide, which is known as dedifferentiation. These cells later specialize again through redifferentiation. This phenomenon is important in formation of cambium and healing of injured tissues. It also plays role in secondary growth of crops.

Role of Cell Organelles: Cell organelles play significant role in growth and development. The nucleus controls genetic activities, mitochondria provide energy, chloroplasts carry out photosynthesis and vacuoles help in maintaining turgidity. Proper functioning of these organelles is essential for normal crop growth.

Impact on Crop Productivity: Efficient cellular growth leads to better leaf area, stronger root system and higher biomass production. Any stress such as nutrient deficiency, drought or temperature stress affects cellular activities and ultimately reduces crop yield.

Conclusion

Growth and development in crops are the result of well-coordinated cellular processes including cell division, enlargement and differentiation. These processes are influenced by genetic makeup, plant hormones and environmental factors. Understanding the cellular basis of growth helps in improving crop management practices and developing high yielding crop varieties. Therefore, cellular level knowledge is essential for sustainable agricultural production.

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The Role of Drones in Precision Horticulture and Spraying

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Abstract

Precision horticulture aims to optimize crop productivity, input efficiency, and environmental sustainability through site-specific management practices. In recent years, unmanned aerial vehicles (UAVs), commonly known as drones, have emerged as transformative tools in precision horticulture. Their application ranges from crop monitoring and stress detection to precision spraying of agrochemicals. Drone-based technologies enable real-time data acquisition, targeted input application, and reduced labour dependency. This article reviews the role of drones in precision horticulture with special emphasis on aerial spraying, highlighting their advantages, operational principles, challenges, and future prospects.

Introduction

Horticultural crops such as fruits, vegetables, flowers, and plantation crops demand intensive management due to their high value and sensitivity to biotic and abiotic stresses. Conventional methods of crop monitoring and pesticide application are often labour-intensive, time-consuming and inefficient, leading to excessive chemical use and environmental contamination. Precision horticulture addresses these limitations by integrating advanced technologies to apply inputs precisely where and when required.

Drones or unmanned aerial vehicles (UAVs) have gained considerable attention as efficient tools for precision agriculture and horticulture. Their ability to fly at low altitudes, capture high-resolution imagery, and perform site-specific spraying makes them particularly suitable for horticultural systems, including orchards, vineyards, and vegetable fields.

Drone Technology in Precision Horticulture

Drones used in horticulture are typically equipped with:

- ✓ High-resolution RGB cameras
- ✓ Multispectral and thermal sensors
- ✓ GPS and GIS-based navigation systems
- ✓ Variable-rate spraying mechanisms

These components allow drones to collect accurate spatial and temporal data, enabling informed decision-making for crop management.

Crop Monitoring and Assessment

Drone-based imagery helps in:

- ✓ Assessing crop vigour and canopy development
- ✓ Detecting nutrient deficiencies and water stress
- ✓ Identifying pest and disease infestation at early stages
- ✓ Monitoring flowering, fruit set, and maturity stages

Vegetation indices such as NDVI (Normal-

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ized Difference Vegetation Index) generated from multispectral images provide quantitative information on plant health, which is particularly useful in orchards and vineyards.

Role of Drones in Precision Spraying

Precision spraying is one of the most impactful applications of drones in horticulture. Drone sprayers are designed to apply pesticides, fungicides, herbicides, and foliar nutrients accurately and uniformly.

Principles of Drone-Based Spraying

Drone spraying operates on the principles of:

- ✓ Low-volume application
- ✓ Uniform droplet distribution
- ✓ Target-specific delivery

Advanced UAV sprayers are equipped with adjustable nozzles, flow rate controllers, and real-time terrain-following systems, ensuring effective coverage even in uneven fields and tall crops.

Advantages of Drone Spraying in Horticultural Crops

Precision and accuracy: Chemicals are applied only to affected areas, minimizing wastage.

Reduced chemical use: Studies indicate a 20-40% reduction in pesticide consumption.

Labour efficiency: Drone spraying significantly reduces dependency on manual labour.

Accessibility: Suitable for orchards, hilly terrains, and waterlogged fields where conventional machinery cannot operate.

Safety: Minimizes human exposure to toxic agrochemicals.

Time efficiency: Large areas can be covered in a short time, especially during critical pest outbreak periods.

Applications in Different Horticultural System

Fruit Crops: In mango, citrus, grape, and pomegranate orchards, drones facilitate canopy-level spraying and disease surveillance. Their ability to penetrate dense canopies ensures better deposition of spray droplets compared to ground sprayers.

Vegetable Crops: Drone spraying is effective in vegetables such as tomato, chilli, cabbage, and onion, particularly for early detection and localized control of pests and diseases.

Plantation and Floriculture Crops: In crops like banana, coconut, and floricultural crops, drones support uniform spraying, growth monitoring, and yield estimation.

Environmental and Economic Benefits

Drone-assisted precision spraying contributes to sustainable horticulture by:

- ✓ Reducing off-target spray drift
- ✓ Lowering soil and water contamination
- ✓ Enhancing input-use efficiency
- ✓ Increasing cost-effectiveness for small and marginal farmers through custom hiring services

Economic analyses suggest that although initial investment is high, operational costs ha^{-1} are reduced over time, especially when drones are used for multiple purposes.

Challenges and Limitations

Despite their advantages, drone applications in horticulture face several challenges:

- ✓ High initial cost of UAV systems
- ✓ Limited payload capacity and battery life
- ✓ Requirement of skilled operators and technical training
- ✓ Regulatory restrictions related to drone operation
- ✓ Limited awareness and adoption among smallholders

Addressing these constraints through policy support, subsidies, and training programs is essential for large-scale adoption.

Future Prospects

The integration of drones with artificial intelligence (AI), machine learning, and Internet of Things (IoT) technologies is expected to further enhance precision horticulture. Future developments may include:

- ✓ Autonomous decision-making drones
- ✓ Real-time disease diagnostics
- ✓ Fully automated variable-rate spraying systems
- ✓ Integration with farm management software

Such advancements will play a crucial role in achieving higher productivity, profitability, and sustainability in horticultural production systems.

Conclusion

Drones have emerged as powerful tools in precision horticulture, particularly in crop monitoring and precision spraying. Their ability to provide timely, accurate, and site-specific interventions makes them highly suitable for high-value horticultural crops. With supportive policies, technological advancements and capacity building, drone technology has the potential to revolutionize horticultural practices and contribute significantly to sustainable agricultural development

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Precision Soil Fertility Management in Smallholder Farming Systems: Technologies, Impacts and Pathways for Adoption

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Abstract

Soil fertility decline remains a major constraint to productivity in smallholder farming systems, particularly in Sub-Saharan Africa and South Asia, where spatial soil heterogeneity and limited access to inputs undermine blanket fertilizer recommendations. Precision agriculture offers a pathway to address within field variability, however, most precision technologies are designed for large scale mechanized systems and are poorly adapted to smallholder contexts. This review combines recent advances in precision soil fertility management approaches relevant to smallholder farming systems, with emphasis on low cost soil assessment tools, remote sensing based diagnostics, digital decision support systems and site specific nutrient management strategies. When compared to uniform fertilizer application, there is evidence that adapted precision techniques, such as micro-dosing and digitally enabled fertilizer recommendations can increase nutrient use efficiency and contribute to better soil fertility outcomes. However, financial obstacles, data shortages, infrastructure deficiencies and inadequate extension services continue to limit adoption. Context specific precision solutions that combine affordable technologies, farmer knowledge, and supportive institutional frameworks are essential for assessing sustainable soil fertility management in smallholder agriculture.

Introduction

In smallholder farming systems, which account for the majority of agricultural production in South Asia and Sub-Saharan Africa, soil fertility is a key factor in determining crop productivity and food security. Widespread soil nutrient depletion and decreased nutrient use efficiency are the results of ongoing cultivation, decreasing organic matter inputs, and uneven fertilizer use. Despite this heterogeneity, fertilizer recommendations for smallholders have traditionally depend on uniform application rates, often failing to account for substantial spatial variability in soil nutrient status at the plot and field level. Such blanket approaches always lead to inefficient nutrient use, economic losses and environmental degradation. Precision agriculture represents a change from uniform to site-specific input management by combining fertilizer application with spatial variability in soil and crop conditions. Developments in sensing technologies, digital soil mapping, remote sensing and decision-support systems have demonstrated considerable potential for improving nutrient management efficiency and soil fertility outcomes.

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The socioeconomic and infrastructure realities of smallholder systems are not aligned with the traditional precision agriculture systems, which are usually costly, data-intensive and designed for large-scale mechanized farming. Simplified, affordable, and scalable precision methods that can function in resource-limited environments are becoming more and more important in recent research. This review critically examines precision soil fertility management approaches suitable for smallholder farming systems, emphasizing on adapted technologies, site-specific nutrient management strategies and their impacts and constraints, with the aim of identifying practical pathways for sustainable intensification.

Precision Soil Fertility Management Approaches for Smallholders

Due to variations in land use history, erosion, organic matter inputs, and farmer management techniques, smallholder farming systems exhibit significant spatial variability in soil fertility. The usefulness of uniform fertilizer recommendations is threatened by the large variability of soil organic carbon, nitrogen, and nutrient balances that often exist even in small plots. Therefore, the need for tools that can document complex variability patterns at a relatively low cost and within a feasible framework is necessary for precision soil fertility management. Recent developments in affordable soil fertility assessment tools for smallholder systems are promising. By reducing reliance on centralized laboratory infrastructure, quick soil analysis techniques, such as portable nutrient testing kits and proximal sensing methods, enable nearly real-time assessment of soil pH and plant-available nutrients (Najdenko *et al.*, 2024). These tools are increasingly being supplemented by smartphone diagnostics, which enable the dissemination of fertilizer recommendations and interpretation of results. Despite the strong analytical performance of optical and ion-selective sensors for nitrogen and phosphorus analysis (Singh *et al*., 2023), their use in smallholder systems is limited by cost and calibration. By using crop response indicators, remote sensing technologies offer a scalable approach to soil fertility variability assessment. To identify patterns of nutrient deficiencies, especially nitrogen, vegetation indices such as the Normalized Difference Vegetation Index are commonly used. A high level of accuracy has also been achieved in the assessment of soil organic carbon and related fertility parameters using satellite imagery and machine learning algorithms (Mundada and Jain, 2025). However, in smallholder systems, cloud cover, small field size and mixed cropping patterns often minimize the validity of remote sensing signals, requiring their complementation with ground truthing. To transform soil and crop information into relevant fertilizer recommendations, digital decision support systems are imperative. Mobile-based decision support systems and GIS-derived soil fertility maps enable localized nutrient management options, while artificial intelligence-based systems combine multi-source information to enhance the accuracy of fertilizer recommendations (Vullaganti *et al.*, 2025).

Research suggests that when supplemented by efficient extension services and farmer involvement, these systems can increase the efficiency of nutrient use. Instead of depending on fully automated variable rate technologies, site-specific nutrient management practices that are more suitable for small-scale farmers are likely to emphasize on more simple methods such as fertilizer micro-dosing and site-specific nutrient management. Comparative analysis suggests that, particularly in the case of nitrogen management, site-specific nutrient application improves the efficiency of nutrient recovery and reduce the risk of nutrient loss compared to uniform fertilizer application (One Earth, 2019).These methods indicate that contextual adaptation, rather than technological advancement, is the key to effective precision soil fertility management in smallholder systems.

Impacts and Constraints of Precision Soil Fertility Management

Precision technologies for soil fertility management have shown positive effects on nutrient use efficiency and soil health in smallholder settings. Site-specific fertilizer application and micro-dosing methods have been found to have positive effects on nitrogen recovery efficiency and prevent nutrient loss compared to uniform fertilizer application (One Earth, 2019). Decision support systems with digital platforms further improve input targeting, resulting in improved nutrient balances and efficient use of limited fertilizer resources (Vullaganti *et al*., 2025). Remote sensing-based systems also help in soil organic carbon and fertility mapping, thus facilitating long-term soil health management (Mundada and Jain, 2025). Despite the benefits, several factors hinder the adoption of precision soil fertility management. Economic constraints, including the costs of sensors, smartphones, and data services, limit the adoption of precision technology by resource-poor farmers (Mizik, 2023). Infrastructure barriers, such as the absence of reliable internet connectivity and soil data, limit the effectiveness of digital decision-support systems. Literacy among farmers and poor extension services further regulate the use and acceptability of precision recommendations, especially in the absence of transparent decision-support models (Dhillon *et al.,* 2023). Furthermore, most soil-sensing technologies require local calibration, which is not always available in developing countries (Najdenko *et al*., 2024). These factors highlight the need for innovation to be complemented by suitable institutional and knowledge structures.

Conclusion and Future Pathways

Precision soil fertility management offers a sustainable pathway for improving nutrient use efficiency and soil health in smallholder farming systems when technologies are properly adapted. Affordable soil diagnostics, remote sensing markers and digital decision-support systems illustrate clear potential to address detailed soil variability that undermines blanket fertilizer recommendations. However, their success depends on affordability, local calibration, and extension support and policy

combination. Future studies should focus on long-term evaluation of soil fertility management, the use of farmers' knowledge and digital platforms, and the development of open-access platforms for soil data. Public-private partnerships and extension services will play a crucial role in scaling up climate-smart precision soil fertility management practices and promoting sustainable intensification in smallholder agriculture.

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Integrated Farming Systems as a Livelihood-Centric Extension Strategy under the Contemporary Agricultural Scenario in India

Mukul Kirar

Abstract

Indian agriculture is increasingly confronted with challenges such as declining farm profitability, climate variability, shrinking landholdings, and growing livelihood insecurity among small and marginal farmers. Conventional mono-enterprise farming systems have proved inadequate in addressing these multidimensional vulnerabilities. In this context, Integrated Farming Systems (IFS) have emerged as a sustainable and livelihood-oriented approach that integrates crops with livestock, horticulture, fisheries, and allied enterprises to enhance resource-use efficiency and resilience. This paper examines IFS as a livelihood-centric extension strategy within the framework of contemporary agricultural extension reforms in India. A multidimensional Livelihood Security Index (LSI) is used to assess the impact of IFS adoption on economic, food and nutritional, employment, social, and ecological security. The findings indicate that farmers practicing IFS exhibit significantly higher livelihood security compared to non-IFS farmers, highlighting the critical role of extension services, institutional support, and gender-inclusive approaches in strengthening sustainable rural livelihoods.

Introduction

Indian agriculture is experiencing increasing pressure due to declining landholdings, rising input costs, market instability, and climate variability. Small and marginal farmers are particularly vulnerable under conventional mono-enterprise farming systems, which often result in seasonal income, limited employment opportunities, and high production risks. Dependence on a single crop exposes farm households to climatic shocks and price fluctuations, thereby weakening their overall livelihood security. Livelihood security is a multi-dimensional concept encompassing economic stability, food and nutritional adequacy, employment generation, social participation, and ecological sustainability. Achieving these outcomes requires farming approaches that move beyond productivity enhancement toward diversification and resilience. Integrated Farming Systems respond to this requirement by combining multiple farm enterprises within a single system, allowing efficient utilization of resources and reduction of production risks. At the same time, agricultural extension in India has evolved toward participatory, demand-driven, and system-based approaches. Extension services increasingly focus on strengthening farmers' capacities, institutional linkages, and access to timely information.

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Within this framework, Integrated Farming Systems function not merely as a production strategy but as a livelihood-centric extension approach.

Conceptual Framework: The conceptual foundation of Integrated Farming Systems is based on the interaction between farmers' socio-economic characteristics, diversified farm enterprises, and extension support mechanisms. Integration of crops with livestock, poultry, horticulture, fisheries, and allied activities enables internal resource recycling, income diversification, and risk minimization. Extension services and institutional support act as enabling factors that facilitate adoption and effective management of integrated systems. Through improved access to technical guidance, capacity building, and institutional convergence, Integrated Farming Systems enhance overall system performance. This process ultimately leads to improved livelihood security across economic, food and nutritional, employment, social, and ecological dimensions.

Integrated Farming System Components and Livelihood Outcomes: Integrated Farming Systems ensure continuous flow of income, food, and employment by combining complementary enterprises. Crop production contributes to household food security, while livestock and poultry provide regular income and nutritional benefits. Horticultural and allied enterprises enhance dietary diversity and offer additional cash income, while resource recycling practices strengthen ecological sustainability. Employment generation is one of the most significant advantages of Integrated Farming Systems.

Activities such as dairy management, poultry rearing, vegetable cultivation, and compost preparation provide year-round engagement of family labour. This reduces dependency on seasonal employment and enhances income stability, particularly for small and marginal farmers.

Role of Extension Services and Institutional Support: Integrated Farming Systems are knowledge-intensive and require continuous advisory support. Extension services play a critical role in promoting adoption through training programmes, on-farm demonstrations, exposure visits, and ICT-enabled advisories. Public extension institutions facilitate research-extension-farmer linkages and ensure dissemination of location-specific technologies. The pluralistic nature of contemporary extension systems, involving governmental agencies, non-governmental organizations, farmer collectives, self-help groups, and digital platforms, further strengthens Integrated Farming Systems. Improved access to information and institutional support enhances farmers' capacity to manage diversified enterprises efficiently and sustainably.

Livelihood Security Index: Dimensions and Measurement: To capture the multidimensional nature of livelihoods, a composite Livelihood Security Index was used to assess the impact of Integrated Farming Systems adoption. The index includes economic security, food and nutritional security, employment security, social security, and ecological security. These dimensions collectively reflect the comprehensive livelihood outcomes asso-

ciated with integrated farming practices. Relevant indicators under each dimension were assessed, normalized, and aggregated to compute dimension-wise indices as well as an overall livelihood security score. This approach enabled a comparative assessment of livelihood security between farmers practicing Integrated Farming Systems and those following conventional farming practices.

Results and Comparative Analysis: The findings indicate that farmers adopting Integrated Farming Systems exhibit substantially higher livelihood security compared to non-adopters across all dimensions. The most pronounced improvements were observed in economic and employment security, reflecting the stabilizing effect of enterprise diversification. Enhanced availability of diverse food products contributed to better food and nutritional security among IFS farmers. Improved social participation and ecological sustainability further strengthened overall livelihood outcomes. These results confirm that Integrated Farming Systems, when supported by effective extension services, offer a resilient and sustainable alternative to mono-enterprise farming systems.

Discussion

The results validate the conceptual premise that Integrated Farming Systems function as a livelihood-centric extension strategy. Diversification of farm enterprises, supported by responsive extension services, significantly enhances farmers' resilience to climatic and market uncertainties. Integrated Farming Systems also promote inclusive livelihood development by encouraging the participation of women in enterprises such as poultry, dairy, and kitchen gardening. Engagement of rural youth in on-farm activities further contributes to employment generation and reduces migration. These outcomes align with national priorities on sustainable agriculture, climate resilience, and inclusive rural development.

Conclusion and Way Forward

Integrated Farming Systems significantly enhance livelihood security when supported by effective extension services and institutional convergence. By simultaneously addressing economic, social, and ecological dimensions, Integrated Faring Systems provide a resilient alternative to conventional farming systems. Future extension efforts should emphasize promotion of location-specific Integrated Farming System models, strengthening of capacity-building programmes, wider use of ICT tools, and adoption of livelihood-based impact assessment frameworks. Policy support aimed at improving access to credit, technical services, and market linkages will be essential for scaling up Integrated Farming Systems and achieving sustainable rural livelihood outcomes.

Enhancing Productivity and Water Use Efficiency through Sugarcane-Chickpea Intercropping under Drip Irrigation in Nandurbar District, Maharashtra

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Abstract

Sugarcane (*Saccharum officinarum* L.) is a major irrigated cash crop in Nandurbar district of Maharashtra, while chickpea (*Cicer arietinum* L.) is an important Rabi pulse crop traditionally grown under residual soil moisture conditions. In the semi-arid agro-climatic environment of the district, efficient utilisation of land and water resources is critical for sustainable agricultural production. Intercropping chickpea with sugarcane under drip irrigation presents a viable strategy to enhance overall system productivity, improve water use efficiency, and promote soil health through biological nitrogen fixation. This article evaluates the suitability of sugarcane-chickpea intercropping, standardized planting geometry, drip irrigation scheduling, and nutrient management practices, with special emphasis on the performance of Mexican Kabuli chickpea varieties under the agro-climatic conditions of Nandurbar district. The system demonstrates potential for increased farm profitability, improved resource-use efficiency, and sustainable intensification of sugarcane-based cropping systems.

Introduction

Nandurbar district, located in the northern part of Maharashtra, is characterised by a semi-arid climate, erratic and unevenly distributed rainfall, and predominance of deep black cotton soils with high moisture-holding capacity. Agriculture in the district largely depends on efficient water management practices due to frequent moisture stress conditions. Sugarcane (*Saccharum officinarum* L.) is one of the most important irrigated cash crops cultivated in areas with assured water supply, while chickpea (*Cicer arietinum* L.) is a major *Rabi* pulse crop contributing significantly to food and nutritional security in the region. Sugarcane is a long-duration crop with wider row spacing during its initial growth stages, resulting in underutilization of inter-row space and available resources such as sunlight, soil moisture, and nutrients. This provides a suitable ecological niche for the introduction of short-duration inter-crops. Chickpea, being a cool-season, deep-rooted, and low water-requiring legume, is well suited for intercropping in sugarcane during the Rabi season. Its erect growth habit and moderate nutrient demand allow it to coexist with sugarcane with minimal

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competition. Intercropping chickpea offers several agronomic and ecological advantages. As a leguminous crop, chickpea fixes atmospheric nitrogen through symbiotic association with *Rhizobium*, thereby improving soil fertility and reducing dependence on synthetic nitrogen fertilisers. Additionally, chickpea contributes to improved soil structure, enhanced microbial activity, and suppression of weed growth within the intercrop system. From an economic perspective, chickpea provides an additional source of income without adversely affecting sugarcane yield, thereby increasing overall land-use efficiency. The adoption of drip irrigation further strengthens the sugarcane-chickpea intercropping system by ensuring precise and efficient delivery of water to the root zone of both crops. Drip irrigation minimizes water losses through evaporation and deep percolation, improves water use efficiency, and facilitates uniform crop growth under semi-arid conditions. Mexican Kabuli chickpea varieties, characterized by bold seed size, superior grain quality, and higher market preference, have shown promising adaptability under irrigated and semi-irrigated environments, making them suitable candidates for intercropping in sugarcane-based production systems of Nandurbar district.

Objectives of Intercropping

- ✓ To improve land use efficiency under sugarcane cultivation
- ✓ To enhance water use efficiency through drip irrigation
- ✓ To increase farmers' income by producing an additional pulse crop
- ✓ To improve soil fertility through biological nitrogen fixation by chickpea.

Agro-Climatic Suitability of Nandurbar District

Climate: Semi-arid with hot summers and mild winters

Soil: Deep black cotton soils with good moisture-holding capacity

Irrigation: Canal, wells, borewells; increasing adoption of drip irrigation

Cropping system: Sugarcane-based systems with scope for *Rabi* intercrops

These conditions are favorable for sugarcane-chickpea intercropping when supported by drip irrigation.

Chickpea Variety: Mexican Kabuli Type

Mexican Kabuli chickpea varieties (such as Combo-743 and similar types) are characterised by:

- ✓ Bold, cream-colored seeds with high market preference
- ✓ Medium duration (100-110 days)
- ✓ Good response to irrigated and drip-irrigated conditions
- ✓ Suitable for intercropping due to erect growth habit

Such varieties are suitable for cultivation as an intercrop in sugarcane fields of Nandurbar district.

Intercropping Pattern and Planting Method

Planting Geometry

Sugarcane: Row spacing: 90 to 120 cm

Chickpea: 1-2 rows between sugarcane rows

Spacing for chickpea: 30-45 cm between rows and

10 cm between plants

Recommended Intercropping Ratio

Sugarcane: Chickpea = 1 : 1 (row ratio)

Chickpeas are sown after sugarcane establishment, preferably during October–November, utilising available inter-row space before the sugarcane canopy closes.

Drip Irrigation Management

Drip System Layout

- ✓ Inline or online drippers with discharge rate of 2-4 L hr^{-1}
- ✓ Lateral lines placed along sugarcane rows, ensuring moisture availability to chickpea root zone

Irrigation Scheduling

- ✓ Light and frequent irrigation during chickpea flowering and pod development
- ✓ Reduced irrigation during maturity to avoid excessive vegetative growth
- ✓ Water requirement of chickpea is much lower compared to sugarcane, making drip irrigation ideal for combined management

Drip irrigation reduces water loss through evaporation and percolation and improves water productivity.

Nutrient Management

Sugarcane

- ✓ Apply recommended NPK doses based on soil testing
- ✓ Split application of nitrogen through fertigation under drip irrigation

Chickpea

- ✓ Basal application of phosphorus
- ✓ Seed treatment with Rhizobium culture to enhance nitrogen fixation
- ✓ Minimal nitrogen requirement due to leguminousnature.

Weed, Pest and Disease Management

- ✓ Early weed control is essential during initial crop growth
- ✓ Regular field scouting for pod borer in chickpea and common sugarcane pests

Adoption of Integrated Pest Management (IPM) practices is recommended.

Advantages of Sugarcane-Chickpea inter-cropping

- ✓ Higher total productivity per unit area
- ✓ Improved water use efficiency under drip irrigation
- ✓ Additional income from chickpea without affecting sugarcane yield
- ✓ Improved soil fertility and sustainability

Better utilisation of inter-row space and resources

Constraints and Management

- ✓ Initial cost of drip irrigation system – can be mitigated through government subsidies
- ✓ Proper synchronization of sowing time to avoid competition
- ✓ Need for technical guidance in drip system management

Conclusion

The sugarcane-chickpea intercropping system under drip irrigation was found to be a technically feasible and economically viable production strategy

for the semi-arid agro-climatic conditions of Nandurbar district. Integration of chickpea as an intercrop effectively utilized inter-row space and available resources during the early growth stages of sugarcane, thereby improving overall land-use and water-use efficiency. The inclusion of Mexican Kabuli chickpea varieties contributed to enhanced system profitability due to their superior grain quality and higher market preference, while simult-aneously improving soil fertility through biological nitrogen fixation. Adoption of drip irrigation ensured precise water application, reduced irrigation losses, and supported optimal crop growth under limited water availability. Overall, the sugarcane-chickpea intercropping system represents a sustainable and resource-efficient approach capable of enhancing farm income, improving soil health, and promoting long-term sustainability of sugarcane-based cropping systems in semi-arid regions.



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Physiology of Stomatal Movement in Relation to Environmental Factor

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Abstract

Stomata are minute pores present on the leaf surface of plants and play a very important role in plant life. The opening and closing of stomata is known as stomatal movement. This movement helps in exchange of gases and loss of water vapour during transpiration. Stomatal movement is mainly controlled by guard cells and also affected by many environmental factors like light, temperature, humidity and carbon dioxide concentration. Proper regulation of stomata is necessary for growth and survival of crop plants. This article describes the physiology of stomatal movement and its relation with environmental factors.

Introduction

Plants continuously interact with their surrounding environment. Stomata act as a link between plant and atmosphere. Through stomata, plants take carbon dioxide for photosynthesis and release oxygen. At the same time, excessive water loss is also controlled by stomatal movement. In crop plants, stomatal behaviour directly influences photosynthesis, transpiration and water use efficiency. Environmental factors greatly affect opening and closing of stomata. Therefore, understanding stomatal physiology is important for better crop production under changing environmental conditions.

Physiology of Stomatal Movement in Relation to Environmental Factors

Role of Guard Cells: Stomatal movement is regulated by specialized cells called guard cells. When guard cells absorb water, they become turgid and stomata open. Loss of water makes guard cells flaccid and stomata close. The movement of potassium ions and sugars inside guard cells changes the osmotic potential. This physiological process controls opening and closing of stomata.

Effect of Light: Light is one of the most important environmental factors affecting stomatal movement. In presence of light, especially blue light, stomata generally open. Light stimulates uptake of potassium ions in guard cells. During darkness, stomata usually close to reduce water loss. Most crop plants show active stomatal opening during daytime.

Effect of Carbon Dioxide Concentration: Carbon dioxide concentration also affects stomatal movement. Low concentration of CO_2 inside leaf causes stomata to open, while high concentration leads to stomatal closure. This mechanism helps plants regulate gas exchange efficiently. In field conditions, CO_2 concentration changes continuously and influ-

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ences stomatal behaviour.

Effect of Temperature: Temperature has direct and indirect effects on stomatal movement. Moderate temperature favours stomatal opening, but very high temperature causes excessive transpiration leading to stomatal closure. High temperature stress often results in reduced photosynthesis due to partial closing of stomata.

Effect of Humidity: Humidity of air strongly influences transpiration rate. Under low humidity conditions, water loss from leaves increases, which may lead to stomatal closure. High humidity reduces transpiration and promotes stomatal opening. Crop plants grown in dry regions often show quick stomatal response to humidity changes.

Effect of Water Availability: Availability of water in soil is an important factor. Under drought conditions, plants close their stomata to prevent excessive water loss. Abscisic acid plays a major role in stomatal closure during water stress. Prolonged drought leads to reduced growth and yield in crops.

Conclusion

Stomatal movement is a complex physiological process influenced by various environmental factors. Proper regulation of stomata helps plants balance photosynthesis and transpiration. Environmental conditions like light, temperature, humidity, CO_2 concentration and water availability play major roles in stomatal behaviour. Understanding stomatal physiology is very useful for improving water use efficiency and crop productivity, especially under stress conditions. Therefore, stomatal movement has great importance in crop physiology and agriculture.

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Package of Practices of Lima Bean (*Phaseolus lunatus*)

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Introduction

Scientific Name: *Phaseolus lunatus*

Family: Fabaceae

Chromosome no: 2n=22

Center of origin: South America (Guatemala)

The lima bean (*Phaseolus lunatus*) is a protein-rich legume cultivated for its flat, crescent-shaped seeds, native to Central America and the Andes, and also known as butter beans. It is found throughout warm temperate climates and in tropical, humid subtropical, and semiarid regions. The crop is long-duration for nine months, which is longer than other legumes. Maharastra's most important crop. When used in cooking, tender pods and immature green beans of cream color are very palatable. Commonly referred to as *Phaseolus lunatus var. Baudet* & *P. lunatus var. lunatus* and *P. lunatus*, is two forms of *Phaseolus lunatus* wild and cultivars. Lima bean seeds, young pods, leaves and sprouts are edible as vegetables. It is very nutritious beans, high protein, thiamine, riboflavin and iron. This also known as Butter bean, Double bean, Madagascar bean, Sieva bean.



Botany: Twining, perennial vines can reach a height of five meters. The stem is obtuse-pentagonal or cylindrical, puberulent. Leaves are alternate, trifoliate. Inflorescence is axillary pseudo racemes 3 to 30 cm long. Corolla is white, pink and bluish. The inflorescence consists of 3-30 cm long axillary pseudoracemes. Seeds are reniform, flat, reddish brown with dark spots. It has a deep rooted system and can withstand periods of drough.

Types

Lima bean have two main growth habits: Bush type and Pole type

Bush Type: It grows up to 2 feet tall. It can be grown in a compact bed. Bush beans don't require any extra support to they grow short and robust. It produces all of its produce at once and matures quite rapidly.It is susceptible to a wider range of diseases and viruses like PM, Anthracnose, and Mosaic virus. Handerson Bush, Burpee Bush, Fordhook 242, Baby Potato, and Baby Fordhook are the bush-type varieties.

Pole Type: It grows up to 12 feet tall. Pole type required a lot of space. Pole beans need a study trellis or bamboo poles to grow up. It take a bit more time to mature but continue producing beans longer. Pole beans are slightly more disease-resistant. The pole type varieties are King of the Garden, Karolina Butter, Challenger, and Florida Butter.

KKL-1 Butter Beans: It is developed at Horticulture Research Station, Kodaikanal.

Pole type, the height is 2-4 meter, Produce

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cluster of pods (11.6 cm, 5-6 beans), bolder seeds, harvest after 100 days, yield of 1200 kg ha^{-1}.

Varieties of semi-pole types: Hopi, Wilbur

Climate: Rainfall must be between 900 and 1500 mm on average. It needed a cool, dry climate. It grows in temperatures between 15°C and 20°C. Seed will be germinate optimum temperatue at 15°C to 30°C. Pollination and fertilization suffer at temperatures above 26°C, which leads to a double reduction in pod development. It can be cultivated as a winter vegetable in plains and during the spring and rainy season in hills and very sensitive to frost.

Soil: Lima beans grown well in moderately rich, well-drained soil with a slightly acidic to neutral pH (6.0 to 6.8). While it was grow in a range of soil types, including sandy loams, they perform best on fertile, well-aerated soils that are loose and friable. Soils that become heavy or crusty should be avoided, as they can hinder seedling emergence.

Sowing Time: It can be cultivated twice a year, once in the spring and once in June, which is the rainy season. Two to three seeds per hill are sowed.

Seed Rate

- ✓ Small-seeded type is 20-35 kg.
- ✓ Large-seeded type is 45-50 kg.

Spacing

- ✓ Pole and semi pole type is 60x40 cm
- ✓ Bush type is 35x25 cm
- ✓ Depth: 2-4 cm

Nutrient Management: FYM 25 t ha^{-1} (during land preparation). N:P:K 40:50:50 (excess N application increase vegetative growth and delays fruiting)

Intrecultural Operation: Weeding the crop often and not too deeply will help it grow quickly. For optimal development and fruit set, pole types should be trained on thin, 150-cm-tall bamboo stakes with horizontals tied 45 cm apart.

Harvesting: In 85 to 90 days, the pods are ready for harvest. There can be 12-14 harvests on average, spaced 15-16 days apart. When the pods turn yellow instead of green, they are considered fully matured. Fully grown dried beans can also be used as a vegetable. Store the lima beans for the fresh market between 37-40°F with a 95% relative humidity.

Yield: 8-12 t ha^{-1}

Post Harvest Management: Fresh beans stored at 25-35% CO prevented bacterial and fungal development without affecting their quality. Store it at 5°-7°C with 90% relative humidity. Extends the shelf life to five to seven days.

Insect pests

- ✓ Stem flies, thrips, are some of the insect pests attacking bean crop.
- ✓ Using fipronil or dimethoate (Rogor) at a rate of 2 milliliters per liter to control stem flies and thrips.
- ✓ Mites can be controlled by spraying fenpy-roximate.

Diseases

- ✓ Among the diseases impacting the bean crop are rust, angular leaf spot, anthracnose, phytophthora pod rot, and rhizoctonia root rot.
- ✓ It can be successfully managed by using 2 kg $liter^{-1}$ of Difoliton or Biltox.

- ✓ Roco Kabach and Captan 2 g liter^{-1} can be soaked to prevent root rot.
- ✓ Dithane M-45 can be sprayed to combat foliar fungal infections.
- ✓ Imidacloprid at a rate of 1.25 milliliters light^{-1} can be used to suppress white flies.
- ✓ Sulfur 2 g liter^{-1} can be sprayed to control rust.

Conclusion

As part of the conclusion, the integration of suitable agronomic practices such as selecting the best variety, preparing the field, determining the optimal planting time, managing balanced nutrients and water, and controlling pests and diseases efficiently is essential for the successful production of lima beans, thereby maximizing yield and quality. Healthy crop growth and effective harvesting depend on following the suggested spacing, soil pH, and cultural operations schedules. Lima beans are a valuable crop in a variety of agricultural systems because post-harvest handling and storage are prioritized, which guarantees the preservation of seed quality and economic value.

Physiological Basis of Climate Resilience in Crop Plants

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Abstract

Climate change has become a major challenge for agriculture all over the world, especially in countries like India. Crop plants are frequently exposed to stresses such as drought, heat, salinity and irregular rainfall. Climate resilience in crops refers to the ability of plants to survive, grow and produce yield under such adverse conditions. This resilience is mainly based on various physiological mechanisms present in plants. Understanding the physiological basis of climate resilience helps in developing stress tolerant crop varieties and improving crop management practices. This article highlights the important physiological processes responsible for climate resilience in crop plants.

Introduction

Agriculture is highly dependent on climatic factors like temperature, rainfall and humidity. Due to climate change, these factors are becoming unpredictable, which directly affects crop growth and productivity. Crop plants respond to climate stress through various physiological adjustments. These responses help plants to tolerate stress and maintain normal growth to some extent. Crop physiology plays a key role in understanding how plants adapt to changing climate. Knowledge of physiological basis of climate resilience is very important for sustainable agriculture and food security.

Physiological Mechanisms Involved in Climate Resilience

Stress Tolerance through Osmotic Adjustment: Under drought and salinity conditions, plants face water stress. To cope with this, crop plants accumulate osmolytes such as proline, sugars and amino acids. This process is known as osmotic adjustment. It helps in maintaining cell turgor and protects cellular structures. Crops like wheat and barley show better osmotic adjustment under water stress conditions.

Efficient Root System: Root physiology plays an important role in climate resilience. Deep and well-developed root systems help plants to absorb water from deeper soil layers during drought. Improved root length and density increase water and nutrient uptake. Many climate resilient crop varieties show better root growth under stress conditions.

Regulation of Stomatal Activity: Stomata control transpiration and gas exchange in plants. Under heat and drought stress, plants reduce stomatal opening to minimize water loss. This physiological response helps in improving water use efficiency. However, excessive stomatal closure may reduce photo-synthesis, so plants maintain a balance.

Antioxidant Defense System: Climate stresses lead

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to production of reactive oxygen species (ROS) in plant cells. These ROS can damage proteins, lipids and membranes. Crop plants possess antioxidant enzymes like catalase, peroxidase and superoxide dismutase which neutralize harmful ef fects of ROS. A strong antioxidant system increases stress tolerance in crops.

Heat Shock Proteins and Stress Proteins: Under high temperature stress, plants produce heat shock proteins (HSPs). These proteins protect cellular structures and help in proper folding of enzymes. Stress proteins help plants to survive extreme temperature conditions. This mechanism is very important for crops grown in tropical regions.

Role of Plant Hormones: Plant hormones such as abscisic acid, auxins and cytokinins regulate stress responses. Abscisic acid plays major role in drought tolerance by controlling stomatal closure and root growth. Hormonal balance helps plants to adapt under unfavorable climatic conditions.

Impact on Crop Productivity and Indian Agriculture

Physiological climate resilience helps crops to maintain yield under stress conditions. Stress tolerant varieties reduce crop failure risk and ensure stable production. In Indian agriculture, climate resilient crops are very useful for rainfed and dryland areas. Adoption of physiological based approaches improves sustainability and farmer income.

Conclusion

Climate resilience in crop plants is mainly governed by various physiological mechanisms such as osmotic adjustment, root development, stomatal regulation and antioxidant defense. Understanding these processes helps in developing climate resilient crop varieties and improving crop management practices. With increasing climate variability, physiological approaches will play a crucial role in achieving sustainable agricultural production and food security.

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Integration of Crop Physiology with Breeding and Agronomy

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Abstract

Crop production depends on many factors such as genetics, physiology and management practices. Crop physiology helps in understanding how plants function, while breeding focuses on developing improved varieties and agronomy deals with field management practices. Integration of crop physiology with breeding and agronomy is very important for increasing crop yield and sustainability. By combining physiological knowledge with breeding and agronomic practices, better performing crop varieties can be developed and managed efficiently. This article discusses the importance of integration of crop physiology with breeding and agronomy in agriculture.

Introduction

Agriculture is becoming more challenging due to climate change, limited resources and increasing food demand. To overcome these problems, it is necessary to combine different branches of agricultural science. Crop physiology explains how plants grow and respond to environmental conditions. Plant breeding improves genetic potential of crops, while agronomy focuses on crop management in field. When these three disciplines work together, crop productivity can be improved in a better way. Integration of physiology, breeding and agronomy helps in developing high yielding and stress tolerant crops.

Integration of Crop Physiology with Breeding and Agronomy

Role of Crop Physiology in Plant Breeding: Crop physiology helps breeders to identify important physiological traits related to yield and stress tolerance. Traits such as photosynthesis rate, water use efficiency and nutrient uptake are considered during breeding programmes. Physiological screening helps in selection of better genotypes at early stages. This makes breeding process more efficient and time saving.

Physiological Traits for Stress Tolerance: Understanding physiological responses to drought, heat and salinity helps breeders to develop stress tolerant varieties. Traits like deeper root system, osmotic adjustment and stomatal regulation are used as selection criteria. Such varieties perform better under adverse environmental conditions.

Integration with Agronomy Practices: Agronomy uses physiological knowledge to decide optimum sowing time, spacing, irrigation and fertilizer application. For example, understanding nutrient requirement at different growth stages helps in proper fertilizer management. Physiological basis of water requirement helps in scheduling irrigation efficiently.

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Improving Resource Use Efficiency: Integration of physiology with agronomy improves use efficiency of water, nutrients and light. Crop varieties developed through breeding respond better to agronomic practices when physiological needs are fulfilled. This integration reduces wastage of inputs and lowers cost of cultivation.

Yield Improvement and Sustainability: By combining crop physiology, breeding and agronomy, stable yield can be achieved under variable climatic conditions. Physiologically efficient varieties managed with proper agronomic practices ensure sustainable crop production. This approach is very useful for Indian agriculture where resources are limited.

Importance in Indian Agriculture

In India, farmers face problems like drought, poor soil fertility and climate variability. Integration of crop physiology with breeding and agronomy helps in developing suitable crop varieties and management practices for different regions. This approach improves crop yield, farmer income and food security.

Conclusion

Integration of crop physiology with breeding and agronomy is essential for improving crop productivity and sustainability. Physiological understanding helps breeders in developing improved varieties and supports agronomists in designing effective crop management practices. Combined efforts of these disciplines can help in meeting future food demands and overcoming agricultural challenges. Therefore, integrated approach is the need of modern agriculture.

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Importance of Crop Physiology in Modern Agriculture

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Abstract

Crop physiology is the foundational study of the metabolic and functional processes within plants that determine growth, development, and ultimate economic yield. In the context of modern agriculture, characterized by precision farming and resource scarcity, crop physiology provides the scientific bridge between genetic potential and field performance. This paper explores how vital functions including photosynthesis, respiration, and nutrient dynamics inform management decisions. By understanding plant-environment interactions, stakeholders can optimize irrigation, fertilization, and stress mitigation strategies to ensure global food security in a changing climate.

Introduction

Modern crop management has shifted from traditional "broad-stroke" farming to high-precision systems. At the heart of this transition lies Crop Physiology. While agronomy often focuses on the "what" and "when" of farming, physiology explains the "how." Plants arebiological factories that convert solar energy into chemical energy. However, this process is frequently limited by environmental stressors such as drought, salinity, and temperature fluctuations. Modern management aims to maximize the Harvest Index (HI) the ratio of harvested grain to total biological yield. By applying physiological principles, farmers can tailor their interventions to the specific phenological stages of the crop, ensuring that resources like water and nitrogen are provided exactly when the plant's metabolic demand is highest.

Key Physiological Aspects in Crop Management

Photosynthesis and Source-Sink Relationships:

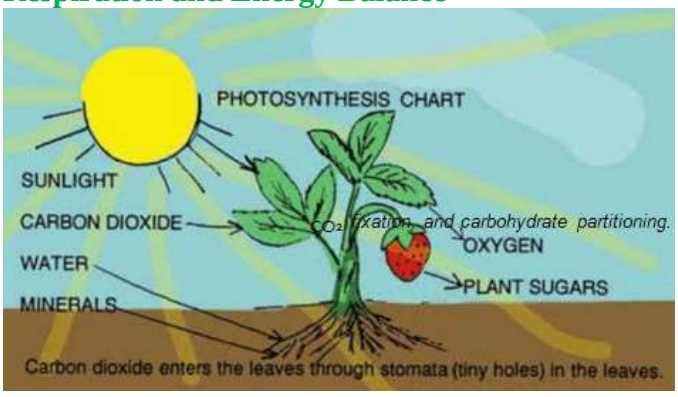
Photosynthesis is the primary driver of yield. Modern management utilizes this knowledge by:

Canopy Management: Optimizing plant spacing and leaf area index (LAI) to ensure maximum light interception.

CO_2 Utilization: Understanding how different crops (C_3 vs. C_4) respond to atmospheric conditions.

Source-Sink Manipulation: Ensuring that the "source" (leaves) efficiently transports sugars to the "sink" (grains/fruits) during the critical grain-filling stage.

Respiration and Energy Balance



While photosynthesis builds biomass, respir-

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ation consumes it to provide energy for growth. Management practices, such as choosing heat-tolerant varieties, help reduce "maintenance respiration" during hot nights, which otherwise depletes the sugars intended for grain production.

Transpiration and Water Use Efficiency (WUE)

Transpiration acts as the plant's cooling system and the vehicle for nutrient transport.

Irrigation Scheduling: By monitoring stomatal conductance and leaf water potential, farmers can practice "Deficit Irrigation" to save water without sacrificing yield.

Antitranspirants: In extreme heat, physiological knowledge allows for the use of specific sprays that reduce water loss.

Mineral Nutrition and Ion Transport

It isn't just about how much fertilizer is applied, but how the plant absorbs it. Crop physiology explains the role of root architecture and membrane transporters in nutrient uptake. This guides the "4Rs" of nutrient management: Right source, Right rate, Right time, and Right place.

Growth Regulators and Phenology

Modern farming uses synthetic Plant Growth Regulators (PGRs) to manipulate plant height, prevent lodging (falling over), and synchronize flowering. Understanding the physiological triggers for seed germination and maturity allows for better harvest planning and post-harvest quality control.

Stress Physiology: The Frontier of Resilience

Abiotic stress (drought, salinity, extreme temperatures) is the leading cause of yield gaps.

Crop physiology identifies

Osmotic Adjustment: How plants accumulate solutes to retain water under salt stress.

Antioxidant Systems: How plants detoxify harmful molecules during heat stress.

By selecting varieties with superior physiological "coping mechanisms," modern agriculture becomes more resilient to climate change.

Conclusion

Crop physiology is no longer just a laboratory science; it is a practical tool for the modern grower. By integrating physiological insights into daily management, we can achievea more sustainable "Evergreen Revolution." This scientific approach ensures that every drop of water and every gram of fertilizer is utilized to its maximum potential, ultimately supporting the global demand for food, fiber, and fuel. Understanding the "pulse" of the crop is the key to unlocking the future of productive and sustainable agriculture.

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Agri-Entrepreneurship in Arunachal Pradesh: Opportunities for Rural Transformation

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Agriculture remains the primary source of livelihood for a large share of the population in Arunachal Pradesh. However, traditional farming systems alone often provide limited income opportunities for rural youth. In recent years, agri-entrepreneurship has emerged as a promising path-way for transforming agriculture into a profitable and sustainable sector. By combining farming with value addition, processing, marketing, and innovative business models, agri-entrepreneurship can generate employment and strengthen rural economies. Across the North-Eastern region of India, the development of agribusiness and agricultural enterprises is increasingly being viewed as a strategy for economic growth and livelihood diversification. The region possesses abundant natural resources, favourable agro-climatic conditions, and rich biodiversity, all of which create strong potential for entrepreneurial ventures based on agricultural products.

The Need for Agri-Entrepreneurship

In many parts of Northeast India, agriculture is still characterized by small holdings, traditional cultivation methods, and limited market integration. As a result, farmers often depend primarily on subsistence production. Scholars studying agri-business development in the region emphasize that transforming agriculture into a market-oriented activity requires entrepreneurial initiatives in areas such as processing, packaging, marketing, and supply chain development. Agri-entrepreneurship helps bridge the gap between agricultural production and markets. Entrepreneurs can create enterprises around agricultural products by processing raw produce into higher-value commodities such as spices, fruit products, herbal items, bamboo products or organic foods. Such activities not only enhance farmers' income but also create employment opportunities for rural youth. For states like Arunachal Pradesh, where geographic isolation and limited industrialization constrain economic growth, promoting entrepreneurship within the agricultural sector can play a crucial role in regional develop-ment.

Agricultural Potential of the Northeast Region

The North-Eastern region is particularly suitable for agribusiness development because of its diverse agro-ecological conditions and wide range of crops. The region produces horticultural crops, fruits,

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spices, medicinal plants and bamboo resources that can be used for value-added enterprises. Studies on agribusiness in Northeast India highlight several potential ventures such as:

- ✓ Food processing enterprises
- ✓ Spice processing units
- ✓ Bamboo-based industries
- ✓ Horticulture and fruit processing
- ✓ Livestock and fisheries enterprises

These sectors provide opportunities for entrepreneurs to develop businesses that are closely linked to local resources and traditional agricultural systems.

Community-Based Entrepreneurship Models

One of the emerging approaches to agricultural entrepreneurship in the region is community-based enterprise development. Instead of individual farmers working separately, community groups, cooperatives, or farmer producer organizations can collectively develop enterprises around agricultural products. Experiences from Mizoram demonstrate that community-based entrepreneurship can successfully promote the production and marketing of agricultural products while strengthening local economies. Such models encourage farmers to pool resources, share knowledge, and improve access to markets and processing facilities. Community-based enterprises also help address common challenges such as limited capital, lack of infrastructure, and weak market linkages by enabling farmers to operate collectively rather than individually.

Opportunities for Agri-Entrepreneurs in Arunachal Pradesh

Arunachal Pradesh offers several opportunities for agri-entrepreneurial ventures. The state's rich natural resources and diverse climate support the cultivation of a wide range of crops including horticultural fruits, spices, medicinal plants, and bamboo. Some of the Agri-entrepreneurship models of Arunachal Pradesh are as follows;

Spice Ziro: Spice Ziro is a social enterprise based in Ziro Valley that focuses on processing and marketing traditional food products of Arunachal Pradesh. The initiative produces items such as bamboo shoot pickles, king chilli pickles, chutneys, and spice blends derived from locally sourced agricultural produce. By transforming traditional recipes into packaged products suitable for wider markets, the enterprise adds value to local agricultural resources while promoting indigenous culinary heritage. Spice Ziro also creates livelihood opportunities by sourcing raw materials from local farmers and engaging rural workers in processing and packaging activities.

Naara Aaba winery: The Naara Aaba winery, located in Hong village of Ziro Valley, represents a successful example of innovation in agri-entrepreneurship. Founded by agricultural engineer Tage Rita Takhe, the winery produces India's first organic kiwi wine using locally grown kiwis. The enterprise emerged as a response to surplus kiwi production in the region and aims to create a stable market for farmers cultivating the crop. By converting raw agricultural produce into a high-

value product, the winery demonstrates how value addition and branding can enhance farm incomes while promoting agro-tourism and regional identity.

Bamboo Straw Production Centre: The Bamboo Straw Production Centre (BSPC) showcases the potential of bamboo-based enterprises in Arunachal Pradesh. Utilizing locally available bamboo resources, the centre produces eco-friendly drinking straws as an alternative to plastic products. This initiative highlights how forest and agricultural resources can be converted into marketable goods while supporting environmental sustainability. In addition to promoting green products, the enterprise provides employment opportunities for local communities and illustrates how bamboo-based industries can contribute to rural entrepreneurship.



Challenges in Developing Agri-Entrepreneurship

Despite the strong potential for agribusiness development, several challenges continue to affect entrepreneurial growth in Arunachal Pradesh and the wider Northeast region.

Common constraints include:

- ✓ Inadequate infrastructure and transportation
- ✓ Limited access to credit and financial services
- ✓ Lack of processing and storage facilities
- ✓ Weak market linkages
- ✓ Limited entrepreneurial training and technical support

Researchers emphasize that addressing these challenges requires coordinated efforts from government institutions, research organizations, and private sector stakeholders. Promoting agri-entrepreneurship requires an integrated approach that combines skill development, institutional support, and market access. Training programs in agribusiness management, entrepreneurship development, and value addition can help rural youth transform agricultural activities into viable enterprises. Strengthening farmer producer organizations, improving infrastructure, and promoting innovation in agricultural value chains will also be essential for fostering a vibrant entrepreneurial ecosystem in the state. Furthermore, linking entrepreneurs with research institutions and extension services can help introduce improved technologies and market information systems that support sustainable agricultural enterprises.

Conclusion

Agri-entrepreneurship holds significant potential for transforming agriculture in Arunachal Pradesh from a subsistence activity into a dynamic economic sector. By encouraging innovation, value addition, and market integration, agricultural enterprises can generate employment opportunities, increase farmer incomes, and promote sustainable rural development. With the right combination of policy support, capacity building, and community participation, agri-entrepreneurship can become a key driver of economic growth and rural transformation in Arunachal Pradesh.

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Agriculture in Transition: Changing Farming Systems in Arunachal Pradesh

Radhe Mamung, Basant Kumar Dadrwal and N. Anthony Baite

Nestled in the Eastern Himalayas, Arunachal Pradesh is known for its dense forests, diverse tribal cultures, and rich biodiversity. For generations, agriculture has been the backbone of rural life in the state. Yet the story of agriculture here is not static, it is a story of gradual transformation. Today, farming systems in Arunachal Pradesh are evolving in response to ecological pressures, market opportunities, and changing socio-economic conditions. For centuries, the dominant agricultural system in Arunachal Pradesh has been shifting cultivation, commonly known as *jhum*. In this system, farmers clear patches of forest, cultivate crops for a few years, and then leave the land fallow to restore soil fertility before moving to another area. The practice is deeply embedded in the cultural traditions of the tribal communities of the region. Shifting cultivation historically functioned as a balanced ecological system when population densities were low and fallow periods were long. The long resting periods allowed the soil to regain fertility and forests to regenerate. In many communities, the system also encouraged cooperation among households and the sharing of labour and resources.

However, in recent decades the situation has changed. Population growth and increasing pressure on land have shortened the fallow cycle. As a result, soil fertility has declined and crop productivity has decreased in many areas. Environmental concerns such as deforestation, soil erosion, and biodiversity loss have also emerged. These pressures have gradually pushed farmers and policymakers to explore alternative agricultural practices.

From Jhum to Settled Farming

One of the most significant changes in Arunachal Pradesh's agricultural landscape has been the gradual transition from shifting cultivation to more permanent forms of farming. In several valleys and accessible regions, farmers have started adopting settled agriculture, horticulture, and agroforestry systems. Certain tribal communities, such as the Apatanis of Ziro Valley, have long practiced permanent wet rice cultivation combined with fish farming, demonstrating that sustainable settled agriculture can thrive in the region. Inspired by such examples, government programs and development initiatives have promoted terrace farming, horticulture plantations, and integrated farming systems.

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Another important development has been the increasing adoption of agroforestry. Traditional agroforestry integrates trees, crops, and sometimes livestock within the same farming system. Farmers grow fruit trees, medicinal plants, timber species, and annual crops together, creating a more diversified and sustainable land-use system. In many parts of the state, agroforestry is gradually replacing the old jhum cycle, providing both ecological and economic benefits.



Source: https://www.downtoearth.org.in/food/the-hidden-valley-56050

Changing Cropping Patterns

Agriculture in Arunachal Pradesh has also undergone significant diversification in terms of crops grown. Traditionally, the farming system focused primarily on subsistence crops such as rice, maize, and millets. These crops remain essential for food security, particularly in rural areas. According to data compiled from Land Use Statistics at a Glance (Ministry of Agriculture and Farmers Welfare), the production of food crops in Arunachal Pradesh increased from 240.9 thousand tonnes in 2005-06 to 377 thousand tonnes in 2020-21.

Crop	2005-06 production (000 tonnes)	2020-21 production (000 tonnes)
Rice	146	247
Maize	58	80
Millet	22	27
Wheat	6	7
Pulses	8	14

Source: Land Use Statistics at a Glance (Ministry of Agriculture and Farmers Welfare)

Rice continues to be the dominant crop in the state and plays a central role in the local food system. However, over time farmers have begun cultivating a wider variety of crops. The production of pulses, oilseeds, vegetables, and spices has increased, reflecting both changing dietary preferences and new market opportunities. High-value crops such as ginger, turmeric, chilli, and sugarcane have seen particularly rapid growth in recent years. These crops offer better income potential compared to traditional subsistence crops, encouraging farmers to shift part of their land toward market-oriented production. The rise of horticultural crops, including fruits and plantation crops, also highlights a gradual shift toward commercial agriculture. This diversification represents an important step toward strengthening rural livelihoods and reducing dependence on a narrow range of crops.

Institutional and Structural Changes

Agricultural transformation in Arunachal Pradesh is not only about crops and farming techniques, it is also about changes in institutions and land systems. Traditionally, land ownership in many tribal communities was collective, with village councils or clan groups managing access to land and forest resources. Over time, however, there has been

a gradual shift toward more individualized forms of land use and management. These changes have influenced patterns of cultivation, investment, and agricultural productivity. At the same time, agriculture in the state remains dominated by small and marginal farmers. Most households cultivate relatively small holdings and rely heavily on family labour. The limited availability of infrastructure, irrigation facilities, and modern agricultural inputs continues to constrain productivity in many areas.

Climate and Environmental Challenges

Agriculture in Arunachal Pradesh faces additional challenges from climate change and environmental vulnerability. The state's mountainous terrain and fragile ecosystems make farming particularly sensitive to climatic fluctuations. Recent studies suggest that while overall rainfall levels may not have changed dramatically, rainfall patterns have become more unpredictable. Changes in temperature, shifts in monsoon timing, and mid-season dry spells are increasingly affecting crop growth. Such changes can disrupt traditional cropping calendars and threaten food security in rural communities. Because much of the state's agriculture remains rainfed and dependent on natural ecosystems, climate variability poses a significant risk to farmers' livelihoods. Addressing these challenges requires climate-resilient agricultural strategies, improved water management, and stronger research support. The transition of agriculture in Arunachal Pradesh reflects a broader struggle to balance tradition and modernization. On one hand, traditional practices such as shifting cultivation and indigenous agroforestry systems embody valuable ecological knowledge developed over generations. On the other hand, economic pressures and environmental constraints demand new approaches that can improve productivity and sustainability. Diversification into high-value crops, promotion of agroforestry, development of horticulture, and improvements in agricultural infrastructure offer promising pathways for the future. Strengthening agricultural research, extension services, and market linkages will also play an important role in supporting farmers during this transition. Ultimately, the future of agriculture in Arunachal Pradesh will depend on strategies that respect the region's cultural heritage while embracing innovation. By integrating traditional knowledge with modern agricultural practices, the state can move toward a more resilient and sustainable farming system.

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Can Arunachal Pradesh Become India's Next Fully Organic State?

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The global demand for organic food has grown rapidly over the past decade, driven by increasing awareness about health, environmental sustainability, and food safety. In India, several states have begun promoting organic agriculture as a pathway toward sustainable rural development. Sikkim's transformation into the country's first fully organic state has demonstrated that such a transition is possible. This brings forward an important consideration: can such transition be replicated in other regions? Arunachal Pradesh, located in the Eastern Himalayan region of India, possesses several ecological and cultural advantages that make it a strong candidate for organic agriculture. At the same time, structural challenges related to infrastructure, certification, and market access continue to shape the prospects of organic farming in the state.

Natural Potential for Organic Agriculture

One of the most significant advantages of Arunachal Pradesh is that much of its agriculture is already close to organic by default. Farming systems across the Northeast region traditionally rely on minimal use of chemical fertilizers and pesticides. According to studies on organic farming in Northeast India, the region's agriculture is largely based on indigenous practices and organic nutrient recycling, which provides a strong foundation for transitioning to certified organic agriculture. The state's rich biodiversity and favourable agro-climatic conditions further strengthen this potential. Arunachal Pradesh supports a wide variety of crops, including rice, maize, millets, pulses, oilseeds, spices, fruits, and medicinal plants. Crops such as ginger, turmeric, large cardamom, kiwi, and citrus fruits have particularly strong prospects in organic markets. Researchers studying organic farming in the region highlight that the Eastern Himalayan ecosystem offers unique opportunities for organic crop production, especially for high-value horticultural crops and spices that can fetch premium prices in national and international markets.

Table 1: Comparison of Fertiliser Sales Across Selected States (*Rabi*, 2024-25)

State	Urea (Lakh metric Tonnes)	DAP (LMT)	MOP (LMT)	NPK (LMT)
Uttar Pradesh	39.01	14.10	1.23	6.86
Assam	1.88	0.34	0.25	0.27
Arunachal Pradesh	0.01	0	0	0

Source: State/UT-wise Details of Fertilizers Requirement, Availability, Sales and Closing Stock (*Rabi*, 2024-25), Open Government Data Platform, Government of India.

Traditional Knowledge and Indigenous Farming

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Systems

The agricultural practices of tribal communities in Arunachal Pradesh have historically been closely aligned with ecological sustainability. Traditional farming systems such as shifting cultivation (jhum) and agroforestry rely heavily on natural nutrient cycles, forest biomass, and mixed cropping. Although shifting cultivation is often criticized for its environmental impacts, many researchers argue that when practiced with adequate fallow periods, it can function as a sustainable system adapted to mountainous ecosystems. Indigenous farming systems also incorporate multiple crops in the same field, which improves resilience against pests, diseases, and climatic variations. In districts such as Tawang and West Kameng, farmers practice diversified farming systems that combine crops, livestock, and forest resources. These integrated systems are often closer to organic agriculture compared to intensive chemical-based farming systems found in many other regions.

Growing Interest in Natural and Organic Farming

In recent years, there has been growing interest in natural farming and organic agriculture across Arunachal Pradesh. Research on natural farming prospects in the state suggests that farmers are increasingly exploring alternatives that reduce dependence on external inputs while improving soil health and environmental sustainability. Government initiatives and agricultural institutions have also begun promoting organic farming clusters, farmer training programs, and demonstration projects. These efforts aim to improve farmers' understanding of organic nutrient management, pest control using biological methods, and certification processes. The expansion of organic farming could also support the development of agri-entrepreneurship, agro-processing and eco-tourism in the region.



Source: https://www.phytojournal.com/archives/2025.v14.i6.15636/economic-viability-and-post-harvest-challenges-of-organic-kiwi-cultivation-in-ziro-valley-arunachal-pradesh)

Economic Opportunities through Organic Value Chains

Organic agriculture offers significant opportunities for value addition and rural income generation. High-value crops such as spices, fruits, medicinal plants, and plantation crops have strong export potential. Studies on organic farming prospects in Arunachal Pradesh emphasize that the state can benefit from niche markets for organic products. Organic ginger, turmeric, and large cardamom already have strong demand in international markets. Developing organic value chains could also create employment opportunities in processing, packaging and marketing of agricultural products. This would help diversi-

fy rural livelihoods and reduce migration from remote mountain regions.

Challenges in Achieving a Fully Organic State

Despite its potential, Arunachal Pradesh faces several challenges in becoming a fully organic state. One of the major constraints is limited infrastructure and market connectivity. Many rural areas remain geographically isolated, making it difficult for farmers to transport perishable organic products to major markets. Another challenge is the lack of organized certification systems. Organic certification requires proper documentation, monitoring and compliance with strict standards. For small and marginal farmers, the certification process can be expensive and complicated. Researchers studying organic farming in Northeast India also highlight the need for stronger extension services and farmer training. Many farmers require technical guidance on organic pest management, soil fertility improvement, and crop diversification. In addition, improving supply chains, storage facilities, and processing infrastructure is essential to ensure that farmers receive fair prices for organic produce. For Arunachal Pradesh to become a fully organic state, a gradual and region-specific strategy is necessary. First, promoting cluster-based organic farming can help reduce certification costs and improve coordination among farmers. Cluster approaches have been successfully implemented in several organic farming programs across India. Second, investments in value chains and infrastructure are crucial. Cold storage facilities, processing units, and better road connectivity would help farmers access national and international markets. Third, strengthening research and extension services is essential. Agricultural universities and research institutions can play an important role in developing organic farming technologies suited to the state's diverse agro-ecological conditions. Finally, policies should integrate traditional knowledge systems with modern organic practices. Indigenous farming methods developed by tribal communities offer valuable insights into sustainable land management in mountain ecosystems.

Table 2: Strengths, Weaknesses, Opportunities and Challenges of Organic Farming in Arunachal Pradesh

Aspect	Key point
Strengths	Low use of chemical fertilizers and pesticides; traditional ecological farming practices; rich biodiversity; suitable climate for spices and horticultural crops
Weaknesses	Poor infrastructure and market access; limited organic certification systems; low farmer awareness about organic standards
Opportunities	Growing demand for organic food; potential for export of spices and medicinal plants; development of organic tourism and niche markets
Challenges	Difficult terrain and transportation; fragmented land holdings; limited extension services and technical support

Sources: Singh *et al*. (2021); Babu *et al.* (2015): Avasthe *et al*. (2013)

Conclusion

Arunachal Pradesh possesses many of the natural and cultural advantages necessary to become a leading organic agricultural region in India. Its low use of chemical inputs, rich biodiversity, and strong indigenous farming traditions provide a strong foundation for organic farming. However, achieving the status of a fully organic state will require coordin-

ated efforts involving government institutions, research organizations, and farming communities. Improvements in infrastructure, certification systems, market linkages, and farmer training will be essential for this transition. With appropriate policy support and sustainable development strategies, Arunachal Pradesh has the potential to emerge as one of India's most important organic farming regions, combining ecological sustainability with improved rural livelihoods.

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Indigenous Technical Knowledge in Arunachal Pradesh: Traditional Wisdom for Sustainable Agriculture

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Agriculture in Arunachal Pradesh has long been shaped by the deep interaction between local communities and their natural environment. For generations, farmers in the state have relied on Indigenous Technical Knowledge (ITK), a body of traditional practices, skills, and innovations developed through experience and observation to manage crops, protect plants, and sustain agricultural productivity. In recent years, as concerns about environmental sustainability and chemical-intensive farming grow, these traditional practices are gaining renewed attention. Indigenous Technical Knowledge refers to the locally developed knowledge systems that evolve within communities through continuous experimentation and adaptation to specific ecological conditions. Such knowledge is usually transmitted orally from one generation to another and reflects a close understanding of local ecosystems, biodiversity, and climate patterns.

Traditional Farming Systems and Ecological Adaptation

In Arunachal Pradesh, indigenous knowledge has played a crucial role in shaping farming systems adapted to mountainous terrain and fragile ecosyste ms. Many communities practice mixed cropping, crop rotation, and integrated farming, which help maintain soil fertility and reduce pest incidence. Shifting cultivation, locally known as *jhum*, is often cited as a traditional farming system that incorporates ecological principles. When practiced with adequate fallow periods, the system allows soil nutrients to regenerate naturally while supporting diverse crop varieties within the same field. Farmers also use natural resources such as forest biomass, compost, and animal manure to improve soil fertility. These practices reflect a holistic approach to agriculture in which farming activities remain closely linked to surrounding ecosystems.

Indigenous Practices in Plant Protection

Indigenous plant protection practices are an important component of traditional agricultural knowledge. Farmers often use locally available plants and natural substances to control pests and diseases. For example, plant extracts, ash, and fermented mixtures are commonly applied to crops as natural pest repellents. Such methods reduce the need for synthetic pesticides while minimizing environmental damage. These practices demonstrate

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how traditional farmers developed effective solute-ons to agricultural problems using locally available materials. The use of botanical extracts and organic materials in pest management has also attracted scientific interest because of their potential role in promoting environmentally friendly agriculture.

Practice	Resource Used	Benefits
Bamboo Drip Irrigation	Bamboo channels	Efficient water management
Rice-Fish Farming	Paddy + Fish	Integrated production and pest control
Herbal Pest control	Local plants and ashes	Eco-friendly pest management



Source:http://www.rainwaterharvesting.org/methods/traditional/bamboo.htm

Community Knowledge and Knowledge Transmission

A key feature of Indigenous Technical Knowledge is that it is community-based and collectively maintained. Knowledge about crop varieties, soil management, pest control, and weather patterns is shared among farmers through observation, experience and oral traditions. Elders and experienced farmers often serve as custodians of this knowledge, passing it on to younger generations through everyday farming practices. Festivals, rituals, and agricultural cycles also reinforce the cultural significance of traditional agricultural knowledge. However, rapid modernization, migration and the increasing adoption of modern agricultural inputs have contributed to the gradual decline of some traditional practices. Documenting and preserving ITKs has therefore become an important priority for researchers and development organizations.

Integrating Indigenous Knowledge with Modern Agriculture

Rather than viewing traditional knowledge and modern science as separate systems, many experts advocate integrating Indigenous Technical Knowledge with scientific innovations. Such integration can help develop sustainable agricultural systems that are both productive and environmentally responsible. For instance, combining traditional pest control methods with modern integrated pest management (IPM) strategies can reduce dependence on chemical pesticides. Similarly, traditional soil management practices can complement modern soil fertility technologies. Innovative approaches such as sustainable aquaculture systems and eco-friendly farming methods are also increasingly drawing inspiration from traditional ecological knowledge.

Importance for Sustainable Agriculture

Indigenous Technical Knowledge offers several advantages for sustainable agricultural development:

- ✓ Environmentally friendly practices that reduce chemical use
- ✓ Adaptation to local climate and ecological conditions
- ✓ Low-cost farming techniques suitable for small farmers
- ✓ Preservation of biodiversity and traditional crop varieties

In regions like Arunachal Pradesh, where agriculture is closely linked with forests, rivers, and mountains, traditional knowledge systems provide valuable insights for maintaining ecological balance while ensuring food security. Recognizing the value of Indigenous Technical Knowledge is essential for promoting sustainable agriculture in Arunachal Pradesh. Efforts should be made to document traditional practices, encourage community participation, and integrate local knowledge into agricultural research and extension programs. Educational institutions and research organizations can play an important role in studying and validating indigenous practices so that useful methods can be incorporated into modern agricultural strategies. At the same time, empowering local communities and respecting their knowledge systems is crucial for preserving these traditions.

Conclusion

Indigenous Technical Knowledge represents centuries of accumulated wisdom developed by farming communities in Arunachal Pradesh. These traditional practices demonstrate how agriculture can be carried out in harmony with nature while maintaining productivity and resilience. As agriculture faces new challenges such as climate change, environmental degradation, and rising input costs, the lessons embedded in traditional knowledge systems may offer valuable guidance. By integrating indigenous knowledge with modern agricultural science, Arunachal Pradesh can build a more sustainable and resilient agricultural future.

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PM-KISAN: A Lifeline for Farmers or Just Temporary Relief?

Radhe Mamung, Basant Kumar Dadrwal and N. Anthony Baite

Agriculture continues to be the backbone of rural livelihoods in India, yet farmers often face unstable incomes due to fluctuating crop prices, rising input costs and climatic uncertainties. Recognizing these challenges, the Government of India introduced the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) scheme in 2019 to provide direct income support to farmers. Under the scheme, eligible farmer households receive ₹6,000 annually in three instalments of ₹2,000, transferred directly to their bank accounts through the Direct Benefit Transfer (DBT) system. The initiative was designed to reduce financial stress among farmers and support agricultural activities.



Immediate Financial Support for Farmers

One of the most significant advantages of PM-KISAN is the direct transfer of funds to farmers without intermediaries. The DBT system ensures transparency and reduces delays in the delivery of benefits. Research conducted in Ri-Bhoi district of Meghalaya indicates that beneficiary farmers experienced measurable improvements in their farm economics. The study observed increases in cost of cultivation, gross returns, and net farm income among farmers receiving PM-KISAN support compared with non-beneficiaries. This suggests that the additional income allowed farmers to invest more in agricultural inputs such as seeds and fertilizers.In many cases, farmers also used the funds to meet urgent household needs, demonstrating the scheme's role in strengthening rural financial stability.

Strengthening Financial Inclusion

Another important contribution of PM-KISAN has been its role in expanding financial inclusion in rural areas. Because the scheme requires bank accounts linked with Aadhaar identification, many farmers who previously relied on informal financial systems have become connected to formal banking channels. Sociological analyses of the scheme highlight that the direct transfer mechanism has improved farmers' trust in government welfare programs. The removal of intermediaries has reduced corruption and improved transparency in benefit distribution. For many rural households, PM-KISAN represents the first time they have received financial support directly into their bank accounts.

Perceptions of Farmers

Despite these benefits, studies show that farm

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Table 1: Economic impact of PM-KISAN on paddy cultivation in Ri-Bhoi District (*Kharif*, 2020-21)

Indicators	Beneficiary Farmers (₹ ha^{-1})	Non-Beneficiary Farmers (₹ ha^{-1})	Difference (₹)	Percentage difference
Cost of cultivation	38,805.25	37,975.75	830	2.14%
Gross Returns	64,103.85	61,070.97	3,033	4.74%
Net Returns	25,298.60	23,095.22	2,203	8.71%

Source: Reddy *et al*. (2021)

-ers have mixed perceptions about the scheme. While the financial assistance is appreciated, many farmers believe that the amount provided is relatively small when compared to the rising cost of agricultural inputs. With increasing expenses for fertilizers, seeds, labour, and machinery, the annual support of ₹6,000 often covers only a fraction of total production costs. As a result, the scheme is frequently viewed as supplementary support rather than a comprehensive solution to farmers' income problems.

Structural Challenges in Implementation

Several structural issues also affect the implementation of PM-KISAN. One major limitation is the exclusion of tenant farmers and sharecroppers, as the scheme is linked to land ownership records. In regions where land leasing is common, many cultivators remain outside the coverage of the scheme. Administrative challenges such as inaccurate land records, incomplete Aadhaar linkage, and delays in updating beneficiary databases have also been reported in various studies. Furthermore, PM-KISAN does not directly address broader issues such as irrigation shortages, market access, or price volatility, factors that significantly influence farmers' incomes.

A Shift in Agricultural Welfare Policy

Despite its limitations, PM-KISAN represents an important shift in India's agricultural welfare approach. Traditionally, government support focused mainly on input subsidies and price support mechanisms. The introduction of direct income transfers marks a move toward farmer-centric welfare policies. Such income support programs provide farmers with flexibility in deciding how to use the funds. Some may invest in agriculture, while others may use the money for household expenses, debt repayment, or education. This flexibility has made PM-KISAN an important component of India's broader rural development strategy.

To enhance the effectiveness of PM-KISAN, policy improvements may be necessary. Expanding the scheme to include tenant farmers and landless cultivators could make it more inclusive. Similarly, improving land record systems and strengthening digital infrastructure would help ensure that benefits reach all eligible farmers. There is also growing discussion about whether the financial assistance provided under the scheme should be revised to reflect rising agricultural costs and inflation. Most importantly, income support programs like PM-KISAN should complement other agricultural policies aimed at improving productivity, infrastructure, and market access.

Conclusion

PM-KISAN has undoubtedly provided financial relief to millions of farmers across India

and improved the transparency of welfare delivery through direct benefit transfers. Evidence from recent studies suggests that the scheme has helped farmers increase investment in agriculture and reduce short-term financial stress. However, the scheme alone cannot resolve the complex challenges facing Indian agriculture. While PM-KISAN provides a valuable safety net, long-term improvements in farmer welfare will require broader reforms in agricultural infrastructure, market systems, and rural development policies.

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Sealing of Porous Pond: A Simple and Effective Methods to Prevent Water Loss

Chamundeshwari Bitli, Vaijnath Aitwar, Sandeep Kumar S. and Neha P.

Abstract

Seepage is one of the severe problem faced by the fishermen for culturing aquatic species in earthen ponds. Sealing helps the earthen ponds to prevent escape of water molecules between voids of soil particles, which can be done by either natural or chemical treatments within the economic/ budget level. Correct propotional mixture of sealing materials are needed like clay soil, lining , cutoff trenches, Bentonite, Chemicals like tetrasodium pyrophosphate, sodium hexametaphosphate and sodium carbonate whereas organic materials are cow dung mixed with stones and cement.

Introduction

Water is the most important resource in aquaculture. However, many fish and shrimp ponds suffer from serious water loss due to seepage through porous soil and weak embankments. This problem is commonly observed in ponds constructed in sandy, gravelly, or poorly compacted soils. Excessive seepage not only increases the cost of pumping and water management, but also affects pond stability, water quality, and overall production. Seepage problems, if not properly controlled, may lead to frequent drying of ponds, cracking of dykes, and failure of embankments. Therefore, sealing a porous pond is an essential step in pond construction and renovation. A well-sealed pond conserves water, reduces operational expenses, and ensures better control of the culture environment. Several methods are available for sealing ponds, ranging from low-cost natural soil treatments to permanent hard and synthetic linings. The choice of method depends on soil type, availability of materials, pond size, and economic feasibility. This article presents simple, practical, and commonly used pond sealing materials and methods suitable for aquaculture purposes.

Natural and Earth-Based Sealing Materials

Natural soil-based methods are the most economical and widely adopted techniques for sealing porous ponds, especially in rural aquaculture systems.

Compaction with Clay Soil: In soils containing a good range of particle sizes, seepage can be controlled by proper compaction. A 0.15-0.2 meter thick layer of surface soil is spread uniformly over the pond bottom and sides. The soil is moistened and compacted thoroughly using manual rammers or mechanical rollers. If the native soil is highly porous,

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good-quality clay soil should be mixed with it before compaction. This method is effective where sufficient clay content is available.

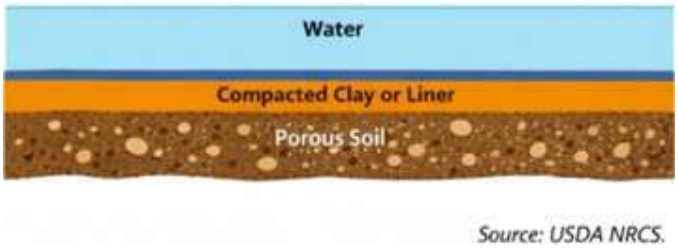


Figure 1: Cross-sectional view of a pond bottom showing a compacted clay or lining layer used to reduce seepage.

Clay Linings and Cutoff Trenches: In earthen embankments, seepage often occurs through the dyke body or foundation. A central clay core inside the dyke helps make it water-tight. Where the foundation soil is pervious, a cutoff trench is excavated and filled with impervious clay material. These practices are commonly followed in aqua-culture pond engineering to improve dyke stability and reduce leakage.

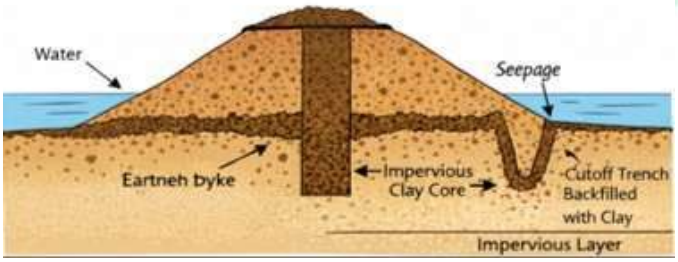


Figure 2: Schematic diagram of an earthen dyke with clay core and cutoff trench for seepage control.

Bentonite Clay: Bentonite is a fine-textured colloidal clay with excellent sealing properties. When it comes in contact with water, it swells several times its original volume and fills soil pore spaces. Bentonite is applied at a rate of 5-15 kilogram per square meter and mixed into the top 0.15 meter of soil, followed by compaction. Alternatively, coarse bentonite can be applied over the water surface, where it settles and forms a sealing layer. Bentonite is particularly effective in sandy and gravelly soil.



Figure 3: Application of bentonite clay in pond bottom and sealing of pore spaces after swelling.

Chemical Sealing Methods: Chemical treatments are used to reduce soil permeability by dispersing fine particles and blocking pore spaces. Commonly used sealing chemicals include Tetra sodium pyrophosphate, sodium hexametaphosphate, and sodium carbonate. These chemicals are mixed with the surface soil and compacted to a depth of about 0.15 meter. Chemical sealing is suitable for ponds with water depths up to 2.5 meter. However, this method is not effective in coarse-textured soils and should be used only where soil conditions permit.

Organic and Cement-Based Sealing Methods

Organic materials combined with soil or cement provide a low-cost and practical solution for seepage control in small ponds.

Cow Dung and Clay Mixture: Mixing 1percentage cow dung with 5-10 percentage clayey soil into the top 0.15-0.20 meter of pond soil helps improve soil binding and reduces seepage. This method is simple, economical, and commonly practiced in village ponds.

Cow Dung and Cement Mixture: In areas where

clay is insufficient, a mixture of 1 percentage cement and 1-5 percentage cow dung can be mixed with the pond surface soil. The treated surface is watered and compacted thoroughly. This combination forms a semi-impervious layer and reduces water loss effectively.

Hard Linings and Masonry: Hard linings provide near-complete seepage control and are suitable for permanent aquaculture structures.



Figure 4: Cement concrete lining over sand cushion for permanent pond sealing.

Cement Concrete Lining: A 0.10-0.12 meter thick cement concrete layer is laid over a compacted sand base using a 1:2:4 mix ratio of cement, sand, and aggregate. This method provides a durable and water-tight lining but involves higher construction costs.

Brick, Stone and Lime Concrete Linings: Brick tiling, stone pitching, and concrete slabs are also used as pond linings. Bricks or stones are set in 1:4 cement mortar over a sand layer. Lime concrete is another traditional lining material used in some regions for pond sealing.

Synthetic Membranes and Polymer Liners: Synthetic liners offer the most effective solution for sealing highly porous ponds. Common materials include Polyethylene, Poly Vinyl Chloride, and Butyl rubber membranes. These liners are laid over a smooth and compacted subgrade and protected with soil or sand layers. Polymer-based chemical coatings are also used to form thin impervious layers, though they increase the overall construction cost.

Conclusion

Sealing a porous pond is a critical requirement for efficient aquaculture pond management. The selection of sealing materials depends on soil type, pond size, availability of resources, and cost considerations. Natural methods such as clay compaction and bentonite application are suitable for most earthen ponds, while organic and cement-based mixtures offer low-cost alternatives. For long-term and high-value aquaculture systems, hard linings and synthetic membranes provide permanent and effective solutions. Proper pond sealing reduces water loss, improves pond stability, and enhances overall aquaculture productivity.

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Strengthening Fruit Crop Production through Extension-Driven Hi-Tech Nursery Management

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Abstract

Fruit crop production is a key component of nutritional security, farm income enhancement, and diversification of Indian agriculture. The success of fruit-based production systems largely depends on the availability of quality planting material that is true-to-type, disease-free, and capable of high productivity. Hi-tech nursery management offers a scientific and technology-driven approach to produce superior planting material using protected structures, modern propagation techniques, and quality control mechanisms. However, large-scale adoption of hi-tech nurseries remains constrained due to limited awareness, skills, and institutional support among farmers and rural entrepreneurs. In this context, agricultural extension systems play a pivotal role in promoting, disseminating, and sustaining hi-tech nursery practices. Extension driven interventions such as capacity building, demonstration, digital advisory services, and policy facilitation significantly enhance the effectiveness of hi-tech nursery management. This article examines the role of extension-led hi-tech nursery management in strengthening fruit crop production, with special reference to India.

Introduction

Fruit crops contribute significantly to agricultural diversification, income generation, and nutritional security, particularly in developing countries like India. With increasing demand for fruits driven by population growth, urbanization, and rising health consciousness, the need to enhance fruit crop productivity and quality has become more critical than ever. One of the most fundamental determinants of successful fruit cultivation is the availability of healthy and genetically superior planting material. Traditionally, fruit nurseries in India have been managed using conventional practi-ces with limited standardization, often resulting in poor quality seedlings, varietal mixtures, and disease transmission. Such limitations adversely affect orchard establishment, productivity, and longevity. Hi-tech nursery management has emerged as a

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promising solution by integrating modern technologies such as tissue culture, protected cultivation, micro-irrigation and scientific propagation protocols. However, technology alone cannot ensure widespread adoption. Agricultural extension systems are essential for translating hi-tech nursery innovations into field-level impact by empowering farmers, nursery entrepreneurs, and stakeholders with knowledge, skills, and institutional linkages.

Hi-Tech Nursery Management: Concept and Importance: Hi-tech nursery management refers to the scientific production of planting material using advanced infrastructure, precision inputs and standardized practices. It involves the use of polyhouses, shade-net houses, mist chambers, and mother plant blocks, along with vegetative propagation techniques such as grafting, budding, and micropropagation. These practices ensure uniform growth, higher survival rates and reduced pest and disease incidence in fruit crops (Singh *et al*., 2018). Quality planting material produced in hi-tech nurseries plays a crucial role in improving fruit yield, quality, and orchard sustainability. The use of certified and virus-free planting material has been shown to increase productivity by 20-40 per cent in several fruit crops, including mango, citrus, banana, and guava (NHB, 2022).



Role of Agricultural Extension in Hi-Tech Nursery Promotion: Agricultural extension acts as a catalyst in promoting hi-tech nursery management by facilitating knowledge transfer, skill development, and behavioural change. Extension personnel bridge the gap between research institutions and end users by organizing training programs, frontline demonstrations, exposure visits, and on-farm trials related to nursery technologies. These interventions help nursery operators and farmers understand the economic and agronomic benefits of scientific nursery practices (Swanson and Rajalahti, 2010).

Extension services also play a vital role in promoting nursery accreditation and certification systems, which enhance farmers' confidence in planting material quality. By supporting nursery entrepreneurs in meeting regulatory standards and accessing government schemes, extension agencies contribute to the institutional strengthening of the horticulture sector.

Extension-Led Digital and Institutional Innovations: The integration of digital tools into extension-driven nursery management has further strengthened its outreach and effectiveness. Mobile-based advisory services, online training platforms, and decision support systems enable real-time dissemination of best practices and problem-solving support. Digital extension initiatives improve accessibility to technical knowledge, particularly in remote and underserved areas (Meena *et al.*, 2020). Institutionally, extension systems support convergence among horticulture departments, Krishi Vigyan Kendra

(KVKs), research organizations, and private stakeholders. National programs such as the Mission for Integrated Development of Horticulture (MIDH) rely heavily on extension mechanisms to promote hi-tech nurseries through subsidies, technical guidance, and monitoring.

Impact on Fruit Crop Productivity and Rural Livelihoods: Extension-driven hi-tech nursery management has a multiplier effect on fruit crop production systems. The availability of quality planting material leads to better orchard establishment, reduced mortality, early bearing, and enhanced fruit quality. At the same time, hi-tech nurseries generate employment opportunities and promote agri-preneurship among rural youth and women. Extension support ensures sustainability by fostering continuous learning, quality assurance, and market linkages (Yadav and Choudhary, 2019).



Conclusion

Strengthening fruit crop production requires a holistic approach that goes beyond varietal improvement and input supply. Hi-tech nursery management provides a strong foundation for sustainable fruit cultivation by ensuring the availability of high-quality planting material. However, the true potential of hi-tech nurseries can only be realized through effective agricultural extension systems. Extension-driven approaches enable technology dissemination, capacity building, institutional support, and policy convergence, thereby enhancing adoption and impact. In the Indian context, strengthening extension services and integrating digital innovations with hi-tech nursery management can significantly improve fruit crop productivity, farmers' incomes, and horticultural sustainability. Future strategies should focus on reinforcing extension research farmer linkages to scale up hi-tech nursery-based interventions across diverse agro-ecological regions.

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Mechanisms of Nutrient Uptake by Roots

Nishant Yadav and Ravinder Kaur

Introduction

Plants require essential nutrients for their growth, development, and reproduction. These nutrients are mainly absorbed from the soil through roots. The process by which roots absorb water and mineral nutrients from the soil is known as nutrient uptake. It is a complex physiological process involving physical, chemical, and biological mechanisms.

Essential Nutrients for Plants

Macronutrients (needed in large amounts): Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Sulfur.

Micronutrients (needed in small amounts): Iron, Manganese, Zinc, Copper, Boron, Molybdenum, Chlorine, Nickel.

Structure of Roots Involved in Nutrient Uptake

Root Hairs: Thin extensions that increase surface area and are the main site of absorption.

Cortex: Stores nutrients and transports absorbed materials toward vascular tissues.

Endodermis: Contains Casparian strip which regulates movement into xylem.

Xylem: Transports absorbed water and nutrients to upper parts of the plant.

Mechanisms of Nutrient Uptake Passive Absorption

Diffusion: Movement of ions from higher concentration to lower concentration.

Facilitated Diffusion: Uses carrier proteins to transport specific ions without energy.

Mass Flow: Movement of nutrients along with water due to transpiration pull.

Active Absorption

Active absorption requires energy (ATP). Ions move against the concentration gradient with the help of carrier proteins and proton pumps. Root cells release hydrogen ions into the soil which helps in nutrient exchange.

Pathways of Nutrient Movement

Apoplastic pathway: Movement through cell walls and intercellular spaces until the Casparian strip.

Symplastic pathway: Movement through cytoplasm of cells connected by plasmodesmata.

Ion Exchange and Other Factors

Ion Exchange mechanism

Cation exchange: Roots release hydrogen ions that replace positively charged ions like potassium, calcium, and magnesium attached to soil particles.

Anion exchange: Roots release hydroxyl or bicarbonate ions to replace negatively charged ions such as nitrate and sulfate.

Role of Mycorrhizae

Mycorrhizae are symbiotic associations between fungi and plant roots. They increase surface area for absorption, especially phosphorus uptake,

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and improve water absorption and disease resistance.

Factors Affecting Nutrient Uptake

Soil pH, soil moisture, temperature, aeration, root health, microbial activity, and nutrient concentration in soil affect nutrient uptake.

Conclusion

Nutrient uptake by roots is essential for plant growth and survival. It involves passive and active mechanisms, ion exchange processes, and controlled pathways. Environmental factors and mycorrhizae play important roles in improving agricultural productivity.

Passive and Active Absorption of Mineral Nutrients

Nivash Kumar and Ravinder Kaur

Introduction

Plants need mineral nutrients basic stuff like nitrogen and potassium to grow and do their thing. They get these from the soil through their roots, usually as ions (charged particles). There are two main ways they do this: passive and active absorption. Knowing how these work helps us grow better crops and take care of the soil. These days, folks are trying to figure out how to get plants to use nutrients better, using tech like biotechnology and smart farming.

What is Mineral Nutrient Absorption?

Basically, it's how ions like nitrate, ammonium, potassium, calcium, and phosphate get into the root cells. How much there is measured is often shown using moles per liter (mol L^{-1}) or millimoles per liter (mmol L^{-1}). How these ions move depends on the cell's doors (membrane permeability), how much of the ion is around (ion gradients), and how much energy the cell has. The cell membrane is like a bouncer, controlling what gets in.

Passive Absorption: Easy does it

Passive absorption is when plants take in mineral ions without using any energy. The ions just move from where there's a lot of them to where there's less like when you open a window, the smell of cookies goes from the kitchen to the living room. This happens through simple diffusion, helped diffusion, and ion channels in the root cell membrane. Since it doesn't need energy, it depends a lot on how much of the ion is outside the plant, the air temperature, and the area of the cell membrane.

What Makes Passive Absorption Special

It doesn't need ATP (energy), it goes with the flow (concentration gradient), and can even happen in dead cells if things are right. How fast it happens depends on how different the ion concentration is inside and outside the cell, and it's measured in moles per square meter per second ($mol \cdot m^{-2} \cdot s^{-1}$).

Active Absorption: Using Some Muscle

Active absorption is when plants pull in mineral ions even when there's more inside the cell than outside, which costs energy, like pushing a boulder uphill. This needs living cells and protein helpers which are stuck in the membrane. Proton pumps (H^+-ATPase) are often part of this, creating a gradient that helps move the ions. This lets plants get the nutrients they need even when there isn't much in the soil.

What Makes Active Absorption Special

It costs energy (ATP), depends on how fast the plant is breathing (respiration rate), and stops if you mess around with the plant's energy production. It's also picky and controlled, allowing plants to keep their nutrient levels just right. How fast it is measured is often shown using $mol \cdot m^{-2} \cdot s^{-1}$.

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What Messes with Nutrient Absorption

A few things: soil pH, air temperature (K or °C), how wet the soil is (%), how much root area there is (m^2), and if there's enough air in the soil. Also, microbes and how the roots work together with other organisms matters. These days, farmers use sensors and computers to get these conditions right so the plants can suck up nutrients better.

Cool, New Stuff

Some cool things are happening, like nano-fertilizers, biofertilizers, and crops with special proteins to help them grab nutrients. Researchers are checking out how to get plants to use nutrients better and waste less fertilizer. Smart hydroponic systems can measure how much of each ion there is in real-time and adjust things automatically, which makes nutrient absorption more efficient and environmentally friendly.

How we measure things

Everything is measured using metric and SI units, like mol L^{-1} and mmol L^{-1}. Transport rates use flux units. Symbols and abbreviations follow international standards.

The Bottom Line

Passive and active absorption help plants get the mineral nutrients they need from the soil, no matter what the conditions are. Passive absorption is cheap and easy when things are flowing the right way, while active absorption makes sure plants get what they need even when it's scarce. Knowing how both these systems work is key for growing better crops, using biotechnology, and taking care of the soil. Better farming methods and molecular biology should help plants absorb nutrients even better in the future.

ATP = Adenosine Triphosphate; H^+ = Hydrogen ion. Data from plant physiology and membrane transport textbooks and journals.

Hydraulic Architecture of Plants and Its Influence on Water Transport

Vikash Kumar and Ravinder Kaur

Abstract

Hydraulic architecture refers to the structural and functional organization of water transport systems within plants. It determines how efficiently water moves from roots to leaves through the xylem and influences plant survival, growth, and adaptation to environmental stresses. Water transport is driven primarily by transpiration pull and regulated by xylem structure, vessel diameter, resistance, and vulnerability to cavitation. Variations in hydraulic architecture among plant species reflect ecological strategies and environmental adaptations. Understanding plant hydraulic systems is essential for predicting plant responses to drought, climate change, and ecosystem dynamics.

Introduction

Water is essential for plant life, playing a key role in photosynthesis, nutrient transport, cell turgor maintenance, and temperature regulation. Plants absorb water from the soil through their roots and transport it upward to the leaves via the xylem. This movement occurs through a continuous column of water driven by transpiration and cohesion-tension forces. The concept of hydraulic architecture describes the arrangement and efficiency of these water transport pathways within plants. It includes structural features such as xylem vessel size, density, branching patterns, and root-to-shoot connectivity. Hydraulic architecture determines how plants balance water transport efficiency with safety from hydraulic failure (such as embolism or cavitation). Differences in hydraulic design explain why some plants thrive in dry environments while others require moist conditions.

Types of Hydraulic Architecture

Hydraulic architecture can be categorized based on structural and functional characteristics:

Based on Xylem Structure

Vessel-bearing plants (Angiosperms): Have wide vessels that allow rapid water transport but may be more vulnerable to cavitation.

Tracheid-bearing plants (Gymnosperms): Contain narrow tracheids that transport water more slowly but provide greater safety from embolism.

Based on Hydraulic Strategy

Efficiency-oriented (High Conductivity) Strategy : Plants with large xylem vessels that maximize water flow but are more vulnerable to drought stress.

Safety-oriented (Hydraulic Safety) Strategy: Plants with smaller vessels that reduce the risk of cavitation under water stress.

Based on Plant Growth Form

Herbaceous Plants: Generally have simpler hydraulic systems and shorter transport distances.

Woody Plants (Trees and Shrubs): Possess

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complex, branched hydraulic networks to transport water over long distances.

Isohydric vs. Anisohydric Behavior

Isohydric Plants: Maintain stable leaf water potential by closing stomata early during drought.

Anisohydric Plants: Allow more fluctuation in water potential and maintain gas exchange longer during drought.

Classification of Hydraulic Architecture

Hydraulic architecture may also be classified based on resistance distribution within the plant:

Root-Dominated Resistance: Most hydraulic resistance occurs in the roots.

Stem-Dominated Resistance: Resistance is primarily in the stem xylem.

Leaf-Dominated Resistance: Leaves provide the highest resistance and regulate overall water flow.

Additionally, plants may be classified according to vulnerability curves, which describe the percentage loss of conductivity under increasing water stress.

Impact on Water Transport

Hydraulic architecture significantly influences water movement through the following mechanisms:

Conductivity: Wide xylem vessels increase hydraulic conductivity and allow rapid water transport to support high photosynthesis rates.

Resistance: Hydraulic resistance along roots, stems, and leaves determines the overall efficiency of water flow.

Cavitation and Embolism: Air bubbles can form in xylem vessels under water stress, blocking water flow. The architecture determines vulnerability to such events.

Transpiration Regulation: Hydraulic properties influence stomatal behavior and transpiration rates.

Growth and Productivity: Efficient hydraulic systems support greater biomass production and canopy development.

Effects of Hydraulic Architecture

Drought Tolerance: Plants with safer hydraulic systems are more resistant to drought-induced embolism.

Climate Adaptation: Hydraulic traits determine species distribution across different climates.

Carbon Assimilation: Water availability affects photosynthesis; thus, hydraulic efficiency influences carbon gain.

Ecosystem Stability: Hydraulic failure in dominant species can affect entire ecosystems.

Agricultural Productivity: Understanding plant hydraulics helps in breeding drought-resistant crops.

Conclusion

Hydraulic architecture plays a central role in regulating water transport within plants. It reflects a balance between efficiency and safety, shaped by evolutionary adaptation to environmental conditions. Differences in xylem structure, hydraulic resistance, and vulnerability to cavitation determine plant survival under stress. As climate change intensifies drought conditions worldwide, studying plant hydraulic systems becomes increasingly important for agriculture, forestry and ecosystem management.

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Nano(bio) Fertilizers

Harshita Sharma and Raj Saini

Introduction

The global population has grown significantly, leading to challenges in producing enough food for everyone. To address this, the agricultural sector has heavily relied on chemical fertilizers and pesticides, to provide essential nutrients to crops and boost crop yields. However, this practice risks public health, contributes to environmental pollution, and leads to decline in soil fertility. Moreover, plants typically utilize only 10% to 50% of the total fertilizer provided, and a significant portion, ranging from 20% to 70%, may be lost to evaporation. The use of beneficial microorganisms (endophytic or rhizospheric) such as bacteria, actinomycetes and fungi, that promote plant growth, is now a popular method for sustainable agriculture. Endophytic plant growth-promoting microbes enter the leaves, flowers or internal tissues of the host plant, while rhizospheric microbes are free-living, soil-associated, residing near the root zone and may form a symbiotic relationship with plant. The use of biofertilizers helps in maintaining soil fertility and nutrient levels through various pathways and processes, such as phosphate solubilization, nitrogen fixation, siderophore production, release of plant growth regulators like indole acetic acid, 1-aminocyclopropane-1-carboxylate deaminase production, and antibiotic production. Additionally, plant growth-promoting microbes enhance the soil's ability to retain moisture and nutrients, while also improving the microbial community through direct and indirect interactions. They also help plants by boosting hormone synthesis and membrane transporter activity, protecting against harmful reactive oxygen species, and regulating stress-related genes that produce proteins, osmolytes, and antioxidants. A new strategy is needed to increase the shelf life and stability of biofertilizers, thus enhancing their effectiveness. Recently, there has been research on the use of nanoparticles (NPs) with one or more dimensions, smaller than 100 nm, to explore the potential applications of nanotechnology in agriculture. The unique optical characteristics, high absorption capacity, high surface-to-volume ratio and controlled release kinetics make nanoparticles attractive candidates for protecting and promoting plant growth.

Advantages and application in agriculture

This is an innovative technology involves the strategic blend of nanoparticles with biofertilizers. Nanobiofertilizer (NBF) is a type of biofertilizer that utilizes NPs to improve the delivery and effectiveness of nutrients to plants. These NBFs are designed

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to release nutrients in a controlled manner, reducing waste and increasing the efficiency of nutrient uptake by plants (Figure 1). This environmentally friendly technique boosts activities of soil enzymes and enhances the availability of key plant nutrients. By customizing the nanoscale components, it is possible to enhance their interaction with plant roots, leading to improved nutrient absorption and promoting healthier plant growth. Bacterial priming involves pre-exposing bacterial cells to certain stimuli, such as nanoparticles or other stressors, which results in a more robust and effective response to later challenges.

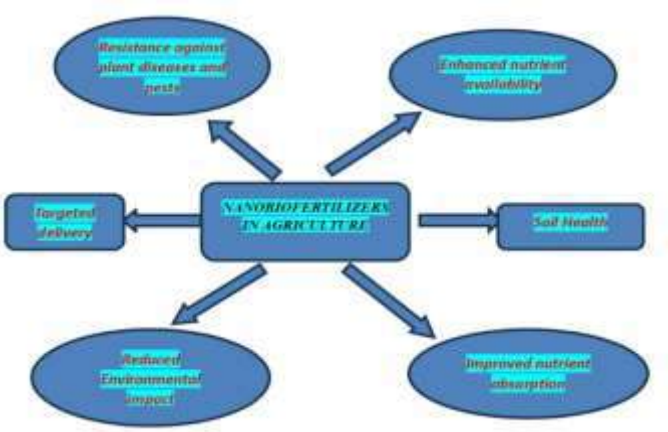


Figure 1: Advantages of Nano(bio)fertilizers

NBFs provide a controlled release of nutrients over a considerable period, leading to improved nutrient utilization efficiency and higher crop yields. This method also extends the shelf life of the biofertilizer, promotes the solubility of nutrients present in insoluble forms in the soil, and is cost-effective and environmentally friendly. This application of nanotechnology in agriculture can harness the unique properties of nanoscale materials to address the pressing issues in agriculture, such as nutrient delivery, crop protection, and sustainable farming practices, nanotechnology heavily relies on biosynthetic or "green" technologies, which are affordable, environmentally friendly, and cause minimal contamination. The biosynthesis of nanoparticles is an efficient bottom-up method that allows for the quick production of large amounts of NP. Nanoparticles made with biological or green technology have numerous advantages over traditionally generated ones, including increased stability and precise size. The application of NBF has been shown to dramatically increase plant growth. Coating nanoparticles with biofertilizers improves biofertilizer efficiency and causes nanoparticles to be released in the plant's rhizosphere slowly and consistently. The usage of NBFs is predicted to increase for agricultural development. Metal nanoparticles are commonly utilized as nano-pesticides, nano-fungicides, nano-biosensors, and nano-fertilizers to boost agricultural productivity. The development of nanotechnology-based technologies has the potential to significantly enhance the quality and productivity of agriculture. These technologies can help reduce chemical contamination, provide protection for crops against environmental hazards, and offer controlled release of nutrients to support plant growth. By improving the efficiency of fertilizers and reducing their environmental impact, nanotechnology-based solutions contribute to sustainable agriculture. Nano-biofertilizers, which combine nanofertilizers and biofertilizers, have the added benefit of promoting

soil fertility, moisture levels, and plant health. This innovative approach also helps minimize mineral losses during fertilization and improve overall crop yields. Nanotechnology offers great potential for addressing agricultural challenges. By employing nanomaterials and biofertilizers through nano-biotechnology, a unique, environmentally friendly, and economically valuable nanobiofertilizer can be developed. For the past 50 years, managing nutrients, particularly in regions with favourable climate conditions, has been crucial for improving global food security. Applying all necessary nutrients for plant growth in precise amounts and at the appropriate times has significantly advanced food production. To reduce the use of inorganic fertilizers and their impact on the environment, nanofertilizers are essential. NPs play a crucial role in reducing heavy metal toxicity and abiotic stress, although some research suggests that they may trigger oxidative stress signals in higher plants. Nanofertilizers enhance plant growth and productivity by providing specific nutrients in a nano form. Nanofertilizers are categorized into three types based on plant nutrient requirements: macro, micro, and nano-particulate fertilizers. Nanofertilizers have a diameter of less than 100 nm and can be in powder or liquid form. They provide nutrients to plants in a readily usable form. Nanofertilizers have important characteristics: (1) they deliver the right nutrients for plant growth through foliar and soil applications; (2) they are cost-effective and sustainable sources of plant nutrients; (3) they have high fertilization efficiency; and (4) they help prevent pollution. Additionally, nanofertilizers, also known as novel fertilizer alternatives, aid in removing pollutants from water. Encapsulating nanoparticles stabilizes bioactive substances that would otherwise be unstable due to extreme temperatures, ultraviolet light and oxidation. Nanoparticles or their ions may impact gene expression and DNA replication. At very low concentrations, nano-ions can interact with respiratory chain enzymes like NADH dehydrogenase, leading to the uncoupling of respiration from ATP generation. Some nanoparticles release harmful elements such as ions or heavy metals, which can be detrimental to bacterial cells. Quantum dots are semiconducting nanocrystals with an organic covering and shell surrounding a core of transition or noble metals. The toxic effects of nanoparticle-protein interactions result from the physical interactions of the nanoparticles with proteins or the generation of reactive oxygen species or other hazardous radicals. When plants face adverse conditions, nanoparticles act as cues that trigger various defence mechanisms. Nanoparticles are a better choice for fertilization due to their lighter weight, higher solubility, and larger surface area compared to regular salts. When combined with biofertilizers, they create nanobiofertilizers, which involve encasing biofertilizers in suitable nanomaterials. This method reduces the negative impacts of environmental stressors and there is a controlled release of nutrients into the soil. Nano-biofertilizers are more cost-effective, reduce the need for chemical fertilizers, increase nutrient availability and uptake,

and are environmentally beneficial. Combining bioinoculants and nanoparticles in nanobiofertilizers increases the likelihood of successful crop establishment by efficient transport of nutrients to desired site. Silicon nanoparticles are found in large quantities in soil and are thought to be beneficial for plants. They exist as monosilicic acids, with the chemical formula $Si(OH)_4$. Applying silicon promotes better plant growth by increasing the synthesis of metabolites and helping plants develop tolerance or resistance under stressful conditions. Plants have Si transporters that move Si against the concentration gradient. Zinc nanofertilizer has a high translocation rate in plants and releases nutrients gradually and in a controlled manner. The physical and chemical properties of the salts are altered when they are transformed into NPs, and this leads to improved plant application outcomes. For more acceptable nanobiofertilizers to be developed and made available to farmers, further research and development are required.

Conclusion

Large-scale commercialization of nanobiofertilizers is still pending. The formation and mode of action of nanobiofertilizers in plants at the molecular level are not well understood. To regulate distribution and release at the target site, the mutual interaction between nanoparticles and biofertilizer should be optimized in the form of nanobiofertilizer. More productive nanobiofertilizers must be created and put to use in real-world situations.

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Diffusion and Osmosis in Relation to Plant Water Relations

Sunny Kumar

Introduction

Plants need water to live and grow. Water helps the plant make food. It also helps in moving nutrients from one part to another. Water keeps the plant fresh and straight. The study of water movement in plants is called plant water relations. Two main processes help water move in plants. These are diffusion and osmosis. These processes work quietly inside the plant and help it survive.

Diffusion: Diffusion means movement of particles from a place where they are more to a place where they are less. It happens on its own. No energy is used in this process. In plants, diffusion happens in many ways. Oxygen goes inside the leaf by diffusion. Carbon dioxide also goes inside the leaf for making food. Water vapour comes out of the leaf during transpiration by diffusion. Diffusion helps the plant breathe and stay active.

Osmosis: Osmosis means movement of water through a thin membrane. Water moves from a place where water is more to a place where water is less. Plant cells have a semi-permeable membrane. Because of this, water can move in and out of the cell. This process keeps the cell alive and healthy.

Types of Osmosis

There are two simple types of osmosis.

Endosmosis: When water goes inside the cell, it is called endosmosis. This happens when the cell stays in plain water. The cell becomes full and firm. This is called turgid.

Exosmosis: When water goes out of the cell, it is called exosmosis. This happens when the cell stays in salty water. The cell becomes weak and soft. This is called flaccid.

Role of Osmosis in Plants

- ✓ Osmosis plays an important role in plants.
- ✓ It helps roots take in water from soil.
- ✓ It keeps the plant straight.
- ✓ It helps cells grow.
- ✓ It helps stomata open and close.
- ✓ It stops the plant from wilting.
- ✓ Without osmosis, the plant cannot stay healthy.

Diffusion and Osmosis in Plant Water Relations

Plant water relations talk about how plants take, move, and lose water. In roots, water goes inside root hairs by osmosis. Then it moves slowly from one cell to another. In leaves, carbon dioxide goes in by diffusion. Oxygen goes out by diffusion. Water vapour also goes out during transpiration. In cells, osmosis keeps the pressure inside the cell. Diffusion keeps gases balanced. So, both processes help the plant manage water.

Importance in Agriculture

These processes help crops grow well. Farmers give water so roots can take it in. Good soil helps water move easily. Healthy plants grow better

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when water stays balanced. So, diffusion and osmosis help in good farming.

Conclusion

Diffusion and osmosis are simple but useful processes in plants. Diffusion helps gases move in and out. Osmosis helps water go in and out of cells. Together they keep the plant fresh, strong, and alive. Without them, plant life is not possible.

The Role of Cocopeat in Modern Agriculture

Priya Satwadhar, Bhavna Sharma and Devshree Panchbhai

Abstract

Cocopeat, which is made from coir pith, is becoming a popular growing medium in soilless farming because it is eco-friendly, holds water well, and allows good air movement for plant roots. It supports healthy root growth, reduces the need for frequent watering, and helps prevent soil-borne diseases. Cocopeat also plays an important role in environmental sustainability. Converting coir pith into cocopeat helps reduce waste from the coconut industry and lowers environmental pollution. It is also an eco-friendly alternative to peat moss, which helps protect peat lands and reduce carbon emissions. Due to its use in hydroponics, greenhouse farming, and urban agriculture, cocopeat is becoming an important part of modern sustainable farming. To achieve the best results, proper addition of organic matter and nutrients is necessary for healthy plant growth and high crop yield.

What is Cocopeat?

Cocopeat, often referred to as coconut coir or coconut peat, is a fibrous material extracted from the husk of coconuts. It is a renewable resource and an excellent example of recycling agricultural waste. The husks of coconuts, which were previously discarded or burned, are now processed to create cocopeat, making it an eco-friendly choice for farmers. Cocopeat comes in various forms, including blocks, bricks, and loose fibers. It has a sponge-like texture and is capable of holding a substantial amount of water while still providing good aeration to plant roots. This unique combination of water retention and aeration properties makes cocopeat an ideal growing medium for a wide range of crops.



Benefits of Cocopeat in Modern Agriculture

Sustainability: One of the primary benefits of cocopeat is its sustainability. Coconut husks are abundant and their utilization in cocopeat production helps reduce waste and supports the coconut industry

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This sustainability aligns well with the growing emphasis on eco-friendly farming practices.

Excellent Water Retention: Cocopeat can hold up to eight to ten times its weight in water. This property is especially advantageous in regions with irregular rainfall or in hydroponic systems where precise control of moisture levels is crucial. It ensures that plants have access to water even during dry spells, reducing the risk of crop failure.

Improved Aeration: Unlike traditional soil, cocopeat has excellent aeration properties. It prevents soil compaction, allowing for better root development and oxygen uptake by plants. This enhances overall plant health and growth.

pH Neutral: Cocopeat has a near-neutral pH, typically ranging from 5.5 to 6.5. This makes it suitable for a wide variety of crops, as it can be easily adjusted to meet the specific pH requirements of different plants. In contrast, some soils may be naturally acidic or alkaline, requiring extensive amendments.

Disease Resistance: Cocopeat has natural antifungal properties, reducing the risk of soil-borne diseases. This benefit is particularly important in organic farming, where chemical pesticides and fungicides are avoided.

Biodegradable: Cocopeat is biodegradable and can be reused or composted after its initial use as a growing medium.

Applications of Cocopeat in Modern Agriculture

Container Gardening: Cocopeat is an excellent choice for container gardening. Its lightweight nature and ability to retain moisture make it perfect for potted plants, flowers, and vegetables. Gardeners can blend cocopeat with other soil components or use it as a standalone medium.

Hydroponics: In hydroponic systems, where plants grow without soil, cocopeat is a popular substrate. It provides support to the plants while allowing their roots to access nutrients and water solutions. The water retention capacity of cocopeat simplifies the management of nutrient solutions.

Seed Starting: Cocopeat is widely used for starting seeds. Its sterile nature and moisture-holding capability create an ideal environment for germination. Seedlings grown in cocopeat tend to establish strong root systems.

Soil Amendment: Cocopeat can also be mixed with traditional soil to improve its structure, water-holding capacity, and aeration. This amendment enhances the overall quality of the soil, promoting healthy plant growth.

Animal Bedding: Beyond plant cultivation, cocopeat is utilized as bedding material for animals. It is absorbent, odor-controlling, and comfortable for livestock, making it an excellent choice for animal welfare.

Erosion Control: Cocopeat can be used in erosion control applications. It helps stabilize soil on slopes, preventing erosion and providing a medium for vegetation to establish itself.

Mushroom Farming: Cocopeat is a common substrate for growing mushrooms. It provides an appropriate base for mycelium growth and helps

maintain moisture levels critical for mushroom cultivation.

Conclusion

Cocopeat has emerged as a game-changer in modern agriculture, offering a sustainable, versatile, and eco-friendly alternative to traditional soil-based growing mediums. Its ability to retain water, provide aeration, and promote healthy plant growth has made it a valuable asset for farmers, gardeners, and horticulturists worldwide.

Fruitful Balconies: Growing Fresh Fruits in Pots at Home

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Abstract

Rapid urbanisation and shrinking green spaces have limited opportunities for conventional fruit cultivation in cities. Growing fruit plants in pots offers a practical, space-efficient and sustainable alternative for urban households. This article highlights the importance of pot orcharding as a means to improve access to fresh, chemical-free fruits while enhancing biodiversity, reducing urban heat and promoting environmental awareness. Suitable fruit crops, including mango, guava, ber, pomegranate, citrus, strawberry, grapes and selected temperate fruits, are discussed with recommended varieties for container cultivation. Practical guidelines on pot selection, growing media composition, sunlight requirements, watering, nutrition, pruning and common problem management are provided to support successful cultivation. Beyond fruit production, pot orcharding contributes to nutritional security, climate-smart urban agriculture and mental well-being. With proper care and planning, even small balconies and terraces can become productive mini orchards, demonstrating that limited space need not limit abundance.

Introduction

Imagine plucking a fresh, juicy guava or lemon straight from a plant growing on your balcony. In today's fast-growing cities, where open spaces are shrinking and fresh produce often travels long distances before reaching our plates, growing fruit plants in pots offers a simple and rewarding solution. Most fruit plants are perennial and with the right varieties, adapt surprisingly well to container cultivation. Even in limited spaces such as terraces, balconies or small courtyards, urban dwellers can create their own "pot orchards." Apart from adding greenery and beauty to homes, potted fruit plants are easier to manage and often face fewer pest and disease problems compared to plants grown in open fields. With increasing awareness about health, nutrition and sustainable living, cultivating fruit plants in pots is becoming more than just a hobby; it is a smart lifestyle choice. For city residents who rarely have access to freshly harvested fruits, pot orcharding brings freshness, flavour, and nutrition right to their doorstep.

Why Grow Fruits in Pots?

In rapidly expanding cities, space has become a luxury. Apartments often lack backyards and independent houses have limited garden areas. Fruit plants grown in pots provide an excellent alternative, allowing residents to utilise balconies, terraces, rooftops and even window spaces productively. With dwarf and grafted varieties now widely available, even mango, guava, pomegranate, lemon and fig can thrive in containers.

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Container-grown fruit plants are easier to care for compared to field-grown trees. Watering, pruning, nutrient management and harvesting can be done conveniently. Since the root zone is confined, fertiliser application becomes precise and efficient. Any nutrient deficiency, wilting or growth issue can be quickly identified and corrected. Plants grown in pots are relatively isolated from surrounding vegetation that may harbour pests and pathogens. This reduces the spread of infestations and infections. Moreover, regular monitoring becomes simpler, allowing early intervention through eco-friendly methods such as neem oil sprays or biological control, thus minimising chemical use. One of the greatest advantages of pot cultivation is mobility. Plants can be moved to optimise sunlight exposure or protected during extreme weather conditions such as heavy rain or heat waves. This flexibility improves plant health and productivity while reducing environmental stress. When fruits are grown at home, there is greater control over inputs. Urban gardeners can adopt organic practices and avoid excessive chemical fertilisers and pesticides. The result is fresh, safe and residue-free produce harvested at peak ripeness, far superior in flavour and nutritive value to fruits transported over long distances. Beyond nutrition, pot orcharding contributes to emotional well-being. Gardening reduces stress, improves mood and fosters a sense of accomplishment. Nurturing a plant from flowering to fruiting creates a deep connection with nature, especially important in fast-paced urban lifestyles.

If every urban household grows even a few fruit plants, the cumulative production can significantly supplement household fruit requirements, enhancing access to fresh vitamins, minerals and antioxidants. Home-grown fruits reduce dependence on long supply chains, lower transportation-related carbon footprints and promote eco-conscious consumption habits. Pot orchards contribute to urban greening, moderate microclimates and support biodiversity. They represent a practical step towards climate-resilient and resource-efficient food production systems within cities.

Best Fruits for Pot Cultivation

Choosing the right fruit species and varieties is the foundation of successful pot orcharding. Dwarf, grafted and compact varieties are always preferred, as they adapt well to restricted root space, bear early and are easier to manage through pruning and training. With proper care, even traditional orchard crops can thrive on balconies, terraces and small urban spaces.



Figure 1: Fruits suitable for pot cultivation

Mango: Mango, often called the “king of fruits,” can be successfully grown in large containers when

suitable varieties are selected. Recommended varieties include Neelam, Amrapali, Bombay and Alphonso. Among these, Amrapali is particularly popular for pot cultivation due to its compact growth habit and regular bearing. With annual pruning and balanced nutrition, mango trees can remain productive for many years in pots.

Guava: Guava is one of the most adaptable fruit crops for container growing. Suitable cultivars include Lucknow 49, Black Guava, Grape Cluster, Benarasi and Harija. These varieties respond well to pruning, which helps maintain a manageable plant size while encouraging flowering and fruiting. Guava plants are hardy and comparatively easy to maintain.

Ber (Indian Jujube): Ber is drought-tolerant and well suited to warm climates, making it ideal for terrace gardening. Varieties such as Dandan, Gola, Umran and Seb can perform well in large pots. Regular pruning helps maintain canopy shape and improves fruit yield.

Pomegranate: Pomegranate is both ornamental and productive, making it a favourite for pot orchards. Recommended varieties include Country Large Red, Ganesh, Muscat Red, Yercaud and Mridula. It is hardy, requires moderate watering and responds well to container conditions.

Citrus Group: Citrus fruits are among the most reliable choices for pot cultivation due to their adaptability and year-round appeal.

Lime (*Citrus acida*) is also suitable for pot cultivation. Citrus plants are ideal for balconies and terraces. Their fragrant blossoms, glossy leaves and colourful fruits add aesthetic value while providing fresh, vitamin-rich produce.

Table 1: Citrus varieties suitable for pot cultivation

Fruit	Botanical Name	Recommended Varieties
Mandarin Orange	*Citrus reticulata*	Nagpur Mandarin, Kinnow Mandarin, Darjeeling Orange
Sweet Orange	*Citrus sinensis*	Jaffa, Washington Navel, Shamanti, Common Malta
Lemon	*Citrus limon*	Lucknow Seedless, Assam Lemon, Kagzi Kalan, Eureka Oblong, Italian Round

Strawberry: Strawberry is perfectly suited for small pots, hanging baskets and grow bags. The variety Pusa Early Dwarf is particularly suitable for container cultivation. With a shallow root system and quick bearing habit, strawberries are ideal for beginners.

Grapes (Climbers): Grapevines can be grown in large containers with proper support structures such as trellises or pergolas. With systematic training and pruning, grapes can produce good yields while enhancing the greenery of terraces and rooftops.

Temperate fruits: Several temperate fruits can also be successfully grown in pots, especially dwarf or grafted varieties. Fruits such as apple, peach, cherry, plum and pear adapt well to container cultivation when provided with suitable climatic conditions, adequate sunlight and proper care. With careful management, these temperate crops can thrive in limited spaces, making them ideal choices for urban pot orchards.

By carefully selecting suitable and preferably dwarf varieties, urban residents can transform limit-

ed spaces into productive mini orchards. Pot cultivation not only ensures fresh, nutritious fruits but also promotes sustainable and climate-smart urban agriculture.

Pot Selection and Growing Media

The success of fruit cultivation in containers largely depends on selecting the right pot and preparing a suitable growing medium. Since fruit plants are perennial and remain in the same container for several years, proper planning at the beginning is essential. The minimum pot size should range from 12 to 24 inches in diameter, depending on the crop and its growth habit. Smaller plants like strawberries can thrive in 12-inch pots, whereas mango, guava or pomegranate require larger containers (18-24 inches or more). Most importantly, the pot must have adequate drainage holes at the bottom. Without proper drainage, excess water accumulates, leading to waterlogging. This condition restricts oxygen supply to the roots and may cause root rot, ultimately affecting plant growth and yield.

Unlike field soil, container plants require a well-balanced and well-aerated growing medium. A simple and effective mixture includes:

40% garden soil: Provides structure and basic nutrients

30% compost or Vermicompost: Supplies organic matter and essential nutrients

20% cocopeat: Improves moisture retention and aeration

10% sand: Enhances drainage and prevents compaction

This combination ensures that the roots receive sufficient air, moisture and nutrients for healthy growth.

Importance of Drainage and Aeration

In pot cultivation, roots are confined to a limited space. If the medium retains too much water, oxygen availability decreases. Roots need oxygen for respiration and poor aeration can lead to fungal infections and root decay. Therefore, maintaining a balance between moisture retention and drainage is crucial to prevent waterlogging and promote strong root development. By selecting the right container and preparing a well-drained growing medium, urban gardeners can create a healthy foundation for productive and long-lasting pot orchards.

Sunlight and Watering: Adequate sunlight and proper watering are crucial for successful fruit production in pots. Most fruit plants require at least 6–8 hours of direct sunlight daily for healthy growth, flowering and fruiting. Insufficient light often leads to poor flowering and reduced yield. Watering should be deep but not too frequent. The idea is to moisten the entire root zone and then allow the top layer of soil to dry slightly before the next watering. Over-watering must be strictly avoided, as it can lead to waterlogging, root rot and nutrient leaching. Applying mulch (such as dry leaves, straw or coco husk) on the soil surface helps retain moisture, regulate soil temperature and reduce evaporation, especially during hot weather.

Nutrition: Since nutrients in pots are limited and can be depleted quickly, regular feeding is essential.

Applying organic manures such as compost or vermicompost every 30-45 days helps maintain soil fertility and supports continuous growth. During flowering and fruiting stages, liquid organic fertilisers (such as panchagavya, seaweed extract or compost tea) can be applied to enhance fruit set and development.

Pruning: Pruning plays a vital role in container fruit cultivation. It helps maintain plant size, improves air circulation and encourages better fruit yield. Removing weak, diseased or overcrowded branches keeps the plant healthy and productive. Additionally, pinching the growing tips of young shoots promotes lateral branching, resulting in a bushier plant with more flowering sites.

Common Problems and Solutions

Even with proper care, fruit plants in pots may face a few common issues. The key is to identify the cause early and take corrective action promptly. Most problems in pot cultivation arise due to improper watering or nutrient imbalance. With careful observation and timely management, these issues can be easily corrected, ensuring healthy growth and good fruit yield.

Table 2: Common Problems in Pot-Grown Fruit Plants and Their Practical Solutions

Problem	Cause	Solution
Yellow leaves	Nutrient deficiency	Add compost or vermicompost regularly
Flower drop	Water stress	Maintain regular and consistent watering
No fruiting	Lack of pollination	Practice hand pollination if necessary
Root rot	Overwatering	Improve drainage and reduce watering frequency

Benefits beyond Fruits

Growing fruit plants in pots offers advantages that extend far beyond harvesting fresh produce. A small pot orchard can positively influence the environment, community and even family lifestyle.

- ✓ Fruit plants create mini ecosystems in urban spaces. They provide habitat and food sources for beneficial insects, birds and microorganisms, thereby supporting local biodiversity even in densely populated areas.
- ✓ Flowering fruit plants attract bees, butterflies and other pollinators essential for fruit set and ecological balance. Encouraging pollinators in cities contributes to healthier urban green spaces.
- ✓ Plants help lower surrounding temperatures through shade and transpiration. Rooftop and balcony gardens can reduce heat absorption by concrete surfaces, contributing to a cooler microclimate and improved air quality.
- ✓ When children participate in growing fruits, they learn where food comes from and develop an appreciation for nature and healthy eating. Gardening nurtures responsibility, patience and environmental awareness from a young age.

Thus, pot orcharding is not merely about fruit production; it is a step towards greener cities, healthier lifestyles and more sustainable urban living.

Conclusion

A single pot placed on a balcony or terrace today can become a bowl of fresh, nourishing fruits tomorrow. Pot orcharding proves that space is not a limitation, only willingness is. With patience, regular care and the right choice of plants, even the smallest

corner of a home can transform into a thriving source of health and happiness. In nurturing a fruit plant, we do more than grow food; we cultivate sustainability, resilience and a deeper connection with nature. Even the most modest space can yield abundance when tended with dedication and hope.

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Application of Crop Physiology in Resource Use Efficiency

Ananya Singh and Ravinder Kaur

Abstract

Crop physiology plays an important role in improving resource use efficiency in agriculture. Resources like water, nutrients, light and land are limited and need to be utilized properly. Understanding physiological processes of crops helps in better management of these resources. Efficient use of resources not only increases crop yield but also reduces cost of cultivation and environmental pollution. This article explains how principles of crop physiology are applied to improve resource use efficiency in modern agriculture.

Introduction

In present time, agriculture is facing the problem of limited natural resources and increasing population. Farmers need to produce more food with less inputs. Crop physiology helps in understanding how plants use water, nutrients and light for their growth and development. By applying physiological knowledge, we can improve efficiency of resource utilization in crops. Resource use efficiency means getting maximum output from minimum input. This concept is very important for sustainable agriculture, especially in countries like India.

Application of Crop Physiology in Improving Resource Use Efficiency

Water Use Efficiency: Water is one of the most important resource in agriculture. Crop physiology helps in understanding transpiration, stomatal regulation and water absorption by roots. By selecting varieties with better root system and efficient stomatal control, water use efficiency can be improved. Techniques like deficit irrigation and mulching are also based on physiological principles. Crops with higher water use efficiency perform better under drought conditions.

Nutrient Use Efficiency: Nutrient use efficiency refers to the ability of plant to absorb and utilize nutrients effectively. Physiological knowledge about nutrient uptake, transport and assimilation helps in improving fertilizer management. Balanced fertilization according to crop growth stage increases nutrient efficiency. Excess use of fertilizers not only waste money but also harm the environment, so proper understanding is necessary.

Light Use Efficiency: Photosynthesis is the main process through which plants convert light energy into chemical energy. Crop physiology helps in improving light interception by proper plant spacing and canopy management. Development of varieties with better leaf arrangement improves light use efficiency. Higher light use efficiency results in more biomass and yield.

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Carbon Use Efficiency: Efficient carbon fixation through photosynthesis increases dry matter production. Reduction in photorespiration losses and improvement in C_3 and C_4 crop performance are part of physiological advancements. Crops like maize (C_4 plant) show better carbon use efficiency compared to some C_3 crops under high temperature.

Integration with Agronomic Practices: Application of physiological principles in agronomy helps in optimizing sowing time, irrigation schedule and nutrient application. For example, understanding critical growth stages of crops helps in applying irrigation at right time. This improves resource utilization and crop productivity.

Importance in Sustainable Agriculture

Improving resource use efficiency reduces production cost and increases profitability of farmers. It also minimizes environmental problems like soil degradation and water pollution. In Indian agriculture, where resources are limited and climate variability is high, efficient use of water and nutrients is very important. Crop physiology provides scientific base for this improvement.

Conclusion

Application of crop physiology in resource use efficiency is essential for sustainable and profitable agriculture. Understanding physiological processes like photosynthesis, transpiration and nutrient uptake helps in better utilization of water, nutrients and light. By integrating physiological knowledge with crop management practices, higher productivity can be achieved with less inputs. Therefore, crop physiology plays significant role in modern agriculture.

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Mineral Nutrition and Its Influence on Crop Growth and Yield

Komal Singh and Ravinder Kaur

Abstract

Mineral nutrition is one of the most important factors affecting crop growth and productivity. Plants require various essential nutrients for proper growth, development and yield formation. These nutrients are absorbed from soil in the form of minerals. Deficiency or excess of any nutrient can disturb plant metabolism and reduce crop yield. Proper management of mineral nutrition helps in improving crop performance and soil health. This article discusses the role of mineral nutrients and their influence on crop growth and yield in agriculture.

Introduction

Plants need nutrients just like human beings need food for proper growth. Mineral nutrition refers to the supply and utilization of essential mineral elements by plants. These nutrients are mainly absorbed through roots from soil solution. In agriculture, balanced mineral nutrition is very important for achieving higher yields. If crops do not get proper nutrients at right time, their growth becomes weak and yield decreases. Therefore understanding mineral nutrition is necessary for farmers and students of agriculture.

Essential Mineral Nutrients and their role

Plants require about 17 essential elements for their normal growth. These nutrients are classified into macronutrients and micronutrients.

Macronutrients: Macronutrients are required in large quantity. These include Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sulphur (S).

Nitrogen is important for vegetative growth and chlorophyll formation. Deficiency causes yellowing of leaves and stunted growth.

Phosphorus helps in root development and energy transfer in plant. Lack of phosphorus may result in poor root growth.

Potassium regulates water balance and enzyme activation. It also improves disease resistance in crops. Improper supply of these nutrients directly affect crop yield.

Micronutrients: Micronutrients are required in small amounts but they are equally important. These include Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Boron (B), Molybdenum (Mo) and Chlorine (Cl).

Deficiency of micronutrients can cause various disorders like chlorosis, poor flowering and low seed formation. In many Indian soils, zinc deficiency is commonly observed.

Influence of Mineral Nutrition on Crop Growth

Mineral nutrients influence various physiological processes such as photosynthesis, respiration

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and protein synthesis. Adequate nitrogen increases leaf area and biomass production. Phosphorus improves early growth and flowering. Potassium enhances stress tolerance and improves grain filling. Balanced nutrition results in healthy plants with better growth and development.

Effect on Crop Yield

Yield is directly related to proper nutrient management. When crops receive balanced fertilizers according to their requirement, yield increases significantly. On the other hand, excess use of fertilizers may cause nutrient imbalance and environmental pollution. So proper dose and timing of fertilizer application is very important.

Integrated nutrient management system is now being promoted to maintain soil fertility and sustain crop productivity.

Conclusion

Mineral nutrition plays a crucial role in determining crop growth and final yield. Essential nutrients are required for various metabolic and physiological processes in plants. Deficiency or imbalance of nutrients can reduce productivity. Therefore, proper understanding and management of mineral nutrition is necessary for sustainable agriculture. Farmers should adopt balanced fertilization practices for better crop performance and soil health.

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Characterization of Soil Texture by Hydrometer-Based Particle Size Analysis

Pankaj Singh, Kumar Anshuman and Ashish Kumar

Introduction

The ratio of clay, silt and sand is called soil texture. Mainly two type of soil determination (1) International pipette method (2) Bouyoucos hydrometer method. International pipette method is most accurate but more time consuming. Hydrometer method is less accurate but less time consuming. International pipette method and hydrometer method based on the principle of Stokes Law (Jury and Horton, 2004). Particle size of soil (According to ISSS) coarse sand 2-0.2 mm, fine sand 0.2-0.02 mm silt 0.02-0.002 mm and clay <0.002 mm. Mainly three group of soil texture classes namely sandy soils, loamy soil and clayey soil and one another textured soil namely silty soil. Sandy soil - At least 70% sand separates and 15% clay particles. Loamy soil defined as mixture of sand, silt and clay particles is equal amount. Clayey soil- At least 35% of clay separate these soils are fine in texture. Silty soil - At least 80% of silt and 12% of clay. Bouyoucos' method is quicker and convenient for routine analysis but less accurate than the Pipette method. Bouyoucos' method is based on the principle that the there is a continuous decrease in the density of soil suspension with time at the rate the particles fall below the level of hydrometer.

Mechanical analysis of soil sample at KNIPSS Sultanpur

Principle: Hydrometer method based on the principle that the density of the particles at a given depth decreases as a homogeneously dispersed suspension settles. First settles of sand particles followed by silt and then by clay. The organic matter is oxidized with H_2O_2 while $CaCO_3$ and oxides of Fe and Al are removed by treating the sample with dilute HCL and soluble salts by filtration with distilled water.

Requirements: Hydrometer, 1000 ml measuring cylinder, Thermometer, Glass rod and mechanical stirrer.

Reagents

- ✓ 10% Sodium hexametaphosphate
- ✓ 30% Hydrogen peroxide (H_2O_2)

Procedure

- ✓ Weighing 50 g of soil sample and add 500 ml of beaker.
- ✓ Add 25 ml Hydrogen peroxide and stirrer well. (Roll of hydrogen peroxide destroy the organic

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matter)

- ✓ Add 200 ml of distilled water, and add 150 ml of sodium hexametaphosphate solution stir with the help of glass rod.
- ✓ Shake the contents of the beaker with the help of mechanical stirrer for 10 minutes.
- ✓ After 10 minutes transfer the contents in a 1000 ml measuring cylinder and volume make for distilled water.
- ✓ Shake the contents of the measuring cylinder by moving up and down the time immediately.
- ✓ Take the first reading exactly 40 seconds after placement of hydrometer.
- ✓ Remove the hydrometer carefully after reading and wash using distilled water.
- ✓ Exactly after 2 hours, place the hydrometer again into the suspension and note the hydrometer reading (second reading).
- ✓ Same the run blank without soil and record the room temperature in °F {temperature recorded in *****1.8**}** **+** 32=Temperature in °F.

Observation Table

	First Reading	Second Readng	Temperature First °F	Temperature Second °F
Blank	2.5	1.2	75.92	72.5
Sample	20.5	6.5	75.92	72.5

Calculation

Correction Factor (CF) = (Actual room temperature in° f – 68) *0.2

Silt + clay (%) = (S-B) +CF/wt. of soil sample (g)*100

Where,

S=first reading of sample

B=first reading of blank

CF = correction factor

CF = (75.92-68)*0.2 =1.584

Clay + silt (%) = **(**20.5-2.5)+1.584/50*100

=29.16% (29%)

Clay (%) = (s-b) + CF/wt. of soil sample (g)*100

CF= (72.5-68)*0.2= 0.9

Clay (%) = (6.5-1.2) +0.9/50*100 =12.4 (12%)

Sand (%) =100-(clay + silt %) =100-29 =71%

Silt (%) = (clay + silt – clay) = 29-12 =17%

Result

Clay + Silt % = 29
Sand = 71%
Silt = 17%
Clay = 12%
Soil Texture = Sandy Loam



Fig. 1: USDA soil textural triangle

Advantages of hydrometer method

- ✓ Hydrometer method is less time consuming than International method
- ✓ It is very simple method
- ✓ It is cost effecting
- ✓ Highly suitable fine particles

Limitations of hydrometer method

- ✓ Hydrometer method is less accurate than International method.
- ✓ Highly present in organic matter so result is not accurate.

- ✓ Effect of temperature change.
- ✓ It is no use of saline and high calcium carbonate soil.



Fig. 2. Hydrometer reading recorded during soil particle size analysis using the Bouyoucos hydrometer method

Conclusion

The hydrometer method is a reliable and cost-effecting technique for determining the particle size distribution of soil. The hydrometer method is based on the principle that the density of the particles at a given depth decreases as a homogeneously dispersed suspension settles. This method is particularly useful for fine texture soils. Dispersing reagent (sodium hexa-meta phosphate or calgon reagent) is added to prevent the clay particles to re-unite. Overall, the hydrometer method remains an important analytical tool for understanding soil texture and its related properties.

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Hydroponics for Leafy Greens

Aarya Kumari

Abstract

Hydroponics has emerged as a promising soilless cultivation technology for the sustainable production of green leafy vegetables under conditions of limited land, water scarcity, and climate variability. By supplying essential nutrients directly through aqueous solutions, hydroponic systems enable precise control over plant growth conditions, resulting in higher productivity, improved quality, and efficient resource utilization. Leafy vegetables such as lettuce, spinach, coriander, fenugreek, amaranths, kale, and mustard greens are particularly well suited for hydroponic cultivation due to their short crop cycle and high market demand. Recent advances in nutrient management, automation, protected cultivation, LED lighting, vertical farming, and integration with smart technologies have further enhanced the efficiency of hydroponic systems. This article discusses the principles, systems, crop suitability, advantages, challenges, recent research developments, and future scope of hydroponic production of green leafy vegetables, highlighting its potential role in climate-smart and urban agriculture.

Introduction

Green leafy vegetables constitute an essential component of human nutrition. They are rich sources of vitamins (A, C, K, and folate), minerals (iron, calcium, magnesium), dietary fiber, and bioactive compounds with antioxidant properties. Regular consumption contributes to improved immunity, prevention of micronutrient deficiencies, and overall health promotion. However, conventional soil-based cultivation of leafy vegetables faces several challenges. Rapid urbanization has reduced cultivable land, while soil degradation, salinity, declining fertility, and unpredictable climatic conditions have affected productivity. Excessive use of fertilizers and pesticides has also raised concerns regarding environmental sustainability and food safety.

Hydroponics, defined as the cultivation of plants without soil using nutrient-rich water solutions, has emerged as a viable alternative production system. The term originates from the Greek words “hydro” (water) and “ponos” (labor), meaning “working water.” Unlike traditional agriculture, hydroponics allows growers to regulate nutrient supply, water availability, and environmental conditions with precision. This makes it particularly suitable for green leafy vegetables, which require rapid vegetative growth and uniform quality. Scientific term of hydroponics is hydroculture which is a method of growing plants without soil, where plant roots are supplied with a nutrient-rich water solution and directly absorbed by roots.

Principles of Hydroponic Cultivation

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- ✓ The fundamental principle of hydroponics is that soil serves primarily as a medium for anchorage and nutrient supply. When nutrients are dissolved in water and delivered directly to plant roots, soil becomes unnecessary.
- ✓ Plants require essential macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, sulphur) and micronutrients (iron, zinc, manganese, copper, boron, molybdenum) for optimal growth. In hydroponics, these nutrients are supplied in balanced concentrations through nutrient solutions. Maintaining appropriate pH (generally 5.5-6.5) and electrical conductivity (EC) ensures efficient nutrient uptake.
- ✓ Oxygen availability in the root zone is critical. Aeration systems or intermittent flow designs prevent root hypoxia. Controlled environmental parameters such as temperature, humidity, and light further enhance growth performance.

Hydroponic Systems for Leafy Vegetables

Leafy vegetables are ideally suited to hydroponic systems due to their shallow root systems and short growth cycles. The most commonly used systems include:

Nutrient Film Technique (NFT): A thin film of nutrient solution continuously flows along channels where plant roots are exposed. NFT is widely adopted for lettuce and similar crops because of its efficient nutrient use and rapid growth.





Deep Water Culture (DWC): It is a simple hydroponic method in which plant roots are suspended directly in a nutrient rich water solution. An air pump with an air stone supplies oxygen to the roots preventing suffocation and promoting faster growth. Plants are grown on floating rafts, with roots submerged in aerated nutrient solution. This system supports uniform growth and is simple to manage. DWC is widely used for growing leafy vegetables such as lettuce, spinach, and herbs.

Media-Based Systems: It is soilless cultivation method where plants grow in an inert supporting medium instead of soil, and nutrients are supplied through ware based nutrient solution. Plants are grown in inert media such as cocopeat, perlite, vermiculite, or rockwool. Nutrients are delivered through drip irrigation.

Vertical Hydroponics: Stacked growing channels maximize production per unit area, making it ideal for urban and indoor farming.

Types of Vertical Hydroponic System

Vertical NFT-Working: A thin film of nutrient solution flows continuously through vertically arranged channels or pipes. Roots absorb nutrients while the excess solution recirculates back to the reservoir.

Tower system: Plants are arranged in vertical columns or towers with planting holes on sides. Nutrient solution is pumped to the top and trickles downward, wetting roots.

Wall mounted system: Plants grow in panels or pockets fixed on walls. Nutrient solution is supplied

through drip irrigation or a thin flowing system.

Stacked media beds: Multiple grow trays filled with inert media (cocopeat, perlite, clay pellets) are stacked vertically. Nutrient solution is supplied by drip or flood-and-drain method.

Suitable Green Leafy Crops

Hydroponic cultivation is particularly effective for:

- ✓ Lettuce (*Lactuca sativa)*
- ✓ Spinach (*Spinacia oleracea)*
- ✓ Fenugreek (*Trigonella foenum-graecum*)
- ✓ Coriander (*Coriandrum sativum)*
- ✓ Amaranthus species
- ✓ Kale (*Brassica oleracea var. acephala)*
- ✓ Mustard greens (*Brassica juncea)*

These crops exhibit rapid vegetative growth, short harvest intervals, and high consumer demand.

Advantages of Hydroponic Leafy Vegetable Production

- ✓ Water Efficiency- Hydroponic systems use up to 80-90% less water than conventional farming due to recirculation.
- ✓ Higher Productivity
- ✓ Precise nutrient management promotes faster growth and increased yield per unit area.
- ✓ Year-Round Production
- ✓ Under protected conditions, crops can be grown irrespective of seasonal variations.
- ✓ Improved Quality and Safety
- ✓ Produce is free from soil contamination and often requires minimal pesticide application.
- ✓ Space Optimization
- ✓ Reduced Weed Pressure
- ✓ Vertical farming increases productivity in limited spaces.
- ✓ Absence of soil eliminates weed competition.

Recent Advances and Research Developments

Recent research has significantly improved hydroponic technology:

LED Lighting Technology: Advances in light-emitting diode (LED) systems allow optimization of light spectra for plant growth. Red and blue light combinations have been shown to enhance photo-synthesis, leaf expansion, and nutrient accumulation in lettuce and spinach.

Automated Nutrient Monitoring: Smart sensors now enable real-time monitoring of pH, EC, dissolved oxygen, and temperature. Automated dosing systems maintain optimal nutrient balance, reducing manual errors.

Integration with IoT and AI: Internet of Things (IoT)-based hydroponic systems allow remote monitoring and data-driven decision-making. Artificial intelligence models are being developed to predict nutrient requirements and optimize growth conditions.

Biofortification Strategies: Research indicates that hydroponic systems can be used to enhance micro-nutrient content, such as iron and zinc enrichment in leafy vegetables, by adjusting nutrient formulations.

Organic and Sustainable Nutrient Solutions: Studies are exploring the use of organic nutrient formulations and microbial inoculants to improve sustainability and reduce chemical dependency.

Vertical Farming and Controlled Environment

Agriculture: Integration of hydroponics with vertical farming under controlled environment agriculture (CEA) enhances land-use efficiency and enables urban food production.

Aquaponics Integration: Combining hydroponics with aquaculture creates aquaponic systems, where fish waste supplies nutrients for plants, promoting circular resource use.

Challenges and Constraints

Despite its benefits, hydroponics has limitations:

- ✓ High initial setup cost
- ✓ Dependence on electricity and infrastructure
- ✓ Requirement for technical expertise
- ✓ Risk of rapid disease spread in recirculating systems
- ✓ Limited suitability for deep-rooted crops

However, technological improvements and decreasing equipment costs are gradually addressing these issues.

Future Prospects in India

Hydroponics offers immense potential in India, particularly in urban and peri-urban areas. With increasing awareness about safe, pesticide-free food and growing consumer demand for fresh produce, hydroponic leafy vegetables can play a crucial role in food systems. Government initiatives supporting startup agriculture, protected cultivation, and smart farming technologies further encourage adoption. Research institutions and agricultural universities are also promoting training and awareness programs. Hydroponics can contribute to climate-resilient agriculture by reducing water use, minimizing land dependency, and enabling production under controlled conditions. For young entrepreneurs and educated rural youth, it provides an opportunity for high-value vegetable production.

Hydroponics of leafy plant growth has been successfully carried out in space:

- ✓ NASA astronaut also grew mustard red roman lettuce in 2015 aboard the International Space station using veggie system
- ✓ After lettuce experiments, astronauts grew mustard green hydroponically on the International Space Station.

Conclusion

Hydroponic cultivation of green leafy vegetables represents a transformative approach to modern agriculture. By eliminating soil constraints and optimizing nutrient delivery, it ensures efficient resource use, enhanced productivity, and improved produce quality. Recent advances in lighting, automation, digital monitoring, and vertical farming have further strengthened its viability. Although challenges related to cost and technical knowledge remain, hydroponics holds strong promise for sustainable, climate-smart, and urban agriculture. In many parts of the country, issues such as soil degradation, salinity, irregular rainfall and declining groundwater levels are affecting productivity of vegetable crops, Hydroponics offer a practical solution by enabling efficient water use, precise nutrient management and in non-arable areas like rooftops, urban spaces and arid regions of Rajasthan and Gujarat With continued research, innovation,

and policy support, hydroponic leafy vegetable production can significantly contribute to future food security and nutritional well-being.

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Membrane Permeability Mechanisms in Plants

Badal Giriraj and Ravinder Kaur

Introduction

Membrane permeability in plants refers to the ability of the cell membrane to control the movement of substances into and out of the cell. The plant cell membrane, also known as the plasma membrane, is selectively permeable, meaning it allows some substances to pass while restricting others. This selective movement is essential for maintaining cellular homeostasis, nutrient uptake, waste removal, and overall plant growth and development.

Structure of the Plant Cell Membrane

The plant cell membrane is primarily composed of a phospholipid bilayer with embedded proteins. The phospholipids have hydrophilic (water-attracting) heads and hydrophobic (water-repelling) tails, which form a semi-permeable barrier. Membrane proteins play a crucial role in transport mechanisms by acting as channels, carriers, or pumps. Carbohydrates attached to proteins and lipids also contribute to cell recognition and communication.

Passive Transport Mechanisms

Passive transport is the movement of substances across the membrane without the use of cellular energy (ATP). It occurs along the concentration gradient, from an area of higher concentration to lower concentration. The main types include:

Diffusion: Movement of small molecules like oxygen and carbon dioxide directly through the lipid bilayer.

Osmosis: Movement of water molecules through a selectively permeable membrane.

Facilitated Diffusion: Movement of molecules through specific protein channels or carrier proteins.

Active Transport Mechanisms

Active transport requires energy in the form of ATP to move substances against their concentration gradient. This mechanism is vital for the uptake of mineral nutrients such as nitrate, potassium, and phosphate ions from the soil into root cells. Protein pumps embedded in the membrane actively transport ions, maintaining proper ion balance within plant cells.

Bulk Transport

Bulk transport involves the movement of large molecules or particles across the membrane. In plants, this includes processes such as endocytosis and exocytosis. Endocytosis allows the cell to take in materials by forming vesicles, while exocytosis helps in secreting substances like enzymes and hormones outside the cell.

Factors Affecting Membrane Permeability

Several factors influence membrane permeability in plants:

Temperature: High temperatures increase membr-

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ane fluidity, while low temperatures reduce permeability.

pH Levels: Extreme pH can damage membrane proteins and affect transport.

Ion Concentration: Changes in ion levels influence osmotic balance.

Chemical Substances: Certain chemicals or toxins may disrupt membrane structure.

Conclusion

Membrane permeability mechanisms are essential for plant survival. They regulate nutrient absorption, water balance, gas exchange, and waste removal. Efficient membrane transport ensures proper photosynthesis, respiration, and growth. Any disturbance in membrane permeability can lead to reduced productivity and stress in plants.

Why Communication Matters more than Technology in Farm Adoption

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Abstract

Despite rapid technological advancements in Indian agriculture, the adoption of many innovations at the farm level remains limited. This article argues that the gap between technological availability and actual adoption is primarily a communication challenge rather than a technological one. Drawing on diffusion theory, empirical studies, and field-level evidence, the article highlights how farmers' knowledge, attitudes, perceptions of risk, and trust in information sources shape adoption decisions. Evidence from India demonstrates that ineffective communication, lack of participatory approaches, and insufficient follow-up support often constrain technology uptake, even when technologies are economically viable. The article further emphasizes the role of extension communication, farmer field schools, digital advisory services, and community media in enhancing adoption outcomes. It concludes that sustainable agricultural development requires prioritizing farmer-centric, participatory, and context-sensitive communication strategies, as technology alone cannot deliver impact without effective communication.

Introduction

Indian agriculture today stands at a paradoxical crossroads. On one hand, farmers have access to improved crop varieties, precision farming tools, mobile-based advisories, soil testing services, and digital platforms. On the other hand, the actual adoption of many of these technologies at the field level remains uneven and often disappointingly low.

This raises a fundamental question: if agricultural technologies are scientifically sound and economically beneficial, why do farmers hesitate to adopt them?

The answer lies not in technology alone, but in communication.

Technology Availability is not the same as Technology Adoption

For decades, agricultural development policies assumed that once a technology was introduced, farmers would adopt it automatically. However, empirical research has consistently shown that adoption is influenced by far more than technical superiority. A classic global review by Feder *et al.* (1985) demonstrated that adoption decisions are shaped by information access, risk perception, resource availability, and farmers' understanding of innovations not merely by their effectiveness.

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Similar conclusions have been drawn in Indian agricultural contexts, where communication effectiveness, perceived benefits, and farmer awareness strongly influence adoption outcomes (Kalariya *et al.*, 2024). Field-level studies in India further confirm that knowledge and clarity about a practice strongly determine whether farmers adopt it or not (Kalariya and Gulkari, 2024).

Communication: The Missing Link between Innovation and the Farmer

Agricultural communication is often misunderstood as the simple transfer of information. In reality, it is a process of meaning-making, where farmers interpret, evaluate, and adapt information within their own socio-economic and agro-ecological context. According to diffusion theory, farmers move through stages awareness, interest, evaluation, trial, and adoption and communication channels play a decisive role at every stage (Rogers, 2003).



When communication fails to:

- ✓ Use local language,
- ✓ Explain benefits clearly,
- ✓ Address farmers' doubts, or
- ✓ Provide opportunities for interaction, technologies remain unused or partially adopted.

Farmers are not resistant they are risk managers

Farmers are often labeled as "resistant to change," but this is a misconception. Farming is inherently risky, shaped by unpredictable weather, market volatility, and limited margins for error. Every new technology represents a potential risk. Studies from Gujarat show that even when farmers are aware of recommended practices, adoption remains constrained due to communication gaps, lack of demonstrations, and insufficient follow-up support (Kalariya and Gulkari, 2024).

These findings underline an important reality: non-adoption is usually a communication failure, not a farmer failure.

Attitude and Perception Matter more than access

Access to technology does not guarantee positive attitudes toward its use. Research examining farmers' attitudes toward information and communication technologies (ICTs) found that socio-personal characteristics significantly influence how farmers perceive and use digital tools (Ganvit *et al.*, 2025). This explains why identical digital advisories may work for some farmers but fail for others. Uniform communication strategies cannot address diverse farmer realities.

Extension Communication: From Telling to Engaging

Agricultural extension systems were designed to bridge the gap between research institutions and farmers. However, extension becomes effective only when it shifts from one-way dissemination to participatory engagement. Participatory approaches such as Farmer Field Schools (FFS) have demonstrated significantly higher adoption of environme-

ntally friendly practices because farmers learn by doing, observing, and discussing (Cai *et al.*, 2022). Such approaches reinforce trust, improve understanding and empower farmers to make informed decisions.

Digital Agriculture Still Needs Human Touch

Mobile phones, apps, and SMS advisories have expanded the reach of extension services. However, evidence shows that digital tools alone produce modest improvements unless supported by interpersonal communication (Aker, 2011). Large-scale digital extension experiments in India were designed to detect small improvements in knowledge and adoption, highlighting that technology is effective only when communication is context-sensitive and credible. Digital tools should therefore be seen as communication enhancers, not replace-ments for human interaction.



Community Media and Local Trust

Community radio offers a powerful example of effective agricultural communication. Locally produced programs, farmer voices, and use of regional language create high credibility. A national evaluation in India found that 78% of listeners perceived community radio programs as useful and socially relevant, demonstrating the strength of localized communication.

Why Communication Must Come First in Farm Adoption

Across studies and field experiences, one message is clear: farmers do not adopt technologies they adopt confidence, clarity and credibility.

When communication is effective: Even low-cost technologies succeed.

When communication is weak: Even advanced innovations fail

Conclusion

India does not suffer from a lack of agricultural technologies. It suffers from a communication gap between innovation and implementation. For sustainable agricultural development, policymakers, extension professionals, and development agencies must prioritize:

- ✓ Farmer-centric communication,
- ✓ Participatory learning,
- ✓ Trust-building mechanisms, and
- ✓ Continuous feedback.

Technology may drive progress, but communication determines impact.

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Post-Harvest Fruit Losses in India: Can Artificial Intelligence Strengthen the Supply Chain?

Bhautik Bagda, B. S. Kalariya and Mohit Kumar

Background

Agriculture and its allied sectors remain the backbone of India's rural economy, providing livelihood to a majority of the population. During 2023-24, the sector contributed about 17.7 per cent to India's Gross Value Added (GVA) at current prices, underlining its continued economic significance (MoA&FW, 2024). Beyond income generation, agriculture plays a crucial role in ensuring food security, rural employment, and sustainable natural resource management (Savaria *et al.* 2020). In recent years, horticulture has emerged as a sunrise sector within Indian agriculture. Supported by diverse agro-climatic conditions and rich genetic diversity, India produces a wide range of fruits throughout the year (Jha *et al.* 2019). Horticulture offers higher value realization than many traditional crops and has become an important driver of farm income, employment, and agricultural exports. During 2023-24, India recorded a total horticultural production of 352.23 million tonnes from an area of 28.63 million hectares. Fruits alone accounted for about 112.73 million tonnes from 7.15 million hectares, with an average productivity of 15.75 metric tonnes ha^{-1} (PIB 2024; MoA&FW, 2024). This strong production base has enabled India to access export markets, with fruit and vegetable exports valued at ₹ 13,185.30 crores (USD 1635.95 million) with fruits contributing ₹ 6,219.46 crores (USD 770.70 million) and vegetables ₹ 6,965.83 crores (APEDA, 2024). Despite this encouraging production and export performance, post-harvest losses remain a serious concern. Post-harvest loss refers to any quantitative or qualitative deterioration of agricultural produce after harvest that reduces its market value. Although India is the second-largest producer of fruits globally, per capita availability of fruits and vegetables remains relatively low at 104 g day^{-1} and 207 g day^{-1}, respectively, compared to the global average of 120 g day^{-1} and 300 g day^{-1} (Gajanana *et al.,* 2011). High post-harvest losses are one of the primary reasons for this gap.

Magnitude and Economic Significance of Post-Harvest Losses

After harvest, fruits and vegetables suffer losses ranging from 15 to 50 per cent due to poor handling during storage, transportation, packaging, processing, *etc.* (Roy, 1989; Kiaya, 2014).

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Singh *et al.* (2014) estimated that nearly 40 per cent of fruits and vegetables are wasted annually because of similar inefficiencies. Although India's food proce-ssing industry ranks 5th globally in terms of production, consumption and exports, the processing rate of perishable produce is only 7 per cent, which is significantly lower than that of developed countries. Post-harvest losses among 11 major fruits, namely, apple, banana, citrus, grapes, guava, mango, papaya, sapota, pineapple, pome-granate and muskmelon, range from 6.02 per cent in pineapple to 15.05 per cent in guava. These losses primarily arise due to inefficiencies in harvesting, sorting, grading, handling and inadequate storage conditions (Kumari and Dhingra, 2024). According to FAO (2016), in developing countries, up to 44 per cent of fruits and vegetables are lost between harvesting and consumption. These post-harvest issues result in 25-33 per cent quality deterioration with 6.9-13 per cent losses occurring during harvest-ing, handling, and storage stages. From an economic perspective, India incurred a total quantitative loss of ₹ 92,651 crores across 45 major crops, of which ₹ 16,644 crores were attributed to losses in 7 major fruits (MoFPI, 2023). During 2021-22, total fruit production stood at 107.10 million metric tonnes with post-harvest losses varying between 6.02 per cent and 15.05 per cent (MoFPI, 2022; NABCONS, 2022).

Why this matters now

The issue of post-harvest losses has gained renewed urgency in recent years due to rising food prices, increasing climate variability, and growing pressure on farmers' incomes. While India has achieved remarkable success in increasing fruit production, the benefits of this growth are increasingly being eroded by inefficiencies after harvest. In an era of changing consumption patterns and tighter market competition, merely producing more fruits is no longer sufficient. Reducing losses and improving value realization have become equally important for ensuring farmer profitability, consumer affordability, and national food security. This shift in focus highlights the need for smarter, more responsive supply chain systems.

Where Losses Actually Occur in the Existing Fruit Supply Chain

To understand where and why post-harvest losses occur, the fruit supply chain must be viewed as a sequence of interconnected stages. After harvest, fruits move from farms to local aggregation points, then to wholesalers, and are subsequently transported to mandis, processing units, retail outlets, or export hubs. At each stage, delays, improper handling, and exposure to unfavourable temperatures increase the risk of spoilage and quality deterioration. In the Indian context, the largest share of losses occurs during aggregation, wholesale handling, and transportation. These stages represent the weakest links in the fruit supply chain, where coordination among stakeholders is limited and infrastructure support is inadequate. As a result, fruits often suffer both quantitative and qualitative losses before reaching final markets. Evidence shows that the fruit

supply chain in India is particularly vulnerable at the wholesaler and transportation levels, leading to substantial deterioration in quality and quantity (FAO, 2016). Although the area, production, and productivity of horticultural fruit crops increased by 61.59 per cent, 115.91 per cent and 33.68 per cent, respectively, between 2001-02 and 2016-17, this rapid growth has intensified post-harvest losses due to inadequate supporting infrastructure (Pundir *et al.*, 2025). Persistent constraints such as poor transportation facilities, insufficient cold storage capacity, limited value addition units, and weak market integration continue to hinder the efficient movement of fruits from farms to consumers. Among major fruits, losses are highest in guava followed by mango (CIPHET, 2015). According to MoFPI (2022), total monetary losses across 54 crops and commodities amounted to ₹ 152,790.42 crores with livestock accounting for 21.07 per cent followed by fruits (19.34%), vegetables (18.61%), cereals (17.02 %), plantation crops & spices (10.74%), oilseeds (7.15%) and pulses (6.08%).

Why Traditional Supply Chains Fail to Protect Value

Conventional agricultural supply chains in India are largely reactive rather than predictive. Decisions related to harvesting schedules, storage allocation, transportation timing, and market selection are often guided by experience or intuition instead of real-time information. Even where cold storage infrastructure exists, it is unevenly distributed and poorly integrated with transportation systems and markets. A major weakness of traditional fruit supply chains lies in the lack of planning and coordination across stages. Harvesting decisions are rarely aligned with storage availability, transport scheduling, or market demand. As a result, fruits frequently arrive at markets at the same time, leading to congestion, sudden price crashes, and distress sales by farmers. These inefficiencies demonstrate that post-harvest losses are not solely the consequence of inadequate physical infrastructure but also of fragmented decision-making. Market arrivals often exceed demand in certain locations, while other markets face shortages, reflecting poor spatial distribution of produce. Without timely information and coordination, even well-produced fruits fail to generate adequate economic returns. In this context, improving fruit supply chains is not merely an infrastructure challenge; it is fundamentally a decision-making challenge. The ability to coordinate actions, time movements, and share information effectively determines whether fruits become a source of profit or end up as waste.

How AI Reorients the Supply Chain from Reaction to Prediction

Artificial Intelligence introduces system-level intelligence into fruit supply chains by digitally linking production, storage, transportation, and markets. AI systems integrate data from weather forecasts, crop estimates, market arrivals, price trends, logistics networks, and consumer demand patterns to support informed and timely decision-

making across the supply chain. In the Indian context, AI-enabled tools are increasingly being used to support demand forecasting, cold storage management, and logistics planning. Digital platforms analyse historical mandi arrivals, price movements, and weather data to anticipate demand trends and guide marketing and movement decisions. For Farmer-Producer Organisations, AI-based advisories help determine when and where to sell produce, how long it can be safely stored, and whether diversion to processing units is economically viable. Unlike conventional systems that respond only after losses occur, AI enables predictive planning. Stakeholders can anticipate harvest volumes, assess market demand, identify potential congestion or price risks, and plan logistics. This shift from reactive to predictive supply chain management is crucial for reducing post-harvest losses in fruits. Importantly, AI does not replace farmers, traders, or market intermediaries. Instead, it complements human judgment by providing timely, actionable insights that improve coordination, reduce uncertainty, and strengthen decision-making across the entire supply chain.

How AI can reduce post-harvest fruit losses

- ✓ Forecast harvest volumes and market demand
- ✓ Allocate cold storage space efficiently
- ✓ Reduce transport delays through route optimization
- ✓ Match produce with suitable markets in advance
- ✓ Prevent distress sales and emergency dumping

Smarter Storage and Cold Chain Decisions

One of the most significant applications of artificial intelligence in fruit supply chains lies in storage and cold chain management. Sensors installed in warehouses and cold storage facilities continuously monitor temperature, humidity, and atmospheric conditions, generating real-time data on storage environments. AI algorithms analyse this information to maintain optimal conditions and accurately estimate the remaining shelf life of fruits.

When produce approaches critical quality thresholds, AI-generated alerts enable the timely prioritisation of its movement to markets or processing units. This targeted decision-making improves the utilisation of limited storage capacity and reduces spoilage caused by delayed or uninformed actions. Such intelligent storage management is particularly important in India, where cold storage infrastructure remains constrained in relation to the scale of fruit production.

Optimising Transportation: Cutting Time, Cost and Losses

Transportation remains one of the most loss-prone stages in fruit supply chains, where delays, poor handling, and inefficient routing often lead to significant quality deterioration. AI-enabled logistics systems improve transportation efficiency by identifying optimal routes, reducing transit time, and minimising handling-related damage. Real-time vehicle tracking further enhances scheduling accuracy and coordination among farmers, aggregators, and markets. In addition, AI-driven load optimisation ensures better utilisation of transport

capacity, reducing per-unit transportation costs and avoiding unnecessary delays. Faster and more reliable movement of fruits not only preserves quality but also expands farmers' access to distant and higher-value markets, thereby improving overall price realisation.

Aligning Supply with Demand through Market Intelligence

AI plays a critical role in strengthening market linkages by forecasting where, when, and how much produce is required. By analysing historical market arrivals, price trends, consumption patterns, and seasonal demand, AI-based systems help identify suitable markets and the optimal timing for sale. This demand-oriented approach reduces the risk of market gluts and sudden price crashes, which are common in traditional marketing systems. As a result, farmers and Farmer Producer Organisations benefit from improved price realisation and reduced uncertainty, while markets experience smoother arrivals and lower price volatility.

Early Warning and Risk Management

AI-based early warning systems enhance risk management by identifying potential disruptions well in advance. Risks such as weather-induced transport delays, oversupply situations, or market saturation can be detected early, allowing timely corrective measures. Advanced alerts enable diversion of produce to alternative markets, cold storage, or processing facilities before losses occur. By facilitating proactive interventions, AI helps prevent emergency dumping and large-scale wastage, particularly during peak harvest periods, thereby improving supply chain resilience.

Benefits of AI-Enabled Supply Chains

AI-enabled supply chain optimisation offers wide-ranging economic benefits across the agricultural system. Reducing post-harvest losses, it increases the marketable surplus without requiring additional investment in production inputs. Farmers benefit through higher and more stable incomes, while consumers gain access to better-quality fruits at more predictable prices. At the same time, improved coordination and data-driven decision-making lower marketing and logistics costs, reduce inefficiencies, and enhance the overall performance and competitiveness of agricultural markets.

Implications for Smallholder Farmers, Aggregators and Markets

Smallholder farmers, who are most vulnerable to post-harvest losses, often face a narrow margin between profit and loss, where even minor declines in fruit quality can lead to sharp price reductions and distress sales. AI-enabled supply chains provide an opportunity for these farmers to protect the value of their produce by improving storage decisions, market timing, and coordination, rather than relying solely on higher production to increase income. When adopted collectively through Farmer-Producer Organisations and cooperatives, AI-based tools strengthen decision-making, enhance bargaining power, and reduce dependence on traditional intermediaries. Such collective adoption enables smallholders to access better market inform-

ation and more efficient supply chain services. Aggregators also benefit from improved coordination, transparency, and lower transaction costs, leading to smoother market operations. At the same time, consumers gain access to better-quality fruits at more stable prices, contributing to improved market efficiency and food availability.

Policy and Institutional Support

The Government of India has launched several initiatives, such as Operation Greens, the PM Formalisation of Micro Food Processing Enterprises (PM-FME) scheme, the Mission for Integrated Development of Horticulture (MIDH), and investments in Mega Food Parks and cold chain infrastructure, to address post-harvest fruit losses. While these interventions provide a strong physical and institutional foundation, their overall effectiveness increasingly depends on how well they are integrated with digital and data-driven tools.

Strengthening digital infrastructure, promoting interoperable data-sharing platforms, and building the capacity of farmers, Farmer-Producer Organisations, and other supply chain actors are essential for scaling the adoption of AI-based solutions. Public-private partnerships can play a crucial role in bringing together technological innovation, operational expertise, and investment. To maximise impact, AI-enabled supply chain solutions should be embedded within existing horticulture and agricultural marketing programmes rather than implemented as standalone initiatives. Greater emphasis on digital literacy, institutional coordination, and decision-support systems will be critical for translating policy intent into effective on-ground outcomes and ensuring that the benefits of AI adoption remain inclusive and farmer-centric.

Conclusion

Reducing post-harvest losses in fruits is no longer merely a matter of expanding physical infrastructure; it has become a challenge of supply chain intelligence. AI-enabled supply chain optimisation provides a practical and scalable approach to converting increases in fruit production into tangible income gains for farmers. By strengthening coordination, improving timing, and supporting data-driven decision-making, AI helps ensure that fruits produced with limited resources reach markets and consumers with minimal loss. In the long term, integrating AI into fruit supply chains can translate production growth into sustainable income growth, deliver better and more stable prices for farmers, enhance market efficiency for consumers, and contribute significantly to national food and nutritional security.

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Above the City, Beyond Limits: The Rooftop Farming Trend

Himani Sharma

With rapid urbanization and shrinking agricultural land, cities are searching for innovative ways to ensure food security and environmental sustainability. One such solution is rooftop farming the practice of growing vegetables, fruits, herbs, and flowers on the roofs of houses and buildings. Rooftop farming transforms unused urban spaces into productive green areas, promoting healthier lifestyles and a cleaner environment.

What is Rooftop Farming?

Rooftop farming, also known as terrace farming, involves cultivating plants in pots, containers, grow bags, or raised beds on rooftops. It can range from small kitchen gardens for household use to large commercial farms that supply fresh produce to local markets. Modern techniques like hydroponics and vertical gardening have further enhanced the scope of rooftop agriculture.

Benefits of Rooftop Farming

Fresh and Chemical-Free Food: Families can grow their own vegetables and fruits without harmful pesticides. This ensures safe, nutritious, and fresh food right at their doorstep.

Environmental Protection: Plants absorb carbon dioxide and release oxygen, helping to reduce air pollution. Rooftop gardens also lower urban heat by cooling buildings naturally, reducing the need for air conditioning.

Efficient Use of Space: In crowded cities where land is limited, rooftops provide an ideal alternative for cultivation without occupying additional ground space.

Rainwater Management: Rooftop gardens can absorb rainwater, reducing water runoff and preventing waterlogging during heavy rains.

Mental and Physical Well-being: Gardening is therapeutic. It reduces stress, encourages physical activity, and creates a peaceful environment in busy urban life.



Challenges of Rooftop Farming

Despite its advantages, rooftop farming faces certain challenges:

- ✓ Structural strength of buildings must be assessed before setting up a garden.
- ✓ Proper waterproofing is essential to prevent leakage.
- ✓ Initial setup costs for soil, containers, and irrigation systems can be high.
- ✓ Regular maintenance is required to ensure plant health.

Conclusion

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Rooftop farming is a sustainable and practical solution to urban challenges. It promotes food security, environmental conservation and healthier living. By utilizing unused rooftop spaces, individuals can contribute to a greener and more self-reliant future. If adopted widely, rooftop farming can transform concrete jungles into vibrant green landscapes, proving that agriculture can thrive even above the ground.

From Crop Improvement to Crop Survival: Stories of Two Breeders

Y. Meghana and Ch. Divya Rani

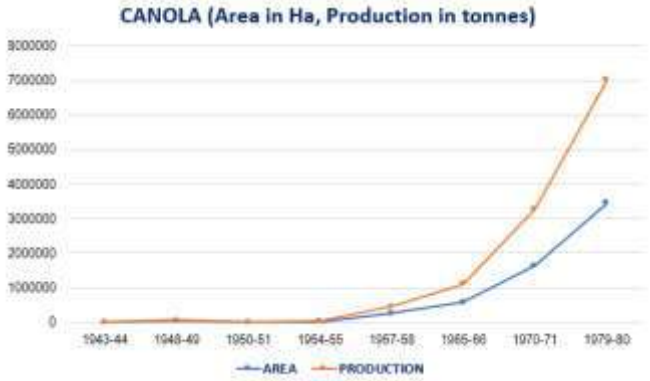
Abstract

This article consists of two different situations to demonstrate the impact of plant breeders. The first one examines how Baldur Stefansson's breeding efforts changed the rapeseed into canola, resulting in a safe and nutritious edible oil that influenced eating habits and agricultural economies around the world and particularly Canada. The second one talks about Nikolai Vavilov's legacy and his works, starting the one of world's first gene banks and discovering the concept of centres of origin in order to preserve crop diversity. Vavilov understood the importance of genetic diversity as the base of crop resilience and long-term food security after experiencing hunger personally. While one breeder succeeded within supportive scientific frameworks, the other faced oppression for defending genetic principles against political ideology. These examples highlight that breeders are more than just crop improvers; they are also guardians of genetic resources, impacting both current food systems and future agricultural resilience.

The Birth of Canola: A Breeder's Vision

Today, canola oil, which is one of the most widely used edible oils in the world, is praised for its lighter taste and heart-friendly fatty acids. Yet few people know that canola did not exist a century ago. It was not naturally present, but was developed by careful plant breeding. During the mid-20th century, Canada faced a challenge: it's main oilseed crop Rapeseed, even though it contains toxic chemicals which were unfit for human consumption it was encouraged to be cultivated as it is valuable for lubricating machines and ships during world war scenario. What followed was a quiet revolution in plant breeding that gave birth to CANOLA- Canadian oil, low acid (Briggs, 2023). Today, that once-toxic oilseed has become one of the world's most important edible oils.

Rapeseed/canola now accounts for about 9% of the global edible oil market, alongside soybean oil (31%) and palm oil (36%).



The Asia-Pacific region dominates the canola oil market, accounting for 36.51% of global revenue in 2024, while the United States market is projected to grow at a strong CAGR in the coming years. In Canada, where the crop originated, canola oil accounts for nearly 79% of household edible oil consumption, highlighting how a breakthrough in

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breeding has transformed not only the nation's agriculture but also global food systems (Grand view research, 2025).

Canada's Economy Growth: Canola breeding transformed Canada's rapeseed industry from a minor industrial crop into a major food oil sector. Within two decades, its value rose from $4.6 million (1950-51) to over $168 million (1970-71) as low-erucic varieties enabled edible oil production. Domestic crushing expanded rapidly, reaching 940,000 tons by 1980, generating edible oil and high-protein meal. By 1979, exports touched 1.99 million tons, adding $631 million to the economy (Bell, 1982). Today, canola contributes about $43.7 billion annually to Canada's economy, supporting over 200,000 jobs (Canola Council of Canada, 2024).

Table 1: Oil composition between rapeseed and canola

Fatty acid / component	Traditional rapeseed oil	Canola oil
Erucic acid (C22:1)	30-50%	< 2% (very low)
Oleic acid (C18:1)	50-60%	55-65%
Linoleic acid (C18:2, ω-6)	15-20%	16-20%
Linolenic acid (C18:3, ω-3)	8-12%	8-10%
Saturated fats	6-8%	~7% (low)
Glucosinolates (meal)	High	Low
Edibility	Not suitable for food	Edible, heart-healthy

High levels of erucic acid in rapeseed oil were found to cause heart muscle damage, poor growth, and metabolic disorders. Because of these risks, rapeseed oil with high erucic acid was considered unsafe for human consumption, creating the need to breed low-erucic acid varieties, which later became canola.

The pioneering work of Baldur R. Stefansson and colleagues at Canada's breeding programs laid foundation. Early cultivars such as 'Oro' and 'Tower', followed by 'Candle' laid the foundation for modern canola. Later varieties, such as 'Stellar', further improved oil quality, making canola one of the most successful examples of crop improvement through conventional breeding. Recent works in *Brassica napus* has identified *BnaC2.MYB28* as one of the major genes controlling seed glucosinolate content, while mapping studies linked the low α-linolenic acid (ALA) trait to the *FAD2* and *FAD3* loci with additive effects, enabling marker-assisted selection. Reduced *FAD2* activity limits the conversion of oleic acid to linoleic acid, increasing oleic acid from ~60% to over 75% and improving oil stability and nutritional quality (Azhar *et al.*, 2025). What started as an unlikely idea in a breeder's mind in the 1950's has evolved into one of the world's most important oil seed crops thanks to decades of perseverance. Scientists like Baldur R. Stefansson and Keith Downey proved that thoughtful breeding could rewrite the entire crop. Canola today stands as an example for this.

Seeds for the Future: The Legacy of Vavilov

Hunger shaped Nikolai Vavilov's life before it ended it. As a child, he always listened to his father's stories of poverty and crop failures and before he was four, an early winter had pushed millions across Russia into starvation. These experiences left a permanent mark on him, leading him to become one of the most significant figures in



plant science. Over the course of his career, he helped establish more than 400 research institutes and led Russian plant exploration missions to over fifty countries. However, his work was driven by a single question: How can humanity protect itself from famine?

After graduating as a botanist from the Soviet Agricultural Academy, Vavilov travelled across Europe to learn from the best scientific minds of his time. In England, he worked with William Bateson (The scientist who coined the term genetics and helped establish heredity as a scientific discipline). These interactions helped him gain knowledge of wild relatives of cultivated crops - plants that carry genes for resilience, drought tolerance, cold resistance and survival. He called them his "miracle plants." (The Daily Gardener, 2021)

Vavilov understood that modern agriculture relied on a narrow genetic base, making crops vulnerable to disease, abiotic stresses, and pests. Wild species and traditional farmer varieties, what we now call landraces, held the genetic diversity needed to strengthen crops through breeding. Preserving this diversity, he believed, was essential for long-term food security.

Over years of fieldwork, Vavilov developed the theory of Centres of Origin, also known as centres of diversity. He proposed that every major crop originated in a specific geographic region and that these regions contained the greatest diversity of wild relatives. He identified eight such centres worldwide, laying the foundation for modern crop improvement and conservation biology. This idea directly led to the development of one of the world's first gene banks, referring to a place where seeds were collected, documented, and preserved for the future generations (Helliwell, 2017). Gene banks were not meant for immediate use; instead, they act as a food security measure to prevent the extinction of crop species. When crops fail, climates shift, or diseases emerge, breeders return to these stored seeds to find solutions. Vavilov understood this decades before the world did. At the same time, Trofim Lysenko rose to power within Soviet biology. Despite heading the Institute of Genetics, Lysenko rejected Mendelian inheritance and natural selection, instead promoting the Lamarckian idea that plants could inherit acquired characteristics. He claimed crops could be "trained" to survive harsh conditions within a single generation - a promise that appealed to political leaders desperate for quick results.

Joseph Stalin sided with Lysenko. Vavilov was ordered to produce his miracle crops within three years or face severe consequences. However, plant breeding follow nature's timeline. Developing new varieties takes multiple generations, careful selection and time often decades.

When Vavilov's work followed the laws of nature rather than ideology, he was accused of treason and sabotage. In 1940, he was arrested and sent to prison in Saratov. In 1943, at the age of fifty-five, Nikolai Vavilov died of starvation - the very fate he had devoted his life to preventing. Inside Vavilov's institute, scientists barricaded themselves to protect the seed vault from rats, looters and desperation. Though starving, they refused to eat the seeds. Nine scientists died of starvation while protecting the collection. (The Daily Gardener, 2021) The vault survived, holding the seeds of life.

When Vavilov was arrested, his brother wrote in his diary:

"His big, useful life is being ruined… a life of tireless and intense work for his homeland, for the people. All his life spent at work, with no other hobbies. Wasn't it obvious to everybody? This is a cruel mistake and an injustice - worse than death." (Joubert, 2023)

Today, every modern gene bank from CGIAR seed vaults to the Svalbard Global Seed Vault - stands on the foundation works of Vavilov. His struggle reminds us that protecting genetic diversity is not just a scientific task, but a moral responsibility. Seeds preserved today are solutions waiting for tomorrow.

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Beetle as Vector of Plant Pathogens

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Abstract

Coleoptera is the largest insect order accounting for over 360,000 species, which constitutes 40% of the known insect species in the world. More than 70 species of beetles are known to transmit viruses that infect economically important vegetables and grain crops. It is estimated that beetles transmit approximately 11% of insect- borne viruses (Bhat and Rao, 2020). Beetle vectors of plant viruses belong to Chrysomelidae, Coccinellidae, Curculionidae, Meloidae families and have a unique mode of transmission of at least six groups of plant virus genera: Machlomovirus, Bromovirus, Carmovirus, Comovirus, Sobemovirus and Tymovirus.

Introduction

Mechanisms of virus acquisition and transmission are associated with the fact that most of the beetle vectors eat plant cells between the leaf veins and regurgitate during feeding, bathing their mouthparts with sap and virus particles. Beetle-associated viruses can be deposited into a chewing wound. Virus particles are translocated in the xylem elements to parts of the plants away from the site where they were deposited by an insect (Gedling *et al*., 2018).

Bacterial wilt cucurbits: *Erwinia tracheiphila* (Erwiniaceae) causes wilt of cucurbits, which can be responsible for millions of dollars yield losses and additional costs spent on indirect preventative measures two species of the Chrysomelidae: *Acalymma vittatum, Diabrotica undecimpunctata.* These involved in the spreading of *E. tracheiphila.*

Bacterial wilt of Maize: Stewart's bacterial wilt: *Pantoea stewartii* (Erwiniaceae) causes Stewart's vascular wilt and leaf blight of maize and sweet corn (Coplin *et al*., 2002), which is responsible for serious crop losses throughout the world. This bacterium is unable to spread from plant to plant without an insect vector (Menelas *et al*., 2006). Several beetle species of the Chrysomelidae, Elateridae, and Scarabeidae families are vectors of *P. stewartii*. In the United States, the spreading of Stewart's wilt disease is fundamentally associated with the *Chaetocnema pulicaria* (Chrysomelidae; Esker *et al*., 2006).

Virus transmission: Cowpea severe mosaic virus (Secovirida) transmitted by beetle (*Epilachna varivestis*) on Soybean.

Fungal transmission

The transmission of fungi by insects occurs usually accidentally. Insects can be contaminated with the fungus or its spores during visiting infected plants, externally (for instance during walking) or internally (through feeding).

Blue strain of fungi: Blue stain fungi (Ophiostomat-

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aceae) are necrotrophic pathogens that are associated with various conifers and bark beetle species of the Curculionidae family. The economic losses caused by beetles in combin-ation with blue stain fungi can be huge. For instance, pine shoot beetle. *Leptographium wageneri* can be responsible for black-stain root disease (BSRD), which can cause considerable damages in conifers forests, for instance, in Northwest America. BSRD can lead to growth reduction, chlorosis development.



Vascular wilt disease of elm Trees

Dutch elm disease: Fungus *Ophiostoma ulmi* cause vascular wilt disease of elm trees (Dutch elm disease, DED) which is considered one of the most destructive diseases of the woody tree. O. novo-ulmi are in a close association with the bark beetles from the genera Scolytus and Hylurgopinus. DED cause higher production of sociochemicals, which attract the insect vector *Hylurgopinus rufipes* (Curculionidae), which increase the efficiency of spreading this pathogen.

Oomycets: *Epitrix* sp. (Chrysomelidae) are considered a serious pest of various species of plants. For instance, *Epitrix tuberis* is primarily associated with members of Solanaceae family, especially with potatoplants. Adults and larvae of *E. tuberis* are harmful to plants. It was noted that *E. tuberis* may enhance dispersal of the *Phytophthora infestans*. The role of this insect in spreading various plant pathogens was reported in the past in the literature. It was indicated that *E. tuberis* can transmit bacteria *Raltsonia solanacearum* responsible for potato brown rot, *Streptomyces scabiei* causing potato scab. Nematode transmission: Transmission of nematodes can take several ways including direct contact between plant roots. Nematodes transmitted by beetles migrate to trees through wounds caused by beetle feeding and through the oviposition slits in the bark

Pine wilt: Pine wood nematode (PWN, *Bursap-helenchus xylophilus*, Aphelenchoididae) is an invasive pathogen that causes pine wilt disease (PWD). Significant losses of pines caused by PWD were reported, e.g., in Japan, Korea. Nematodes are transmitted by beetles and enter the tree through the wounds caused by beetle feeding or oviposition slits in the bar. Pine wilt disease is caused by pine wood nematode, *Bursaphelencus xylophilus*. Cerambycid, *Monochamus alternatus* as vector in Japan; *M. carolinensis* in USA. Adult emerges from dead pine trees in early summer, carrying numerous nematodes in its tracheae and transmits them to healthy trees through the feeding scar.

Conclusion

Beetles play a significant role as vectors of various plant pathogens, contributing to the spread

and severity of plant diseases in agricultural and natural ecosystems. Their feeding habits, mobility, and interactions with infected plant material facilitate the transmission of bacterial, fungal, and viral pathogens. Notably, species such as bark beetles, cucumber beetles, and weevils are implicated in economically important plant diseases. Understanding the ecology and behavior of these beetle-pathogen relationships is crucial for developing integrated pest and disease management strategies. Effective monitoring, biological control, and cultural practices can help mitigate the impact of beetle-vectored diseases, ultimately enhancing crop health and productivity.

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Comprehensive Overview of Date Palm Farming in Ariyakulam, Dharmapuri District of Tamil Nadu

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Abstract

The date palm (*Phoenix dactylifera*) is emerging as a cost-effective and sustainable crop in India due to its ecological adaptability, nutritional value, and commercial potential. Its ability to thrive in harsh environmental conditions makes it ideal for arid and semi-arid regions. In Tamil Nadu's Dharmapuri district, the successful implementation of a date palm cultivation model has demonstrated its potential to support rural livelihoods and drive regional development. This model, if replicated across similar agro-climatic zones, can significantly contribute to national economic growth and enhance the standard of living for farmers through improved income and long-term sustainability.

Introduction

Date palm (*Phoenix dactylifera*) belongs to the family Arecaceae. The major date palm-growing countries are Egypt, Iraq, Saudi Arabia, Pakistan, Iran, Algeria, Morocco, Tunisia, Sudan, and many other Near East and North African countries. Dates are a good source of antioxidants, mainly carotenoids and phenolics. Vitamin B-complex and vitamin C are the major vitamins in dates. Date flesh is found to be low in fat and protein but rich in sugars, mainly fructose and glucose. It is a high source of energy, as 100 g of flesh can provide an average of 314 kcal. Ten minerals have been reported, the major ones being selenium, copper, potassium, and magnesium. The consumption of 100 g of dates can provide over 15% of the recommended daily allowance of these minerals (Mohamed Ali Al-Farsi *et al*., 2008).

Medicinal Properties of Date Palm

Due to their high phenolic content, date palms have antifungal, antibacterial and antiviral characteristics. They can also help prevent chronic inflammation, cardiovascular disease, and assist in immune system regulation (Muhammad Umar Nasir *et al*., 2014). They also contain elemental fluorine, which is useful in protecting teeth against decay, and selenium, another element that helps prevent cancer. Date palm cultivation in India is practiced in some parts of Gujarat, Rajasthan, Maharashtra, Tamil Nadu, and Kerala.

Date Palm Cultivation in Tamil Nadu

Date palms can be cultivated in any kind of soil, there is no specific soil requirement. A soil pH range between 8 and 11 is ideal for cultivation. They can withstand high soil salinity because the plants have a salt exclusion mechanism. Sandy loamy soils with good moisture retention, aeration, and proper drainage are ideal for optimal development and yields. Calcium carbonate-rich soils should be avoid-

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ed for date farming. Date palm cultivation in Tamil Nadu was first initiated by a 61-year-old farmer, Mr. Nizamuddin. He got the idea of cultivating dates while working in Saudi Arabia. Currently, he is growing 32 different varieties of dates on 11 acres of land in Ariyakulam, Dharmapuri district. He has been promoting date cultivation across the nation for more than 10 years. He said that he planted more than 75 plants per acre, with a spacing of 7 x 7 m. He mentioned that date palms can be propagated sexually by seeds and asexually by offshoots. The plants grown from seeds are 50% female and take longer to develop. The plants grown from offshoots are identical to the parent and take less time to develop. However, the major problem with both seed and offshoot propagation is a low survival rate (< 34%). So, he adopted the tissue culture method, which is the best choice for producing genetically stable plants. This method allows for mass production, has a high success rate for survival, and ensures faster growth. Care should be taken at the initial stage when seedlings mature and are transplanted into the main field. Before transplanting the seedlings, pits of 1x1x1m should be dug in the main field, with a spacing of 7x7 m. The pits should be exposed to sunlight for two weeks. A mixture of 10 kg of farmyard manure, 4 kg of vermicompost, and ½ kg of neem cake should be added to control date palm root-knot nematodes. After that, the plants should be irrigated once a week. Excessive irrigation should be avoided as it can damage the roots. Older date palm trees require irrigation once a week during the summer, and 100 liters of water is enough per tree for 6 months. The remaining 3 months of rainfall will suffice, so no irrigation is needed. The date tree is resistant to illnesses and tough weather conditions. Although the environment in Dharmapuri is unfavourable for most crops, date palms thrive there. As the trees get older, they produce greater yields.

The date fruit starts bearing from the third to the fourth year, depending on the variety, with some trees beginning to bear fruit as late as the sixth year. Flowering begins from January to February, and the fruit is harvested from June to July. He started harvesting matured or half-ripened fruits based on market demand and consumer preferences. The date trees take time to produce fruits in the early years but can continue to bear fruit for the next 60 to 70 years. In the first year of cultivation, the tree may produce up to 50 kg of dates. In the second year, it yields between 50-200 kg. By the third year, the same tree can produce over 200-300 kg. One of the best date varieties, called Barhee, yields more than 200 kg tree^{-1} and sells for Rs 160 to Rs 200 kg^{-1}. He earns an average income of Rs 20,000 tree^{-1}. Kanijee, another excellent variety, yields 200-250 kg tree^{-1} and he exports these fruits to Singapore, Indonesia, and Cambodia.





Conclusion

The date palm, due to its ecological charact-

eristics, benefits to human health, and commercial value, has become a cost-effective plant for various regions in our country. It is also a driving force in the sustainable development of the Dharmapuri region. The high adaptability and tolerance of the date palm to a wide range of severe environmental conditions explain the success of the experimental planting model in this area (Jenito Samuel *et al*., 2025). This model can be adapted on a larger scale by farmers across the country and can contribute significantly to the country's economic growth and improve farmers' living standards.

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Green Lacewings: A potential Biocontrol Agents in Sustainable Agriculture

E. Manikandan and R. Kanagarajan

Introduction

The management of various insect pests in agriculture heavily relies on synthetic insecticides due to their rapid and effective action. However, their indiscriminate application has led to several adverse consequences, including ecological imbalance, resurgence of pest populations, development of pesticide resistance, and detrimental effects on non-target organisms (Prakash *et al.*, 2008). Consequently, there is a growing need to explore alternative, environmentally sustainable pest control strategies. Biological control has emerged as a viable and ecologically benign option. Both augmentative and inoculative releases of natural enemies have promising results in field crops (Gupta *et al*., 2019). Green lacewings are recognized as one of the most effective and economically significant biocontrol agents. Their wide host range, adaptability across agroecosystems, insecticide tolerance, and voracious larval feeding behaviour make them particularly suitable for managing sucking pests. Moreover, their capacity for mass rearing facilitates their integration into pest management programs. Adoption of such biologically based approaches is essential to achieving residue-free vegetable production and promoting sustainable agricultural practices.

Taxonomic Diversity and Global Distribution of Green Lacewings

Green lacewings, commonly referred to as golden-eyed lacewings or aphid lions, (Neuroptera: Chrysopidae), constitute a taxonomically rich family comprising over 1,200 described species within more than 80 genera, and are distributed across all major biogeographical regions. The family is currently classified into three extant subfamilies: *Apochrysinae*, *Nothochrysinae*, and *Chrysopinae*. Among these, *Chrysopinae* exhibits the greatest taxonomic richness, encompassing approximately 97% of all extant species, thereby representing the primary lineage contributing to the global diversity of green lacewings**.** It is widely distributed across various regions, including countries such as South Africa, Tanzania, Rwanda, Kenya, and island nations like the Comoros and Madagascar. Its range also extends through parts of Asia and the Pacific, including Japan, China, eastern Australia, India, Indonesia, Papua New Guinea, New Caledonia, Vanuatu, and the Solomon Islands. In India, 65 species of chrysopids belonging to 21 genera have been recorded from various crop ecosystems.

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Biology of Green lacewings

Green lacewings undergo complete metamorphosis, progressing through four distinct stages: egg, larva, pupa and adult. Their life cycle usually spans 3 to 4 weeks.

Egg: Freshly laid green lacewing eggs are pale green, oval-shaped, and measure approximately 0.3-0.6 mm in length. Females lay their eggs either singly or in small clusters of 10 to 12, positioning them on the tips of slender, hair-like stalks measuring 11-26 mm in length. This stalked arrangement helps prevent cannibalism among larvae. As the eggs near hatching, their color gradually changes from green to grey. During peak egg-laying periods, a single female may produce 9 to 23 eggs per day.

Larva: The larva/grub has 3 instars which are completed in 8-10 days. The newly hatched larva has three pairs of legs and white to pale yellow in colour. The first instar larva was 3.13 mm in length and white to pale yellow color. The first instar larva starts elongating in size with tapering gradually toward the head and the body had small bristles on lateral side. The second instar larva was larger in size and darker in colour. Prominent stripes with grey or brown colour were distinct. The third instar larva have prominent stripes with grey or brown colour distinctly on the wholebody region of larva. The larval body have distinctly bristles on lateral side. The mature larvae possess the sickle shaped mandibles with well-developed proboscis which was used to capture and draw fluid from their prey.

Pupa: The larva spun a white coloured spherical cocoon with 6 mm diameter and pupated inside, which covered with silken threads. The cocoons became green in colour in a day before adult emergence.

Adult: Adults were soft bodied, usually light green in colour with transparent wings. The wing span of male and female are larger than the body length. In male, the abdomen was narrow and tapering while in female it was 2 to 3 times broader than the males. Compound eyes were copper or golden in colour. Adults on emergence mate repeatedly. Generally, pre-oviposition period lasts for 3-7 days. Adult females start laying eggs from 5th day onwards and peak egg-laying period is between 9-23 days after emergence. The male longevity is 30-35 days and female can even live up to 60 days and lays about 600-800 eggs.



Host range of green lacewings: The green lacewings is a cosmopolitan predator found in a wide range of agricultural habitats. The larvae are voracious predators that feed on a multitude of soft bodied insects like coccids, mealybugs, aphids,

thrips, psyllids, whiteflies and larvae of many lepidopteran pests and mites infesting on various crops (Memon *et al.,* 2019). Adult lacewings feed upon nectar, pollen, and sugary plant secretions (Hemalatha *et al.,* 2014). A single larva can consume up to five hundred aphids during its lifetime. When the food source is scarce, they exhibit cannibalism.

Mass rearing techniques of green lacewings: Adults were collected and placed in oviposition cages measuring 75 cm × 30 cm. The sides of the cages were fitted with nylon wire mesh for ventilation and the sliding top was covered with black muslin cloth to facilitate the collection of eggs. A nutrient-rich diet, composed of equal parts honey, protein supplement, yeast extract and water were provided using cotton swabs placed in glass vessels. Yeast extract was included for its high content of vitamins B-complex and essential minerals, which support adult fecundity and longevity. Eggs deposited on the muslin cloth were collected daily by gently dislodging them. One-day eggs were either used for direct field release or reserved for subsequent stages of mass multiplication. For larval rearing, chrysopid eggs were introduced into containers along with 0.75 ml of sterilized *Corcyra cephalonica* eggs as the initial food source. Upon hatching, the larvae began feeding on the *Corcyra* eggs. By the third day hatching, individual larvae were transferred into separate glass vials to prevent cannibalism. The vials were replenished with fresh *Corcyra* eggs every three days and maintained until the larvae pupated. Silken cocoons were collected 24 hours after formation and transferred to clean oviposition cages for adult emergence. Newly emerged adults were then used to continue the rearing cycle. The egg can be stored at 10°C in B.O.D. incubator or refrigerator for about 21 days.

Field Release of *Chrysoperla*: Chrysopids are recommended for use against different crop pests @ 50,000 or 1,00,000 1st instar larvae ha^{-1} and 4-6 larvae plant^{-1} or 10-20 larvae fruit^{-1} plant. Small pieces of egg cards are stapled to the leaf of the infested plant.

Conclusion

Green lacewings act as a valuable biocontrol agent in pest control due to their predatory nature, particularly during the larval stage, where they aggressively feed on aphids, whiteflies, thrips, mealybugs, and other soft-bodied pests. Their integration into Integrated Pest Management (IPM) programs significantly reduce the pesticide load on agricultural ecosystems. Advancements in mass rearing technologies have made their augmentative release more feasible and cost-effective for farmers. Incorporating green lacewings into pest management strategies not only helps control pest populations naturally but also contributes to ecological sustainability, conservation of biodiversity, and production of residue-free crops.

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Importance of Regenerative Agriculture on Climate, Soil Health and Biodiversity

Mohit Kumar Sharma, S. P. Singh, Ankita Jhajhria and Tarun Tomar

Abstract

The global agricultural sector confronts a tripartite crisis: the widespread degradation of edaphic resources, the acceleration of anthropogenic climate change, and the collapse of biodiversity. Conventional intensification, characterized by mechanical tillage, monoculture cropping, and synthetic inputs, has severed the biological link between plants and soil, rendering agriculture a net carbon source. This paper provides a comprehensive analysis of Regenerative Agriculture (RA) as a necessary paradigm shift toward restoring the soil microbiome. We examine the mechanistic "Carbon Pathway," wherein root exudates stimulate microbial processes specifically the production of glomalin by Arbuscular Mycorrhizal Fungi (AMF) to stabilize Soil Organic Carbon (SOC) and rebuild soil aggregates. RA's efficacy in climate mitigation, supporting the "4 per 1000" initiative through carbon sequestration and the reduction of potent nitrous oxide (N_2O) and methane (CH_4) emissions. Hydrological resilience is addressed through data demonstrating improved water infiltration and storage capacity, which are critical for drought-proofing rain-fed systems. Furthermore, the paper explores the restoration of biodiversity across trophic levels and validates Adaptive Multi-Paddock (AMP) grazing as a viable method for net-negative carbon livestock production. Finally, we analyse the socio-economic implications, specifically the "profitability paradox," where reduced input costs enhance farm margins despite potential yield drags during the transition period. The study concludes that RA represents a scalable, knowledge-intensive strategy to reverse the carbon flux and ensure food security in the Anthropocene.

Introduction

We exist in the Anthropocene, a geological epoch defined by human impact. Nowhere is this impact more visible than in the pedosphere living skin of the Earth. Soil is the interface between the lithosphere, atmosphere, hydrosphere and biosphere. It is a non-renewable resource on human timescales; the genesis of a mere 2.5 cm of topsoil can take 500 to 1,000 years under natural conditions. Current industrial agricultural practices are eroding this vital resource at rates estimated to be 10 to 40 times faster than its natural replenishment.

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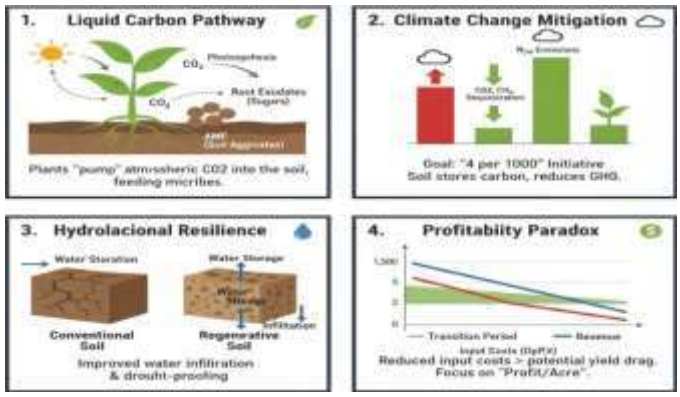


Fig. 1: Mechanisms of Regenerative Agriculture

According to the Food and Agriculture Organization (FAO), approximately 33% of global soils are moderately to highly degraded due to erosion, salinization, compaction, acidification and chemical pollution. This physical and biological degradation fundamentally compromises the soil's capacity to function as a carbon sink. Historically, agricultural soils have lost between 50% and 70% of their original Soil Organic Carbon (SOC) pool, releasing gigatons of carbon dioxide (CO_2) into the atmosphere. Concurrently, the Agriculture, Forestry, and Other Land Use (AFOLU) sector accounts for approximately 23% of total net anthropogenic greenhouse gas (GHG) emissions (IPCC, 2019). Beyond CO_2, this sector is the primary anthropogenic source of nitrous oxide (N_2O) a greenhouse gas 298 times more potent than CO_2 over a 100-year period largely due to the inefficient application of synthetic nitrogen fertilizers. Regenerative Agriculture is not merely a nostalgic return to pre-industrial farming methods. It is an advanced, knowledge-intensive system that leverages complex biological processes to close the carbon and nutrient cycles. Its primary objective is to reverse the carbon flux moving carbon from the atmosphere back into the pedosphere, thereby mitigating climate change while simultaneously restoring agricultural productivity and ecosystem resilience.

Biogeochemistry of Living Soil

To understand the transformative potential of Regenerative Agriculture, one must first deconstruct the biological mechanisms that drive soil fertility. In conventional agronomy, soil is often treated as a chemical substrate, balanced by the stoichiometry of Nitrogen, Phosphorus and Potassium (N, P, K). However, authentic soil fertility is fundamentally biological and driven by the sun.

Carbon Pathway: The theoretical cornerstone of RA is the "Carbon Pathway." Photosynthesis converts solar energy and atmospheric CO_2 into chemical energy in the form of photosynthates (simple sugars). Crucially, plants do not utilize 100% of these photosynthates for their own biomass accumulation. Depending on the plant species and growth stage, 20% to 40% of this fixed carbon is exuded into the rhizosphere soil zone directly surrounding the roots as "root exudates." These exudates are not waste products they are a biological currency. Comprising sugars, amino acids and organic acids, they serve as the primary carbon substrate for soil microbiota. This interaction represents a symbiotic exchange:

- ✓ **Plant provides Carbon (Energy):** The exudates feed bacteria and fungi that lack the capacity to photosynthesize.
- ✓ **Microbes provide Nutrients (Minerals):** In

Table 1: Comparative Analysis of Conventional vs. Regenerative Agriculture

Metric / Aspect	Conventional Agriculture	Regenerative Agriculture (RA)
Primary Goal	Maximization of Yield (Biomass accumulation).	Restoration of Ecosystem Function (Soil microbiome & resilience).
Soil Management	Mechanical Tillage: Breaks aggregates, oxidizes carbon, and disrupts fungal networks.	Least Disturbance (No-Till): Preserves soil aggregates and protects sequestered carbon.
Carbon Impact	Net Carbon Source: Releases stored Soil Organic Carbon (SOC) as CO_2.	Net Carbon Sink: Sequesters atmospheric CO_2 via the "Liquid Carbon Pathway" and glomalin production.
Fertility Source	Synthetic Inputs: Reliance on N-P-K chemical fertilizers (low use efficiency).	Biological Cycles: Root exudates feed microbes which solubilize soil minerals; Legumes fix Nitrogen.

exchange, these microbes solubilize mineral nutrients (e.g., phosphorus, zinc, calcium, magnesium) from the soil mineral matrix and transport them to the plant in bio-available forms.

This process, sometimes referred to as the "Microbial Carbon Pump," challenges the older "Humification" theory, which posited that stable soil carbon was primarily formed from the decomposition of recalcitrant plant matter (lignin/cellulose). Modern isotopic tracking reveals that the most stable soil carbon is microbial necromass dead bodies of bacteria and fungi that fed on root exudates. Therefore, keeping a living root in the ground is more effective for long-term sequestration than simply adding compost.

Role of Arbuscular Mycorrhizal Fungi (AMF): Among the most critical organisms in this pathway are Arbuscular Mycorrhizal Fungi (AMF). These obligate symbionts penetrate the root cortical cells of the host plant and extend microscopic filaments called hyphae far into the soil matrix. These hyphae effectively expand the root surface area by 100 to 1,000 times, accessing water and nutrients in micropores that plant roots are too large to enter. AMF produces a recalcitrant glycoprotein known as glomalin. Discovered in 1996 by USDA scientist Sara Wright, glomalin acts as a "soil superglue." It binds individual soil particles (sand, silt, clay) into stable macro-aggregates. This aggregation is the primary mechanism of SOC sequestration and physical protection. Carbon occluded within these aggregates is physically protected from microbial oxidation, increasing its mean residence time (MRT) in the soil from years to decades or even centuries. Furthermore, this aggregation creates essential porosity, allowing for rapid water infiltration and gas exchange, which prevents the hypoxic (anaerobic) conditions that lead to methane and nitrous oxide emissions.

Climate Mitigation

The potential for soil to mitigate climate change is quantified by the "4 per 1000" initiative, launched at the COP21 Paris Climate Conference. It posits that an annual growth rate of 0.4% in the soil carbon stocks of the top 30-40 cm of soil would significantly reduce the CO_2 concentration in the atmosphere related to human activities.

Sequestration Mechanics: Regenerative practices maximize sequestration through the principle of Least Disturbance.

- ✓ **Tillage and Oxidation:** Mechanical tillage (ploughing) breaks apart soil aggregates, expos-

ing the protected organic carbon to oxygen. This stimulates a burst of microbial respiration, where bacteria rapidly consume the carbon and release it as CO_2. It is akin to opening the damper on a wood stove the fuel burns faster.

- ✓ **No-Till Systems:** By utilizing no-till drills that slice a thin slot for the seed, RA keeps the soil armoured and the aggregates intact. The carbon remains sequestered underground.

Emission Reduction: Climate mitigation is not just about drawing down CO_2 it is about reducing the efflux of more potent gases.

- ✓ **Nitrous Oxide (N_2O):** Synthetic nitrogen fertilizers have a low Use Efficiency (NUE), often less than 50%. The excess nitrogen is converted by denitrifying bacteria into N_2O. By integrating legumes (which fix atmospheric nitrogen via *Rhizobia* bacteria) and reducing synthetic inputs, RA drastically cuts N_2O emissions.
- ✓ **Methane (CH_4):** While ruminants emit methane, healthy soils contain methanotrophic bacteria (methanotrophs). These bacteria oxidize methane using it as an energy source. In conventional, chemically treated soils, methanotroph populations are often decimated. In regenerative soils, they serve as a bio-filter, consuming a portion of the methane before it reaches the atmosphere.

Albedo and Cooling Effect: Beyond greenhouse gases, bare soil contributes to global warming through the "heat dome" effect. Bare soil absorbs solar radiation and re-radiates it as sensible heat. Covered soil (via cover crops or residue) reflects more radiation (albedo) and crucially, cools the microclimate through transpiration. Plants release water vapor, which consumes latent heat, actively cooling the air.

Soil Health and Hydrological Resilience

Climate change manifests primarily through water: too much (floods) or too little (droughts). Regenerative agriculture restores the soil's capacity to buffer these extremes.

Infiltration and Porosity: The aggregate structure built by glomalin creates macropores. These pores act as vertical pipelines for water. At the famous Brown's Ranch in North Dakota, soil infiltration rates improved from <0.5 inches per hour (in a tilled model) to over 8 inches per hour (in a regenerative model). This means that during a heavy storm, the water enters the soil profile rather than running off, reducing downstream flooding and soil erosion.

Water Holding Capacity (WHC): Soil Organic Matter (SOM) acts as a sponge. Authentic data from the USDA Natural Resources Conservation Service (NRCS) indicates that for every 1% increase in SOM, an acre of soil can hold approximately 20,000 to 25,000 gallons of additional plant-available water.

- ✓ **Drought Resilience:** In rain-fed agricultural systems (which comprise 80% of global agriculture), this storage capacity is the difference between a crop failure and a harvest during a drought year. This "green water" resource is critical for food security in a warming world.

Nutrient Cycling and Density: In the conventional

model, crops are force-fed soluble nutrients. This "luxury consumption" produces large biomass but often dilutes nutrient density. In regenerative systems, the microbial loop ensures that nutrients are delivered as needed. Fungi can solubilize rock phosphate and chelate micronutrients like zinc and iron that are otherwise chemically locked in the soil. This leads to crops with higher mineral density, linking soil health directly to human health.

Biodiversity: Restoring the Web of Life

Biodiversity loss is often cited as the "silent crisis" alongside climate change. Industrial agriculture, with its reliance on monocultures and broad-spectrum biocides, creates biological deserts. Regenerative agriculture restores biodiversity across three trophic levels

Soil Microbiome (Below Ground): The foundation of biodiversity is invisible. A teaspoon of healthy soil contains more microbes than there are humans on earth. Tillage and chemical fumigation (like methyl bromide) sterilize this community. RA fosters a diverse microbiome through the principle of Plant Diversity. Different plant roots exude different cocktails of sugars and enzymes, recruiting different microbial communities. A rotation that includes warm-season grasses (corn), cool-season grasses (wheat), warm-season broadleaves (sunflower) and legumes (soy/vetch) ensures a balanced and resilient microbiome. This diversity suppresses soil-borne pathogens through competitive exclusion essentially beneficial microbes outcompete the pathogens for space and resources.

Insect and Pollinator Populations: Above ground, the integration of flowering cover crops and the maintenance of "beetle banks" or hedgerows provide habitat for beneficial insects.

- ✓ **Predatory Insects:** Ground beetles, lacewings, and ladybugs are natural predators of crop pests like aphids. By providing habitat, RA farmers reduce the need for insecticides.
- ✓ **Pollinators:** 75% of the world's food crops depend at least partially on pollination. Mono-cultures provide food for pollinators only for a few weeks a year (e.g., when almonds or canola bloom). Diverse regenerative systems provide a continuous bloom sequence, supporting bee and butterfly populations year-round.

Higher Trophic Levels (Birds and Mammals): The restoration of insect populations leads to the return of insectivorous birds. Case studies, such as those at White Oak Pastures in Georgia, have documented the return of apex predators like bald eagles, signalling a restored trophic cascade. The farm moves from being a factory to being an ecosystem.

Role of Livestock: Adaptive Multi-Paddock (AMP) Grazing

Perhaps the most controversial aspect of the climate-agriculture debate is the role of livestock. Ruminants are often vilified for their methane emissions. However, from an ecological perspective, grasslands and grazers co-evolved. The Great Plains of North America, one of the world's largest carbon sinks, was built by millions of bison.

Regenerative agriculture distinguishes between continuous grazing (which degrades soil) and Adaptive Multi-Paddock (AMP) grazing. In AMP grazing, livestock are moved frequently (sometimes daily or hourly) in high-density herds, followed by long recovery periods for the grass. This mimics the predator-prey dynamics of wild herds. The physical trampling incorporates standing biomass (litter) into the soil, feeding the microbes. The concentrated urine and manure provide a pulse of nitrogen. The "tug" of grazing stimulates the grass to release root exudates to regrow, pumping carbon into the soil. Life Cycle Assessments (LCA) have shown that when managed this way, the soil carbon sequestration can outweigh the enteric methane emissions, making the beef production system net carbon negative.

Economic and Social Implications

The sustainability of any system relies on its economic viability. "Sustainability" that leads to bankruptcy is not sustainable.

Profitability Paradox: Regenerative corn fields to conventional ones. The regenerative fields produced 29% less grain by volume but were 78% more profitable. The conventional farmer spends a significant portion of revenue on inputs: proprietary seeds, synthetic fertilizers, herbicides, fungicides and drying costs. The regenerative farmer replaces these expensive inputs with ecosystem services. They "farm the sunlight" and "farm the nitrogen" (via legumes) rather than buying it.

Human Health: There is a growing body of evidence linking soil health to the nutrient density of food. The "dilution effect" observed in modern crops where yields increase but mineral content decreases is partly attributed to the disruption of the fungal networks that transport micronutrients. By restoring these networks, RA has the potential to address "hidden hunger" (micronutrient deficiency) in human populations.

Challenges to Adoption

Despite the clear benefits, RA adoption is not universal. The barriers are significant

Yield Drag: Transitioning from a chemical to a biological system takes time (3-5 years). During this "weaning" period, yields can drop before the soil biology rebuilds, creating a financial "valley of death" for farmers.

Policy Structures: Crop insurance and subsidies in many nations are linked to yield history and specific commodities (corn/soy), disincentivizing diversity and cover cropping.

Knowledge Gap: RA is knowledge-intensive, not product-intensive. It requires a farmer to be an ecologist, understanding C:N ratios and microbial dynamics, rather than just following a spray schedule.

Conclusion

Regenerative Agriculture represents a convergence of ancient wisdom and modern ecology. It recognizes that the soil is not a machine to be driven, but a living system to be stewarded. The evidence suggests that by restoring the soil microbiome, we can achieve multiple simultaneous

objectives stabilizing the climate, ensuring food security through drought resilience and revitalizing rural economies through reduced input costs. While not “silver bullet” fossil fuel emission reductions remain, paramount RA provides a necessary bridge. It offers the only scalable technology currently available to actively draw down carbon from the atmosphere while producing the food required for a growing population. The future of agriculture lies not in the chemistry lab, but in the complex, dark and living universe beneath our feet.

Small Millet Fodder: A Nutritious Boost for Cattle

Devshree D. Panchbhai, Priya P. Satwadhar, Bhavna Sharma and S. A. Maqdoom Sha

In an era of climate uncertainty and resource scarcity, livestock farmers face mounting pressure to secure nutritious, sustainable fodder for cattle. Small millets resilient grains like finger millet (ragi), pearl millet (bajra), barnyard millet, and little millet emerge as a game- changer, thriving on marginal lands with minimal water and inputs while delivering superior nutrition. This article explores their rich mineral profile, digestibility advantages over corn or sorghum, and proven boosts to milk yield and calf health, drawing from agronomic research and farm trials. By integrating harvesting best practices and sustainability benefits, small millets offer a pathway to carbon-neutral livestock farming. Small millets like finger millet, barnyard millet, and little millet serve as highly nutritious fodder options for cattle, offering superior mineral content, protein digest-ibility and water efficiency compared to traditional feeds like corn or sorghum. These resilient crops thrive in marginal lands and dry conditions, making them ideal for sustainable livestock farming. Farmers feeding small millets report healthier calves, higher milk yields, and reduced feed costs. The proper time to harvest small millet for green fodder is at the emergence of panicles, which is when the panicles just start to appear. For dry fodder or grain (seed) harvest, it is best to harvest when the panicles change color and the lower leaves start to yellow, indicating maturity of the seeds.

Harvesting Small Millet Green Fodder

- ✓ Harvest at panicle emergence stage.
- ✓ This stage offers maximum nutrient availability and good quality green fodder.

Usually occurs around 50 to 60 days after sowing depending on variety and conditions.

Harvesting Small Millet Dry Fodder (Seed)

- ✓ Harvest at physiological maturity indicated by panicle color change and yellowing of lower leaves.
- ✓ Seeds become hard and grain moisture reduces to around 12-13%.
- ✓ Typically occurs about 60 to 90 days after planting.

Harvesting at these stages balances the yield and nutritive value of the small millet for either green fodder or dry fodder use effectively. There are various other ethnobotanical uses of small millets as depicted in Fig. 1. Nutritional Powerhouse Small millets pack essential nutrients vital for cattle health. Finger millet provides twice the calcium of corn, four to five times more phosphorus, and ample potassium, addressing deficiencies that stunt growth and milk production. Pearl millet offers comparable protein and fiber to corn silage while requiring less supplemental protein in dairy diets. Barnyard millet stands out with high iron, zinc, fiber, and protein

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levels per 100 g dry matter, enhancing digestibility over rice or wheat straw. Pearl millet silage matches corn in supporting milk yield and composition when replacing up to 30% of the diet. Finger millet grain supplementation boosts milk fat, solids-not-fat, and yield by 1.9 liters per cow daily while lowering urea levels.

Nutritional Powerhouse

Small millets pack essential nutrients vital for cattle health. Finger millet provides twice the calcium of corn, four to five times more phosphorus, and ample potassium, addressing deficiencies that stunt growth and milk production. Pearl millet offers comparable protein and fiber to corn silage while requiring less supplemental protein in dairy diets. Barnyard millet stands out with high iron, zinc, fiber, and protein levels per 100 g dry matter, enhancing digestibility over rice or wheat straw. Pearl millet silage matches corn in supporting milk yield and composition when replacing up to 30% of the diet. Finger millet grain supplementation boosts milk fat, solids-not-fat and yield by 1.9 liters per cow daily while lowering urea levels.



Fig. 1: Ethnobotanical uses of small millets

Benefits for Dairy and Livestock

Dairy cows on finger millet forage wean healthier calves and digest feed better due to methionine content. In India, it cuts water use by 10-20% versus sorghum, vital in water- scarce regions. Pearl millet forage yields similar dry matter intake as sorghum for goats, with superior protein uptake. (AICRP on Sorghum and Small Millets agronomy reports). For mid- lactation cows, brown mid-rib finger millet silage maintains production equal to corn silage. Straw from small millets like little and barnyard sustains productivity with biofertilizers, cutting fertilizer needs by 15-30 per cent (Bhatt *et al.*, 2022). It improves milk quality and volume without extra protein. Small millets fodder enhances reproductive health in high-urea cows by balancing feed's rumen-degradable protein can lower urea toxicity effects on hormones and uterine pH, supporting better fertility outcomes. This aligns with sustainable fodder options like small millets, which may help maintain reproductive performance in urea-stressed cows.

Sustainability edge of small millets

Small millets align with carbon-neutral farming by growing on poor soils with minimal inputs. Low nutrient uptake preserves soil fertility over intensive corn. In drought-prone areas, they outperform traditional fodders, reducing irrigation demands. This makes them a greener choice for livestock nutrition amid climate challenges.

Conclusion

Small millet fodder revolutionizes cattle nutrition by combining high protein, minerals, and fiber with unmatched resilience to drought and low

fertility. Farmers adopting these crops achieve healthier herds, higher yields, and lower costs, paving the way for eco- friendly dairy systems amid global challenges. Future research should scale biofortified varieties and farmer training to fully unlock their potential in sustainable agronomy.

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Gene Editing for Green Solutions: CRISPR-Cas Applications in Plant Pathology

R. Nilesh Kumar, Ranbir Singh and S. K. Singh

Abstract

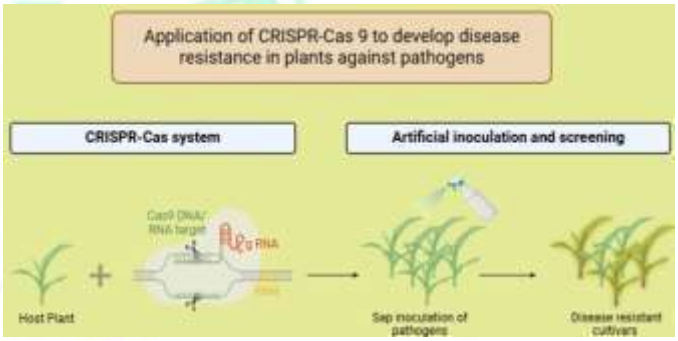
The advent of CRISPR-Cas gene editing technology has revolutionized the field of plant pathology, providing innovative strategies to combat plant diseases that threaten food security. This communication explores the myriad applications of CRISPR-Cas systems in enhancing disease resistance, improving crop resilience and fostering sustainable agricultural practices. By leveraging the precision of gene editing, we can pave the way for a more resilient agricultural future that addresses the challenges posed by global climate change and emerging pathogens.

Introduction

The global agricultural landscape is increasingly threatened by plant pathogens, which are responsible for significant crop losses and food insecurity. Traditional disease management strategies, including chemical fungicides and resistant crop varieties developed through conventional breeding, often fall short in addressing the rapid evolution of pathogens and changing climatic conditions. CRISPR-Cas gene editing has emerged as a pioneering approach to enhance plant health, allowing for targeted modifications that can bolster resistance against a wide range of pathogens. This communication aims to elucidate the potential of CRISPR technology in transforming plant pathology and contributing to sustainable agricultural practices.

Applications of CRISPR-Cas in Plant Pathology

Enhancing Disease Resistance: CRISPR-Cas systems facilitate the precise editing of plant genomes to enhance disease resistance.



By targeting specific genes associated with susceptibility, researchers can develop crop varieties with improved resilience to diseases caused by fungi, bacteria and viruses. For instance, studies have demonstrated that editing the SWEET gene family in rice not only confers resistance to bacterial blight but also minimizes yield loss under pathogen pressure (Jiang *et al.*, 2020). In addition to knocking out susceptibility genes, CRISPR can also be used to introduce or enhance the expression of genes that

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encode for antimicrobial peptides or pathogenesis-related proteins. This not only strengthens the plant's intrinsic defense but also promotes a faster response to pathogen attack, thereby reducing disease severity.

Developing Resilient Crop Varieties: The unpredictable nature of climate change presents a significant challenge to agriculture, often exacerbating the impact of plant diseases. CRISPR-Cas technology can be harnessed to develop crops that are not only disease-resistant but also resilient to abiotic stresses such as drought, heat and salinity. For example, researchers have successfully edited genes in maize that regulate water use efficiency, resulting in plants that maintain productivity even under limited water availability (Sami *et al*., 2021). This dual approach of enhancing both disease resistance and stress tolerance is crucial for maintaining yield stability in the face of climate variability.

Rapid Pathogen Detection and Response: In addition to enhancing plant traits, CRISPR technology is proving valuable in the realm of pathogen detection. The development of CRISPR-based diagnostic tools allows for rapid and accurate identification of specific pathogens, enabling farmers to respond effectively to outbreaks. These diagnostic tests can be designed to detect minute quantities of pathogen DNA in plant tissues, providing timely information that can guide management decisions. Researchers have developed CRISPR-based assays that can detect viral infections in crops within hours, significantly reducing the lag time associated with traditional diagnostic methods (Ramachandran *et al*., 2021). This rapid response capability is crucial for preventing the spread of diseases that can devastate entire crops.

Addressing Regulatory and Ethical Considerations: While the potential applications of CRISPR-Cas in plant pathology are promising, ethical and regulatory considerations must be addressed. The regulatory landscape for gene-edited crops varies globally, with some countries adopting permissive frameworks while others impose stringent regulations similar to those for genetically modified organisms (GMOs). Engaging with policymakers and the public to foster understanding and acceptance of gene editing technologies is essential for widespread adoption. Moreover, ongoing research should prioritize the ecological impacts of deploying gene-edited crops in agricultural systems

Challenges and Future Directions: Despite the significant potential of CRISPR-Cas technology, several challenges remain. One of the primary concerns is the potential for off-target effects, where unintended modifications may occur in the genome. Continued advancements in CRISPR delivery systems and editing precision are crucial to mitigate these risks. Future research should also explore the possibilities of multiplex gene editing, which allows for simultaneous editing of multiple genes to achieve complex traits, such as stacking resistance to multiple pathogens or combining stress tolerance with yield enhancement.

Conclusion

The integration of CRISPR-Cas gene editing into the field of plant pathology offers transformative potential in addressing the challenges of plant diseases and environmental stresses. By enhancing disease resistance, developing resilient crop varieties and enabling rapid pathogen detection, CRISPR technology provides a pathway toward sustainable agricultural solutions. Continued research, ethical considerations and collaborative efforts will be essential to harness the full potential of CRISPR technology, ultimately contributing to food security and environmental sustainability in our changing world.

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Role of Biofertilizers in Sustainable Crop Production

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Abstract

Modern agriculture has achieved remarkable gains in crop productivity through the intensive use of chemical fertilizers. However, their excessive and imbalanced application has led to soil degradation, nutrient imbalance, environmental pollution and declining soil biological activity. In this context, biofertilizers have emerged as an eco-friendly and sustainable alternative for maintaining soil fertility and crop productivity. Biofertilizers are formulations containing beneficial microorganisms that enhance nutrient availability to plants through natural biological processes such as nitrogen fixation, phosphate solubilization, potassium mobilization and stimulation of plant growth. In addition to improving nutrient use efficiency, biofertilizers contribute to soil health, reduce production costs and support sustainable agricultural systems.

Introduction

Indian agriculture is highly dependent on soil fertility for sustaining crop production. During the past few decades, the continuous and indiscriminate use of chemical fertilizers has undoubtedly increased crop yields, but it has also resulted in serious problems such as depletion of soil organic matter, deterioration of soil structure, reduced microbial activity and environmental contamination. These issues threaten the long-term sustainability of agricultural production systems. To address these challenges, biofertilizers have gained considerable importance as an integral component of sustainable and eco-friendly agriculture. Biofertilizers not only supplement chemical fertilizers but also improve soil biological properties, thereby ensuring long-term soil fertility and crop productivity.

What are Biofertilizers?

Biofertilizers are preparations containing living microorganisms which, when applied to seed, soil or plant surfaces, colonize the rhizosphere or the interior of the plant and promote growth by increasing the availability of essential nutrients. Unlike chemical fertilizers, biofertilizers do not directly supply nutrients to crops; instead, they convert unavailable forms of nutrients into forms that can be easily absorbed by plants through biological processes. Thus, biofertilizers play a catalytic role in improving nutrient use efficiency in agricultural soils.

Types of Biofertilizers

Biofertilizers are classified on the basis of the type of nutrient they make available and the microorganisms involved.

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Nitrogen Fixing Biofertilizers

These microorganisms convert atmospheric nitrogen into ammonia, which can be utilized by plants.

***Rhizobium*:** Symbiotic nitrogen-fixing bacteria associated with leguminous crops such as soybean, groundnut, chickpea and other pulses.

***Azotobacter*:** Free-living nitrogen-fixing bacteria commonly used for cereals, vegetables and cotton.

***Azospirillum*:** Associative nitrogen fixer widely used in crops like maize, sorghum, sugarcane and millets.

***Blue Green Algae* (BGA):** Photosynthetic nitrogen fixers extensively used in flooded rice ecosystems.

Phosphate Solubilizing Biofertilizers (PSB)

A large proportion of soil phosphorus exists in insoluble forms. Phosphate solubilizing micro-organisms convert these forms into soluble phosphorus through the secretion of organic acids.

- ✓ *Bacillus spp.* and *Pseudomonas spp.* are commonly used PSB.

Potassium Mobilizing Biofertilizers

These microorganisms mobilize potassium from insoluble mineral forms present in soil, making it available to plants.

- ✓ *Frateuria aurantia* is an important potassium mobilizing bacterium.

Mycorrhizal Biofertilizers

Mycorrhizal fungi form symbiotic associat-ions with plant roots. Arbuscular mycorrhizal (AM) fungi enhance the uptake of phosphorus, micro-nutrients such as zinc and improve water absorption, especially under stress conditions.

Mechanism of Action of Biofertilizers

Biofertilizers promote plant growth through multiple biological mechanisms. Nitrogen-fixing microorganisms possess the enzyme nitrogenase, which converts atmospheric nitrogen into ammonia. Phosphate solubilizing microorganisms secrete organic acids such as gluconic and citric acid that lower soil pH and solubilize insoluble phosphates. Some biofertilizers produce siderophores that chelate iron and make it available to plants. In addition, many beneficial microorganisms synthesize plant growth-promoting substances such as indole acetic acid (IAA), gibberellic acid and cytokinins, which enhance root development and overall plant growth.

Role of Biofertilizers in Soil Health: Biofertilizers play a vital role in maintaining and improving soil health. They enhance soil microbial diversity and activity, leading to increased enzyme production and organic matter decomposition. Improved microbial activity results in better soil aggregation, aeration and water-holding capacity. Biofertilizers also help in restoring degraded soils by improving nutrient cycling and maintaining a balanced soil ecosystem, which is essential for sustainable crop production.

Crop-wise Use of Biofertilizers: Different crops respond differently to specific biofertilizers. Cereals such as wheat and maize respond well to *Azotobacter* and *Azospirillum*. Pulses require *Rhizobium* inoculation for effective nitrogen fixation. Rice cultivation benefits from the use of *Blue Green Algae* and *Azolla*. Oilseed crops respond well to a combi-nation of *Rhizobium* and phosphate solubilizing

bacteria, while vegetables show improved growth with the combined application of *Azotobacter*, PSB and mycorrhizal fungi.

Application Methods of Biofertilizers: Biofertilizers can be applied through seed treatment, seedling root dip and soil application. Seed treatment involves coating seeds with biofertilizer culture before sowing, ensuring early colonization of roots. In transplanted crops, seedlings are dipped in biofertilizer suspension before transplanting. Soil application involves mixing biofertilizers with compost or farmyard manure and applying them to the field, which helps in uniform distribution of beneficial microorganisms.

Advantages of Biofertilizers: Biofertilizers are eco-friendly, non-toxic and safe for humans and the environment. They improve soil fertility and structure, reduce dependence on chemical fertilizers and lower the cost of cultivation. Biofertilizers enhance crop yield and quality while maintaining long-term soil productivity, making them an important component of sustainable agriculture.

Limitations of Biofertilizers: Despite their advantages, biofertilizers have certain limitations. They generally have a short shelf life and are sensitive to high temperature and moisture. The effectiveness of biofertilizers depends on soil conditions and crop type. Inadequate quality control and lack of farmer awareness also limit their widespread adoption.

Future Prospects of Biofertilizers: With the increasing emphasis on organic and sustainable farming, biofertilizers have immense potential in Indian agriculture. Recent developments such as liquid biofertilizers, consortium formulations and improved carrier materials have enhanced their efficiency and shelf life. Government initiatives promoting organic farming and sustainable agriculture can further accelerate the adoption of biofertilizers on a large scale.

Conclusion

Biofertilizers are an essential component of sustainable agricultural systems. They enhance nutrient availability, improve soil health and reduce environmental pollution caused by excessive use of chemical fertilizers. The integration of biofertilizers with chemical fertilizers and organic manures can ensure long-term soil fertility and sustainable crop productivity. Promoting the use of biofertilizers through farmer awareness and policy support is crucial for achieving sustainable agricultural development.

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Scaling Agricultural Innovation through KVKs

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Introduction

Agriculture is the backbone of India's economy and science-driven innovation is key to improving its productivity. To ensure that agricultural technologies developed in research institutions reach the grossroots, the Indian Council of Agricultural Research (ICAR) established Krishi Vigyan Kendras (KVKs) in 1974. Each KVK functions as a district-level agricultural Farm Science Centre, focusing on technology assessment, refinement and dissemination. It acts as a bridge between research and farmers' fields, promoting sustainable, profitable and climate-resilient agriculture.

Objectives of KVKs

- ✓ To assess, refine and demonstrate new technologies under local conditions.
- ✓ To build capacity training programmes among farmers, women and rural youth.
- ✓ To provide scientific farm advisory and diagnostic services.
- ✓ To support entrepreneurship, FPOs and value addition.
- ✓ To ensure sustainable resource management and soil health improvement.

Mandates of KVKs

On-Farm Testing (OFT): Assessing location-specificity of agricultural technologies under various farming systems through field-based trials on crops, livestock and allied sectors.

Frontline Demonstration (FLD): Demonstration of improved varieties, cropping systems and machinery directly in farmers' fields to prove their efficiency and profitability.

Capacity Development: Updating knowledge and skills of farmers, women, rural youth and extension personnel through trainings, skill orientation and vocational training programmes in modern agricultural technologies.

Knowledge and Resource Centre: Supporting public, private and voluntary initiatives to improve the district's agricultural economy.

Production and Availability: Producing and supplying quality technological products like seeds, planting material, bio-agents and livestock to farmers.

Major Projects and Schemes Implemented by KVKs

National Innovations on Climate Resilient Agriculture (NICRA): Demonstrates climate-resilient technologies such as drought-tolerant crops, water harvesting and soil conservation, livestock

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interventions and institutional interventions. Conducting capacity building training programmes, animal health camps, field and exposure visits.

Tribal Sub-Plan (TSP) and Scheduled Caste Sub-Plan (SCSP): Supports tribal and SC/ST farmers with inputs, demonstrations and training in crops, livestock and nutrition gardens for promoting livelihood.

Cluster Frontline Demonstrations (CFLDs) under NFSM: Conducted on oilseeds and pulses to enhance yield and seed replacement rates.

ARYA (Attracting and Retaining Youth in Agriculture): Promotes youth-based agri-enterprises like mushroom cultivation, dairy, vermi-compost and beekeeping.

NARI (Nutri-sensitive Agriculture Research Innovation): Promotes kitchen gardens, dietary diversity and nutrition awareness among rural women.

Natural Farming & PKVY: Demonstrates eco-friendly and low cost natural farming using different organic products.

Soil Health Card: Through Soil Health Card Scheme, testing samples and training farmers to interpret reports and manage soils sustainably.

Digital Extension and Mobile Advisory: Through Kisan Sarathi, WhatsApp groups, call centres, apps and YouTube channels for real-time technology dissemination and weather-based advisories.

Conclusion

Krishi Vigyan Kendras (KVKs) serve as the lighthouses of agricultural transformation, playing a pivotal role in bridging the gap between research and field application. They ensure that innovations under various projects and government schemes effectively reach farmers at the grassroots level. Beyond functioning as mere extension centers, KVKs act as catalysts for comprehensive rural development. By integrating scientific advancements with real-world farming conditions, they empower farmers to enhance productivity, adopt sustainable practices and build resilience against emerging challenges. Strengthening the KVK system will therefore be crucial in securing future food security and ensuring the long-term prosperity of farmers.

Self-Help Group under DAY-NRLM

Raj Jaiswal and Hariom

Abstract

This study examines Self-Help Groups (SHGs) under DAY-NRLM, highlighting their critical role in women's empowerment and large-scale poverty reduction in India. Currently mobilizing 10.05 crore women across 90.90 lakh SHGs, these 10 to 20-member groups facilitate regular savings and mutual financial aid. Guided by Panch-sutra principles and elected leaders, SHGs integrate into broader Village Organisations and federations. Furthermore, specialized community resource persons, known as "Sakhis," support this grassroots model to drive lasting financial inclusion.

Introduction

A self-help group is a voluntary group of women who join willingly. Generally, an SHG consists of 10 to 20 women members. They are mainly promoted and supported by the Ministry of Rural Development through Deendayal Antyodaya Yojana-National Rural Livelihoods Mission (DAY-NRLM) for rural areas and Deendayal Antyodaya Yojana-National Urban Livelihoods Mission (DAY-NULM) for urban areas. India has achieved a major milestone in community mobilisation through the Self-Help Group (SHG) movement. As of January 2025, 10.05 crore women households have been organised into about 90.90 lakh Self-Help Groups (SHGs) across different States and Union Territories, reflecting the scale and depth of women-led collective action in the country. Uttar Pradesh alone accounts for more than 8.42 lakh SHGs, mobilising around 95.1 lakh women households, making it one of the largest contributors to the SHG programme in absolute terms (PIB, 2025).

Table 1: Top 10 States and Union Territories in India based on the number of Self-Help Groups (SHGs) (Source: PIB (2025)

State	Total SHGs	Households Mobilized
West Bengal	1192980	12251533
Bihar	1097100	12713428
Andhra Pradesh	855600	9075289
Uttar Pradesh	842101	9509884
Maharashtra	640719	6525549
Odisha	551141	5775035
Madhya Pradesh	487291	5829972
Telangana	442979	4820573
Assam	361516	4111020
Karnataka	360684	4207374

In an SHG, women regularly save small amounts, as agreed. Savings may be collected weekly or monthly in small amounts, depending on members' capacity. If any woman faces financial problems related to health, education, agriculture, or starting a small business, the group provides financial help from its collective savings. In this way, SHGs help women overcome difficulties, support

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income-generating activities, and promote women's empowerment in rural areas.

Functioning of Self-Help Groups (SHGs)

In a typical Self-Help Group, three primary office bearers are elected from among the members:

President/ First Leader: The President is the overall leader and custodian of the group's functioning. She ensures regular conduct of SHG meetings (weekly/fortnightly/monthly as per norms) and motivates members to attend. The president represents the SHG in the primary federation / Village Organisation (VO) and in meetings with banks, PRI representatives, NGOs, and government officials.

Secretary/ Second Leader: The Secretary organises and convenes SHG meetings in accordance with the agreed schedule and informs members of the date, time, venue, and agenda. She acts as custodian of all SHG records and property minute's book, attendance and savings register, loan ledger, cash book, passbooks, resolutions, etc. With the bookkeeper, she prepares a monthly transaction -cum-information sheet / monthly progress report and submits it to the VO/federation.

Treasurer/ Third Leader: The Treasurer is directly responsible for all cash and financial matters of the SHG. She handles all financial transactions, including deposits and withdrawals from the bank, loan repayments to the bank, and disbursement of loans to members (after group decision).

Through regular meetings, collaborative decision-making, and disciplined financial habits, SHGs serve as robust grassroots organisations that promote financial inclusion and empower women in their communities. To run a self-help group smoothly and successfully, members should follow the principles of Panch-sutra:



Figure 1: Panch-Sutra of SHG

Administrative Setup (NRLM Model)

The structure is designed to ensure grassroots community ownership while providing administrative and technical support through higher-level institutions.

Village Organisation (VO): When 10 to 15 Self-Help Groups (SHGs) come together, they form an Organisation within the same Gram Panchayat, known as a Village Organisation (VO). The VO functions as a supportive and supervisory body, providing guidance, coordination, and monitoring to the member SHGs.



Fig. 2: Institutional Structure (NRLM Model)

Cluster Level Federation (CLF): CLFs serve as Intermediate institutions that aggregate multiple VOs, providing support services, capacity-building, and financial intermediation.

Higher Level Federations: Block, District, State and National level federations that evolve into strong support organisations, enabling policy advocacy and large-scale livelihood interventions

Financial Support Systems for SHGs

Self-Help Groups (SHGs) under schemes like DAY-NRLM receive tiered financial support to cover setup costs, revolving capital, and investments. These funds follow specific eligibility like group maturity and adherence to Panch Sutras (regular savings, meetings, audits, etc.).

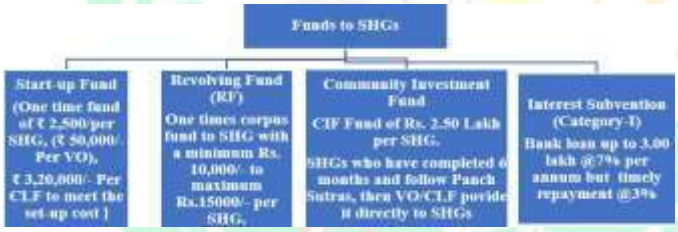


Fig. 3: Financial Support Systems for SHGs

Community Resource Persons (Sakhis)

The mission has trained 3.5 lakh Krishi and Pashu Sakhis and 47,952 Bank Sakhis who serve as last-mile service providers:

Bank Sakhis: Trained SHG members stationed at bank branches to facilitate account opening, transactions, and credit linkage, acting as critical bridges between formal financial institutions and rural women.

Krishi Sakhis: Community Agriculture Service Providers promoting sustainable agricultural practices, building capacity in agro-ecological methods, and facilitating produce aggregation and marketing.

Pashu Sakhis: Community Animal-care Service Providers delivering veterinary services in areas where professional care is scarce or costly.

This community cadre model ensures sustainability while creating employment for rural women.

Conclusion

DAY-NRLM demonstrates that large-scale poverty reduction requires balancing standardisation with contextual flexibility, financial access with capacity building. The program's success in mobilising women offers replicable models, but realising full potential demands addressing capacity deficits, strengthening qualitative monitoring, and deepening sectoral convergence.

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Foraging by Adult Lepidopterans

Priyanka Kaundal and Usha

Introduction

Foraging is how organisms acquire resources, such as food and shelter, in a varied environment. Insects make deliberate decisions to maximize benefits and minimize energy use. Among different insects, the adult moths and butterflies are efficient foragers as they require high energy for flight. Their foraging mainly supports flight, thermoregulation, mating, dispersal, and oviposition. Differences in nutrition, habitat, and evolutionary history lead to specialization on specific food sources. As a result, adult lepidopterans can be broadly classified by their main foraging strategies.

Nectar feeders: constitute the majority of butterflies and moths. Floral nectar serves as a carbohydrate-rich energy source that supports sustained flight and other energy-intensive activities (Fig. 1).

Fruit/Sap-feeders: These are prevalent in tropical regions and prefer rotting fruits, tree sap, and decaying organic matter, which contain higher concentrations of minerals, amino acids, and fermentation by-products than nectar, providing additional nutritional benefits.

Puddling: It is a behaviour in which numerous male butterflies, and occasionally females, gather on moist soil, mud, dung, carrion, or sweat-soaked surfaces to ingest mineral-rich fluids (Fig. 2). This activity allows butterflies to obtain essential nutrients such as sodium and nitrogen, which are vital for sperm production and are subsequently transferred to females during mating. Example, *Halpe* butterfly, which is attracted to the salts found in human sweat.



Fig. 1: *Dryas julia* feeding on the nectar of *Lantana camara* flowers (Krenn, 2008)



Fig. 2: Mud-puddling by *Cepora nadina* (Lesser Gull) from dry stream bed (Wikimedia, 2016)

Pollen feeders: Pollen feeders such as *Heliconius* butterflies, actively collect pollen, which they mix with nectar and digest to obtain essential amino acids. This strategy significantly extends their lifespan and enhances reproductive output.



Fig. 3: Vampire moth, *Calyptra thalictri*, feeding on human thumb (Kevin, 2015)



Fig. 4: Julia butterfly (*Dryas iulia*) feeding on the tears of crocodile i.e. lachryphagy (Thomas, 2014)

Specialized feeders: Many lepidopteran insects exploit unconventional nutrient sources. For example, insects like *Calyptra thalictri* feed on blood (Fig. 3), while others consume tears from mammals,

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birds, or reptiles' eyes, a behaviour termed lachryphagy (Fig. 4). Tears provide valuable salts and proteins that are often scarce in nectar.

How do they locate their food?

Lepidopterans use a combination of visual, olfactory and gustatory cues to locate food. The relative importance of these cues varies among species and is strongly influenced by activity period (diurnal or nocturnal), habitat type, and the nature of the food resource.

Visual Cues: Floral colours such as white, yellow, and blue are especially effective in attracting lepidopterans, as these colours are easily detected against natural backgrounds. Many butterflies are also capable of perceiving ultraviolet light, enabling them to recognize nectar guides, patterns on flowers that direct the insect toward the nectar source.

Olfactory cues: are equally important, especially for nocturnal moths and fruit-feeding species. Floral scents, released as complex blends of volatile compounds such as alcohols and esters, can attract lepidopterans from considerable distances. Fermenting fruits emit strong odours that guide fruit-feeding butterflies and moths to suitable feeding sites, even in low-light conditions where visual cues are limited. In many species, olfaction provides the primary long-range signal, while visual cues become more important at shorter distances.

Gustatory cues: These are important for food suitability. Adult Lepidopterans possess taste receptors in their mouthparts and tarsi. When the insect lands on the food source, these gustatory sensors enable them to rapidly assess the surface's chemical composition and determine whether it provides an appropriate nutrient source. This immediate evaluation prevents unnecessary feeding attempts on unsuitable substrates and enhances overall foraging efficiency.

Role of proboscis and other body parts in foraging

Efficient foraging in adult lepidopterans is made possible by a suite of specialized mouthparts and sensory structures that enable detection, evaluation, and exploitation of liquid food resources. Among these, the proboscis is the most distinctive and functionally important structure involved in feeding.

Proboscis: The proboscis is a long, flexible, tube-like structure formed by the fusion of paired galeae of the maxillae (Fig. 5). When not in use, it remains tightly coiled beneath the head, uncoiling rapidly during feeding. The length, diameter, and flexibility of the proboscis strongly influence the range of food sources a lepidopteran can exploit. Species with short proboscises typically feed on shallow, open flowers, while those with elongated proboscises as in case of hawk moths, that can access nectar hidden deep within tubular flowers. The tip of the proboscis bears sensory structures that help assess nectar quality and regulate suction during feeding

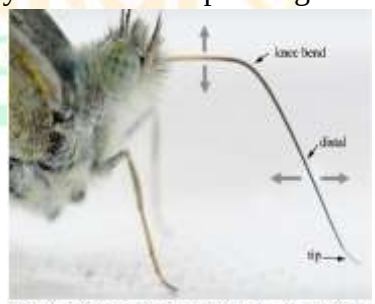


Fig. 5: Proboscis of *Pieris canidia* (Zhou and Zhang, 2013)

Labial palps: are sensory appendages near the mouthparts that aid in olfaction and mechano-reception, helping lepidopterans assess food sources and protect the proboscis during feeding.

Antennae: bear numerous chemoreceptors that detect floral scents and other volatile cues from a distance, playing a crucial role in food location, especially in nocturnal moths.

Compound eyes: enable efficient food detection, with butterflies possessing colour and ultraviolet vision for locating flowers, while moths have eyes adapted for low-light foraging.

Summary

Adult lepidopterans exhibit diverse and highly efficient foraging strategies shaped by their energetic demands and ecological conditions. They exploit a wide range of liquid food sources, including nectar, fruits, mineral-rich substrates, pollen, and even unconventional resources such as blood and tears. Food location is achieved through an integrated use of visual, olfactory, and gustatory cues, while specialized structures such as the proboscis, antennae, labial palps, and compound eyes enable precise detection and efficient feeding.

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The Therapeutic Potential of *Drynaria quercifolia* in Modern Medicine

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Introduction

Drynaria quercifolia is deciduous epiphytic fern commonly known as Oak leaf fern native to India, China and Southeast Asia. It has dimorphic fronds one is nest frond which is sterile condition and another is fertile frond it supposed to produce fertile spores. Fern is nothing but plant doesn't produce flower instead of flowering spores are produced above the matured leaves. The leaf and rhizome have extraordinary healing properties with the potential to treat extensive health issues from inflammation to diabetics. It is commonly grown in trees and rock instead of growing in the soil. In Tamil Nadu and other region of India, peoples prepare soups from the rhizome which relieve Rheumatic arthritis problems, and it helps to promote bone healing as well as strengthening of teeth.

Ethnomedical properties with uses

In the earlier days it is used as traditional medicine to improve the hair growth and treating for hyperthyroidism. The entire plant are helps to anthelmintic, tonic, expectorant, headache and body pain. The rhizome of *Drynariya quecifolia* used to cure cancer, syphilis, diarrhoea. It is one of the sources for anti-diabetic, anti-oxidant action and anti-inflammatory properties. It is also used for lowering the body temperature (antipyretic agent). The rhizome from the plant is used to cure typhoid fever, jaundice and anti-fertility agent. The anti-bacterial character helps to eradicating pathogens which affect the urinary system along with this it is mostly helps to cure Rheumatic problems.

Phytoconstituents: The phytochemical screening test shows different kind of phytochemicals combination present in it, the presence of tannins, coumarins, amino acids, sterols, saponin, alkaloids, flavonoids, terpenoids, proteins then absence of volatile oil and glycosides then β-amyrin, β -sitosterol, 3,4 dihydrroxyl benzoic acid, acetyl lupeol and flavone glycosides.





Anti-inflammatory activity: Naringin, friedelin and quercetin are the compounds activates the anti-inflammatory activity in rhizome and fronds of *Drynaria quercifolia*, some studies shown its effectiveness in inhibiting rat paw oedema and stabilizing red blood cell membrane. The inhibition of inflammatory markers through cytokines like TNF-α and IL-6, squalene compound inhibits the cyclooxygenase-2 enzyme (COX-2), it also posses free radical scavenging and reduce the protein denaturation.

Anti-bacterial activity: The extracts of the rhizome

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are primary source for anti-bacterial activities, ethanolic and methanolic extract have exhibits wide range of antibacterial activity. The microorganism like *Pseudomonas aeruginosa*, *Streptococcus pyrogens*, and *Enterococcus faecalis* this causes urinary tract infections, it was inhibited by the *Drynaria quercifolia* by preventing the microbial growth and inhibiting it.

Anti-diabetic property: The extract of the rhizome restricts the enzymatic activity of alpha-amylase and alpha-glucosidase, it proven that the extract had positive effect on glucose uptake, anti-oxidant properties also help to manage diabetes if an oxidetive stress is a major factor. *Drynaria quecifolia* controls lipid metabolism and inhibit hyperglycemia.

Analgesic activity: Analgesic activity was conducted in animal models (Acetic acid-induced writhing) was screened in the scientific studies with Swiss albino mice was tested with acetic acid injection and *Drynariya quercifolia* in three different concentrations for 20 min before the acetic acid injection, the different concentration of *Drynaria quercifolia* shows similar inhibition of writhing up to 88% in mice.

Anti-pyretic activity: *Drynaria quercifolia* is considered as wide range of nontoxic alternative for toxic effect of aspirin, paracetamol in various organ. Extract of the rhizome can reduce experimentally induced fever in the animals. This extract has anti-pyretic effect of maintaining the normal body temperature which is proven in the experiment of milk induced elevated rectal temperature in rabbits.

Anti-oxidant activity: *D. quercifolia* are rich in phenolic and flavonoids compounds this are primary source for anti-oxidant in both rhizome and frond. Here various studies had proved that it has free radical scavenging potential present in this plant. Anti-oxidant is rich in natural compounds like tannins, vitamins, phenolic acids, and catechin.

Bioactive compounds: Alkaloids are naturally present in the plants and it's made up of different group of amino acids. Due to the presents of nitrogen, alkaloids act as bases and turn red litmus paper into blue colour. The saponin provides analgesic and anti-inflammatory effects. Phenolic compounds in leaf and rhizome are responsible for the anti-oxidant, anti-inflammatory and neuroprotective effects. Flavonoids like naringin have high medical properties such as anti-oxidant and anti-bacterial activities.

Conclusion

This herbal medicine cures a wide range of health problems, so the focus at research on *Drynaria quercifolia* is going on. The conclusion that D.quercifolia was used as traditional medicine for treatment for anti-inflammation, anti-bacterial, anti-oxidant, anti-pyretic, skin problems, typhoid fever, liver cancer, and helpful for body aches. This plant is one of the most important beneficial properties recommended for all people.

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The Role of Biochar in Soil Health Management

Atikur Rahman, Pompy Deka and Mrinal Choudhury

Introduction

Soil health is an essential element of sustainable agriculture, environmental health, and food security. Soil deterioration due to erosion, loss of nutrients, acidification and pollution is compromising agricultural productivity and ecosystem resilience. To this, new and sustainable soil management strategies are gaining momentum among them, the application of biochar has emerged as an important one. Biochar is a carbon-rich solid material derived from the process of pyrolysis, a thermochemical process wherein organic biomass is heated at high temperatures (normally 300-700°C) in the absence or with very limited oxygen. In contrast to normal charcoal, which is generally employed as fuel, biochar is tailored to be made with environmental uses in mind, with specific emphasis on soil amendment and carbon sequestration.

Composition and characteristics

The physical form of biochar varies significantly with the feedstock (e.g., wood chips, agricultural crop residues, manure) and pyrolysis conditions (e.g., temperature, rate of heating, residence time). High content of carbon (up to 80-90%), alkaline pH, porosity and high surface area, high cation exchange capacity (CEC), sufficiently high stability and resistance to biodegradation are some of the important properties of biochar. These properties are responsible for the long life of biochar in soils and its sustained effect on soil health.

Types of biochar

Based on the feedstock and pyrolysis method, biochar can vary significantly in structure and function. Common types include:

- ✓ Wood-derived biochar - rich in stable carbon but lower in nutrients
- ✓ Manure-based biochar - nutrient-rich but may degrade more quickly
- ✓ Crop residue biochar - widely used and often available locally

Difference between biochar and other amendments

Although other materials such as manure and compost also improve soil health, biochar is distinct in that it is recalcitrant, resisting microbial decomposition. This renders it a longterm carbon storage solution as well as a permanent improvement to soil structure, supplementing more nutrient-based amendment.

Mechanisms of biochar in soil health sustainability

Biochar impacts soil health through a variety of physical, chemical, and biological mechanisms.

Physical mechanisms

Improvement in soil structure: Biochar's porous

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nature and high surface area help improve soil aeration, porosity, and aggregation. This is especially beneficial for compacted or clay-heavy soils, as it enhances root penetration and reduces bulk density.

Enhanced water retention: Due to its sponge-like structure, biochar can hold significant amounts of water, making it useful in drought-prone areas. It improves soil water-holding capacity while also facilitating better drainage in waterlogged soils.

Chemical mechanisms

pH adjustment: Biochar is normally alkaline in nature, and when it is added to acidic soils, it can neutralize them. This increases the availability of nutrients, especially phosphorus, and enhances the efficiency of microbial activities.

Cation exchange capacity (CEC): The large surface area and functional groups in biochar increase its CEC, enabling it to adsorb and exchange more nutrients such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). This reduces the leaching of nutrients and enhances fertilizer efficiency.

Immobilization of contaminants: Biochar has the capability to sequester heavy metals, pesticides, and organic pollutants by sorption, hence minimizing their mobility and bioavailability in the soil. It is thus effective in soil remediation activities.

Biological mechanisms

Microhabitat for soil microbes: Biochar's porous nature creates a favorable microhabitat for healthy soil microbes, such as bacteria, fungi and actinomycetes. This enhances a lively food web in the soil as well as nutrient cycling.

Improved symbiotic interactions: Biochar may increase plant-mycorrhizal fungi symbiosis, contributing to improved nutrient uptake, especially phosphorus. It may also facilitate nitrogen-fixing bacteria, essential for legumes.

Suppression of disease: Other research indicates that biochar is capable of inhibiting soil-borne disease by increasing beneficial microbial populations and modifying soil pH and chemistry in a manner detrimental to disease-causing pathogens.

Benefits of biochar in soil health management

Biochar offers a wide range of benefits for soil health, making it a valuable tool in sustainable agriculture and land management. These benefits span physical, chemical, and biological aspects of soil, contributing not only to improved crop productivity but also to long-term environmental sustainability.

Enhanced soil fertility: Biochar increases the retention of nutrients by enhancing the cation exchange capacity (CEC) of the soil. This enables the soil to retain vital nutrients like nitrogen, potassium, and phosphorus for longer durations and make them more accessible to plants. In low-fertility soils, biochar serves as a buffer, avoiding leaching losses and enhancing fertilizer efficiency.

Improved water holding capacity: One of the most important advantages of biochar is that it maintains moisture. This is especially valuable in dry and semi-arid areas, where lack of water constrains

farming productivity. Biochar can enhance drought resistance, slow down irrigation intervals, and reduce water runoffs.

pH control and soil improvement: Alkaline properties of biochar can reverse acidic soils that are prevalent in most tropical and subtropical ecosystems. pH adjustment in the soil improves the availability of nutrients such as phosphorus and calcium and creates a more hospitable environment for root growth and microbial life.

Promotion of soil microbial communities: Biochar acts as a shelter and home for beneficial soil organisms, including nitrogen-fixing bacteria and mycorrhizal fungi. These beneficial organisms are responsible for nutrient cycling, plant health, and the suppression of diseases. Better microbial activity may result in increased soil organic matter and biological fertility.

Carbon sequestration: Due to its carbon stable structure, biochar is resistant to decomposition and persists in the soil for hundreds or thousands of years. This renders it a useful tool for sequestering atmospheric CO_2 and thus reducing climate change. Its use in agriculture supports carbon-negative or low emission agriculture practices.

Reduction of greenhouse gas mission: Biochar can lower soil emissions of strong greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4). Biochar accomplishes this by changing microbial activity in the soil and stabilizing carbon in organic matter, which would otherwise be released when decomposing.

Remediation of contaminated soils: Because of its adsorption capacity, biochar can trap heavy metals and organic contaminants like pesticides and petroleum hydrocarbons. This quality makes it a valuable asset for the restoration of degraded or polluted lands, such as mining areas and industrial wastelands.

Cost-effective and locally available: Biochar can also be made from readily available agricultural wastes like crop residues, animal dung, or forestry residues. This minimizes production expenses and promotes circular economic models in agriculture communities.

Challenges and limitations of biochar in soil health management

While biochar offers many promising benefits, its application is not without challenges and limitations. Understanding these is crucial to developing effective strategies for its use in soil health management.

Variability in biochar properties: Biochar's characteristics depend heavily on the feedstock type and pyrolysis conditions such as temperature and duration. This variability can lead to inconsistent effects on soil and crops. For example, biochars produced at higher temperatures tend to have higher carbon stability but lower nutrient content.

Potential negative effects on soil: In some cases, biochar application can cause nutrient imbalances or pH increases that negatively affect sensitive crops or soil biota. Excessive biochar application may also reduce soil nitrogen availability due to nitrogen

immobilization, which can temporarily limit plant growth.

Lack of standardized production and quality control: Currently, there are no universally accepted standards or certifications for biochar quality. This makes it difficult for farmers and land managers to select suitable biochars and apply them correctly. Poor-quality biochar may contain contaminants such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), or persistent organic pollutants.

Economic and logistical constraints: While biochar can be produced locally, setting up pyrolysis units requires capital investment and technical knowledge. In some regions, the cost of production and transportation may outweigh the perceived benefits, limiting its adoption by smallholder farmers.

Limited long-term field data: Although many short-term studies show positive effects, there is a relative lack of long-term, large-scale field trials assessing the sustained impact of biochar on soil health, crop productivity, and environmental outcomes across diverse soil types and climates.

Interaction with other soil amendments: Biochar's interactions with fertilizers, compost, and pesticides are complex and not fully understood. Misapplication could lead to reduced efficiency of other soil inputs or unintended ecological effects.

Environmental concerns: While biochar production reduces biomass waste, pyrolysis can release pollutants such as volatile organic compounds (VOCs) and particulate matter if not properly controlled. Sustainable biochar production must incorporate pollution control technologies.

Biochar holds significant potential as a versatile tool in sustainable soil health management and climate mitigation. Advances in production technologies, scientific understanding, and policy support are shaping its future use.

Conclusion

Biochar is a robust and versatile resource for enhancing soil health and solving urgent global environmental issues like soil erosion and global warming. Biochar's physical, chemical and biological processes improve soil fertility, water storage, microbial function and carbon sequestration. The demonstrated advantages across various agricultural systems ranging from ancient Amazonian Terra Preta soils to farm trials demonstrate its worldwide applicability and scope to aid in sustainable agriculture. Nonetheless, the efficacy of biochar is contingent on proper planning of feedstock type, production, and site-specific soil conditions. Difficulties like inconsistency in biochar characteristics, cost factors, and requiring standardized quality control need to be overcome to reap safe and effective utilization. Ongoing research, policy encouragement, and incorporation into other sustainable agriculture practices will be crucial for the realization of the full potential of biochar. As the globe looks for new ways to ensure food production and reduce climate change, biochar presents a promising option.

POLY4: A Multi-Nutrient Mineral Fertilizer for Balanced Nutrition and Sustainable Agriculture

Anil Jakhar, Priyanka Choudhary, Rahul Jakhar and Priyanka Choudhary

Introduction

The intensification of agriculture over the past five decades has substantially increased crop productivity, yet it has also exposed limitations in conventional fertilization strategies. The predominant focus on nitrogen, phosphorus and potassium (NPK) fertilizers has often resulted in the neglect of secondary nutrients such as sulphur, magnesium and calcium. Continuous cropping without balanced replenishment has contributed to nutrient mining, declining soil fertility and reduced nutrient use efficiency. In this context, Poly4, a natural multi-nutrient fertilizer derived from the mineral polyhalite, has emerged as a promising alternative for sustainable and climate-resilient agriculture. Poly4 offers a unique combination of potassium, sulphur, magnesium and calcium in a single granule. Its multi-nutrient composition and low environmental footprint position it as a strategic input for integrated nutrient management systems. With increasing emphasis on climate-smart agriculture, soil health restoration and carbon footprint reduction, Poly4 has gained attention in both research and commercial agriculture.

Mineralogical Origin and Composition

Poly4 is produced from polyhalite, a naturally occurring evaporite mineral with the chemical formula $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$. Unlike chemically synthesized fertilizers, polyhalite is mined and processed with minimal chemical alteration. The fertilizer typically contains approximately 14% K_2O, 19% sulphur as sulfate, 6% MgO and 17% CaO. Each of these nutrients plays a critical physiological role in plant growth. Potassium regulates stomatal activity and enzyme activation, sulphur is essential for amino acid synthesis and protein formation, magnesium forms the central atom in chlorophyll molecules and calcium strengthens cell walls and improves soil structure. The simultaneous supply of these nutrients ensures balanced nutrition, particularly in soils where secondary nutrient deficiencies are increasingly observed.



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Evolution of Poly4 in Agricultural Research

Interest in polyhalite as a fertilizer source increased during the early twenty-first century as agronomists sought alternatives to chloride-based potassium fertilizers. Initial research focused on understanding nutrient solubility and release dynamics in soil systems. Subsequent field experiments compared polyhalite with conventional muriate of potash across diverse agro-ecological zones. Early studies demonstrated that polyhalite could provide competitive crop yields while improving nutrient balance. Research evaluating maize production in Tanzania showed comparable grain yields between polyhalite and muriate of potash, indicating its suitability as a potassium source. Later investigations examined nutrient retention and release patterns, revealing that polyhalite dissolves gradually in soil, thereby synchronizing nutrient availability with crop demand and reducing leaching losses. As research expanded geographically, Poly4 was evaluated in cereals, oilseeds, legumes and horticultural crops. Evidence suggested improvements not only in yield but also in crop quality parameters such as protein content, oil composition and bulb size in vegetable crops. These findings strengthened the scientific basis for recommending Poly4 within integrated nutrient management frameworks.

Mechanisms of Nutrient Release and Soil Interaction

One of the defining characteristics of Poly4 is its moderate solubility. Unlike highly soluble potassium salts that release nutrients rapidly after application, polyhalite dissolves gradually. This controlled release reduces the risk of nutrient losses through leaching, particularly in sandy or high rainfall regions. Sulphur supplied in sulfate form is immediately plant-available, supporting early vegetative growth and protein synthesis. Magnesium enhances photosynthetic efficiency, while calcium contributes to improved soil aggregation and root development. The cumulative effect of these nutrients can enhance nutrient uptake efficiency and physiological resilience. Additionally, the low chloride content of Poly4 makes it suitable for chloride-sensitive crops such as tobacco, potato and certain fruits. Its neutral reaction in soil also minimizes risks of soil acidification associated with some conventional fertilizers.

Poly4 in Climate-Smart Agriculture

Climate-smart agriculture aims to increase productivity, enhance resilience and reduce greenhouse gas emissions. Poly4 contributes to these goals in multiple ways. First, its low processing requirement results in a comparatively lower carbon footprint than many synthetic fertilizers. Reduced industrial synthesis translates into lower energy consumption and greenhouse gas emissions during production. This feature aligns with global efforts to decarbonize agricultural supply chains. Second, balanced nutrient supply improves nutrient use efficiency. Efficient nutrient uptake reduces excess fertilizer application, thereby minimizing nitrous oxide emissions and nutrient runoff. By supporting stronger root systems and improved soil structure,

Poly4 can enhance water retention and drought tolerance, traits that are increasingly valuable under climate variability. Third, Poly4 integrates well with precision agriculture technologies. In variable rate application systems, its multi-nutrient composition allows farmers to address multiple deficiencies simultaneously. When combined with soil testing, remote sensing and digital nutrient management tools, Poly4 can support site-specific nutrient management strategies.

Role in Regenerative and Sustainable Farming Systems

Beyond climate-smart frameworks, Poly4 fits within regenerative agriculture models that prioritize soil health restoration. Continuous application of balanced nutrients helps maintain soil fertility and biological activity. Calcium and magnesium contribute to cation exchange capacity and soil structural stability, supporting beneficial microbial communities. In organic and low-input systems, where nutrient sources are limited, Poly4's natural mineral origin offers additional appeal. Although regulatory acceptance varies by country, its minimal chemical processing aligns conceptually with sustainable nutrient sourcing. Moreover, Poly4 has shown positive effects on crop quality, including improved oil content in mustard and enhanced nutrient uptake in vegetable crops. Quality improvements contribute to better market value and nutritional outcomes, linking soil management directly with food quality.

Economic and Agronomic Considerations

From an economic perspective, adoption depends on both yield response and input cost. While Poly4 may not always be the least expensive potassium source per unit nutrient, its multi-nutrient composition reduces the need for separate sulphur, magnesium and calcium fertilizers. This consolidation can simplify fertilizer programs and potentially lower total application costs. Long-term agronomic benefits, including improved soil structure and sustained fertility, may not be immediately visible but can contribute to stable productivity over time. In regions experiencing widespread sulphur deficiency due to reduced atmospheric deposition, Poly4 provides a strategic solution without requiring additional sulphur supplementation.

Future Prospects and Research Needs

Although existing research supports Poly4's agronomic potential, further long-term studies are necessary to evaluate cumulative soil effects, carbon balance and economic returns across diverse agro-ecological conditions. Comparative life cycle assessments would provide stronger evidence of its environmental advantages. Future integration with digital agriculture, nutrient decision support systems and carbon accounting frameworks could further enhance its role in sustainable farming. As global agriculture transitions toward nutrient efficiency and environmental stewardship, multi-nutrient fertilizers such as Poly4 are likely to become increasingly relevant.

Conclusion

Poly4 represents a significant advancement

in mineral fertilizer technology by combining potassium, sulphur, magnesium and calcium in a single, naturally derived product. Its balanced nutrient composition, gradual release pattern and compatibility with climate-smart and regenerative agriculture systems position it as a viable alternative to conventional fertilizers. By addressing both productivity and sustainability objectives, Poly4 contributes to a more resilient and resource-efficient agricultural future.

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The Nutritional Treasure inside Pumpkin Seeds

Priyanka Deka

Abstract

Pumpkin (Cucurbita L.) seeds, commonly known as pepitas and mainly obtained from *Cucurbita pepo*, are nutrient-dense edible seeds with significant health and functional value. They are rich in protein, healthy fats, dietary fiber, vitamins, essential minerals (such as magnesium, zinc, and iron), and bioactive compounds including antioxidants and phytochemicals. Regular consumption is associated with benefits such as improved heart health, enhanced immunity, better sleep, stronger bones, and overall wellness. Owing to their nutritional richness and therapeutic potential, pumpkin seeds are increasingly utilized in functional foods, nutraceuticals, and health-promoting dietary applications.

Introduction

Cucurbita (L.) is a prominent genus belonging to the family Cucurbitaceae. Botanically, pumpkin is described as a perennial, vigorous, trailing or climbing plant characterised by an extensive vine system that may reach up to 12 meters in length. The plant bears large, verdant leaves, branched tendrils, and produces fruits that exhibit remarkable diversity in morphology, including variations in shape, size, weight, and rind color (Chahal *et al.*, 2022).In India, pumpkin is commonly referred to as “Kashiphal” or “kaddu,” and it is taxonomically classified under the family Cucurbitaceae and the genus Cucurbita. Beyond its botanical and agricultural relevance, pumpkin occupies a significant position in socio-cultural and culinary contexts.It is traditionally used in a variety of culinary preparations and also holds symbolic importance in certain customary practices. Whether utilised for decorative purposes at household entrances or incorporated into diverse traditional dishes, pumpkin has secured a distinguished place in both dietary patterns and cultural traditions. Pumpkin seeds, also known as pepitas, are edible seeds derived primarily from pumpkins (*Cucurbita pepo*) and other species within the genus Cucurbita.Morphologically, the seeds are typically flat and oval in shape, possessing two axes of symmetry. They are characterised by a white outer hull (seed coat), while the dehulled kernels exhibit a distinctive light green colouration. Certain pumpkin cultivars are hull-less and are specifically cultivated for their edible seeds (Song et al., 2011). In recent years, pumpkin seeds have gained considerable attention owing to their nutritional richness and functional properties. They are widely consumed as roasted snacks and are incorporated as ingredients in various bakery products, including bread and cakes, particularly in developed countries. The term “pumpkin seeds” may refer either to the whole, unhulled seeds or to the

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hulled kernels; however, it most commonly denotes the roasted seed product marketed and consumed as a snack. Beyond their role in traditional food applications, pumpkin seeds are increasingly utilised in culinary, medicinal, and functional food formulations, reflecting their growing economic and nutritional significance. Pumpkin seeds have received considerable attention in recent years because of their notable nutritional and health benefits (George, 2019). They are rich sources of protein, vitamin E, provitamins, carotenoids, saponins, fibre, and essential minerals such as calcium, magnesium, iron, sodium, and copper. In addition, pumpkin seeds contain important phytochemicals, including polyphenols, phyto-estrogens, and fatty acids, which contribute to various health benefits, such as cardiovascular support and the management of sex hormone imbalances in menopausal women (Patel and Rauf, 2017). Furthermore, pumpkin seeds are both nutrient- and calorie-dense, with particularly high levels of fat, especially linoleic acid and oleic acid alongside substantial amounts of protein, dietary fibre, and numerous micronutrients.

Health Benefits of Pumpkin Seeds

Supports Heart Health: Pumpkin seeds are rich in zinc, magnesium, and healthy fatty acids, all of which are beneficial for heart health. Regular consumption may help lower bad cholesterol (LDL) levels while increasing good cholesterol (HDL). They also play a role in maintaining healthy blood pressure levels.

Strengthens the Immune System: These seeds are an excellent source of iron and zinc, nutrients that are essential for a strong immune system. A healthy intake can help the body fight off colds, infections, and other viral illnesses more effectively.

Improves Sleep Quality: Pumpkin seeds contain tryptophan, an amino acid that helps the body produce melatonin and serotonin. These hormones regulate sleep patterns and reduce stress. Eating a small handful of roasted pumpkin seeds before bedtime may promote better sleep.

Aids Digestion: High in dietary fiber, pumpkin seeds help relieve constipation and support regular bowel movements. They promote healthy digestion, reduce bloating, and may help ease common stomach issues such as gas and heartburn.

Boosts Brain Function: The zinc, magnesium, iron, and antioxidants found in pumpkin seeds contribute to improved brain function. They help enhance memory, increase concentration, reduce stress, and keep the brain active. This makes them beneficial for both children and older adults.

Supports Men's Health: Pumpkin seeds are particularly beneficial for men's health. The zinc they contain supports reproductive health, improves sperm quality, and may help reduce prostate-related issues. For this reason, many experts recommend that men include a small amount of pumpkin seeds in their daily diet.

Strengthens Bones: Pumpkin seeds provide essential nutrients such as calcium, magnesium, and phosphorus, which are important for maintaining strong bones. Regular consumption may help impro-

ve bone density and reduce the risk of conditions like osteoporosis, especially as people age.

Enhances Skin and Hair Health: The zinc, vitamin E, and omega-3 fatty acids in pumpkin seeds help nourish hair follicles and strengthen hair. They also help maintain skin moisture, reduce wrinkles, and promote a healthy glow. Including pumpkin seeds in your diet can naturally support healthier skin and hair.

Supports Weight Management: Rich in protein and fiber, pumpkin seeds help you feel fuller for longer periods. This can reduce hunger and cravings, leading to lower calorie intake. As a healthy snack option, they are beneficial for those trying to manage or lose weight.

Nutritional Value of Pumpkin Seeds

Table 1: Nutritional Value of Pumpkin Seeds (per 100 g) (Amin *et al.*, 2019 and Rezig *et al.*, 2019)

Nutrient	Nutritional Value Dry basis	Nutritional Value Wet Basis
Moisture (mg)	56.74	6.96
Ash (mg)	3.54	3.47
Energy (kJ)	311.54	-
Carbohydrate (mg)	5.18	-
Total sugars (mg)	9.73	1.15
Protein (mg)	21.31	40.00
Fat (mg)	23.45	35.53
Total fiber (mg)	46.65	12.89
Ascorbic acid (mg)	15.00	-
Sodium (mg)	1.35	189.81
Potassium (mg)	434.71	471.70
Iron (mg)	6.02	7.07
Calcium (mg)	4.00	44.92
Zinc (mg)	18.78	8.42
Phosphorus (mg)	0.74	1471.24
Copper (mg)	0.31	89.84
Manganese (mg)	1.35	3.93
Magnesium (mg)	4.35	527.85

Rich in Antioxidants: Pumpkin seeds contain powerful antioxidants, including phenolic compounds, vitamin E, and carotenoids. These compounds help protect the body from damage caused by free radicals, slow cellular ageing, and support overall health.

Conclusion

Pumpkin seeds are a highly nutritious and versatile food that offer significant health benefits despite their small size. They are rich in protein, healthy fats, fiber, vitamins, minerals, and powerful antioxidants, and they offer a wide range of health benefits. From supporting heart health and strengthening immunity to promoting better sleep, stronger bones, and improved brain function, these nutrient-dense seeds can be a simple yet powerful addition to a balanced diet.Consumption of pumpkin seeds may contribute to improved heart health, stronger immunity, better sleep quality, enhanced brain function, and healthier bones. Their rich nutrient profile also supports skin and hair health while promoting satiety, making them a smart choice for weight management.Their high content of magnesium, zinc, iron makes them especially beneficial for overall wellness. Whether enjoyed roasted as a snack, added to salads and smoothies, or incorporated into baked goods, pumpkin seeds provide both flavor and nourishment. Including them regularly in your diet can be a natural and effective way to support long-term health and vitality.

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Harnessing Mycorrhizal Fungi: An Eco-Friendly Approach to Combat Plant Pathogens

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Abstract

Mycorrhizal fungi establish symbiotic associations with roots of agricultural crops and soils, playing a vital role in suppressing diseases caused by soil-borne pathogens including *Phytophthora*, *Rhizoctonia*, *Pythium*, *Aphanomyces*, *Verticillium*, *Fusarium*, *Macrophomina* and others. Plant pathologists and ecologists have shown growing interest in utilizing mycorrhizal fungi as biological control agents against root pathogens. Root colonization by these beneficial fungi reduces disease severity through multiple mechanisms such as nutrient competition with pathogens, antibiotic production, hydrolytic enzyme induction, PR-protein enhancement, phytoalexin stimulation and activation of defense-related enzymes. Plants benefit from mycorrhizal associations through improved efficiency in nutrient and water acquisition. These fungi significantly enhance phosphorus uptake, promoting better plant growth and productivity. They contribute to maximizing ecological advantages while reducing environmental risks. Mycorrhizal fungi improve rhizosphere conditions by modifying soil physical and chemical characteristics, promoting beneficial microorganisms, and competing with pathogenic species.

Introduction

Biological management of plant pathogens represents a fundamental approach in sustainable agriculture, aiming to reduce dependence on synthetic pesticides while providing alternative strategies for pathogen control. This approach enhances crop yields through pathogen suppression, improved plant resistance, and effective protection mechanisms. Biological control offers multiple benefits including environmental safety, absence of pesticide resistance development, minimal risk factors, and compatibility with sustainable farming systems. Mycorrhizal fungi have emerged as significant bio-control agents within integrated disease management frameworks. These organisms constitute essential natural components of soil ecosystems, colonizing roots of over 80% of terrestrial plant species, including numerous agriculturally important crops. Franciszek Kamienski (1881) first discovered the symbiotic fungus-root association in *Monotropa hypopitys*. Professor Albert Bernhard Frank introduced the term 'mycorrhiza' in 1885. Initially classified under Zygomycota, recent 18S ribosomal RNA studies indicate ancestral connections with Ascomycota and Basidiomycota, leading to reclassification into the monophyletic phylum Glomeromycota. Among various endomycorrhizal types, Vesicular-arbuscular (VA), ericoid, arbutoid, orchid,

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and monotropoid mycorrhizae are well-recognized. Arbuscular mycorrhizal fungi (AMF) represent the most prevalent, biomass-rich, and significant beneficial fungal group, exhibiting specific antagonistic properties against soil-borne pathogens. Sustainable agriculture increasingly relies on biological disease control to minimize synthetic fungicide usage and provide alternative management options for soil-borne infections. Commercial biocontrol agents including *Pseudomonas fluorescens*, *Bacillus subtilis*, *Trichoderma harzianum*, *T. viride*, mycorrhizal fungi (*Glomus* spp.) and *Agrobacterium radiobacter* strains 84 and K1026 effectively combat soil-borne pathogens. AMF reduce damage from fungi, nematodes, bacteria, and other pathogens affecting crops such as cucumber, strawberry, tomato, citrus, olive, alfalfa, melon, maize, potato, banana, while simultaneously decreasing pesticide requirements.

Arbuscular Mycorrhizal Fungi (AMF)

AM fungi represent the most widespread mycorrhizal association, forming mutualistic relationships with over 80% of vascular plants. Vesicular arbuscular mycorrhizae develop distinctive structures including arbuscules and vesicles produced by Glomeromycota fungi, previously classified as Endogonales under Zygomycetes. These fungi assist plants in capturing soil nutrients, particularly phosphorus and micronutrients. The evolution of arbuscular mycorrhizal symbiosis played a crucial role in plant colonization of terrestrial environments and vascular plant development (Siddiqui *et al*., 2008; Kakraliya *et al*., 2020). All AMF fungi are obligate biotrophs, completely dependent on plant hosts for survival. Important genera include *Glomus, Acaulospora, Gigaspora, Scutellospora, Enterophospora* and Sclerocystis (Ejersa, 2021). This article summarizes action mechanisms against fungal, bacterial, nematode, and viral pathogens (Table 1) along with mycorrhizal formulation application methods.

Mechanism of Action of Mycorrhizae

Mycorrhizal fungi have attracted considerable research attention due to their biocontrol potential and agricultural applications. These organisms employ multiple mechanisms that operate independently or synergistically. Challenges in utilizing AM fungi for biocontrol include their obligate nature, limited understanding of involved processes, and environmental influences on these interactions. Mycorrhizal symbiosis controls plant diseases through several mechanisms:

Physical/Mechanical Barrier Formation against Pathogen Penetration: VAM fungi create mechanical barriers that impede pathogen entry and subsequent spread. These physical obstacles provide non-chemical hindrance preventing pathogen access or movement. Ectomycorrhizal fungi associated with over 46 tree species across eight genera form fungal mantles of varying thickness on root surfaces, protecting against pathogenic fungi and nematode infections. Ericoid mycorrhizal fungi control *Phytophthora cinnamomi* (pine root rot) by developing a mental covering over cortical cells, preventing

fungal penetration into roots (Mohammad, 2019).

Antibiotic/Metabolite Secretion for Pathogen Inhibition: Various mycorrhizal and associated saprophytic fungi produce diverse antibiotics and metabolites that inhibit pathogenic organisms and protect root systems. Species including *Amanita spp., Boletinus spp., Cenococcum spp., Lactarius spp., Laccaria laccata, Leucopaxillus cerealis var. piceina, Pisolithus tinctorius, Suillus luteus* and *Thelephora terrestris* produce antifungal, anti-bacterial, and antiviral metabolites. *Leucopaxillus cerealis* var. *piceina* produces Diatretyne nitrile, Diatretyne amine, and Diatretyne-3, which inhibit numerous pathogens including nive *Phytophthora* species, twenty-four *Phthium* species, five *Rhizoctonia* species, *Sclerotium bataticola* and *Cylindrocladium scoparium* (Sharma *et al*., 2014).

Nutrient Competition with Pathogens in Rhizo-sphere and Root Surface

Mycorrhizal fungi excel in competing with pathogens due to adequate carbohydrate, amino acid, vitamin, and mineral supplies from root exudates combined with host root protection. These associ-ations utilize surplus root exudate carbohydrates, converting sucrose or monosaccharides (hexose) into less soluble sugars including trehelose, mannitol, and sorbitol. Pathogenic fungi propagules (*Pythium, Phytophthora, Rhizoctonia, Sclerotium, Fusarium*) require nutrients for germination, which become less available in mycorrhizosphere, reducing propagule germination and root attractiveness to pathogens. Mycorrhizal colonization stimulates host roots to produce and accumulate sufficient metabolite conce-ntrations (terpenes, phenols) that impart resistance against pathogen invasion. AMF-enhanced nutrition and growth enable mycorrhizal plants to better tolerate pathogens and compensate for root damage and photosynthate loss (Roy *et al.,* 2018).

Anatomical and Morphological Root System Changes: AMF colonization induces root morphology modifications. Colonized roots exhibit increased branching compared to non-colonized plants, with larger adventitious root diameters providing additional potential infection sites. Fusarium wilt infection in tomato and cucumber may be delayed due to morphological changes in endodermal root cells of AM plants, involving lignification and thickening. Enhanced lignification protects roots from other pathogens while increasing phenolic metabolism in host plants. Cell wall thickening through lignification and additional polysaccharide synthesis inhibits root pathogen entry (Tahat *et al.,* 2010).

Competition for Colonization and Infection Sites: Physical competition between AMF and rhizosphere microorganisms for root architecture space represents the primary mechanism explaining AMF-soil microorganism interactions. This competition stimulates microbial activity in the root zone (Rhizosphere, Rhizoplane), limiting pathogen access to roots. VAM/AM-colonized roots may harbour actinomycetes that become antagonistic to root pathogens (Tahat *et al.,* 2010).

Prevention of Nutrient Leakage from Host Cells:

Table 1: Important mycorrhizal fungi used to manage pathogenic organism in plants

Biocontrol of mycorrhizal fungi	Targeted organism	Disease management
Mycorrhizal fungi used to manage pathogenic fungi in plants		
Glomus versiforme	*Erysiphe flexuosa*	Powdery mildew in cowpea
Glomus fasciculatum and *Acaulospora laevis*	*Fusarium oxysporum f. sp. lycopersici*	Wilt in tomato
Glomus clarum and *Glomus deserticola*	*Pythium aphanidermatum*	Foot rot, stem rot, and root rot in pawpaw tree
Funneliformis mosseae	*Gaeumannomyces graminis*	Take-all disease in wheat
Glomus intraradices	*Fusarium verticillioides*	Root rot, stalk rot, seedling blight, and ear rot in maize
Glomus mosseae, Glomus etunicatum, Glomus fasciculatum, Gigaspora margarita	*Phytophthora capsici*	Phytophthora blight in pepper
Glomus mosseae	*Gaeumannomyces graminis var. tritici*	Take-all disease in barley
Glomus mosseae	*Fusarium oxysporum f. sp., Lycopersici* (Fol.)	Wilt disease in tomato
Glomus fasciculatum	*Fusarium oxysporum f. sp. ciceris*	Wilt in chickpea
Glomus clarum and *Glomus deserticola*	*Rhizoctonia solani*	Collar rot and web blight in cowpea
Glomus etunicatum	*Rhizoctonia solani*	Black scurf and stem canker in potato
Glomus boninense	*Ganoderma boninense*	Basal stem rot in oil palm
Glomus etunicatum and *Glomus monosporum*	*Phytophthora fragariae*	Red stele disease in strawberry
Mycorrhizal fungi used to manage pathogenic bacteria in plants		
Arbuscular mycorrhizal fungi	*Pseudomonas solanacearum*	Bacterial wilt in eucalyptus seedlings
Glomus mosseae	*Pseudomonas syringae*	Bacterial blight infection in soybean
Glomus macrocarpum	*Pseudomonas lacrymans*	Angular leaf spot in cucumber
Glomus fasciculatum or Glomus mosseae	*Pseudomonas syringae pv. mori*	Bacterial leaf spot in mulberry
Arbuscular mycorrhizal fungi	*Actinomycetes*	Apple replant disease in apple seedlings
Arbuscular mycorrhizal fungi	*Pseudomonas*	Bacterial inflorescence rot, stem canker in grapevine
Glomus mosseae	*Pseudomonas syringae*	Bacterial speck in tomato
Mycorrhizal fungi used to manage pathogenic viruses in plants		
Arbuscular mycorrhizal fungi	Grape vine fanleaf virus	Grape vine
Rhizophagus intraradices (Syn. *Glomus intraradices* isolate BEG141)	Grape vine fanleaf virus	Grapevine rootstock
Funneliformis mosseae (Syn. *Glomus mosseae* BEG12)	Tomato yellow leaf curl virus	Tomato
Rhizophagus irregularis	Potato virus Y	Potato
Funneliformis mosseae (Syn. *Glomus mosseae*)	Cucumber mosaic virus (CMV-Y, yellow strain)	Cucumber cv. Tokiwa Jibai
Funneliformis geosporum (Syn. *Endogone macrocarpa var. Geospora*)	Citrus leaf rugose virus	Alemow, Grape fruit, Sour orange
Rhizophagus intraradices (Syn. *Glomus intraradices*)	Potato virus Y	Potato
Rhizophagus irregularis	Cucumber green mottle mosaic virus (CGMMV)	Cucumber
Rhizophagus irregularis	Tobacco mosaic virus (TMV)	Tobacco
Claroideoglomus etunicatum (Syn. Glomus tincture)	Citrus tristeza virus	Alemow, Grape fruit, Sour orange
Rhizophagus intraradices (Syn. *Glomus intraradices*)	Tobacco mosaic virus (strain U1)	Tobacco
Mycorrhizal fungi used to manage pathogenic nematode in plants		
Glomus mosseae	*Meloidogyne incognita*	Root-knot disease in several crop plants

Source: Adapted from Himaya *et al*., 2020

AMF colonization often increases host root tissue phosphorus levels, modifying phospholipid composition and root membrane permeability. This reduces net leakage of sugars, carboxylic acids, and amino acids into the rhizosphere. These changes diminish pathogen chemotactic effects on plant roots and impede pathogen entry. Symbiotic associations enhance inhibitor concentrations several times higher than non-symbiotic roots. Pine (*Pinus sylvestris*) seedlings with variegatus symbiosis produce eight-fold higher concentrations of fungi-static compounds including terpenes and sesquiter-penes. Similar compounds occur in ectomycorrhizal fungi like *Amanita* and *Rhizopogon*. Various mycor-rhizal fungi including *Amanita rubescans, Boletus variegatus, Pisolithus tinctorious* and *Hebeloma sarcophyllum* produce volatile organic compounds (ethanol, isobutanol, isoamylalcohol, acetoin, isobutyric acid) inhibitory to pathogenic fungi such as *Phytophthora cinnamomi*, *Rhizoctonia undulata, Phymatyotrichum omnivorum, Fomes annosus* and *Pestalotia rhidodendri* (Roy *et al.*, 2018).

Methods of Mycorrhiza Culture Application

Mycorrhizal inoculants are available in liquid, powder, and granular formulations. Application methods include soil incorporation, seed coating, root or seedling treatment, soil drenching, sprinkling onto roots during transplantation, and irrigation system delivery. Seed treatment before or during sowing yields excellent results.

Soil Application/Treatment: Mix 4-5 kg mycorr-hiza culture (powder formulation) with 200-300 kg well-decomposed farm yard manure (FYM) during field preparation. Thorough mixing followed by covering with jute bags, sugarcane leaves, or paddy straw and 1-2 weeks of shaded incubation allows proper multiplication. Maintain moisture and turn the mixture every 3-4 days before field broadcasting. Apply the mycorrhiza-enriched FYM to fields 15 days before sowing. This mixture suits furrow, pit, or pot application during transplanting or sowing, covering one acre. For crops exceeding 40,000 plants per acre, mix 8-10 kg culture with 400-500 kg well-decomposed FYM.

Root Treatment: Vegetables and plantation crops benefit from root treatment. Prepare a suspension by mixing 20 g mycorrhiza culture with 15-20 g jaggery in 1 liter water. Dip seedling roots for 15-20 minutes and transplant immediately. This method effectively controls soil-borne diseases. For vegetable crops with wider plant spacing, create small pits in prepared fields using a spud and mix 2 g culture per pit during sowing or planting.

Plantation-Time Application: Apply mycorrhiza culture at 5 g per plant for 3x3 feet pits, placed 3-4 inches deep during plantation. In established orchards, combine 5-10 g culture per plant with well-decomposed FYM during February or July fertilizer applications in pits.

Nursery Bed Treatment: Mix 1-2 kg mycorrhiza culture (powder formulation) with 40-50 kg well-decomposed FYM, compost, or vermicompost. Broadcast over one acre during evening hours under appropriate moisture conditions.

Soil Drenching: Mix 2-3 kg mycorrhiza culture formulation in 200 liters water for drenching one acre, or use 15-20 g per liter water for nursery soils with periodic applications. Maintain optimal soil moisture during application.

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Flaxseed: Health Benefits, Nutraceutical and Functional Properties

Sakshi Pandey and Mamta Kumari

Flaxseed has been the integral part of traditional medicine for thousands of years and have important role in human nutrition. Flaxseed is scientifically named as *linum usitatissimum* in India. It is known as tisi, alsi, aksebija, jawas based on the region it is cultivated. It ranks among the earliest domesticated oilseed crop and has remarkable benef-its such as nutritional, therapeutic, nutra-ceuticals, functional, industrial etc. At present it has grabbed attention towards itself due to its scientific interest as functional food and nutraceuticals which caters a promising health benefit due to its nutritional composition.



Nutraceuticals property

Flaxseed has been added to nutraceuticals due to presence of the bioactive compounds with in it.

Alpha linolenic acid: Compound such as Alpha linolenic acid 45% protects heart health and act as anti -inflammatory

Lignans: Namely Secoisolariciresinol diglycoside (SDG) and other phenolic compounds which act as an antioxidant and also reduces the risk of hormone related cancers anti-inflammatory etc.

Dietary fibre: (35%) prevent constipation, bowel regulation, promotes digestive health and maintain blood sugar level.

Functional properties

Flaxseed has several functional properties.

- ✓ It finds a wide use as a binding agent in food industry.
- ✓ It's my nutty flavour makes it distinctive from others.
- ✓ Egg is replaced by gel in bakery industry.

Health Benefits

Conventionally it was used to improve digestive health.

- ✓ Flaxseed is a rich source of dietary fibre which plays a pivotal role in role in preventing constipation.
- ✓ Flaxseed soluble fibre improves gut health while insoluble gives bulk to the faces, regulates bowl movement and has a great water holding capacity which help us to improves overall digestive health.
- ✓ Maintains blood sugar level as its slows down the glucose absorption, which helps to maintain blood sugar level of a person who is diabetic.
- ✓ It maintains heart health due to the presence of Alpha linolenic acid (ALA) and also lessen the

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risk of hypertension.

- ✓ It prevents cancer due to the presence of the dietary fibre which is related inversely to colorectal cancer and lignans adsorbs carcinogens and reduces the risk of hormone dependent cancers namely the prostate cancer and breast cancer.
- ✓ Another health benefit of flaxseed include brain development in children, antioxidant, anti-inflammatory, lowers cholesterol. flaxseed is super food with nutritional properties and functional properties with a great source of Omega 3 fatty acid, lignans, dietary fibres i.e., variety of nutrients and promising health benefits which make it more important so we should consume daily in our diet to remain healthy.

Benefits of flax seed in disease condition

Heart Health: presence of Alpha linolinic acid in flaxseed is a boon for heart health. ALA is a plants based Omega 3 fatty acids. It modulates lipid by reducing triglyceride and low density liquid cholesterol and elevates high density lipid cholesterol level. Soluble fibre of flaxseed prevent intestinal absorption of cholesterol. Lignans present in flaxseed reduces oxidative stress and endothelial dysfunction which prevents the development of artheroschlorosis and coronary artery disease

Hypertension: Daily intake of flaxseed is related to reduce in systolic and diastolic pressure of blood. These effects are related to Alpha linolenic acid metabolites which produces endothelial nitric oxide and improves vascular elasticity. Lignans reduces inflammation and oxidative stress which prevents progression of hypertension.

Diabetes: Flaxseed plays an important role in blood sugar level management fibres present in flaxseed slows down glucose absorption and gastric emptying which leads to improve blood glucose levels post-meal. Lignans present in flaxseed improves insulin sensitivity and reduces inflammatory markers.

Obesity: High fibre content present in flaxseed enhances feeling a fullness which leads to reduce in energy intake ultimately preventing obesity.

Antioxidant: Due to the presence of lignans, phenolic compound, and tocopherols flaxseed possess antioxidant activity

Neurological and Brain health: Presence of Alpha linolic Acid in the flaxseed support brain health, development and function. Lignans present in flax seed boosts mood and act as an anti-depressant.

Gastrointestinal Health: High fibre content in flaxseed helps to prevent constipation and enhances smooth functioning of bowel movement. It promotes beneficial gut microbiota by becoming food for it.

Cancer: Flaxseed consists of lignans, fibre and omega-3 fatty acid. These possess anti-cancerous effects and also help us to prevent or reduce the chance of breast cancer and prostate cancer

Incorporation of flaxseed in daily diet

Bakery: Flaxseed can be incorporated in various items such as muffins, cake, bread, bun, snack bars etc.

Curries: Flaxseed powder can be incorporated in various curries e.g bottle-guard curries, plain curry.

etc.



Laddu: It can be used in laddus. It is more beneficial for special group of people such as lactating women, children and old age group people.

Soups: It can be incorporated in various soups to make it more-healthier (powdered form).

Dry pasta products: It can be used in dry pasta products instead of refined flour which will be a healthy alternative especially for children group.

Soaked flaxseed: Flaxseed can be soaked with different nuts and seeds and can be consumed early morning.

Juice: It can be mixed in juices and shakes which will make a healthy and tasty alternative especially for children.

Anthocyanin Extraction and Ascorbic acid Extraction Process in Purple Cauliflower

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Anthocyanin Extraction

Anthocyanins are water-soluble flavonoid pigments responsible for the purple coloration of purple cauliflower and are recognized for their strong antioxidant properties. In this study, a standardized ultrasonic-assisted extraction method was employed to efficiently extract and analyse anthocyanins. Fresh purple cauliflower samples were washed thoroughly, cut into small pieces and dried under controlled conditions (40-45°C) to remove moisture. The dried material was ground into a fine powder to ensure uniformity and improved solvent penetration. For extraction, the powdered sample was mixed with acidified ethanol (80% ethanol containing 1% hydrochloric acid or citric acid) at a sample-to-solvent ratio of 1:10 (w/v). The acidic medium helped stabilize anthocyanins and prevented degradation. The mixture was subjected to sonication in an ultrasonic bath for 30 minutes, which enhanced cell wall disruption and improved pigment release. The extract was then centrifuged at 8000 rpm for 15 minutes to separate solid residues from the coloured supernatant. The supernatant was further purified using a solid-phase extraction (SPE) column to remove co-extracted impurities such as sugars and proteins. Finally, the purified anthocyanin extract was analysed using a UV-visible spectrophotometer at 520 nm. This method provided a stable, efficient and high-purity extraction of anthocyanins suitable for quantitative and qualitative analysis.



Ascorbic acid Extraction process

Ascorbic acid content in purple cauliflower was estimated under laboratory conditions using the 2,6-dichlorophenol indophenol (DCPIP) dye titration method. Fresh purple cauliflower curds were collected, thoroughly washed with clean water to remove adhering soil and impurities and excess moisture was removed. A known quantity of fresh sample (10 g) was finely chopped and transferred to a mortar and pestle. The sample was homogenized with 3% metaphosphoric acid, which served as an extracting and stabilizing agent to prevent oxidation of ascorbic acid during extraction.

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Figure: Extraction and estimation process of ascorbic acid in purple cauliflower using DCPIP dye titration method

The homogenized mixture was then filtered through filter paper to obtain a clear extract containing dissolved ascorbic acid. An aliquot of 10 ml of the filtrate was pipetted into a clean conical flask for titration. The extract was titrated against standardized DCPIP dye solution filled in a burette. During titration, the dye was added dropwise with continuous swirling of the flask. As long as ascorbic acid was present in the extract, the blue colour of the dye disappeared immediately due to reduction of the dye by ascorbic acid. The end point of the titration was identified by the appearance of a light pink colour that persisted for about 15 seconds, indicating complete oxidation of ascorbic acid. The volume of DCPIP dye consumed was recorded and used for calculation of ascorbic acid content. The results were expressed as milligrams of ascorbic acid per 100 grams of fresh weight of purple cauliflower curd. This method is simple, reliable and widely accepted for the determination of ascorbic acid in vegetable crops and is suitable for quality assessment in horticultural research.

Significance

Both extraction methods are simple, reliable and widely accepted for biochemical analysis. The combined estimation of anthocyanins and ascorbic acid provides a comprehensive assessment of antioxidant capacity and quality attributes of purple cauliflower.

Sustainable Organic Horticulture in India: Integrating Biofertilizers, Biopesticides and Natural Farming Systems

Sanjeev Kumar, Mohit Chaudhary, Net Ram and Ajeet Singh

Abstract

Horticulture in India is undergoing a transformative shift toward sustainability, driven by ecological challenges, consumer demand for chemical-free produce, and government initiatives supporting organic and natural farming practices. This article explores how biofertilizers, biopesticides, and natural farming systems are being integrated into Indian horticulture to enhance soil health, increase productivity, and build climate resilience. It presents current data on adoption patterns, productivity outcomes, and region-specific trends from Indian states. It also highlights technological innovations and institutional frameworks that are enabling large-scale transition to sustainable organic systems. Through an evidence-based and context-rich analysis, this article provides actionable perspectives for researchers, extension professionals, growers, and policymakers.

Introduction: Horticulture at a Crossroads in India

India is one of the world's largest producers of horticultural crops, including fruits, vegetables, spices, and flowers. In recent decades, the sector has seen unprecedented growth due to improved varieties, expanded irrigation and market diversification. However, the intensive use of chemical fertilizers and pesticides has led to soil degradation, reduced microbial diversity, increased input costs, and consumer concerns regarding food safety. Recognizing these challenges, states like Sikkim, Madhya Pradesh, Andhra Pradesh, Maharashtra, Uttar Pradesh and Karnataka have accelerated organic and natural farming adoption, positioning horticulture as a driver of sustainable agriculture, rural employment, and export growth.

Biofertilizers in Indian Horticulture: Enhancing Biological Nutrient Cycling

One of the most impactful practices in sustainable horticulture is the use of biofertilizers formulations of beneficial microbes that enhance nutrient availability and soil biological activity. In India, the rapid expansion of biofertilizer use is supported by the Department of Agriculture & Farmers' Welfare and state-level missions focused on soil health and organic production. Field trials conducted by ICAR and state universities show

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Table 1: Biofertilizer Adoption and Yield Impact in Indian States (2023-24)

State	Biofertilizer Use (% of horticulture area)	Average Yield Increase (%)	Major Horticultural Crops
Andhra Pradesh	48	10.8	Mango, Tomato, Chilli
Maharashtra	52	11.5	Grapes, Pomegranate, Banana
Uttar Pradesh	41	9.2	Potato, Onion, Guava
Karnataka	57	12.3	Banana, Brinjal, Citrus
Tamil Nadu	45	10.1	Banana, Tomato, Okra

Data Source: ICAR State Horticulture Reports, 2024

Table 2: Biopesticide Use Trends and Pest Control Outcomes in Selected States

State	Biopesticide Adoption (%)	Reduction in Chemical Pesticide Use (%)	Key Crops Benefitting
Maharashtra	62	35	Grapes, Pomegranate
Himachal Pradesh	55	30	Apple, Pear
Rajasthan	47	25	Onion, Garlic
Odisha	42	22	Tomato, Brinjal
Uttarakhand	51	27	Kiwi, Strawberry

Data Source: Directorate of Plant Protection & Organic Mission Reports, 2024

Table 3: Natural Farming Outcomes in Organic Vegetable Production (State Level, 2024)

State	Water Use Efficiency (WUE)	Soil Microbial Biomass (mg kg^{-1})	Disease Incidence (%)
Sikkim (Organic)	75.5	840	7
Andhra Pradesh (ZBNF)	68.3	710	11
Karnataka Organic Zones	66.9	690	12
Uttar Pradesh Organic Blocks	62.5	640	15

Data Source: NABARD Organic Farming Division Reports, 2024

consistent improvements in soil fertility and crop performance when biofertilizers are integrated into nutrient management systems. This impact is particularly pronounced in states with extensive horticulture activity, where soil microbial diversity often declines under conventional practices (Table 1). This data highlights that states with proactive biofertilizer programs experience significant yield advantages, especially for perennial fruit crops and high-value vegetables.

Biopesticides: Ecological Pest Management in Indian Farms

In Indian horticulture, pests such as fruit flies, aphids, mites, and fungal diseases severely reduce yields and quality. Conventional chemical pesticides have caused ecological imbalance and pesticide residue issues, especially in export-oriented commodities like grapes and pomegranate.

Biopesticides including microbial agents, botanical extracts, and entomopathogens provide safer alternatives that are compatible with organic certification standards (Table 2). Government initiatives such as the "National Biopesticides Development Programme" and state organic missions are promoting the adoption of biopesticides through farmer training, subsidized supply, and demonstration trials. Farmers in Maharashtra and Himachal Pradesh, for example, are increasingly using *Bt* formulations, neem oil, and *Trichoderma* to manage pests in apples, grapes, and vegetables.

Natural Farming Systems: Integrating Traditional Wisdom and Modern Science

Natural farming systems such as Zero Budget Natural Farming (ZBNF) and organic production systems have gained traction in several Indian states. In Andhra Pradesh and Sikkim, large-scale adoption

of natural farming practices has shown benefits in soil fertility, water use efficiency, and economic sustainability. Natural farming emphasizes the use of locally available inputs such as compost, vermi-compost, fermented bio-inputs (Jeevamrit and Panchagavya), and green manures to build soil organic matter and microbial biomass. States like Sikkim have achieved 100% organic certification for land under certain crops, setting a precedent for ecological transformation (Table 3). These results indicate that organic and natural farming systems significantly improve soil biological functioning, conserve water, and reduce disease incidence, which are crucial for horticultural sustainability under climate stress.

Integration of Organic Components: The Indian Perspective

The integration of biofertilizers, biopesticides and natural farming practices forms a resilient production system where each component reinforces the others. Farmers in states like Maharashtra, Andhra Pradesh, and Karnataka are adopting integrated organic packages that combine microbial inoculants with cultural practices like mulching, crop diversification, organic manures, and eco-friendly pest control. This integrated approach enhances nutrient use efficiency, reduces input costs, and builds long-term soil fertility. It also aligns with organic certification frameworks such as NPOP (National Programme for Organic Production) and state organic missions, facilitating market access and premium pricing.

Economic and Market Trends: Organic Produce Demand in India

India's domestic and export markets for organic produce are expanding rapidly. Consumer demand for residue-free fruits and vegetables has risen due to health awareness and digital access to product information. According to the India Organic Market Study 2024, India's organic food market is valued at approximately USD 2.3 billion, with demand growing at a compound annual growth rate (CAGR) of 18-22%. Horticultural products constitute nearly 45% of this market due to preferences for organic fruits, vegetables, spices, and plantation crops like coffee and tea. Price premiums for certified organic horticultural produce range from 20-50% above conventional prices, providing incentives for farmers to transition.

Government Policies and Support Mechanisms

Several Indian government policies and schemes are driving the expansion of sustainable horticulture. Key initiatives include:

Paramparagat Krishi Vikas Yojana (PKVY): Promotes organic farming clusters with financial assistance.

National Mission on Natural Farming (NMNF): Supports ZBNF and other natural systems through subsidies and training.

Soil Health Management (SHM): Encourages soil testing, biofertilizer use, and balanced nutrient management.

Mission Organic Value Chain Development for North Eastern Region (MOVCDNER): Boosts

organic market linkages and certification.

State organic missions in Sikkim, Andhra Pradesh, Madhya Pradesh, and Himachal Pradesh provide additional infrastructure support, capacity building, and certified input access, enabling rapid adoption of sustainable horticulture.

Challenges and the Way Forward

Despite promising outcomes, several challenges remain for scaling organic horticulture across India. These include transitional yield fluctuations, limited access to affordable certified inputs, certification costs, and the need for robust value chains that connect farmers to premium markets. Strengthening farmer producer organizations (FPOs), expanding extension support, and investing in region-specific research can expedite adoption. Advances in digital advisory, precision organic farming tools, and soil microbiome technologies will further enhance scientific management of organic systems.

Conclusion

Sustainable organic horticulture in India is a dynamic and promising pathway that aligns agricultural productivity with ecological restoration, climate resilience, and consumer health priorities. Through the integration of biofertilizers, biopesticides and natural farming systems, Indian states are demonstrating measurable improvements in soil health, yield stability, water use efficiency, and pest management. With supportive government policies and growing market demand, organic horticulture is poised to become a central pillar of India's agricultural transformation in the 21st century.

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Role of Nanotechnology in Enhancing Nutrient Use Efficiency in Fruit and Vegetable Crops

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Abstract

Nanotechnology is reshaping agricultural paradigms by enabling precision delivery of nutrients, improved uptake efficiency, reduced environmental losses, and enhanced crop performance. In horticulture particularly fruit and vegetable crops nutrient use efficiency (NUE) remains a critical challenge due to high nutrient demand, poor soil retention, and excessive reliance on conventional fertilizers. Nano-enabled fertilizers, nano-encapsulated nutrients, and smart nanosensors offer transformative potential to optimize nutrient delivery. This article explores scientific principles, recent innovations, Indian field data, challenges, economic implications, and future opportunities in integrating nanotechnology to boost nutrient use efficiency in horticultural systems. With emerging government support, start-up involvement, and research investments, nano-agriculture is poised to play a significant role in sustainable, climate-smart horticulture in India.

Introduction: The Imperative of Nutrient Use Efficiency in Horticulture

Fruit and vegetable crops are among the most nutrient-demanding crop groups in agriculture. High nutrient uptake particularly nitrogen (N), phosphorus (P), potassium (K), and micronutrients is essential to ensure vegetative growth, flowering, fruit set, quality and post-harvest shelf life. However, conventional fertilization practices often suffer from inefficiencies: large proportions of applied nutrients are lost through leaching, volatilization, fixation, or runoff, leading to economic loss, soil degradation, and environmental pollution.

Nutrient Use Efficiency (NUE) defined as the ratio of nutrient output in crop harvest to nutrient input remains suboptimal in many horticultural systems. In India, NUE for nitrogen in vegetables averages around 30-40%, meaning 60-70% of applied N is not used by the crop, contributing to greenhouse gas emissions and groundwater contamination.

Nanotechnology offers innovative solutions by enabling controlled nutrient release, targeted delivery to plant roots and leaves, and real-time monitoring of soil and plant nutrient status. These advances align with sustainable production goals, reduced fertilizer dependency and improved horticu-

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ltural productivity.

Fundamentals of Nanotechnology in Agriculture

Nanotechnology involves the manipulation of materials at nanoscale (1-100 nanometers), where unique physical and chemical properties emerge due to high surface area and quantum effects. In agriculture, nanomaterials are being developed to improve delivery systems for nutrients, pesticides, plant growth regulators, and diagnostic tools. In the context of nutrient delivery in horticulture, nanotechnology applications broadly fall into three categories:

Nanofertilizers: Engineered formulations that enhance solubility, stability, and targeted nutrient release.

Nano-encapsulated nutrient systems: Particles coated with polymers or biodegradable materials for controlled nutrient release kinetics.

Nanosensors: Devices that detect soil nutrient levels, moisture and crop stress in real time, enabling precision management.

These nano-enabled systems offer advantages over conventional fertilizers, such as reduced nutrient losses, improved root absorption, and enhanced metabolic efficiency.

Nano-Enabled Fertilizers: Enhancing Macro and Micro-Nutrient Use Efficiency

Nano-fertilizers are synthesized using nanoparticles (NPs) of elements like zinc (Zn), iron (Fe), magnesium (Mg), silicon (Si), and phosphorus (P), often formulated with slow-release characteristics. For example, nano-zinc oxide (ZnO) and nano-iron oxide (Fe_3O_4) are being tested in horticultural crops such as tomato, chilli, and banana for micro-nutrient sufficiency and improved quality traits.

Table 1: Impact of Nano-Enabled Nutrient Applications in Indian Field Trials (2023-24)

State	Crop	Nano-Fertilizer Type	Yield Increase (%)	Nutrient Use Efficiency (%)
Karnataka	Banana	Nano-ZnO	12.6	18.9
Maharashtra	Grapes	Nano-NPK	15.3	22.4
Uttar Pradesh	Tomato	Nano-Fe + Zn	11.8	17.5
Andhra Pradesh	Chilli	Nano-Si	14.1	20.2
Tamil Nadu	Brinjal	Nano-Cu (CuO)	10.7	16.8

Source: ICAR and State Agri-Universities Field Reports, 2024

These results highlight that nano-enabled nutrient systems can enhance yield and NUE significantly compared to conventional fertilizer regimes. The improved efficiency arises from targeted nutrient availability at critical crop growth stages and reduced nutrient immobilization in soil.

Mechanisms of Enhanced Nutrient Use Efficiency through Nanotechnology Controlled and Slow-Release Dynamics

Nanocarriers can be designed to release nutrients in sync with plant uptake patterns. Biodegradable polymer coatings and smart structures respond to soil moisture and pH, gradually releasing nutrients and minimizing losses.

Enhanced Root Absorption: Due to nanoscale size and surface charge properties, nano-fertilizers adhere more effectively to root surfaces, increasing nutrient diffusion into root tissues. This results in improved

metabolic uptake and assimilation.

Foliar Delivery Efficiency: Foliar applications of nano-nutrients such as nano-zinc and nano-iron show greater stomatal penetration and tissue mobility compared to conventional foliar sprays. This is particularly useful in fruit crops where micronutrient deficiencies affect fruit quality traits.

Reduced Soil Fixation and Losses: Nanocarriers mitigate nutrient fixation by clay and organic matter, especially phosphorus, which is commonly immobilized in alkaline and acidic soils. Controlled release reduces leaching losses and increases effective nutrient availability.

Nanosensors and Precision Nutrient Management

Nanosensors represent a breakthrough in real-time monitoring of soil and plant nutrient dynamics. These sensors detect:

- ✓ Soil nitrate and phosphate levels
- ✓ Soil moisture content
- ✓ Plant stress markers (e.g., ethylene, chlorophyll changes)

Integrating nanosensors with IoT and mobile platforms enables farmers to receive near-real-time nutrient recommendations. For example, early detection of nitrogen deficiency through nanosensor data prompts corrective action before yield loss becomes irreversible. In pilot projects across Indian horticultural zones (Andhra Pradesh, Maharashtra, and Uttarakhand), nanosensor networks reduced fertilizer inputs by 15-25%, without compromising yield, due to precise nutrient scheduling.

Nanotechnology for Micronutrient Enrichment and Quality Improvement:

In fruit and vegetable crops, micronutrients such as Zn, Fe, Mn, and Cu are vital for physiological processes and nutritional quality. Conventional micronutrient supplements often face issues of low solubility and rapid fixation. Nano-micronutrient formulations address these constraints by enhancing solubility and bioavailability. Studies in tomato and capsicum have shown that nano-zinc applications not only improve yield but also increase antioxidant content and shelf life, making produce more appealing to health-conscious consumers.

Environmental and Economic Implications: Nano-fertilizers and nutrient delivery systems offer environmental advantages by reducing nutrient runoff and greenhouse gas emissions. When nutrients are released efficiently, soil eutrophication and nitrate leaching into groundwater are minimized, contributing to environmental protection. Economically, although initial costs of nano-inputs may be higher than conventional fertilizers, improved NUE, higher crop quality, and reduced total input requirements result in net economic benefits. Market readiness for value-added horticultural produce further enhances profitability.

Challenges and Safety Considerations

While nanotechnology offers immense promise, several challenges must be addressed:

Standardization and Regulation: Lack of standardized guidelines for nano-fertilizer use and safety assessments.

Health and Environmental Safety: Potential unint-

ended effects of nanoparticles on soil microbiota and food safety require long-term studies.

Cost and Adoption Barriers: High initial costs and limited awareness constrain adoption among smallholder farmers.

Scaling and Quality Control: Ensuring consistent nano-particle size, stability, and field performance is required for wider scalability.

Current Indian Policy Support and Research Initiatives: India's Department of Science & Technology (DST) and Indian Council of Agricultural Research (ICAR) have initiated programs supporting nanotechnology research in agriculture. Dedicated research clusters are developing nano-fertilizers, nanosensors, and smart delivery systems tailored to Indian soils and crops. State initiatives in Karnataka, Telangana, and Tamil Nadu include pilot projects testing nano-nutrient sprays in horticultural crops, with early results showing improved crop responses in yield and quality. These innovation ecosystems support academia-industry partnerships and start-ups focused on nano-agriculture solutions.

Conclusion

Nanotechnology offers a paradigm shift in enhancing nutrient use efficiency in fruit and vegetable crops. Nano-enabled fertilizers, nano-encapsulated delivery systems, and nanosensors improve nutrient dynamics by enabling precision delivery, controlled release, and data-driven decision support. Current Indian field data shows significant improvements in yield and NUE across major horticultural states, indicating strong potential for scaling. While challenges related to safety, regulation and cost remain, ongoing research, policy support, and private sector innovation are positioning nanotechnology as a cornerstone of future sustainable and climate-smart horticulture in India. The integration of nano-agriculture with digital advisory systems and precision nutrient management can transform nutrient use efficiency, resource conservation and crop productivity, meeting the dual goals of sustainability and profitability.

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Water-Smart Agronomy: Innovations in Micro-Irrigation and Moisture Conservation

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Abstract

Water scarcity has emerged as one of the most critical challenges in modern agriculture. Increasing climate variability, declining groundwater levels, and inefficient irrigation practices threaten sustainable crop production. Water-smart agronomy offers an integrated solution by combining micro-irrigation technologies, soil moisture conservation practices, precision nutrient management, and digital decision-support tools. This approach enhances water use efficiency (WUE), reduces environmental degradation, and improves crop productivity. The present article explores innovations in drip and sprinkler irrigation, fertigation, mulching, conservation tillage, sensor-based irrigation scheduling, and climate-responsive water management. It highlights how these technologies and agronomic practices together create resilient farming systems capable of sustaining productivity under water-limited conditions.

Introduction: The Need for Water-Smart Strategies

Growing Water Scarcity in Agriculture: Agriculture is the largest consumer of freshwater resources globally. In countries like India, nearly 80 percent of freshwater withdrawals are used for irrigation. However, conventional irrigation systems such as flood irrigation are inefficient, leading to excessive water losses through runoff, deep percolation, and evaporation. Rapid urbanization, industrial demand, and climate change have intensified pressure on limited water resources. Erratic rainfall patterns and prolonged droughts further worsen the situation.

Importance of Water Use Efficiency (WUE): Water Use Efficiency refers to the amount of crop yield produced per unit of water consumed. Improving WUE is essential to produce more food with less water. Traditional irrigation practices often result in low WUE because water is applied without considering crop growth stages, soil characteristics, and climatic conditions. Water-smart agronomy addresses these inefficiencies through scientific water management and technological integration.

Concept of Water-Smart Agronomy

Definition and Core Principles

Water-smart agronomy is an integrated management approach that optimizes water use through improved irrigation methods, soil moisture

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conservation techniques, and climate-responsive decision-making. The system focuses on maximizing productivity while minimizing water waste and environmental impact.

Components of Water-Smart Agronomy

The approach includes micro-irrigation systems, fertigation, mulching, conservation tillage, soil moisture monitoring, and digital advisory tools. Each component plays a complementary role in conserving water and enhancing crop growth.

Micro-Irrigation Systems: Precision Water Delivery

Drip Irrigation Technology: Drip irrigation delivers water directly to the root zone through a network of pipes and emitters. Water is applied slowly and precisely, reducing evaporation losses and preventing waterlogging. Drip systems are particularly effective in horticultural crops such as banana, tomato, grapes and sugarcane. Drip irrigation improves root development and nutrient uptake. Studies show that it can reduce water use by 30-50 percent while increasing yields by 20-40 percent. The system also suppresses weed growth since water is localized around crop roots rather than across the entire field.

Sprinkler Irrigation Systems: Sprinkler systems distribute water in the form of artificial rainfall. These systems are suitable for crops like wheat, maize, pulses, and groundnut. Sprinklers ensure uniform water distribution and are especially useful in sandy soils where infiltration rates are high. Compared to traditional flood irrigation, sprinkler systems improve irrigation efficiency and reduce soil erosion.

Fertigation: Integrating Water and Nutrient Management

Concept of Fertigation: Fertigation involves applying fertilizers through irrigation systems. This technique ensures that nutrients are delivered directly to the root zone in soluble form. It enhances nutrient availability and reduces losses due to leaching or volatilization.

Benefits of Fertigation: Fertigation improves nutrient use efficiency by synchronizing nutrient supply with crop demand. Crops such as tomato, cotton, and banana show improved growth, higher fruit size, and better quality under fertigation. Additionally, fertilizer application rates can be reduced without compromising yield.

Soil Moisture Conservation Practices

Mulching for Moisture Retention: Mulching involves covering the soil surface with organic or inorganic materials. Organic mulches include straw, crop residues, and compost, while plastic films represent inorganic mulches. Mulching reduces evaporation, regulates soil temperature and suppresses weeds. In vegetable crops, mulching maintains higher soil moisture levels during dry periods, leading to improved flowering and fruit development.

Conservation Tillage and Residue Management: Conservation tillage reduces soil disturbance and maintains crop residues on the surface. This practice protects soil from direct sun exposure, decreases

evaporation, and improves water infiltration. Over time, conservation tillage increases soil organic matter, enhancing the soil's water-holding capacity.

Cover Cropping: Cover crops protect the soil during fallow periods and improve soil structure. Leguminous cover crops also enhance soil fertility and moisture retention. By preventing soil erosion and improving infiltration, cover crops contribute to sustainable moisture management.

Role of Digital Technologies in Water Management

Soil Moisture Sensors: Soil moisture sensors and tensiometers provide real-time data on soil water content. Farmers can use this information to irrigate only when necessary, preventing over-irrigation. Sensor-based scheduling improves water savings and crop performance.

Weather-Based Irrigation Scheduling: Weather data such as temperature, humidity, and wind speed influence evapotranspiration rates. Integrating weather forecasts into irrigation planning allows farmers to adjust irrigation timing according to climatic conditions.

Mobile Advisory and Smart Irrigation Systems: Mobile applications and smart irrigation controllers help automate irrigation based on sensor readings. These digital tools reduce human error and improve water productivity.

Economic and Environmental Benefits

Improved Crop Productivity and Profitability: Water-smart agronomy enhances yields while reducing water and fertilizer costs. Farmers adopting micro-irrigation and fertigation systems report higher net returns due to improved crop quality and reduced input wastage.

Environmental Sustainability: Efficient irrigation reduces groundwater depletion and prevents nutrient runoff. Lower water usage also reduces energy consumption for pumping, contributing to reduced carbon emissions.

Challenges in Implementation

High Initial Investment: Micro-irrigation systems require significant upfront investment, which may deter smallholder farmers.

Technical Knowledge and Maintenance: Proper installation and maintenance are critical for system efficiency. Lack of training can reduce system performance.

Need for Policy and Institutional Support: Government subsidies, extension services, and farmer training programs are essential to promote widespread adoption.

Future Prospects and Innovations

Integration with Artificial Intelligence: AI-driven irrigation scheduling models can analyze large datasets and optimize irrigation decisions automatically.

Smart Water Management Systems: Internet of Things (IoT)-enabled irrigation systems are becoming more affordable and accessible. Automated drip systems that adjust water flow based on real-time soil conditions represent the future of irrigation.

Climate-Resilient Crop Varieties: Combining water-efficient agronomic practices with drought-tolerant crop varieties will further strengthen agricu-

ltural resilience.

Conclusion

Water-smart agronomy is a comprehensive and forward-looking approach to managing agricultural water resources. By integrating micro-irrigation systems, fertigation, moisture conservation techniques, and digital technologies, farmers can significantly improve water use efficiency and crop productivity. In the face of increasing climate variability and water scarcity, adopting water-smart strategies is essential for sustainable agricultural development. With supportive policies, technological innovation, and farmer awareness, water-smart agronomy can ensure food security, environmental sustainability, and economic resilience for future generations.

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Carbon Farming and Regenerative Agronomy: Restoring Soil While Enhancing Productivity

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Abstract

Climate change, soil degradation, and declining farm profitability have made sustainable agricultural transformation a global priority. Carbon farming and regenerative agronomy are emerging as powerful approaches to restore soil health, enhance biodiversity, and increase farm resilience while mitigating greenhouse gas emissions. By adopting practices such as conservation tillage, cover cropping, agroforestry, biochar application, and integrated nutrient management, farmers can increase soil organic carbon (SOC) levels and improve productivity. This article explores the science, principles, field practices, economic benefits, carbon markets, and future prospects of carbon farming. It also presents recent data on soil carbon sequestration potential and productivity gains under regenerative systems, demonstrating how ecological restoration and economic profitability can go hand in hand.

Introduction: Agriculture at the Crossroads of Climate and Soil Crisis

Agriculture is both a contributor to and a victim of climate change. Conventional farming practices intensive tillage, monocropping, heavy chemical inputs have resulted in declining soil organic matter, erosion, nutrient depletion, and greenhouse gas emissions. Globally, cultivated soils have lost 30-50% of their original organic carbon stock over the past century. This decline directly impacts soil fertility, water retention, and crop productivity.

Carbon farming and regenerative agronomy offer a solution by reversing soil degra-dation. These systems aim to increase soil organic carbon while enhancing ecosystem services and farm income. Unlike extractive agriculture, regenerative systems rebuild soil structure, restore microbial diversity, and improve long-term productivity.

Understanding Carbon Farming

Concept of Carbon Sequestration in Agriculture

Carbon sequestration refers to the process of capturing atmospheric carbon dioxide (CO_2) and storing it in soil and vegetation. Through photosynt-

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hesis, plants absorb CO_2 and convert it into biomass. A portion of this carbon enters the soil via root exudates and crop residues, forming stable organic matter. Healthy soils act as carbon sinks. Increasing soil organic carbon (SOC) by even 0.4% annually can significantly offset global greenhouse gas emissions.

Carbon Pools in Agricultural Systems

Carbon in agroecosystems is stored in:

- ✓ Soil organic matter
- ✓ Crop residues
- ✓ Roots and rhizosphere
- ✓ Agroforestry trees
- ✓ Biochar amendments

Principles of Regenerative Agronomy

Regenerative agronomy focuses on rebuilding soil health while maintaining productivity. It is guided by five core principles:

- ✓ Minimizing soil disturbance
- ✓ Maintaining soil cover
- ✓ Increasing biodiversity
- ✓ Living roots throughout the year
- ✓ Integrating livestock where possible

These principles improve nutrient cycling, enhance microbial activity, and increase soil carbon accumulation.

Key Practices in Carbon Farming

Conservation Tillage and No-Till Systems: Conventional ploughing exposes soil carbon to oxidation, releasing CO_2 into the atmosphere. No-till and reduced-till systems minimize soil disturbance, preserving soil aggregates and microbial habitats.



Studies indicate that no-till farming can sequester 0.3-0.6 tons of carbon per hectare annually. Additionally, it reduces fuel consumption and improves soil moisture retention.

Cover Cropping and Crop Rotation: Cover crops such as legumes, grasses, and brassicas protect soil from erosion and add biomass. Leguminous cover crops fix atmospheric nitrogen, reducing fertilizer requirements.



Crop rotation enhances biodiversity and breaks pest cycles. Diverse root systems increase soil carbon input at multiple depths.

Agroforestry Systems: Agroforestry integrates trees with crops or livestock. Trees store significant amounts of carbon both above and below ground. Depending on species and density, agroforestry systems can sequester 2-9 tons of CO_2 ha^{-1} annually.



Trees also improve microclimate, reduce wind erosion and enhance biodiversity.

Biochar Application: Biochar is a stable carbon-rich material produced from biomass under limited oxygen conditions. When applied to soil, it enhances carbon stability for hundreds of years.





Biochar improves soil structure, water retention and nutrient availability. Research shows yield improvements of 10-20% in degraded soils.

Impact on Soil Health and Productivity

Improvement in Soil Organic Carbon: Regenerative practices increase SOC levels gradually. Even small increases significantly enhance soil fertility.

Table 1: Soil Organic Carbon Improvement under Regenerative Practices

Practice	Annual SOC Increase (%)	Yield Increase (%)
No-Till	0.2 - 0.4	5 - 10
Cover Cropping	0.3 - 0.5	8 - 15
Agroforestry	0.5 - 1.0	10 - 20
Biochar Application	0.4 - 0.8	10 - 25

Water Retention and Drought Resilience: Soils rich in organic matter hold more water. A 1% increase in soil organic matter can increase water-holding capacity by up to 20,000 liters per hectare. This reduces irrigation requirements and enhances drought tolerance.

Enhanced Nutrient Cycling: Higher microbial activity improves nutrient mineralization and uptake. Farmers often observe reduced fertilizer needs after several years of regenerative management.

Economic Opportunities: Carbon Credits and Farm Profitability

Carbon markets reward farmers for increasing soil carbon. Farmers adopting carbon farming practices can earn carbon credits by verifying SOC improvements.

Table 2: Economic Benefits of Carbon Farming

Parameter	Conventional Farming	Regenerative Farming
Fertilizer Cost	High	Reduced by 15-30%
Irrigation Requirement	High	Reduced by 10-20%
Yield Stability	Moderate	High
Carbon Credit Income	None	Additional revenue

Although initial transition costs may be higher, long-term profitability improves due to reduced input costs and ecosystem benefits.

Environmental Benefits

Carbon farming contributes to:

- ✓ Reduction in greenhouse gas emissions
- ✓ Improved biodiversity
- ✓ Reduced soil erosion
- ✓ Enhanced pollinator populations
- ✓ Improved water quality

These environmental services support long-term sustainability.

Challenges in Adoption

Despite its benefits, carbon farming faces certain challenges:

- ✓ Lack of awareness and training
- ✓ Difficulty in measuring soil carbon
- ✓ Delayed economic returns
- ✓ Policy and institutional gaps

Standardized carbon measurement tools and

supportive government policies are essential for scaling adoption.

Future Prospects and Innovations

Emerging technologies such as remote sensing, satellite monitoring, soil carbon modeling, and AI-based advisory systems will improve carbon accounting and farm management decisions.

Integration of regenerative agriculture with climate-smart policies can transform agriculture into a net carbon sink sector.

Conclusion

Carbon farming and regenerative agronomy represent a paradigm shift from extractive to restorative agriculture. By rebuilding soil organic carbon, enhancing biodiversity, and improving water retention, regenerative systems simultaneously address climate change and productivity challenges. Data clearly show that practices such as no-till, cover cropping, agroforestry, and biochar application improve soil health and farm profitability. Although challenges remain, technological innovation and supportive policy frameworks can accelerate adoption. The future of agriculture lies not in exploiting soil resources but in regenerating them for sustainable food security and environmental resilience.

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Future of Agronomy: Robotics, Automation and Smart Farming Technologies

Net Ram, Upendra Baliyan, Sanjeev Kumar, Mohit Chaudhary and Ajeet Singh

Abstract

Agronomy is entering a new era powered by robotics, automation, and smart farming technologies. These innovations are transforming crop management, improving efficiency, conserving resources, and building resilience against climate change. From autonomous tractors and robotic harvesters to IoT sensors, drones, AI and digital decision support systems, smart agronomy integrates data and machine intelligence with field operations. This article explores key technologies, adoption trends with Indian data, field applications, economic benefits, challenges, and future prospects, making it ideal for agricultural professionals, extension agents, and magazine readers interested in next-generation farming.

Introduction: Agronomy Meets the Digital Revolution

Agronomy is the science of growing crops and managing soil resources is rapidly evolving due to emerging technologies that integrate data, robotics, and automated systems. Traditional practices based on human experience and intuition are being supplemented with smart tools that improve decision accuracy, optimize input use, and enhance sustainability. With challenges such as labor shortages, climate variability, water scarcity, rising input costs, and demand for sustainable food production, the adoption of smart technologies is no longer optional it is essential.

The fusion of agronomy with automation and digital intelligence holds promise for significantly improving resource use efficiency and farm profitability.

Robotics and Automation in Agronomy

Autonomous Tractors and Field Machinery: Autonomous tractors equipped with GPS, machine vision, and AI systems can operate without human intervention.





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These tractors perform tillage, seeding, spraying, and other field tasks precisely, reducing labor and input waste.

In India, pilot projects in Punjab, Haryana, and Maharashtra show that autonomous machinery can reduce labor dependence by up to 40% while enhancing operational accuracy.

Robotic Harvesters: Robotic harvesters use machine vision and robotic arms to detect and harvest ripe produce such as strawberries, tomatoes, and leafy vegetables. These systems reduce crop damage, improve harvest speed, and help address labor shortages during peak seasons.

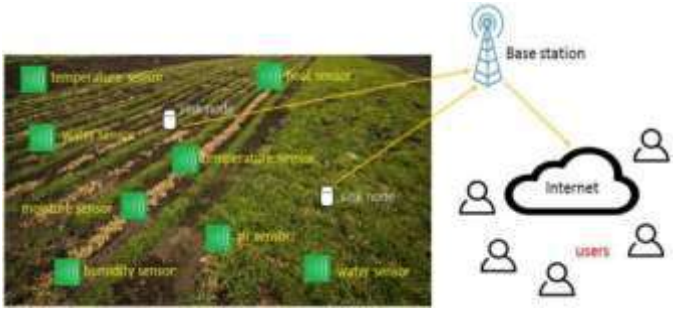


Weeding and Crop Care Robots: Autonomous weed removal robots reduce herbicide use by mechanically targeting weeds. In high-value vegetable fields, such robots have demonstrated 70% weed control efficiency with zero chemical input.



Precision Agriculture and Sensor Technologies

IoT Sensor Networks: Soil moisture sensors, nutrient probes, and weather stations collect real-time data that helps farmers make informed decisions about irrigation, nutrient application and crop health. In Andhra Pradesh and Karnataka, farms with sensor networks have reported 25-35% reduction in irrigation water use and improved nutrient management.



Weather Stations and Analytics: On-farm weather stations gather localized climate data to support irrigation scheduling, frost alerts, and disease risk forecasting. Accurate weather data reduces guesswork and improves farm management outcomes.

Aerial Robotics: Drones for Smart Agronomy

UAV Crop Monitoring: Unmanned Aerial Vehicles (UAVs or drones) equipped with multispectral, thermal, and RGB cameras provide high-resolution field imagery. These images help detect crop stress, nutrient deficiency, pest infestation, and water stress early often before human observation.



Drone Spraying and Targeted Applications

Drones are increasingly used for spraying micronutrients, biopesticides, and plant growth regulators, especially in orchards and fragmented farms where ground equipment is impractical.

Artificial Intelligence and Data Analytics in Smart Agronomy

AI for Crop Predictions: Machine learning models analyze data from sensors, satellites, and historical records to predict crop performance, irrigation needs, pest outbreaks, and yield. AI improves decision-making accuracy by learning from patterns in large datasets.

Prescription Mapping for Variable Rate Application: GIS and AI tools generate prescription maps that guide variable rate application (VRA) of water, fertilizers, and agrochemicals. This ensures that each part of the field receives exactly what it needs no more, no less.

Digital Twin and Simulation Technologies

Digital Twin Farms: A digital twin is a virtual model of a farm that mirrors real-world conditions in real time. Data from sensors, drones, and machinery feed into the model, enabling scenario analysis and optimization before actual field implementation. For example, irrigation plans or nutrient schedules can be simulated before execution, reducing risks and uncertainties.

Benefits of Smart Farming Technologies

Enhanced Resource Use Efficiency: Smart agronomy technologies streamline water and nutrient use, significantly reducing wastage and environmental impact.

Labor Savings and Operational Efficiency: Automation helps mitigate labor scarcity by performing repetitive or labor-intensive tasks efficiently.

Improved Yield Stability and Quality: Real-time monitoring and early stress detection help optimize crop management, resulting in stable yields and improved quality vital for export markets.

Adoption Trends and Data: India Perspective

Table 1: Adoption and Impact of Smart Farming Technologies in India (2024)

Technology	Adoption Level (% of Farmers)	Water Saving (%)	Yield Improvement (%)
IoT Sensor Networks	17%	28	14
Drones for Monitoring	22%	20	12
Sprayer Drones	16%	18	10
Autonomous Machinery (Pilots)	5%	35	15
AI Decision Tools	13%	25	11

Source: India Smart Agriculture Survey 2024

Economic and Policy Drivers

Agritech Start-Ups and Investment Boom: India's agritech ecosystem is expanding rapidly, with investments in smart agtechnologies growing at an estimated 20-25% CAGR. Start-ups are developing AI platforms, precision devices, drones and autonomous machinery tailored for Indian conditions.

Government Initiatives and Support: Policy frameworks such as the Digital Agriculture Mission, AgriStack, Precision Farming incentives, and IoT subsidies are encouraging technology adoption. State schemes further subsidize drip irrigation and automation equipment to support efficient farming practices.

Challenges in Adoption

High Initial Cost and Capital Barriers: Advanced robotics and smart technologies come with high upfront investment, which limits adoption by small-

holder farmers.

Technical Skills and Digital Literacy: Effective use of smart tools requires digital literacy and technical training. Strengthening extension systems and rural training programs is critical.

Data Governance and Privacy Concerns: As agriculture becomes data-driven, issues of data ownership, security, and privacy require clear regulatory frameworks.

Future Prospects and Emerging Innovations

Swarm Robotics: Small swarms of collaborative robots can cover fields conduct tasks cooperatively offering scalable, low-cost automation solutions.

Robotics for Controlled Environment Agriculture: In greenhouses, vertical farms, and protected cultivation, robots automate transplanting, climate control, pruning, and harvesting enabling year-round production.

Integration with Blockchain and Supply Chain Traceability: Robotic and digital systems combined with blockchain technology can ensure real-time traceability, certification, and transparency from farm to fork boosting consumer trust and export potential.

Conclusion

The future of agronomy is intrinsically linked with robotics, automation, and smart farming technologies. These innovations address core issues labor shortages, inefficient resource use, climate variability, and quality demands while enabling farmers to produce more with less. With growing investment, supportive policies, and improving infrastructure, India is positioned to be a leader in smart agronomy adoption. Smart technologies are not just tools; they are catalysts for transforming agriculture into a modern, efficient, resilient, and sustainable enterprise.

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Babul (*Acacia nilotica*): A Multi-Purpose Tree

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Abstract

Acacia nilotica (Babul) is a multipurpose leguminous tree that provides timber, fuelwood, medicinal products and fodder, supporting rural livelihoods. As a leguminous tree, it fixes atmospheric nitrogen, improves soil fertility, reduces soil erosion and facilitates the reclamation of degraded wastelands. Its combined ecological and economic benefits make it important for sustainable agriculture and agroforestry systems. By promoting income generation, fodder availability and environmental management, it enhances the productivity and resilience of farming systems. Integrating this species into agricultural landscapes supports both livelihood security and long-term sustainability of agro-ecosystems.

Introduction

Acacia nilotica L., locally known as 'Babul' or 'Kikkar', belongs to the Leguminosae family and is widely distributed across India, Africa, Myanmar (Burma), Sri Lanka and the Eastern Mediterranean region. The genus *Acacia* comprises approximately 1380 species, of which two-thirds are native to Australia, while the remaining species are distributed across sub-tropical regions, particularly in the Middle East, Africa and the Indian subcontinent. In India, it is naturally found in sub-tropical and dry regions of Maharashtra, Gujarat, Rajasthan, Haryana, Andhra Pradesh and Karnataka. It is a medium-sized, thorny evergreen tree that attain a height of up to 15 m under favourable conditions. The bark changes colour from orange yellow to dark brown from the young to the old stage. Thorns are shed during the later stages of growth. The flowers are bright golden yellow and are borne in attractive globular heads measuring approximately 1.2-1.5 cm in diameter. Inflorescences are borne in axillary or whorled clusters on slender peduncles. The flowering habit not only enhances its ornamental value but also contributes to its ecological importance by supporting pollinator activity.

Biochemical composition: Plant contains numerous bioactive compounds, including gallic acid, ellagic acid, stearic acid, vitamin C (ascorbic acid), carotene, crude protein, crude fiber, arabin, calcium, magnesium, selenium, isoquercitin, leucocyanadin, kaempferol-7-diglucoside, glucopyranoside, rutin, apigenin-6,8-bis-C-glucopyranoside and m-catechol. In addition, it exhibits significant anti-plasmodial, molluscicidal, anti-fungal and anti-microbial properties, along with inhibitory effects



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against Hepatitis C virus (HCV) and human immunodeficiency virus (HIV-1).

Traditional Uses: *A. nilotica* is a multipurpose tree and is widely used in the traditional healthcare system due to its rich source of polyphenolic compounds. The young twigs and shoots are commonly used as a natural toothbrush (dantoon) to prevent dental ailments like toothache and pyorrhoea. The roots have been traditionally used for the treatment of tumours and cancer, particularly those affecting the ear, eye and testicular regions. They are also used in the management of tuberculosis and disorders associated with enlargement and hardening of the liver and spleen. The bark is highly valued for its astringent, cooling, aphrodisiac, diuretic, expectorant and nutritive properties. In traditional medicine, it is widely used for the treatment of haemorrhage, wounds, ulcers, leprosy, leukoderma, smallpox, various skin disorders, biliousness, burning sensations, dysentery and seminal weakness.

Environmental and Ecological Benefits: *A. nilotica* plays an important role in environmental conservation and ecosystem stability. Its well-developed deep root system effectively reduces soil erosion and improves soil structure and fertility through the addition of organic matter and biological nitrogen fixation. The species also contributes to carbon sequestration, supporting climate change mitigation by storing carbon in its biomass and improving soil carbon content. Owing to its high tolerance to drought and salinity, it is well suited for the reclamation of degraded, saline and wastelands. Therefore, its integration into agroforestry and dryland farming systems promotes sustainable land-use practices, enhances ecological resilience and ensures long-term environmental stability.

Pharmacological Importance

Antimicrobial and Antibacterial Activity: Several studies have reported that *Acacia nilotica* extracts exhibit strong antimicrobial activity against a wide range of pathogenic microorganisms. Ethanolic leaf extracts have shown strong inhibitory effects against *Campylobacter coli*, while stem bark extracts are effective against both Gram-positive and Gram-negative bacteria such as *Streptococcus viridans*, *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis* and *Shigella sonnei*. The plant has also shown activity against multidrug-resistant bacterial strains and fungal pathogens such as *Candida albicans*. Extracts from leaves and bark have demonstrated measurable zones of inhibition, particularly against *Escherichia coli*, indicating strong antibacterial efficacy.

Antifungal and Antiviral Activity: Methanolic and aqueous extracts of *A. nilotica* have shown considerable antifungal activity with high percentage inhibition against pathogenic fungi. Additionally, methanolic extracts have exhibited antiviral activity against animal viruses such as Newcastle disease virus and fowl pox virus, highlighting their promising potential as a natural source of antiviral compounds for therapeutic applications.

Antimalarial and Antidiarrheal Activity: Root

extracts of *A. nilotica* have shown significant antimalarial activity against *Plasmodium berghei* and *Plasmodium falciparum* in both *in-vivo* and *in-vitro* studies. The plant has demonstrated effectiveness against chloroquine-sensitive as well as chloroquine-resistant strains, with low IC_{50} values, indicating strong anti-plasmodial potential. Various extracts have shown inhibitory activity against *Escherichia coli* and shown significant antidiarrheal effects in experimental models by reducing intestinal motility and frequency of loose stools.

Antioxidant Activity: *A. nilotica* is rich in polyphenolic compounds that contribute to its strong antioxidant potential. Methanolic extracts containing bioactive compounds such as kaempferol have shown effective free radical scavenging activity. The plant has shown significant inhibition of protein denaturation and reduced oxidative stress by decreasing reactive oxygen species levels. Bark extracts have also demonstrated strong inhibition of lipid peroxidation and enhancement of antioxidant enzyme activities, including catalase, superoxide dismutase, glutathione peroxidase and glutathione-S-transferase, indicating its potential as a natural antioxidant source.

Spasmogenic and Antispasmodic Activity: *A. nilotica* shows both spasmogenic (muscle-contracting) and antispasmodic (muscle-relaxing) activities depending on the type of extract used. The aqueous seed extracts enhance calcium influx into smooth muscle cells, thereby inducing contraction of intestinal smooth muscles. In contrast, the methanolic extract blocks calcium channels, which reduces calcium entry and relaxes the muscles. Due to this relaxing effect on smooth muscles, it may also help lower blood pressure.

Economic Importance: *A. nilotica* is an important tree that provides diverse economic benefits to farmers and rural communities. It produces gum arabic, which is widely used in the pharmaceutical and food industries, with emulsifying and binding properties. The wood is extremely hard, durable and resistant to termite attack, making it suitable for high-quality furniture, agricultural implements and construction purposes. The species is also valued for charcoal production due to its high calorific value. Its leaves serve as nutritious fodder for livestock, particularly in arid and semi-arid regions where green forage is limited. Furthermore, various parts of the plant are extensively used in traditional medicine for the treatment of multiple ailments.

Conclusion

A. nilotica is a multipurpose and resilient tree species with considerable ecological and economic significance. Its low input requirements and strong adaptability to dry and marginal lands make it particularly suitable for small and marginal farmers. The species requires minimal management and is capable of withstanding harsh environmental conditions, thereby ensuring relatively stable returns with limited investment. When integrated into farming systems, it improves farm productivity, enhances resource-use efficiency, supports soil health, and promotes environmental sustainability.

Therefore, *A. nilotica* plays a significant role in income generation, livelihood security, and the long-term sustainability of rural farming systems.

Amaranth: A Crop for Health, Nutrition and Economic Prosperity

Sheetal Rana, Happy Dev Sharma and Vipin Sharma

Introduction

In the changing agricultural scenario, farming is no longer limited to increasing production alone; it has become a crucial means for ensuring nutritional security, enhancing farmers' income and addressing the challenges posed by climate change. Under present conditions, there is a growing need to promote crops that involve low cost, minimal risk and stable productivity even under adverse climatic situations, thereby securing farmers' livelihoods. In this context, amaranth (Amaranthus) is emerging as an important crop of the future. Amaranth is a significant pseudo-cereal cultivated for both its seeds and leaves. It is a short-duration, nutrient-rich crop capable of providing higher economic returns with comparatively low investment. The genus includes more than 70 species ranging from grain, leafy vegetable, ornamental to weed types among which 17 are recognized as vegetable species and three as grain types. Owing to its remarkable adaptability to diverse agro-climatic conditions and high anti-oxidant content, amaranth possesses strong potential as a climate-smart crop.

The crop exhibits excellent tolerance to drought and salinity stress. Nutritionally, amaranth is well known for its high protein content, superior to many cereals and contains all essential amino acids including lysine, which is often deficient in major grains. Rich in both soluble and insoluble dietary fiber, it supports digestive health, promotes satiety and helps reduce cholesterol levels. Tender shoots and young leaves, including those from naturally occurring types are commonly marketed as fried, cooked or boiled vegetables. Due to its attractive colors, pleasant taste and high nutritional value, amaranth has gained popularity as a leafy vegetable across Asian as well as global cuisines. In the present climate scenario, diversification through under-utilized crops such as amaranth offers India immense untapped potential to enhance environmental sustainability, food security and combat poverty and malnutrition. With proper cultivation and market linkage, farmers especially emerging growers can generate stable and sustainable income through amaranth cultivation.

The multidimensional importance of this valuable crop can be understood through the following aspects:

Role in Nutritional Security: Amaranth is often referred to as a "nutritional powerhouse" due to its richness in protein, iron, calcium, phosphorus and vitamins A and C. Regular consumption helps combat anemia and plays an important role in physical growth and development among children. It is particularly beneficial for women's health and contributes to strengthening the body's immune

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system. Owing to its high nutritional value, amaranth is emerging as an effective crop for reducing malnutrition especially in rural areas.

Enhancing Farmers' Income: Amaranth is a short-duration crop with the first harvest obtainable within 25-30 days after sowing. This enables farmers to receive quick economic returns, improving financial stability. The crop requires relatively low investment and enjoys consistent market demand. Multiple harvests from a single sowing ensure regular income, while favorable local market prices make it an economically reliable cash crop, particularly for small and marginal farmers.

Short Duration and Low-Risk Crop: Due to its short growing period of about 30-45 days, amaranth offers a low-risk cultivation option. The reduced crop duration minimizes losses caused by natural calamities or market fluctuations. The crop can be grown multiple times in a year, ensuring efficient land utilization. Moreover, it performs well as an intercrop or mixed crop providing additional income opportunities to farmers.

Suitable under Climate Change Conditions: With changing climatic conditions affecting the stability of traditional crops, amaranth has emerged as a climate-resilient alternative. It tolerates high temperatures and performs successfully under limited water availability. Its drought tolerance is superior to many other leafy vegetables. The ability to produce satisfactory yields under unfavorable conditions makes it an effective crop for reducing climate-related agricultural risks. Particularly in rainfed and resource-limited regions, amaranth represents a sustainable and secure option for future farming systems.

Ideal for Small and Marginal Farmers: Amaranth cultivation is highly suitable for small and marginal farmers due to its ability to produce good yields even on small landholdings. The crop requires low investment and simple management practices and can easily be integrated into family-based farming systems. It is also an excellent choice for kitchen gardens, ensuring continuous availability of fresh and nutritious green vegetables for household consumption and improving family nutritional security.

Market and Processing Opportunities: Amaranth offers vast opportunities for marketing and value addition. Its tender leaves are widely consumed as green vegetables while its grains commonly known as *Rajgira* are nutritionally valuable and widely used in health foods and during religious fasting periods. Leaf powder prepared from amaranth can be incorporated into various food products. Growing health awareness has significantly increased demand for amaranth-based products, creating strong prospects for value addition and enhanced farmer income.

Contribution to Sustainable Agriculture: Amaranth plays an important role in promoting sustainable and environmentally friendly agricultural systems. The crop helps maintain soil structure and fertility and requires comparatively fewer chemical inputs, making it suitable for organic farming.

Inclusion of amaranth in crop rotations improves soil productivity and helps reduce pest and disease incidence. Thus, amaranth contributes not only to increased production and income but also to the development of long-term sustainable farming systems.

Conclusion

The above discussion clearly indicates that amaranth is not merely a leafy vegetable but a multifunctional and future-oriented crop capable of strengthening nutritional security, enhancing farmers' income and supporting climate-resilient agriculture. Its short duration, low cultivation cost, stable performance under adverse climatic conditions and adaptability make it especially beneficial for small and marginal farmers. At a time when agriculture faces challenges such as climate change, malnutrition and economic instability, integrating underutilized yet highly nutritious and resilient crops like amaranth into farming systems has become essential. Its diverse uses, growing market demand, and value addition potential can ensure stable and sustainable income for farmers. Therefore, promoting scientific and commercial cultivation of amaranth, increasing farmer awareness and incorporating it into crop diversification programs are essential steps toward strengthening livelihoods, ensuring nutritional security and achieving sustainable agricultural development.

Rainwater Harvesting and Soil Recharge

Gaytri Soni

Introduction

Rainwater harvesting and soil recharge are sustainable water management practices that focus on conserving rainfall and enhancing groundwater resources. With increasing water scarcity, declining groundwater levels, and irregular rainfall patterns due to climate change, efficient utilization of rainwater has become essential. Instead of allowing rainwater to flow away as surface runoff, rainwater harvesting systems collect, store, and direct it for productive use, while soil recharge techniques enable water to infiltrate into the ground, replenishing aquifers. Rainwater harvesting involves capturing rainfall from rooftops, land surfaces, or catchment areas and storing it in tanks, ponds, or recharge structures. Soil recharge, on the other hand, promotes percolation of water into the soil profile through methods such as recharge pits, trenches, percolation tanks, and check dams. Together, these practices help improve groundwater levels, maintain soil moisture, reduce soil erosion and support agricultural productivity. For regions facing groundwater depletion and erratic monsoon patterns, especially in semi-arid areas, rainwater harvesting and soil recharge offer cost-effective and environmentally friendly solutions. They not only ensure water availability for domestic and agricultural purposes but also contribute to ecological balance and long-term water security.

Importance of Rainwater Harvesting

Rainwater harvesting is a vital practice for sustainable water management, especially in regions facing water scarcity and declining groundwater levels. Its importance can be understood from environmental, agricultural, economic, and social perspectives.

Recharges Groundwater: Rainwater harvesting helps in replenishing underground aquifers by allowing rainwater to percolate into the soil. This improves groundwater levels and ensures long-term water availability.

Reduces Water Scarcity: By collecting and storing rainwater, communities can reduce their dependence on external water sources such as rivers, canals, and borewells, particularly during dry seasons.

Supports Agriculture: Stored rainwater can be used for irrigation, improving crop productivity and maintaining soil moisture. For you, as someone interested in soil science and agriculture, this directly links to sustainable land and water management practices.

Prevents Soil Erosion and Flooding: Harvesting rainwater reduces surface runoff, which in turn minimizes soil erosion, nutrient loss, and urban flooding.

Improves Water Quality: When rainwater filters through soil during recharge, it undergoes natural

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purification. This can improve the quality of groundwater over time.

Cost-Effective and Eco-Friendly: Rainwater harvesting systems are relatively low-cost and easy to maintain. They reduce energy use associated with pumping and transporting water.

Promotes Sustainable Development: It contributes to water security, environmental conservation, and climate resilience, making it an essential component of sustainable development planning.

Principles of Soil Recharge

Soil recharge refers to the process of allowing water to infiltrate into the soil and replenish underground aquifers. It is an important component of sustainable water management, especially in agriculture and groundwater conservation.

The main principles of soil recharge are:

Infiltration and Percolation: The basic principle of soil recharge is promoting infiltration (entry of water into the soil surface) and percolation (movement of water downward through soil layers). Soil texture, structure, and porosity play a major role in determining the rate of recharge.

Maximizing Surface Contact Time: Water should be allowed to remain on the surface for a longer time so that it can slowly infiltrate rather than flow away as runoff. Structures like recharge pits, trenches, check dams, and percolation tanks help increase contact time.

Reducing Surface Runoff: By slowing down water flow using bunds, contour trenches, and vegetative barriers, runoff velocity decreases, giving more time for water to seep into the soil.

Maintaining Soil Porosity: Healthy soil with good aggregation and organic matter content enhances pore space, improving water infiltration and storage capacity. Compacted soils reduce recharge efficiency.

Filtration and Natural Purification: As water moves through soil layers, physical, chemical, and biological processes filter impurities. Thus, soil acts as a natural filter before water reaches groundwater aquifers.

Site-Specific Design: Recharge methods should be selected based on soil type, slope, rainfall intensity, and land use. For example, sandy soils allow faster recharge compared to clayey soils.

Sustainable Withdrawal: Groundwater extraction should not exceed the natural recharge rate. Balance between recharge and withdrawal is essential for long-term groundwater sustainability.

Components of a Rainwater Harvesting System

A rainwater harvesting system consists of several essential components that work together to collect, filter, store and recharge rainwater efficiently.

Catchment Area: The catchment is the surface where rainfall is collected. It can be a rooftop, paved area, or open land surface. Rooftop catchments are commonly used in urban areas, while ground catchments are used in rural and agricultural fields.

Conveyance System: This includes gutters, down-pipes, and channels that transport rainwater from the catchment area to the storage or recharge structure.

Proper slope and leak-proof pipes ensure smooth water flow.

First Flush Device: The first flush system diverts the initial runoff, which may contain dust, leaves, and contaminants from the roof. This helps improve the quality of collected water.

Filtration Unit: Filters remove suspended particles and impurities before water enters the storage tank or recharge pit. Common filter materials include sand, gravel, charcoal, and mesh screens.

Storage Tank: Collected rainwater is stored in tanks made of plastic, concrete, fiberglass, or metal. Tanks may be placed above ground or underground depending on space and requirement. Stored water can be used for domestic, irrigation, or other non-potable purposes.

Recharge Structure: Instead of storage, water can be directed to recharge structures such as recharge pits, trenches, percolation tanks, or borewell recharge systems. These structures allow water to infiltrate into the soil and replenish groundwater.

Overflow Mechanism: An overflow pipe ensures excess water is safely directed away when the storage tank becomes full, preventing damage or flooding.

Distribution System: Pumps, taps, or pipelines distribute stored rainwater for use in irrigation, gardening, or household activities.

Advanced Techniques for Soil Recharge

Advanced soil recharge techniques focus on enhancing groundwater replenishment using scientific design, improved materials and better hydrological understanding. These methods are especially useful in areas facing groundwater depletion and irregular rainfall.

Managed Aquifer Recharge (MAR): Managed Aquifer Recharge (MAR) involves the intentional recharge of water into aquifers for storage and later recovery. It includes methods such as recharge basins, infiltration ponds, and injection wells. MAR is widely used to restore declining groundwater levels in semi-arid regions.

Recharge Wells (Injection Wells): Recharge wells directly inject treated rainwater or surface water into deeper aquifers. This method is effective in urban areas where surface infiltration is limited due to paved surfaces.

Percolation Tanks with Lining Control: Improved percolation tanks are designed using hydrogeological surveys to identify highly permeable zones. Proper desilting and maintenance increase recharge efficiency.

Subsurface Dykes: Subsurface dykes are underground barriers constructed across seasonal streams to obstruct groundwater flow and increase water storage within the soil profile. They help raise the water table upstream without affecting surface land use.

Aquifer Storage and Recovery (ASR): Aquifer Storage and Recovery (ASR) involves injecting water into an aquifer during surplus periods and pumping it back during dry periods. This technique ensures year-round water availability.

Recharge Shafts: Recharge shafts are deep vertical structures that bypass low-permeability surface laye-

rs and allow water to reach permeable strata directly. They are suitable for clayey or compacted soils.

Use of Geospatial and Remote Sensing Tools: Modern recharge planning uses GIS and satellite data to identify suitable recharge zones based on slope, soil type, land use, and drainage patterns. Since you are learning remote sensing, this is an advanced area where NDVI, DEM analysis, and watershed mapping can help in locating optimal recharge sites.

Conclusion

Rainwater harvesting and soil recharge are essential components of sustainable water resource management. By capturing and conserving rainfall, these practices reduce surface runoff, enhance soil moisture, and replenish declining groundwater reserves. They not only ensure reliable water availability for domestic and agricultural use but also protect soil health and prevent erosion. In the context of sustainable agriculture, rainwater harvesting and soil recharge improve crop productivity, strengthen climate resilience, and promote efficient resource use. When combined with scientific planning, proper design, and modern tools like GIS and remote sensing, these methods become even more effective and site-specific. Overall, adopting rainwater harvesting and soil recharge techniques is a practical, eco-friendly, and long-term solution for achieving water security, soil conservation, and sustainable agricultural development.

Medicinal Mushrooms: Nature's Hidden Pharmacists

P. G. Gameti

Abstract

Medicinal mushrooms are a distinct group of macro-fungi capable of synthesizing diverse bioactive compounds with well-established therapeutic relevance. Evolving in microbe-rich and competitive environments such as forest floors and decaying organic substrates, mushrooms rely on chemical defense systems for survival. These defense molecules-including β-glucans, polysaccharides, terpenoids, triterpenes, phenolics, lectins and antioxidants such as ergothioneine exhibit immunomodulatory, antimicrobial, antiviral, anti-inflammatory, antioxidant and metabolic regulatory effects in humans. Scientific evidence accumulated over recent decades has validated many traditional medicinal claims, confirming mushrooms as genuine therapeutic agents rather than mere dietary components. This article discusses the ecological basis of medicinal activity, major bioactive compounds, key medicinal mushroom species, antimicrobial relevance from a plant pathology perspective and future prospects, thereby justifying medicinal mushrooms as "nature's hidden pharmacists."

Introduction

Natural products have historically formed the backbone of medicinal discoveries, with plants and microorganisms contributing significantly to modern pharmaceuticals. Among these, mushrooms occupy a unique position due to their exceptional biochemical diversity. Although widely consumed as food, many mushroom species possess well-documented medicinal properties and have been used for centuries in traditional systems such as Ayurveda and Traditional Chinese Medicine. Only in recent decades, however has scientific research systematically validated their therapeutic potential. Unlike plants, mushrooms lack structural defense mechanisms and instead depend on chemical defenses to survive in hostile environments. This evolutionary reliance on biochemical protection has resulted in the production of a wide range of secondary metabolites with potent biological activity. These compounds, originally evolved to suppress competing microorganisms and environmental stressors, now underpin the medicinal value of mushrooms, justifying their description as "nature's hidden pharmacists."

Ecological Basis of Medicinal Properties in Mushrooms

The medicinal attributes of mushrooms are closely linked to their ecological niche. Mushrooms thrive in environments rich in bacteria, viruses, nematodes and competing fungi, where intense competition for nutrients exists. To successfully colonize these substrates, mushrooms synthesize

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antimicrobial and protective compounds that inhibit or regulate surrounding microorganisms. Numerous studies have shown that these ecologically important metabolites also exert pharmacological effects in humans, including antimicrobial, antioxidant and immunomodulatory activities (Wasser, 2011; Venturella *et al*., 2021).

Bioactive Compounds Responsible for Medicinal Effects: The therapeutic value of medicinal mushrooms arises from a diverse range of bioactive compounds. Polysaccharides, particularly β-glucans, are the most extensively studied and function as biological response modifiers. Rather than over-stimulating immunity, β-glucans regulate immune responses by activating macrophages, natural killer cells and T-lymphocytes through receptors such as dectin-1 and complement receptor-3 (Han *et al*., 2020; Cerletti *et al.*, 2021). Medicinal mushrooms also contain terpenoids and triterpenes with anti-inflammatory, antiviral and hepatoprotective properties, especially in *Ganoderma lucidum* (Lindequist *et al*., 2005).

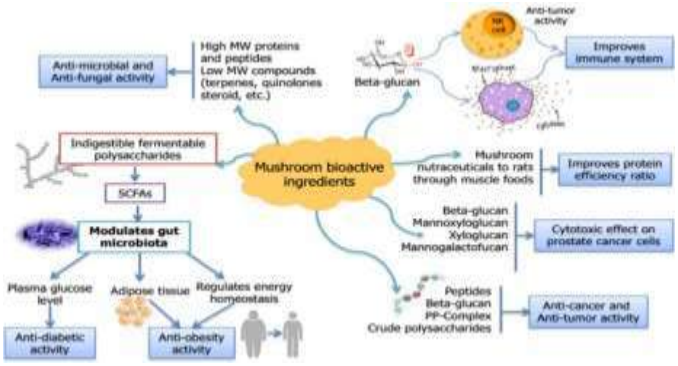


Fig. 1: Bioactive compounds of medicinal mushrooms

Phenolic compounds contribute anti-oxidant activity by scavenging reactive oxygen species, while lectins participate in immune signaling and pathogen recognition. Ergothioneine, a sulfur-containing antioxidant uniquely abundant in mushrooms, provides cellular protection against oxidative and inflammatory damage (Phillips *et al*., 2022). The synergistic action of these compounds explains the wide therapeutic spectrum of medicinal mushrooms.

Key Medicinal Mushrooms Acting as Natural Pharmacists

Several mushroom species exemplify the pharmaceutical potential of fungi. *Ganoderma lucidum* (Reishi) is rich in triterpenoids and polysaccharides that exhibit immunomodulatory, anti-inflammatory, antiviral and cardioprotective effects. Traditionally used to enhance vitality and disease resistance, its immune-regulating properties are now scientifically well established (Wasser, 2011; Phillips *et al*., 2022). *Lentinula edodes* (Shiitake) produces lentinan, a β-glucan with antiviral, antibacterial and anticancer activity. Shiitake extracts have demonstrated inhibitory effects against a wide range of bacterial and fungal pathogens, reinforcing their role as natural antimicrobials (Hearst *et al*., 2009). *Trametes versicolor* (Turkey Tail) contains protein-bound polysaccharides (PSK and PSP) widely used as immune-enhancing adjuncts in cancer therapy (Venturella *et al*., 2021). *Cordyceps* species synthesize cordycepin, which exhibits antiviral and anti-inflammatory properties while influencing energy metabolism and respiratory health. *Hericium erinaceus* (Lion's Mane) is disting-

uished by neuroactive compounds that stimulate nerve growth factor synthesis while also supporting immune function (Friedman, 2015).

Expanding the Medicinal Spectrum: Additional mushroom species further strengthen the concept of mushrooms as natural pharmacological systems. *Agaricus bisporus* contains ergothioneine and phenolic compounds with antioxidant and anti-inflammatory activity, alongside immunomodulatory polysaccharides (Cerletti *et al*., 2021). *Grifola frondosa* (Maitake) produces D-fraction β-glucans that enhance immune function and improve insulin sensitivity, making it valuable in immune and metabolic disorders (Venturella *et al*., 2021). *Pleurotus ostreatus* (Oyster mushroom) contains β-glucans, lectins and natural statins such as lovastatin, contributing to immune enhancement, antimicrobial activity and cholesterol reduction (Patel *et al*., 2021). *Flammulina velutipes* (Enoki) exhibits antioxidant and anti-inflammatory effects, while *Auricularia auricula-judae* (Wood Ear) contains anticoagulant polysaccharides that support vascular health (Wasser, 2011).



Fig. 2: Different medicinal mushroom

Inonotus obliquus (Chaga) is rich in polyphenols, triterpenes and melanin, providing strong antioxidant and immune-modulating effects (Lindequist *et al*., 2005; Patel *et al*., 2021).

Antimicrobial and Immunomodulatory Relevance from a Plant Pathology Perspective: From a plant pathology perspective, medicinal mushrooms are significant due to their ability to suppress pathogenic microorganisms. Mushroom-derived compounds inhibit pathogens through membrane disruption, enzyme inhibition, and interference with nucleic acid synthesis (Seo and Choi, 2021). Their multi-target mechanisms reduce the risk of resistance development, while immunomodulatory effects enhance host defense, offering a dual approach to disease management.

From Traditional Medicine to Modern Therapeutics: Medicinal mushrooms have been used empirically in traditional medicine for centuries. Modern research has now validated many of these uses through *in-vitro*, *in-vivo* and clinical studies. Advances in extraction and analytical techniques have enabled standardization of mushroom-derived compounds, facilitating their integration into nutraceutical and pharmaceutical applications (Wasser, 2011; Venturella *et al*., 2021).

Challenges and Future Prospects: Despite their promise, medicinal mushrooms face challenges related to variability in bioactive compound content due to species, substrate, climate and extraction methods. Limited large-scale clinical trials and lack of standardization restrict broader pharmaceutical

acceptance. Addressing these issues is essential to fully harness mushrooms as therapeutic agents.

Conclusion

Medicinal mushrooms represent one of nature's most sophisticated therapeutic systems. Far from being mere decomposers, mushrooms function as natural pharmacists, producing bioactive compounds that regulate immunity, suppress pathogens, reduce inflammation and protect cellular health. Accumulating scientific evidence strongly supports their medicinal status and fully justifies the title "Medicinal Mushrooms: Nature's Hidden Pharmacists."

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Herbal Gardens as Nutrition-Sensitive Urban Agriculture: Integrating Medicinal and Aromatic Plants for Health, Livelihoods and Sustainability

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Abstract

Urban India is witnessing a rapid rise in lifestyle-related disorders, nutritional deficiencies and declining green spaces. Medicinal and Aromatic Plants (MAPs) offer a unique opportunity to address nutrition, preventive health and urban sustainability simultaneously. Herbal gardens comprising medicinal plants, aromatic crops, herbal tea species and medicinal flowers can serve as "living nutrition pharmacies" in cities. This article presents a practical, crop-based herbal garden framework using plants such as Kalmegh, Ashwagandha, Tulsi, Lemongrass, Chamomile, Lavender and Geranium, supported by scientific production practices and policy convergence. The National Medicinal Plants Board (NMPB), Ministry of Ayush, is promoting herbal gardens under its Central Sector Scheme (2026) with financial assistance for home, school and institutional models. By integrating horticultural innovation, nutrition-sensitive agriculture and AYUSH systems, herbal gardens can improve dietary diversity, enhance immunity, generate green livelihoods and conserve medicinal biodiversity.

Introduction

India possesses nearly 7,500 medicinal plant species, of which about 1,500 species are actively used in Ayurveda, Siddha, Unani and folk healthcare systems. However, rapid urbanization has resulted in shrinking green spaces, erosion of traditional knowledge and increased dependence on synthetic healthcare solutions. At the same time, India faces a growing burden of non-communicable diseases (NCDs) such as diabetes, liver disorders, hypertension and stress-related ailments, especially in urban populations. Medicinal and Aromatic Plants (MAPs), traditionally grown in rural landscapes, are increasingly recognized as nutrition-sensitive horticultural crops suitable for urban and peri-urban agriculture. Herbal gardens offer a low-cost, scalable and sustainable approach to improve functional nutrition, immunity and mental well-being, while also creating livelihood opportunities and strengthening biodiversity conservation.

Medicinal and Aromatic Plants as Nutrition-Sensitive Crops

Unlike conventional horticultural crops that primarily supply calories or vitamins, MAPs are rich in bioactive compounds such as andrographolides, withanolides, eugenol and citral. These compounds

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play a crucial role in:

- ✓ Strengthening immunity
- ✓ Improving liver and digestive health
- ✓ Managing metabolic disorders
- ✓ Reducing stress and anxiety

Table 1: Selected MAPs and their nutrition-health relevance

Crop	Major Bioactive Compound	Functional Benefit
Kalmegh (*Andrographis paniculata*)	Andrographolide	Liver health, immunity
Ashwagandha (*Withania somnifera*)	Withanolides	Stress reduction, vitality
Tulsi (*Ocimum sanctum*)	Eugenol	Respiratory & immune health
Lemongrass (*Cymbopogon flexuosus*)	Citral	Digestive health
Chamomile (Matricaria recutita)	Flavonoids	Sleep & mental wellness

Framework of an Integrated Herbal Garden

A scientifically planned herbal garden can be organized into four functional zones, ensuring diversity, ease of management and multiple outputs.

Medicinal Plants Zone: Key crops include Kalmegh, Ashwagandha, Stevia and Bhumi Amla. These plants are suitable for beds, containers and community plots and are widely used in household remedies and AYUSH formulations.

Fragrance Plants Zone: Geranium, Tuberose, Lavender and Rose contribute to aromatherapy, mental wellness and urban floriculture. These crops also support value addition through essential oils and natural fragrances.

Herbal Tea and Infusion Zone: Tulsi, Lemongrass and Chamomile are increasingly used as functional beverages and herbal teas, supporting immunity and digestive health while creating small-scale enterprise opportunities.

Medicinal and Aromatic Flower Zone: Salvia, Kapoor Tulsi, Rosemary and Patchouli enhance pollinator diversity and supply raw material for cosmetics and wellness products.

Practical Crop Planning for Urban Conditions

Most MAPs are low-input, drought tolerant and adaptable to container cultivation, rooftops and institutional campuses. Their short crop cycles and perennial nature make them ideal for urban farming systems. Crop calendars and spacing recommend-ations, as standardized by CSIR-CIMAP and ICAR institutes, ensure optimal growth and yield even in limited spaces.

Policy Support: Role of NMPB Herbal Garden Scheme (2026)

Recognizing the importance of medicinal plants in public health, the National Medicinal Plants Board (NMPB) is promoting herbal gardens under its Central Sector Scheme on "Conservation, Develop-ment and Sustainable Management of Medicinal Plants".

Financial assistance includes

- ✓ Home Herbal Gardens: ₹2,500 per household (20 species)
- ✓ School Herbal Gardens: ₹25,000 establishment + ₹7,000 $year^{-1}$ maintenance
- ✓ Institutional Herbal Gardens: ₹3 lakh ha^{-1} + ₹60,000 $year^{-1}$ maintenance (up to 4 years)

The scheme encourages convergence with Poshan Vatika, Smart Cities Mission, AMRUT, and

Ayushman Bharat, enabling states and urban local bodies to mainstream herbal gardens into development planning.

Urban Livelihoods and Extension Opportunities

Herbal gardens provide multiple livelihood avenues:

- ✓ Nursery raising of MAP seedlings
- ✓ Herbal tea and dried leaf products
- ✓ Primary processing and packaging
- ✓ Women SHGs and urban farmer collectives

Urban Resident Welfare Associations (RWAs), schools, universities and NGOs can act as extension nodes, promoting herbal literacy and community participation.

Contribution to Sustainable Food and Health Systems

Herbal gardens contribute to

- ✓ Nutrition-sensitive agriculture
- ✓ Reduced healthcare expenditure
- ✓ Conservation of medicinal plant diversity
- ✓ Climate-resilient urban landscapes

They align with SDG-2 (Zero Hunger) and SDG-3 (Good Health and Well-being) and support ICAR's vision of sustainable and inclusive agriculture.

Way Forward

Mainstreaming herbal gardens requires

- ✓ State-level herbal garden missions
- ✓ ICAR-CSIR-AYUSH technical convergence
- ✓ Standardized planting kits for urban users
- ✓ Digital tools for herbal knowledge dissemination

With appropriate policy support and scientific guidance, herbal gardens can transform Indian cities into green, healthy and resilient living systems.

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Integrated Management of Vertebrate Pests in Agriculture: Protecting Crops from Wild Boars, Birds, Peacocks and Rodents

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Introduction

Agriculture in India, particularly in Telangana, is increasingly challenged by vertebrate pests such as wild boars, deer, rodents, peacocks, and grain-feeding birds. These pests cause significant crop losses from sowing to harvest, affecting cereals, oilseeds, pulses, fruits, and vegetables. To mitigate these losses, scientific and eco-friendly management practices are being promoted by institutions such as Professor Jayashankar Telangana State Agricultural University and the All India Vertebrate Pest Management Division.

An integrated approach combining physical barriers, biological fencing, repellents, sound deterrents, and community participation provides the most sustainable and effective solution.

Nature of Damage and Emerging Concerns

Wild boars are omnivorous animals feeding on roots, tubers, grains, fruits, insects, and small animals. They typically move in groups of 15-35 and forage during early morning and night hours. Shrinking forest habitats and declining natural predators have contributed to population increases, resulting in severe crop damage.

Rodents damage crops by cutting seedlings, feeding on developing grains, and creating burrows that weaken field bunds and irrigation systems. Birds such as parrots, sparrows, pigeons, and peacocks cause damage particularly during grain filling and fruit maturity stages. Habitat disturbance and ecological imbalance have intensified wildlife-agriculture conflicts, making integrated management essential.



Management Strategies

Physical Barriers

Physical exclusion is one of the most reliable preventive methods against wild animal intrusion.

Barbed Wire Fence: Three rows of barbed wire fixed one foot above ground level along field boundaries restrict wild boar entry. Estimated cost: Approximately ₹6,000 per acre (including labor).

Razor Wire (Circular Coil) Fence: Circular razor wire installed at 2-3 feet height discourages wild boars due to mild injury upon contact. Estimated cost: ₹19,000-₹20,000 per acre.

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Solar Fence: Solar-powered fencing (12-volt system) delivers a mild shock upon contact, preventing repeated intrusion. Estimated cost: ₹90,000-₹1,10,000 per acre. Highly suitable for areas with chronic wild boar problems.

Trench Method: Digging trenches (3 ft width × 2 ft depth) around fields prevents entry and helps conserve soil moisture. Estimated cost: ₹7,500 per acre.

Chain-Link Fence: Iron mesh fencing of 3 ft height installed along boundaries. Estimated cost: ₹12,500-₹13,500 per acre.

Nylon Net Method: HDPE nylon nets (100 mm mesh, 6 ft width) fixed tightly with bamboo poles and GI wire provide 70-80% protection. Estimated cost: ₹2,600 per acre. Economical and suitable for small and medium farmers.

Live Fencing (Biological Methods)

Biological fencing reduces pest entry while generating additional income.

Castor around maize fields: Strong odor masks maize scent and deters wild boars.

Safflower around groundnut: Thorny plants discourage digging.

Ginger and turmeric along boundaries: Mask crop odor and offer high market value.

Spiny trees like Vakkaya: Form natural protective barriers and provide fruit income.

Live fencing enhances farm profitability and ecological sustainability.

Bird Management Techniques

Flash Ribbon Method: Red and white reflective ribbons tied above crop canopy create glare and sound, deterring birds.

Neem Seed Extract Spray: Spray 20 ml neem extract per litre of water to discourage bird feeding for 7-10 days.

Rotten Egg Spray: Spraying diluted rotten egg solution during grain filling produces a foul odor that repels birds. Cost: Approximately ₹225 per acre.

Distress Call Method: Playback of recorded bird alarm calls using solar or electric devices protects 4-5 acres per unit.

Leaf Wrapping (Maize): Wrapping maize cobs during the milk stage conceals grains from birds.

Rope Barrier Method (Peacock Control): Coconut or jute ropes tied horizontally and vertically at one-foot height prevent peacock landing.

Alternative Habitat and Ecological Balance

Planting forest fruit trees such as tamarind, cashew, and Vakkaya along bunds and wastelands diverts birds away from crops while providing additional income. Beneficial birds such as egrets, drongos, kingfishers, and bee-eaters consume large numbers of insects, reducing pest populations naturally by 40-60%. Preserving ecological balance is vital for sustainable agriculture.

Integrated Rodent Management (IRM)

Rodents are among the most destructive vertebrate pests in Indian agriculture, causing damage from field to storage.

Major species in Telangana include:

- ✓ *Bandicota bengalensis* - Field rat
- ✓ *Rattus rattus* - House rat

- ✓ *Bandicota indica* - Larger burrowing rat

Assessment of Rodent Population

Active Burrows per Acre	Damage Level
Less than 25	Low
25-50	Moderate
More than 50	Severe

Close all burrows in the evening and check the following morning. Reopened burrows indicate active infestation.

Cultural Control

- ✓ Remove weeds and alternate hosts
- ✓ Practice deep summer ploughing
- ✓ Maintain proper irrigation and drainage
- ✓ Reduce bund size in paddy
- ✓ Maintain field sanitation

These measures reduce food and shelter availability.

Mechanical Control

Trapping: Place 20 traps per acre in active zones.

Burrow Fumigation: Pump smoke into active burrows for 2–3 minutes using a fumigator, ensuring operator safety.

Chemical Control (Rodenticide Baiting)

Chemical control should follow proper assessment and safety measures.

For moderate infestation, Bromadiolone (0.005%) is recommended. Prepare bait by mixing 960 g broken grains, 2 g edible oil, and 2 g Bromadiolone. Make 10-15 g packets and place one in each active burrow during evening hours.

For severe infestation, Zinc Phosphide baiting is adopted in two stages. First, conduct pre-baiting for two days using 980 g broken grains and 2 g oil. On the third day, prepare poison bait using 960 g broken grains, 2 g oil, and 2 g Zinc Phosphide. Place 10 g packets in active burrows. Dead rodents must be collected and buried safely. Prevent exposure to children and livestock.

Community-level synchronized baiting is highly effective in preventing reinfestation.

Conclusion

Vertebrate pests significantly threaten agricultural productivity and farmer income. However, adopting an Integrated Vertebrate Pest Management approach combining physical barriers, live fencing, eco-friendly repellents, sound deterrents, rodent management, and community participation can substantially reduce crop losses. No single method is sufficient. The integration of preventive, mechanical, biological, and chemical measures ensures long-term sustainability, cost-effectiveness, and ecological balance. Collective action at the village level further enhances effectiveness.

By implementing scientifically validated and environmentally responsible strategies, farmers can protect crops, improve yields, and strengthen livelihood security while maintaining harmony with the surrounding ecosystem.

Traditional Livestock Wisdom: The Role of ITK in Sustainable Animal Farming

Amit M. Kadam and Swapnil M. Bagul

Introduction

Indigenous Technical Knowledge (ITK) refers to the cumulative body of knowledge, practices and beliefs developed by rural and tribal communities through prolonged interaction with their agro-ecological environment. Unlike formal scientific systems, ITK evolves through experiential learning, observation, cultural transmission and adaptation to local climatic and socio-economic conditions. In livestock production systems, ITK encompasses feeding strategies, breeding practices, ethno-veterinary medicine, housing management and manure utilization. In a country like India, where mixed crop-livestock farming systems predominate and smallholder farmers constitute the majority of producers, ITK plays a crucial role in ensuring resilience, sustainability and cost-effectiveness. Even in the era of precision livestock farming and advanced veterinary therapeutics, traditional live-stock wisdom continues to influence day-to-day animal management practices in rural households.

Why ITK Matters Today

Even with modern technological advance-ments, traditional knowledge remains relevant. ITK practices are generally low-cost, eco-friendly and suited to local climatic conditions. They promote sustainable use of natural resources and reduce dep-dependency on expensive inputs. Documentation of ITK is essential to preserve this valuable heritage before it is lost. Many traditional practices may complement scientific technologies and inspire further research.

Conceptual Framework of Indigenous Technical Knowledge

ITK is characterized by:

- ✓ Location specificity
- ✓ Low external input dependence
- ✓ Ecological sustainability
- ✓ Cultural embeddedness
- ✓ Empirical validation over generations

Scientifically, ITK can be understood as an informal innovation system rooted in adaptive management. Many traditional practices are based on phytotherapeutic principles, nutritional modulation and environmental manipulation that align with contemporary scientific understanding of animal physiology and microbiology.

The documentation and validation of ITK are particularly relevant in the context of sustainable development, climate resilience and reduction of antimicrobial resistance. Ethno-veterinary practices, in particular, offer promising alternatives to indiscriminate antibiotic usage.

Traditional Feeding Practices and Productivity

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Enhancement

Fertility Enhancement Practices: Several indigenous formulations are traditionally administered to improve reproductive performance in cattle and buffaloes. Feeding chopped Onion (*Allium cepa*) mixed with salt is believed to stimulate estrus and enhance fertility. From a biochemical perspective, onions contain sulfur compounds and flavonoids that may influence metabolic and endocrine functions. Similarly, preparations involving Fenugreek (*Trigonella foenum-graecum*) and Almonds boiled in milk are used as strengthening tonics. Fenugreek seeds are rich in phytoestrogens, saponins and galactagogues, which may positively influence ovarian function and lactation physiology.

These practices may function through:

- ✓ Improved energy balance
- ✓ Hormonal modulation
- ✓ Enhanced rumen microbial activity
- ✓ Antioxidant effects

Scientific validation through controlled trials is required to establish dosage, efficacy and safety.

Milk Yield Enhancement: Traditional livestock keepers incorporate soybean, cowpea and wheat flour mixtures into concentrate feeds to enhance milk yield. These ingredients provide high-quality protein, essential amino acids and fermentable carbohydrates, which support rumen microbial protein synthesis and mammary gland productivity.

In some Himalayan regions, extracts of *Angelica glauca* are administered to dairy animals. This plant contains bioactive compounds with potential digestive and immunomodulatory properties.

From a scientific standpoint, such practices may improve:

- ✓ Nitrogen utilization efficiency
- ✓ Rumen fermentation kinetics
- ✓ Metabolizable protein supply
- ✓ Immune status of lactating animals



Traditional Preparation of Herbal Livestock Feed Mixtures

Ethno-Veterinary Practices in Animal Health Management

Ethno-veterinary medicine forms a major component of ITK in livestock systems. These practices rely on medicinal plants, household ingredients and locally available resources.

Wound Management: Turmeric (*Curcuma longa*) paste is widely applied on wounds. Curcumin, the active compound, exhibits antimicrobial, anti-inflammatory and antioxidant properties. Scientific studies confirm its role in accelerating wound healing by promoting collagen deposition and reducing oxidative stress.

Respiratory Disorders: Herbal decoctions containing Tulsi (*Ocimum sanctum*), Ginger (*Zingiber officinale*) and Garlic (*Allium sativum*) are administ-

ered for cough and cold. These plants possess:

- ✓ Antimicrobial activity
- ✓ Immunomodulatory effects
- ✓ Anti-inflammatory properties
- ✓ Mucolytic action

Such formulations may help reduce pathogen load and improve respiratory function in livestock.

Diarrhea Management: Pineapple leaf juice and tamarind pulp are traditionally used to control diarrhea. Tamarind contains tannins and organic acids that exhibit mild astringent and antimicrobial properties, potentially stabilizing gut microflora.

Mastitis Management: Aloe vera combined with turmeric is applied externally to manage mastitis. Aloe vera possesses anti-inflammatory and wound-healing properties, while turmeric offers antimicrobial action. These may reduce local inflammation and bacterial proliferation.

Although such treatments may provide symptomatic relief, scientific standardization is required to ensure therapeutic reliability.



Application of Herbal Paste for Mastitis Management

Indigenous Practices in Small Ruminant Production

Sheep and goat rearing is integral to dryland and semi-arid agriculture in India. Traditional systems emphasize low-input management and ecological integration.

Sheep Penning for Soil Fertility: Sheep penning involves confining animals overnight on agricultural fields, allowing direct deposition of dung and urine. This practice enhances soil fertility through:

- ✓ Organic matter enrichment
- ✓ Nitrogen and phosphorus addition
- ✓ Improved soil microbial activity
- ✓ Enhanced soil structure

Scientifically, sheep manure is rich in readily mineralizable nutrients, making it an effective organic fertilizer.



Traditional Sheep Penning in Crop Fields

Scientific Relevance and Sustainability Dimensions

ITK contributes significantly to:

- ✓ Reduction in input costs
- ✓ Minimization of chemical residues
- ✓ Lower antibiotic dependence
- ✓ Climate-resilient livestock management
- ✓ Biodiversity conservation

In the context of global sustainability frameworks, ITK aligns with the goals of ecological intensification and circular bioeconomy. The integration of traditional wisdom with modern veterinary science can enhance:

- ✓ Evidence-based herbal therapeutics
- ✓ Functional feed development
- ✓ Probiotic and phytogenic additives
- ✓ Organic livestock certification systems

Institutions such as Indian Council of Agricultural Research have increasingly emphasized documentation and validation of indigenous livestock practices.

Challenges in Integration

Despite its strengths, ITK faces several limitations:

- ✓ Lack of standardized dosage and protocols
- ✓ Regional variability
- ✓ Limited experimental validation
- ✓ Risk of misinformation
- ✓ Gradual erosion due to modernization

A multidisciplinary approach involving animal scientists, veterinarians, ethnobotanists and microbiologists is required to systematically validate and refine these practices.

Future Perspectives

Future research should focus on:

- ✓ Phytochemical characterization of traditional herbal remedies
- ✓ Controlled clinical trials in livestock
- ✓ Standardization of preparation methods
- ✓ Development of validated ethno-veterinary pharmacopeia
- ✓ Integration into extension education programs

Digital documentation platforms and participatory rural appraisal methods can help preserve indigenous wisdom for future generations.

Conclusion

Indigenous Technical Knowledge represents a valuable reservoir of practical wisdom accumulated over centuries. In livestock production systems, ITK provides affordable, eco-friendly and locally adapted solutions for animal health, nutrition and productivity enhancement. While not a substitute for modern veterinary science, it offers complementary strategies that can enhance sustainability and resilience. The scientific validation and systematic documentation of ITK are essential to prevent knowledge erosion and to harness its full potential in sustainable livestock development.

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The Secret Life of Pollinators: How Plants and their Pollinators Keep Nature Thriving

V. Ratnakar, S. Srinivasnaik, M. Rajashekhar and Y. Swathi

Pollinators bees, butterflies, birds, bats, and even some mammals play a crucial role in nature. They help plants reproduce by transferring pollen, which ensures seed and fruit production. This intricate partnership has evolved over millions of years, shaping the colors, scents, and shapes of flowers, and the behaviors and traits of pollinators. Understanding these relationships helps us appreciate the delicate balance of our ecosystems and highlights why pollinator conservation is so vital.

Co evolution: Plants continuously evolve new adaptations through cross-pollination, enhancing their ability to attract the right pollinators while limiting access to their valuable nectar and pollen. These adaptations ensure that only specific, reliable pollinators are rewarded, helping plants maximize their reproductive success. By controlling which species can interact with them, plants safeguard their resources and maintain mutually beneficial relationships with their loyal pollinators. The size and shape of flowers play a crucial role in this selective process. Large, vividly colored flowers act as visual signals, guiding pollinators from a distance, while also accommodating the physical needs of visitors like bumblebees, which require sturdy landing platforms. Similarly, intricate flower shapes can restrict access to nectar, favoring pollinators with specialized adaptations. For instance, long tubular flowers conceal nectar deep within, allowing only long-tongued pollinators such as hummingbirds, butterflies, certain moths, and specific bee species to reach it, ensuring precise and efficient pollination.

Mutual Benefits: Pollination benefits both plants and their helpers. Plants achieve reproduction and genetic diversity, while pollinators receive food in the form of nectar, pollen, and other nutrients. Beyond individual benefits, pollinators support ecosystems and agriculture by enabling the production of fruits, vegetables, nuts, and seeds that sustain humans and wildlife alike.

Threats to Pollinators: Modern human activities are putting this delicate balance at risk. Habitat loss from urbanization and agriculture, widespread pesticide use, climate change, and invasive species

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all threaten pollinator populations. Disruptions can lead to reduced pollination, affecting plant reproduction, biodiversity, and food security.

Conservation and Management: Efforts to conserve pollinators include restoring natural habitats, creating urban green spaces, and using pollinator-friendly farming practices. Reducing harmful chemicals, planting native flowers, and providing nesting sites all help. Public awareness and education programs encourage communities to participate in protecting pollinators, ensuring the survival of these essential species. By understanding and protecting these relationships, we safeguard the future of our planet, ensuring that both plants and pollinators continue their ancient dance for generations to come.

Meadow Horticulture: A New Approach to Intensive Fruit Crop Production

Shivam Singh, Aditya Kumar Giri, Saumya and Ankit Singh Bhadauria

Abstract

As global demand for land and food resources continues to grow, the horticulture industry is moving toward "intensive" growing systems. The Meadow Orchard System (MOS), or meadow horticulture, represents a shift in growing systems toward an ultra-high-density planting (UHDP) approach. In this paper, we examine the physiological principles, agronomic practices, and economic benefits of the Meadow Orchard System. The system relies on extreme planting densities (from 5,000 to more than 70,000 plants ha^{-1}) and intensive canopy management through extreme pruning, repeated pruning, which re-alters plant energy allocation from vegetative growth to reproductive growth and maximizes light capture. API has successfully studied two innovative and adaptive cases with fruit species of guava and apple. The CISH model with guava has effectively utilized the guava plant's characteristic of bearing fruit on new growth to produce early bearing (first year harvest) and high yields (40-60 tonnes ha^{-1}). The "fruit wall," or "pedestrian orchard" model with apples, relies on a combination of removing vegetative growth (through dwarfing rootstocks like M-9 or M-27) and using support system trellises to produce higher quality fruit with aspect lending itself more to mechanized production. Although the MOS system has significant benefits, especially in terms of quick returns on investment, increases in productivity, and value fruit, it is also a high-risk system of production. The main challenges being high establishment costs, reliance on high skilled labour to prune intensively, and less economic life of trees in MOS plantings compared to more traditional orchards. The paper summarizes possible futures for the repeatability of MOS production in modern food systems for fruit production, including precise living systems, mechanization, and robotics of efficient farming as described as "fruit factory" systems.

Introduction

The agricultural sector globally faces an unprecedented crisis. An increasing global population and increasing pressures from climate change and land degradation necessitate novel strategies to produce more food on less land. In horticulture, growers have begun to move rapidly on a continuum from traditional low-density orchards to high-density

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systems in response to this challenge and high-density planting (HDP) systems are becoming the new norm. However, an even more extreme and productive system is evolving: the meadow orchard system (MOS), otherwise termed “meadow horticulture” consisting of ultra-high-density planting (UHDP) systems that set out to 'redesign' the fruit tree, minimizing it from traditional large, perennial plants to a smaller, manageable, and very precocious “fruit bush”. The meadow orchard system is undeniably a high capital and labour commitment, but it has a fundamentally new approach to improved productivity, precocity, and fruit quality that changes the economic and agronomic model of contemporary fruit production. This is a system that has extremely high planting density, ranging from 5,000 to more than 70,000 trees per hectare, depending on crop. The meadow orchards deliberately do not provide trees the advantage of adequately spaced growth space for decades like a conventional orchard, but operates in the philosophy of optimizing both light interception and land use (as a resource) in the first year of establishment. The meadow orchard accomplishes this from a synthesis of three sets of technologies: ultra-high density spacing, the use of dwarf rootstock or vigorous limb pruning to control tree size and a low-impact, repeatable intensive canopy manage-ment protocol. As a general endeavour, this paper will provide a discussion of the physiological principles, agronomic practices, economic implications and case studies of the meadow orchard system, focused on the successful examples of guava and apple.

Core Principles of the Meadow Orchard System:

The grassland orchard does not solely rely on placing trees close together and allowing the plants to exhibit their natural growth habits. Instead, it works at managing the plant's natural growth habits. The overriding principle is to maximize the plant's energy toward reproductive growth (flowers and fruit) and minimize energy spent on vegetative growth (wood and leaves). The most important aspect is managing light. A significant portion of solar radiation is wasted to the ground in a traditional orchard, especially during the initial years. A dense canopy of the meadow orchard works to intercept more than 70-80% of the available sunlight right away. As stated by one researcher in high-density systems, “The objective of any HDP system is to develop a canopy that maximizes light interception and provides for good light distribution throughout the tree canopy” (Webster, 2005). The creation of a “fruit wall” or continuous low spreading “meadow” of foliage is far more effective in capturing light unites of land that can be achieved with a few large, round canopies. Aggressive, unavoidable canopy management is necessary to keep these plants from shading each other out to maintain the density. This factor is where the meadow orchard system deviates the most from conventional systems, and is based on cycles of harsh pruning. In crops like guava, this is the only means of dwarfing. Young plants are “topped” (cut at the main stem) just months after planting to break apical dominance and force out lateral branches.

Those lateral branches produce fruit, and then are pruned again, often by 50%. This constant "hedging" or "mowing" keeps the plant as a small bush and renews the fruiting wood. In other foods such as apple, this effect is supplemented with chemical plant growth regulators (PGRs) to suppress vegetative vigor and promote fruit bud formation.

Case Studies in Meadow Horticulture

The meadow orchard concept has been most successfully and commercially implemented in two very different crops: guava and apple.

Guava: An Exemplary Tropical Situation

The Central Institute for Subtropical Horticulture (CISH) in Lucknow, India, has pioneered the meadow orchard system for guava, a milestone in tropical fruit growing. Guava is an excellent crop for the system because it has a short window from flowering to fruit harvest and bears fruit on the current season's growth. The CISH model consists of 5,000 plants per hectare, spaced generally 2 meters between rows and 1 meter between plants. The management is accurate. Plants are topped at the height of 30-40 cm at two to three months after planting. This stimulates the growth of three to four primary shoots. Once the primary shoots are at a mature length, they are pruned back to 50% of their length. This second pruning forces the emergence of new, tertiary shoots, which carry the flowers and fruit. All of these combined enables harvesting to be completed at the end of the first year of planting, an extremely shortened interval when compared to the three to four years required in traditional systems.

After each harvest, the fruit-bearing shoots are pruned back again, starting the next cycle all over again. This enables multiple harvests, in a regulated manner, in each year. The contrast is apparent. A traditional guava orchard of fifteen to twenty tonnes per hectare suffers in comparison to a mature meadow orchard of forty to sixty tonnes per hectare, yet keeping the overall tree height below 1 meter for efficient, ladder-free harvesting.

Apple: The Pedestrian Orchard

The meadow orchard is the extreme level of intensification for apple production in temperate fruit growing. Horticultural scientists began investigating systems as intense as 70,000 trees per hectare in the 1970s, using spacings of 30 x 45 cm. While trade-offs were difficult with these intense density levels, they are the precursor of the "super-spindle," or "fruit wall," systems that have developed modern meadow orchards. The systems are fully reliant on dwarfing rootstocks, such as M-27 and M-9, with a permanent support system, such as a trellis, to support the "wall" of trees. The value of the system conceptually is to create a "pedestrian orchard", providing all pruning, thinning, and harvesting to be done in the ground. This two-dimensional system is remarkably efficient in light intercept, and generates exceptionally high and uniform quality fruit, especially with regard to color, due to sunlight being able to penetrate the entire shallow canopy. This system was also designed from the ground up for mechanization, including mechanical pruning and, increasingly, robotic harvesting, which is far more

straightforward on a two-dimensional "wall" as opposed to a complex three-dimensional tree.

Economic and Managerial Analysis

Transitioning to a meadow orchard system entails a transition that involves some risk on the front end for a long-term reward. The benefits are immense, but so too are the challenges.

Advantages: The High-Reward

Precocity and High Early Yields: The most significant economic benefit is the rapid return on investment. Fruiting in the first or second year, combined with high yields, means the orchard begins generating income almost immediately.

Increased Production: Often the yield per hectare is two to four times higher than in traditional systems, fully realizing the financial potential of your property.

Better Quality Fruit: Better light penetration and improved distribution of light results in more uniform fruit, higher colour grades (in apples), and often higher Total Soluble Solids (sugars), thereby achieving better prices.

Labor efficiencies: All materials and practices are on the ground, which cuts down on labor costs commonly associated with ladder use. Pesticide and/or fungicide (chemical) application will also have increased efficiency and potency because the spray will have the opportunity to penetrate the small canopy more thoroughly, therefore eliminating pesticides application waste.

Disadvantages: The High-Risk

Prohibitive Establishment Cost: This is the primary barrier to adoption. The cost of planting material alone for 5,000 plants is immense, compared to 400 in a traditional system. Furthermore, a meadow orchard is unfeasible without a high-efficiency drip irrigation and fertigation system, and in the case of apples, an expensive trellis system (Robinson, 2010).

Intensive Labor and Skill: This system is not for the passive farmer. It requires a highly skilled and consistent workforce to execute the precise and relentless pruning schedules. A mistake in pruning timing or severity can compromise an entire season's crop.

Shorter Economic Lifespan: The intensive pruning and heavy, continuous cropping place immense physiological stress on the plants. The economic life of a meadow orchard is significantly shorter, often 10-15 years, compared to the 30-40 years of a traditional orchard.

High Nutrient Demand: Producing such a high biomass of fruit each year "mines" the soil of nutrients at a rapid rate. This makes the system entirely dependent on a sophisticated "fertigation" program, where nutrients are supplied constantly through the drip irrigation system.

Ecological Challenges and Future Innovations

The microclimate created by a dense, humid canopy of a meadow orchard can be problematic on two fronts. Spraying will be simplified but the airflow is scarce in these circumstances which can create the right environment for fungal diseases such as powdery mildew or apple scab. With a dense root

system, it is possible that these trees will also be susceptible to soil-borne pathogens. Therefore, preventative management must be the focus of minimal intervention. The future of the meadow orchard system is clearly a marriage with technology. In fact, this system was designed for precision agriculture and mechanization. The uniform appearance of a hedge is an ideal condition for robotic pruners and harvesters in development now. Sensor technology can be used to monitor water stress and nutrient needs in real time and delivered with precision with the fertigation system. This technology alleviates the high labor costs and turns the orchard into a highly controlled, highly efficient "fruit factory".

Conclusion

Meadow horticulture takes conventional orchards and converts them into compact, ultra-high-win density cultivars focusing on early and productive fruiting. The achievement of high shift models in crops such as guava and apple has often resulted in precious yields and quality produce, this system requires expensive input and competent management combined with sophisticated practices. The system does require high productivity coupled with labor and capital, however, with its productive efficiency and progressive systems afforded by the system, meadow horticulture looks positive in addressing increased food demands in limited land space.

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Value Addition: How Small Farmers Can Earn More from their Produce

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Introduction

Smallholder farmers form the backbone of food systems across much of the developing world. Yet despite producing a large share of fruits, vegetables, milk, pulses and other staples, many small farmers receive only a small fraction of the final consumer price. Value addition the set of activities that increase the economic worth of agricultural produce after harvest is a powerful pathway for small farmers to capture more income, reduce post-harvest losses and build resilience. This article explains practical value-addition options that small farmers can realistically adopt, steps to implement them, challenges to expect and supportive measures that make success more likely.



Why value addition matters

Raw agricultural commodities often have low and volatile prices, short shelf-life and weak bargaining power for farmers. Value addition addresses these problems by:

- ✓ Extending shelf life (drying, canning, pickling), enabling farmers to sell later at better prices.
- ✓ Increasing product appeal (grading, pack-aging, branding), attracting higher-paying buyers.
- ✓ Creating differentiated products (organic, fortified, ready-to-cook), accessing premium markets.
- ✓ Opening new market channels (direct sales, consumer packs, e-commerce), cutting out middlemen.
- ✓ Generating year-round income (processing seasonal crops into shelf-stable goods).

For small farmers, value addition can mean moving from selling raw produce at farm-gate rates to earning the profit margin that comes from processing, packaging and marketing.

Practical value-addition options for small farmers

Aggregation and collective processing: Individually, small farmers seldom achieve the volume required for economically viable processing. Farmer groups, cooperatives, producer companies, or self-help groups can pool produce and share the costs of simple processing units dryers, small mills, cold

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rooms, or vacuum packagers. Collective action spreads risk, lowers per-unit costs and improves negotiating power with buyers.

Minimal processing to extend shelf-life

Low-capital, high-impact techniques include:

- ✓ Solar or mechanical drying of fruits, vegetables, herbs and spices to make dried snacks or ingredients.
- ✓ Sorting and grading to separate premium quality produce for higher prices.
- ✓ Simple cleaning and waxing (for certain fruits) to extend shelf life for local markets.
- ✓ Fermentation and pickling (traditional value-added products with long shelf life).

These require modest training and low equipment costs but can drastically reduce losses and open new markets.

Packaging and small-pack retail formats: Investing in basic, attractive packaging and offering consumer-sized packs (e.g. 250 g and 500 g) considerably raises retail price per unit compared to bulk farm-gate sales. Even low-cost laminated pouches, labelled jars, or the use of re-sealable bags with basic product information can create perceived value and improve hygiene standards.

Product diversification and processing: Transforming raw produce into higher-value products such as jams, sauces, flours, nut butters, pickles, powder spices, or ready-to-cook mixes increases margins. For example, surplus tomatoes can become pulp and sauce; excess mangoes can become dried slices, pickles or powdered pulp. Processing can be done at micro-scale with simple, well-planned recipes and basic food safety practices.

Branding, certification and quality standards: Local branding that tells a product story origin, variety, traditional processing method resonates with urban and niche consumers. Certifications (organic, fair-trade, geographic indication) often require time and investment but can access premium segments. Even basic quality control and a visible label with contact details build trust.

Cold chain and controlled storage: For perishables like milk, fish, fruits and vegetables, access to cold storage and proper handling preserves quality and allows farmers to time sales to favorable prices. Community cold rooms or pay-per-use chilling services are scalable solutions for groups of farmers.

Direct marketing and value chain linkages: Selling directly to consumers (farmers' markets, roadside stalls), restaurants, schools, corporate canteens and farm-to-table programs captures margins otherwise kept by intermediaries. Digital marketplaces and simple phone-based order systems can connect producers with buyers without heavy investment.

By-product utilization and circular models: Value can be gained by using waste: fruit peels for pectin, husks for compost or fuel, whey for animal feed, or seed oil extraction from waste seeds. Circular approaches reduce costs and can produce additional revenue streams.

Steps for small farmers to start value addition

Assess local demand and margins: Start with

products that local consumers or nearby towns want. Simple market surveys, talking to shopkeepers and restaurants, or piloting small batches helps reveal demand.

Choose low-risk, high-impact activities: Begin with drying, pickling, sorting or small-packaging activities that need little capital but reduce losses and increase price.

Form or join a group: Cooperatives or producer groups make equipment purchases and market negotiations feasible.

Develop a simple business plan: Estimate costs (raw materials, packaging, labour, transport), pricing and breakeven points. Keep records.

Learn food safety and basic quality control: Training in hygiene, safe storage and minimal legal requirements avoids rejection in markets. Local extension services, NGOs, or vocational programs can provide practical training.

Start small and iterate: Produce a small batch, test with local buyers, collect feedback and refine product and packaging.

Leverage existing support: Explore government schemes, microfinance, rural entrepreneurship programs and NGOs that support small-scale processing units and training.

Use simple marketing: Labels, a clear product story, social media posts (even via a shared smartphone) and participation in local fairs build demand.

Overcoming common challenges

Access to finance: small loans, microfinance institutions, group lending and government grants targeted at rural entrepreneurs can bridge initial capital needs.

Technical knowledge: Partner with local extension services, agricultural universities, or NGOs for training. Peer learning within farmer groups is effective.

Quality and food safety compliance: Start with basic good manufacturing practices (GMP) and scale to formal certifications when volumes and markets justify them.

Market access: Aggregation, direct sales, tie-ups with local eateries or retail outlets and participation in farmers' markets reduce dependence on exploitative middlemen.

Seasonality and storage: Make shelf-stable products from seasonal gluts (drying, canning) and diversify product lines to smooth income over the year.

Policy and institutional supports that help

Governments and development agencies can multiply impact by providing: inexpensive common user facilities (kitchen/processing centers, cold storage), market information systems, training in business and food safety, microcredit with flexible repayment schedules and simplified certification pathways for small processors. Public procurement programs (e.g., schools, hospitals) that prioritize local, small-scale suppliers also create stable demand.

Realistic business models and examples

Community drying units: A cluster of farmers pool

mangoes for solar drying; dried mango is packed in small retail pouches and sold in nearby towns.

Village milk collection and value chain: Smallholder milk producers deliver to a village collection centre with chilling; the cooperative processes milk into ghee and paneer for local and urban markets.

Herb and spice micro-processing: Farmers aggregate and sun-dry aromatic herbs, vacuum-pack them in small sachets with a branded label and sell through local organic stores and online platforms.

These models illustrate that scale can be achieved through cooperation and simple, profitable forms of processing.

Environmental and social co-benefits

Value addition can reduce food waste, increase rural employment (processing creates local jobs, especially for women) and encourage sustainable practices when linked to organic or regenerative production. By capturing more of the value chain locally, communities keep more income circulating in rural economies.

Conclusion

For small farmers, value addition is not an abstract notion but a practical route to higher incomes, greater stability and stronger market presence. By beginning with low-risk processing (drying, grading, packaging), organizing collectively and learning basic business and food safety skills, small producers can capture a larger share of the value created from their crops. Supportive policies, access to finance and training and market linkages amplify the impact. Value addition transforms produce and often livelihoods turning modest harvests into sustainable incomes and resilient rural enterprises.

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Soil to Plant: The Nutrient Connection

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There are 17 essential nutrients as per the criteria of essentiality given by (Arnon and stout, 1939 and further refined by Arnon in 1954). Among the17 essential nutrients 3 (C, H and O) are known as essential non mineral nutrients as their main source is air and water whereas remaining 14 (N, P, K, Ca, Mg, S, Cl, Fe, Mn, B, Zn, Cu, Ni and Mo are known as essential mineral nutrients as they were derived from minerals which are formed from weathering of rocks. Plants uptake nutrients from the soil in ionic form. Nutrient mobility in soil depends upon (i) mobility of cations (+ive charge) and anions (-ive charge) in soil and (ii) Reactivity of cations and anions. Clay particles are –ive charge, they attract the cations (+ive charge) and repel the anions and anions come in soil solution. Therefore, anionic forms of nutrients such as NO_3, Cl^- and SO_4^- are highly mobile in the soil solution. Cationic forms of nutrients are slightly immobile in soil solution. This is also reason that plant prefer to uptake nitrogen in nitrate form (NO^-_3) than in ammonical form (NH_4^+) form. Essential macro nutrient phosphorus and micronutrient zinc and copper are highly reactive and due to their high reactivity in soil solution they immediately formed complex (insoluble compounds) with other nutrient present in soil such as Ca, Mg, Fe and Mn and get adsorbed on clay particles through electrostatic force which decreased their mobility in soil solution. Therefore, anionic form of phosphorus ($H_2PO_4^-$ and HPO_4^{2-}) and cationic form (Zn^{2+} and Cu^{2+}) are immobile in soil solution. They come in soil solution only through the process of cation exchange capacity. This is the only reason that, the whole quantity of phosphorus recommended for crops is applied as basal dose so that after fixation it can released in soil solution within 20-30 days after its application where as in case micronutrient Zn and Cu Foliar application is recommended.

Plant uptake nutrients only when they are available in the soil solution. From soil solution, inorganic ions reached to the root surface through mass flow and diffusion where as only 1-2% of nutrients were directly goes inside root through root interception. Although plant uptake nutrient in the inorganic form but application of organic fertilizers besides providing macro nutrients they also provide micronutrients in the soil solution. Organic fertilizers also improve the physical chemical and biological properties of the soil

Why we apply organic manure in to soil if plant had to uptake it in inorganic ionic form?

- ✓ Urea (Synthetic Fertilizer)
- ✓ Vermicompost (Organic Manure)

Urea (Synthetic Fertilizer): It also known as carbamide, is an organic compound with chemical formula $CO(NH_2)_2$. It is manufactured artificially by

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reacting natural gas (which act as source for hydrogen gas), from atmospheric air (which act as source for nitrogen) and water which form ammonia and carbon dioxide. Further, commercially liquid ammonia and liquid carbon dioxide under high pressure and elevated temperature (200ºC) were reacted to form ammonium carbamate which then decomposes at low pressure to form urea and water. Further, Urea is evaporated and processed by prilling or granulating to produce a solid end product which is white in colour.



Fig 1: Urea and its application in field

What happen to Urea when applied in soil and how nitrogen through urea is available to plants?

Inorganic fertilizer urea which is a water soluble compound, when added to moist soil, it reacts with water and to the urease enzyme present in soil and is quickly dissolve and converted into ammonium ions and then into nitrate ions ,which is readily available to the crop plants . This conversion is known as 'hydrolysis of urea'.In this reaction the hydrogen ions (H^+) are consumed, causing the soil pH near the fertilizer to rise. If the pH increased above 7, a significant amount of gaseous ammonia can form in soil for a few days following urea application. Some gaseous loss of nitrogen in the form of ammonia is lost from the surface during the warm weather period and if urea is applied in the vicinity of the roots it cause damage to the crops because of ammonia toxicity. The severity of both the process depends largely upon the concentration of ammonia formed in the soil. On, the other hand when urea is added in totally, dry soil condition it remains as such and no further reaction occur. When urea is applied at the surface, the formation of ammonia at the soil surface takes place due to urea hydrolysis. Further, ammonia is converted into ammonium ions (NH_4^+) in soil. Ammonium ions get converted in to nitrate (N03-) by two step biological oxidation process known as Nitrification. It is known as biological oxidation because involves living microorganisms (chemoautotrophic and hetero autotrophic bacteria).

The reaction involved in the process of Nitrification is as follows:

$$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O$$

In the first step, ammonium ions get converted in to nitrites (NO_2^-) with the help of (Nitrosomanas, Nitrosolobus, Nitrosospira and Nitrosovibrio) which are chemoautotrophic in nature as they derived their energy from CO_2 which is obtained from oxidation of inorganic substances present in soil. Therefore, they are called chemo autotrophs. Heterotrophic bacteria are also involved but their contribution is very less.

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

In the second step, Nitrites get converted in to nitrate ($N0_3^-$) with the help of Nitro bacteria which is also chemoautotrophic in nature. When soil is in well aerated conditions, having oxygen nitrite is converted immediately into nitrate with the help of

aerobic microorganisms. Nitrate ions are negatively charged and soil particles are also have negative charged, due to same negative charge on both the particles, repulsion take place between both the ions. Due to which mobility of Nitrate ions increased in soil solution, which increased their availability in the soil solution and finally crop plant uptake urea in the form of nitrates.

Organic manure (Vermicompost)



Fig 2: Vermicompost and its application to crop plant

Vermicomposting is the biological decomposition of organic waste with the help of specific microorganisms and worms resulting in formation of Vermicompost. It is also known as 'worm composting' or 'worm castings'. Vermicompost is the product left after worms eat (food scrapes) and digest (left after). It is the dark rich soil amendment also known as, worm stool. The process of formation of Vermicompost started with worms eating and digesting the organic waste. The actual decomposition of organic waste started once the worms starts ejecting the stool, the stool of the worms remain in soil, the microorganisms present in soil continue to break it down, resulting in formation of black colour substance similar to humus. The food eaten by worms and other organic wastes move inside the digestive tube, while moving inside digestive part, esophagus part provide calcium carbonate to eliminate excess calcium. Than the food travels through the gizzard. Gizzard crushes organic waste in to tiny particles. The pH and moisture levels of the organic waste are also control by microorganisms. Worms also eat microbes, which are their main food source. The worms only absorb 5% to 10% of the ingested food. The leftovers are discharged as worm castings contain nutrients, undigested plant material, significant amounts of microbes, and soil. The microbial activity in worm castings is significantly higher than in the soil and other types of organic matter.

The earth worms don't do much composting, they only take part in breakdown of organic wastes, and mix it with beneficial bacteria. However, a large portion of the composting happens once the worm discharges its castings.

Benefits of Vermicompost in soil other than nutrient supply to the plants

- ✓ Vermicompost is a decomposed organic material which is processed by earth worms. The earth worms blend the organic material from the surface with the mineral matter of the soil and then eject this material as casts. There are numerous enzymes present in cast which continue to disintegrate organic matter even after they are excreted as casts. This process is responsible for giving rise to crumble texture of fertile soil. The crumby texture of the soil helps in easily penetration of plants roots into the soil leading to root extension and proper nutrient uptake.
- ✓ Vermicompost on decomposition add organic matter. Organic matter contain organic acids

which increases the H^+ ions and surface charge of the soil, causing the soil's cation exchange capacity to increase.

- ✓ Vermicompost is packed with all essential micro and macro plant nutrients, with the average nutrient content greater than other types of compost. It is rich in nitrogen, phosphorus, potassium and calcium etc. which are essential for plant to live and thrive. The average nutrient contents in Vermicompost include N (1.5-2%), P (1.8-2.2%) and K (1-1.5%) along with other micronutrients required for plant growth such as zinc (Zn), magnesium (Mg), and iron (Fe). After application of Vermicompost these nutrients are readily available to the plants and can be absorb easily and quickly to promote growth of healthy plant.
- ✓ The burrowing activity of earth worms influence the mechanical and hydraulic properties of soil, creating macro pores for water percolation in soil profiles. Vermicompost when added to soil increases the porosity which increases the infiltration of water in the deeper layers which further increase the water table in the soil and reduce surface runoff. Addition of Vermicompost in soil also increases aeration in soil which increases oxygen in soil resulted in increased microbial growth which increases mineralization in soil by breakdown of organic matter more quickly and further increase nutrients release in to the soil and uptake by plant.
- ✓ Earth worms add mucus in Vermicompost which prevents washing away of nutrients and also enhance the soil's structure by causing aggregation of soil particles.
- ✓ Different types of microorganisms inhabit the by-product of worm during the process of Vermicomposting by releasing a number of enzymes and secrete phytohormones such as auxins, gibberellins, cytokinin and brassinosteroids during the process of vermicomposting. Brassinosteroids are a group of essential steroid hormones vital for plant growth and development. Their signaling roles promote cell division and expansion and are crucial in reproduction and etiolation and improve plant growth.
- ✓ Vermicompost is also abundant in polysaccharides, which helps to cause aggregate stability in soil. Vermicompost is also rich in vesicular arbuscular mycorrhiza (VAM) propagules, which helps to enhance microbial activity to make phosphorus and nitrogen readily available to the crop plants.
- ✓ Vermicompost is also rich in Humic acid and different plant growth regulators that helps enhance nutrient accumulation in nutrient scarce soil.
- ✓ Vermicompost also improves the biological properties of the soil, including the organic carbon, microbial biomass and more. It also increases the nitrogen content, ultimately improving the nitrogenase activity in the soil and supporting plant growth.

- ✓ The most significant secondary effects of vermicompost is disease suppression in crop plants. This is mainly associated with the release of coelomic fluid from earthworms, which kills pathogens in waste material during the vermi-composting process. Consequently, Vermicompost possesses insecticidal and antifungal properties due to coelomic fluid and other bioactive compounds released by worms, making it effective in suppressing insects and diseases. Coelomic acid is secreted from dorsal pores of worms and functions in defense mechanism due to its anti-microbial properties.

Conclusion

Extensive application of synthetic fertilizer for crop production has negatively affected soil health, crop productivity, and the environment while Organic manures have been proposed as an efficient alternative for enhancing soil and plant health. Organic manures like vermicompost can be a good substitute for chemical fertilizers as its usage could contribute to producing healthy, contaminant-free food for the growing population without negatively affecting the environment.

Flowering Behaviour of Mango (*Mangifera indica* L.)

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Introduction

Mango (*Mangifera indica* L.) is one of the most important and popular tropical fruit crops of the world and is rightly known as the "King of Fruits." India is the largest producer of mango, contributing a major share to global production. The economic success of mango cultivation largely depends on its flowering behaviour, as flowering directly influences fruit set, yield and quality. Understanding the flowering behaviour of mango is therefore essential for orchard management, crop regulation and improving productivity. Mango is a perennial, evergreen tree exhibiting complex and highly variable flowering behaviour, influenced by climatic conditions, varietal differences, physiological factors and orchard management practices. Unlike many annual crops, mango flowering is seasonal and irregular, often leading to problems such as biennial bearing and low fruit set.

Nature of Flowering in Mango

Mango produces flowers in the form of a panicle, which is a terminal, pyramidal inflorescence borne at the tip of shoots. Flowering usually occurs on mature shoots formed during the previous season. The inflorescence length varies from 10 to 40 cm depending on the cultivar and environmental conditions. Each panicle bears a large number of flowers, ranging from 1,000 to 6,000 or even more. However, only a very small percentage of these flowers ultimately develop into fruits. Mango flowers are polygamous, consisting of both male (staminate) and bisexual (hermaphrodite) flowers on the same panicle. Generally, male flowers are more numerous than bisexual flowers, and the proportion varies with cultivar and season.

Types of Flowers

Male flowers: These flowers possess functional stamens but lack a functional ovary. Their primary role is pollen production.

Bisexual flowers: These flowers contain both functional stamens and a pistil and are capable of fruit set.

The ratio of male to bisexual flowers plays a crucial role in determining fruit set. Cultivars with a higher proportion of bisexual flowers generally show better fruiting potential.

Flowering Season and Duration: In India, mango flowering generally occurs during December to February, depending on the region and cultivar. In South India, flowering starts earlier (December-January), while in North India it usually occurs during January-February. Flowering duration in a tree may last for 20-30 days, whereas the entire orchard may remain in bloom for 30-45 days. The time of flowering is strongly influenced by temperature. Cool night temperatures and dry weather

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during the pre-flowering period are considered favourable for floral induction.

Floral Induction and Initiation

Floral induction in mango refers to the physiological process by which vegetative buds are transformed into floral buds. This process is influenced by several internal and external factors.

Role of Temperature: Low temperature during winter is one of the most important factors inducing flowering in mango, especially in subtropical regions. Prolonged exposure to cool temperatures (15-20°C) promotes floral bud differentiation.

Role of Water Stress: Mild water stress before flowering is known to favour floral induction by suppressing vegetative growth and promoting reproductive growth. This principle is often utilized in orchard management by withholding irrigation during the pre-flowering period.

Role of Plant Growth Regulators: Plant growth regulators such as paclobutrazol are widely used to induce flowering, especially in high-density orchards and in regions where natural flowering is irregular. Paclobutrazol inhibits gibberellin biosynthesis, thereby promoting flowering and reducing excessive vegetative growth.

Biennial Bearing and Flowering: One of the major problems associated with mango flowering is biennial or alternate bearing, where a heavy crop in one year (on-year) is followed by little or no flowering and fruiting in the subsequent year (off-year). In on-years, excessive fruiting exhausts carbohydrate reserves and suppresses floral bud formation for the next season. Varieties such as 'Dashehari', 'Langra' and 'Chausa' are highly prone to biennial bearing, whereas 'Alphonso' and 'Tota-puri' show relatively regular bearing behaviour.

Pollination and Fruit Set: Mango is predominantly cross-pollinated and insects play a major role in pollination. Houseflies, bees and other insects are the principal pollinators. Successful pollination and fertilization are essential for fruit set, which usually ranges from 0.1 to 1 per cent of total flowers. High flower drop is a common phenomenon in mango and may occur due to poor pollination, adverse weather conditions, nutritional imbalance and hormonal factors.

Environmental Factors Affecting Flowering

Temperature: Cool and dry weather favours flowering, while high temperature and humidity may promote vegetative growth.

Rainfall: Rain during flowering adversely affects pollination and increases disease incidence.

Light: Adequate sunlight is necessary for carbo-hydrate accumulation, which supports flowering.

Varietal Differences in Flowering Behaviour

Mango cultivars differ widely in flowering time, panicle size, flower composition and bearing habit. Early flowering varieties are suitable for southern regions, while late flowering types perform better in northern India. Understanding varietal behaviour helps in selecting suitable cultivars for different agro-climatic zones.

Management Practices to Improve Flowering

✓ Pruning after harvest to encourage new shoots

- ✓ Regulation of irrigation to induce mild stress
- ✓ Balanced nutrition, especially nitrogen and potassium
- ✓ Use of growth regulators like paclobutrazol
- ✓ Control of pests and diseases during flowering

Conclusion

Flowering behaviour in mango is a complex process governed by environmental, physiological and genetic factors. Proper understanding and management of flowering can help overcome problems such as irregular bearing and low productivity. Adoption of scientific orchard management practices can significantly improve flowering, fruit set and overall yield of mango, ensuring sustainable production of this economically important fruit crop.

Phytochemicals from Fruits and their Roles in Human Health

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Introduction

Fruits are an important component of a balanced human diet and are widely recommended for maintaining health and preventing diseases. In addition to supplying essential nutrients such as vitamins, minerals, carbohydrates, and dietary fiber, fruits are rich sources of phytochemicals. Phytochemicals are naturally occurring bioactive compounds present in plant foods that contribute significantly to health promotion and disease prevention. Although they are not considered essential nutrients, regular consumption of fruits rich in phytochemicals has been associated with reduced risk of chronic non-communicable diseases such as cardiovascular diseases, cancer, diabetes, and neurodegenerative disorders. Therefore, phytochemicals from fruits have gained considerable importance in nutrition, horticulture, and food science.

Definition of Phytochemicals

Phytochemicals are non-nutritive, biologically active chemical compounds produced by plants for protection against environmental stress, pests, and diseases. When consumed by humans, these compounds exert beneficial physiological effects such as antioxidant, anti-inflammatory, antimicrobial and anticancer activities. They play an important role in maintaining health and reducing the risk of lifestyle-related diseases.

Importance of Phytochemicals in Human Nutrition

The importance of phytochemicals lies in their protective role against oxidative stress and chronic inflammation. Free radicals produced during normal metabolism can damage cellular components, leading to various diseases. Phytochemicals help neutralize these free radicals and protect cells from damage. Epidemiological studies have shown that populations consuming diets rich in fruits and vegetables have lower incidence of chronic diseases, highlighting the significance of phytochemicals in human nutrition.

Classification of Phytochemicals in Fruits

Phytochemicals present in fruits are classified based on their chemical structure and biological functions. The major classes include polyphenols, carotenoids, alkaloids, organosulfur compounds, and phytosterols. Among these, polyphenols and carotenoids are the most abundant and widely studied in fruits. Each class contributes uniquely to health promotion and disease prevention.

Polyphenols in Fruits

Polyphenols are the largest group of phyto-

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chemicals found in fruits and are known for their strong antioxidant properties. They are widely distributed in fruits such as apples, grapes, berries, citrus fruits, and bananas. Polyphenols include flavonoids, phenolic acids, stilbenes, and lignans.

Flavonoids: Flavonoids are the most common polyphenols in fruits and are further classified into flavonols, flavanols, flavanones, flavones, and anthocyanins. Anthocyanins are responsible for the red, purple, and blue colors of fruits such as grapes, strawberries, blueberries, and cherries. They exhibit strong antioxidant activity and help in protecting the cardiovascular system and improving cognitive function. Flavanols such as catechin and epicatechin, present in apples and grapes, improve heart health by enhancing endothelial function and reducing blood pressure. Flavanones such as hesperidin and naringenin, found in citrus fruits, possess anti-inflammatory and lipid-lowering properties.

Phenolic Acids: Phenolic acids are present in fruits such as apples, pears, grapes, and berries. Important phenolic acids include gallic acid, caffeic acid, and ferulic acid. These compounds exhibit antioxidant, antimicrobial, and anti-inflammatory activities and contribute to gut health by supporting beneficial intestinal microorganisms.

Stilbenes: Stilbenes are present in smaller quantities in fruits but have strong biological effects. Resveratrol, mainly found in grapes and berries, is the most important stilbene. It is known for its cardioprotective, anti-inflammatory, and anti-aging properties and plays a role in reducing the risk of cardiovascular diseases.

Carotenoids in Fruits

Carotenoids are fat-soluble pigments responsible for the yellow, orange, and red colors of fruits such as mango, papaya, watermelon, guava, and apricot. They play an important role in antioxidant defense, vision, and immune function. Beta-carotene is a provitamin A carotenoid that is converted into vitamin A in the human body and is essential for vision, skin health, and immunity. Lycopene, found in watermelon and guava, is a powerful antioxidant associated with reduced risk of cardiovascular diseases and certain cancers. Lutein and zeaxanthin accumulate in the retina and protect the eyes from age-related disorders such as macular degeneration and cataracts.

Other Phytochemicals in Fruits

Alkaloids are nitrogen-containing compounds found in fruits such as bananas and citrus fruits. These compounds influence neurological functions and mood regulation. Organosulfur compounds, although more common in vegetables, are present in certain fruits and exhibit antimicrobial and detoxifying properties. Phytosterols are plant-derived sterols found in fruits such as avocados, apples, and berries. They reduce blood cholesterol levels by inhibiting cholesterol absorption in the intestine and thereby help in preventing cardiovascular diseases.

Role of Fruit Phytochemicals in Human Health

Fruit phytochemicals play a significant role in maintaining health and preventing diseases. Their antioxidant activity helps in scavenging free radicals

Table 1: Role of Fruit Phytochemicals in Human Health

Fruit	Major Phytochemicals	Key Nutrients	Health Benefits
Apple	Quercetin, Catechins, Phenolic acids	Dietary fiber, Vitamin C	Antioxidant, heart health, gut health
Banana	Dopamine, Serotonin precursors	Potassium, Vitamin B_6	Energy metabolism, mood regulation
Orange	Hesperidin, Naringenin, Carotenoids	Vitamin C, Folate	Immunity, cardiovascular protection
Mango	Beta-carotene, Mangiferin	Vitamin A, Vitamin C	Vision health, antioxidant activity
Grapes	Resveratrol, Anthocyanins, Flavanols	Vitamin K, Potassium	Cardioprotection, anti-aging
Papaya	Beta-carotene, Lycopene	Vitamin A, Vitamin C	Digestive health, immunity
Watermelon	Lycopene, Citrulline	Vitamin C, Water	Hydration, antioxidant support
Pomegranate	Ellagic acid, Anthocyanins	Vitamin C, Polyphenols	Anti-inflammatory, heart health

and protecting cells from oxidative damage. Anti-inflammatory effects reduce chronic inflammation, which is a major cause of many lifestyle diseases. Phytochemicals also improve cardiovascular health by lowering blood cholesterol levels, regulating blood pressure, and enhancing blood vessel function. Additionally, many phytochemicals possess anti-cancer properties and support gut health by modulating intestinal microbiota.

Conclusion

Phytochemicals present in fruits play a crucial role in promoting human health and preventing chronic diseases. Regular consumption of a variety of fruits ensures adequate intake of different phytochemicals, each contributing uniquely to antioxidant protection, immune support, cardiovascular health, and disease prevention. From an ICAR and UGC perspective, understanding fruit phytochemicals is essential for students of agriculture, horticulture, food science, and nutrition, as it highlights the importance of fruits in sustainable diets and public health.

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Safeguarding Crop Diversity through Ex-situ Conservation

Janapareddy Rajesh and Dasari Sivaji

Abstract

Ex-situ conservation is a key approach for protecting plant genetic resources by maintaining species, varieties, and genetic material outside their natural habitats under controlled conditions. It helps reduce the risk of extinction, conserve elite and endangered germplasm, and support crop improvement, research, and climate resilience. This system includes seed gene banks, field gene banks, in vitro conservation, cryopreservation, and botanical gardens, each suited to specific biological traits of crops. Seed gene banks are the most economical and widely used method, particularly for species with orthodox seeds. In contrast, vegetatively propagated crops and recalcitrant seed species require alternative conservation techniques. Differences in seed physiology, storage behaviour, and longevity largely guide the selection of suitable methods, ensuring long-term agricultural sustainability and food security.

Ex-Situ conservation

Ex-situ conservation refers to the protection and maintenance of plant species, varieties, or genetic material outside their natural ecosystems under carefully controlled and managed conditions.

Importance of Ex-Situ conservation

- ✓ Protects species from extinction
- ✓ Preserves elite, rare and endangered germplasm
- ✓ Supports plant breeding and crop improvement
- ✓ Acts as a backup against climate change, pests, diseases, and natural disasters
- ✓ Ensures availability of material for research and reintroduction

Components of Ex-Situ conservation

Seed Gene banks: Seed gene banks represent the most common and cost-effective method of ex-situ plant conservation. In this system, seeds are dried to a low moisture level and stored at sub-zero temperatures, generally around -18°C, to retain their viability for extended periods. This method is mainly suitable for orthodox seeds, which can tolerate desiccation and freezing.

Objectives of seed gene banks

- ✓ Long-term conservation of plant genetic diversity
- ✓ Prevention of genetic erosion
- ✓ Supply of germplasm for crop improvement and research
- ✓ Conservation of indigenous and exotic germplasm
- ✓ Providing backup material against natural disasters

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Types of seed gene banks

Seed gene banks are categorized based on storage duration, temperature, and purpose.

Long term seed gene banks: These are designed for prolonged storage. Seeds are dried to very low moisture levels (3-7%) and stored at -18°C or below. Under these conditions, seeds can remain viable for 50 to 100 years. At the national level, a network system operates with the National Gene Bank at New Delhi serving as the central facility for base collections.

Medium term seed gene banks: These store seeds for about 10 to 20 years at temperatures ranging from 0 to 10°C. In India, germplasm for active use is maintained at National Active Germplasm Sites (NAGS).

Short term seed gene banks: These preserve seeds for short durations, usually 1 to 5 years, either at room temperature or under refrigeration.

Safety duplication seed gene banks: Safety duplication gene banks store duplicate samples of valuable germplasm at separate locations to reduce the risk of loss due to accidents or disasters. A notable example is the duplication of national collections at the Svalbard Global Seed Vault.

Regional and community seed gene banks: These operate at local or village levels and are managed by farmers, non-governmental organizations, or community groups to conserve locally important varieties.

Field gene banks

Field gene banks conserve living plants grown under natural field conditions. This method is essential for crops that are propagated vegetatively or produce recalcitrant seeds, which cannot be stored using conventional seed banking techniques.

In-Vitro conservation (Tissue culture storage)

In-vitro conservation involves maintaining plant tissues such as shoot tips, nodal segments, or embryos under sterile laboratory conditions. Plant growth is intentionally slowed by adjusting temperature, nutrient composition, or growth regulators. This method is particularly effective for conserving vegetatively propagated crops.

Cryopreservation

Cryopreservation is an advanced ex-situ conservation technique in which biological materials are stored in liquid nitrogen at -196°C. At this ultra-low temperature, metabolic processes completely stop, allowing genetic material to be preserved for an indefinite period. Commonly conserved materials include shoot tips, embryos, and pollen.

Botanical gardens

Botanical gardens maintain living plant collections for conservation, education, and research purposes. They play a significant role in preserving rare, endemic, ornamental and economically important plant species.

Conclusion

Ex-situ conservation serves as a critical approach for protecting biological diversity and agricultural genetic resources from progressive genetic erosion. The success of this approach largely depends on aligning conservation techniques with the physiological nature of the material being preser-

Table 1: Comparison of various components of ex-situ conservation

Component	Material conserved	Storage condition	Key use
Seed bank	Orthodox seeds	Low temp & moisture	Long-term storage
Field gene bank	Whole plants	Open field	Clonal crops
In-vitro bank	Tissues	Sterile lab	Medium-term storage
Cryopreservation	Cells/tissues	-196°C	Long-term genetic stability
Botanical garden	Living plants	Garden/greenhouse	Education & conservation

Table 2: Comparison of handling the orthodox and recalcitrant seeds for conservation

Parameter	Orthodox seeds	Recalcitrant seeds
Definition	Orthodox seeds are seeds that tolerate drying to very low moisture contents and survive storage at low or sub-zero temperatures for long periods without losing viability	Recalcitrant seeds are seeds that do not tolerate drying below a relatively high moisture content and are sensitive to low temperatures
Desiccation tolerance	Present	Absent
Drying requirement	Required before storage	Not recommended (only surface drying)
Safe drying temperature	30-40 °C (≤45 °C for short duration)	Ambient only (20-30 °C)
Critical moisture level	Can be dried below 5-7 %	Injury occurs below 20-30 %
Moisture content for storage	Short-term: 8-10 % Medium-term: 6-8 % Long-term: 3-7 %	High MC required: 30-60 % (species-dependent)
Storage temperature	Short-term: 10-20 °C Medium-term: 0–-10 °C Long-term: -18 to -20 °C	10-20 °C (chilling sensitive)
Freezing tolerance	Yes	No
Longevity in storage	Years to decades	Days to months
Examples	Wheat, rice, maize, barley, pulses, oilseeds	Mango, jackfruit, cocoa, rubber, coconut
Suitability for seed banks	Suitable	Not suitable
Alternative conservation methods	Conventional seed storage	Field gene banks, in-vitro storage, embryo cryopreservation

ved. Seed banks continue to be the most reliable and cost-effective option for crops producing orthodox seeds, as these seeds can be safely maintained for extended periods at low temperatures. In contrast, species with recalcitrant seeds and vegetatively propagated crops require alternative conservation systems such as field gene banks and in-vitro storage, which involve higher operational demands and greater sensitivity to environmental disturbances. Cryopreservation provides a highly secure method for long-term storage by halting metabolic activity and maintaining genetic integrity, although it requires advanced technical facilities. Consequently, an effective ex-situ conservation framework must employ a combination of complementary methods from local and regional collections to international repositories to ensure sustained access to genetic resources for future crop improvement and species recovery initiatives.

Natural Farming: An Ecological Pathway to Sustainable Agriculture

Nikita Kumari Meel

Natural farming is not merely a crop production technique but a holistic agroecological philosophy that emphasizes harmony between agriculture and natural ecosystems. It is based on the principle that farmers are integral components of nature rather than external controllers of it. Popularized by Masanobu Fukuoka as the "natural" or "do-nothing" farming system, it advocates minimal external intervention and reliance on natural biological processes for maintaining soil fertility, pest regulation and crop productivity. Scientifically, natural farming is defined as a chemical-free, low-external-input agricultural system rooted in agro-ecological principles. It integrates crops, trees, livestock, soil microorganisms and biodiversity into a self-sustaining production system, where nutrient cycling and pest control are regulated biologically (https://naturalfarming.dac.gov.in).

Four Pillars of Natural Farming

Jivamrut: Jivamrut is a liquid bio-inoculant that functions as a microbial catalyst rather than a direct nutrient source. It stimulates beneficial soil micro-organisms responsible for nutrient mineralization and availability. It is prepared by fermenting fresh cow dung, cow urine, pulse flour, jaggery (or brown sugar), water and native soil for about 48 hours under shade. Applied through irrigation or soil drenching (about 500 L ha^{-1}), Jivamrut enhances soil microbial biomass, enzymatic activity and nutrient cycling efficiency.

Beejamrut: Beejamrut is a biological seed and planting material treatment used prior to sowing or transplanting. It protects seeds from soil and seed-borne pathogens and improves seedling vigor and root establishment. Prepared using cow dung, cow urine, lime or lemon juice and native soil, Beejamrut replaces chemical seed dressers and reduces disease incidence during early crop stages.

Mulching: Mulching is a key soil management practice aimed at conserving moisture, regulating temperature, suppressing weeds and improving soil organic carbon. Three types are practiced:

- ✓ Soil mulch, which reduces evaporation;
- ✓ Straw or residue mulch, which protects soil from erosion and moisture loss; and
- ✓ Live mulch, using cover crops or intercrops that add biomass and improve soil fertility.

Whapasa: Whapasa refers to a condition of optimum soil moisture combined with adequate aeration, rather than saturated soil. Natural farming emphasizes restricted and need-based irrigation, often in alternate furrows and preferably during afternoon hours. This practice improves water use efficiency by maintaining a balance of air and water in soil pores, enhancing root respiration, microbial activity and nutrient uptake while preventing water-

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logging.

Four Principles of Natural Farming

No Tillage: Mechanical tillage and soil inversion are avoided. Soil structure is maintained through biological processes such as root penetration, earthworm activity and microbial action. This preserves soil organic carbon and microbial habitats.

No Weeding (Weed Regulation): Weeds are not eliminated but managed through mulching and crop cover. Weeds contribute to nutrient recycling, soil protection and biodiversity, helping maintain ecological balance.

No Reliance on Chemical Inputs: Synthetic fertilizers, pesticides, herbicides and growth regulators are completely avoided. Nutrient supply and pest regulation are achieved through biological processes and natural formulations, ensuring long-term soil fertility.

Natural Self-Regulation: Crop health is maintained through biodiversity, intercropping and ecological interactions rather than external chemical control.

Benefits of Natural Farming

Benefits to Farmers: Natural farming reduces dependence on purchased inputs, significantly lowering production costs. Improved soil structure and moisture retention reduce irrigation frequency. Stable yields, intercropping and rising demand for chemical-free produce enhance farmers' income and economic security.

Benefits to Soil Health: Continuous organic cover and biological inputs increase soil organic carbon, aggregation and microbial diversity. Improved water-holding capacity and reduced evaporation make soils more resilient to drought and climate stress.

Environmental Benefits: Natural farming improves groundwater recharge through better infiltration and reduced runoff. Elimination of chemical inputs minimizes contamination of soil, water and food systems. Lower carbon and nitrogen footprints contribute to climate change mitigation and ecological sustainability.

Health and Nutritional Benefits: Crops produced under natural farming are free from chemical residues, reducing health risks associated with agrochemicals. Improved nutritional quality of produce supports better human health.

Economic and Social Benefits: Natural farming creates local employment through input preparation, value addition and marketing. Surplus income is often reinvested within villages, strengthening rural livelihoods and self-reliance (https://naturalfarming.niti.gov.in/).

Conclusion

Natural farming offers a sustainable, climate-resilient and economically viable alternative to chemical-intensive agriculture. By restoring soil health, conserving water, reducing input costs and protecting the environment, it addresses critical challenges related to food security, farmer income and ecological sustainability. When practiced effectively, natural farming supports long-term agricultural productivity while aligning with environmental and international quality standards.

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Biochar in Modern Agriculture: Linking Soil Health, Productivity and Climate Mitigation

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Abstract

Biochar has gained global recognition as a multifunctional soil amendment capable of addressing key challenges in modern agriculture, including soil degradation, declining productivity and climate change. Produced through the pyrolysis of organic biomass under oxygen-limited conditions, biochar is characterized by high carbon content, porous structure, and long-term stability in soils. Its incorporation into agricultural soils influences a wide range of physical, chemical, and biological properties, leading to improved soil structure, enhanced water-holding capacity, increased nutrient retention, and stimulation of beneficial microbial activity. Biochar also interacts with applied fertilizers, reducing nutrient losses through leaching and volatilization while improving fertilizer use efficiency. Beyond agronomic benefits, biochar contributes to long-term carbon sequestration and mitigation of greenhouse gas emissions, positioning it as a climate-smart agricultural input. The effectiveness of biochar varies depending on feedstock source, production conditions, soil type, crop species, and management practices.

Introduction

Concern the adverse effects of global climate change on soil health and crop productivity, it is crucial to maintain the threshold level of organic matter in the soil for maintaining physical, chemical and biological integrity of the soil and also to perform its agricultural production and environmental functions. Biochar addition to soil has potential to increase soil carbon over a long period of time due to its recalcitrant nature and half-life of biochar in soil is estimated to range from hundreds to several thousand years Therefore conversion of organic waste to biochar using pyrolysis process is one of the viable options that can enhance long term carbon sequestration in the soil, reduce farm waste and improve the soil quality.

Biochar

Bio = Biological in origin Char = Charcoal

Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass which has been subjected to thermo-chemical conversion process (pyrolysis) at temperatures ~350-600°C in an environment with little or no oxygen.

Why Biochar?

It can:

- ✓ Play a part in conservation of natural resources

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- ✓ Reduce greenhouse gases in the atmosphere
- ✓ Improve soil health and fertility
- ✓ Have economic and social benefits

How it is used?

- ✓ Soil Amendment
- ✓ Carbon Sequestration
- ✓ Waste management
- ✓ Renewable energy source
- ✓ Composting agent

Role of Biochar in Agriculture

Effect on soil physical properties

Bulk density: Biochar application probably reduces the density of the bulk soil through the mixing or dilution effect. The extent of this effect can be particularly large when the difference in density between materials is large. Effect of biochar for reducing bulk density on clayey soils can be smaller than that on sandy soils because the difference in bulk density between biochar (~0.6 g cm^{-3}) and clayey sols (~1.1 g cm^{-3}) is smaller than that between biochar (~0.6 g cm^{-3}) and sandy soils (~1.5 g cm^{-3}). Second, biochar could also reduce bulk density in the long term by interacting with soil particles and improving aggregation and porosity.

Soil porosity: The large decrease in soil bulk density and particle density with biochar application can affect soil porosity. Decrease in soil bulk density with biochar application directly results in an increase in soil porosity. Biochar can increase soil porosity by:

- ✓ Reducing soil bulk density
- ✓ Increasing soil aggregation
- ✓ Interacting with mineral soil particles
- ✓ Reducing soil packing

Tensile strength: Biochar application can, in general, reduce tensile strength by 42 to 242% regardless of soil textural class. Thus the decreased tensile strength of soil following biochar addition indicates that biochar probably weakens the inter particle bonding and reduces the density and overall cohesiveness of the soil. Thus addition of biochar can contribute to micro structural development and soil resilience against external forces.

Moisture retention: This attribute of biochar may lessen the effects of drought on crop productivity in drought-prone areas. Moisture-retention capacity is largely related to the high surface area and porosity of biochar. If climate change leads to even drier conditions in many agricultural production areas, biochar as a soil amendment may still have some positive effect on retaining soil moisture, even if it is variable from various feedstock sources, water infiltration and saturated and unsaturated hydraulic conductivity. Addition of biochar:

- ✓ Reduces water infiltration and hydraulic conductivity in sandy loams
- ✓ Increases water infiltration and hydraulic conductivity in clay loam or compacted soils
- ✓ Has limited or no effects on medium-textured soils

Soil thermal properties

These properties directly influence the energy balance and the storage and transfer of heat through the soil. First, biochar application can mode-

rate soil temperature extremes or regulate abrupt fluctuations in soil temperature. Second, biochar application can consistently reduce the amount of heat transferred through the soil (known as thermal conductivity). Addition of biochar can also change the soil reflectance by altering the soil surface colour. It also indicates that, biochar can impact soil thermal properties by altering other soil properties such as bulk density, porosity, water content.

Effect on Soil Chemical Properties

pH: Low pH in soil can result in toxicity to plants due to available metals such as Al. Often, elements toxic to plant roots and growth are easily available at low soil pH. Application of biochar can significantly increase soil pH and thereby reduce toxic effects of elements, whereas the availability of essential and beneficial elements is substantially enhanced in soil. When biochar is incorporated into soil, alkaline substances are released from biochar that can counteract acidification.The liming effect of biochar may decrease with time due to oxidation and leaching processes and therefore its pH decreases with age. The pH of biochar is influenced by the type of feedstock, production temperature and production duration. For example, at the same production temperature of 300°C, the biochar producedfrom straws of corn, peanut and soybean were all alkaline, but the pH values of biochar produced from straws of canola, wheat and hull were 6.48, 6.42 and 6.43, respectively. Biochar application increased soil pH and exchangeable cations and reduced Al saturation in soils. Association of H^+ ions with biochar and decarboxylation processes were likely to be the main factor neutralizing soil acidity.

Soil salinity: The soil salinity impedes crop production in many parts of the world. High concentrations of ions and total dissolved solids in the soil solution block the plant roots to absorb water by osmosis effects. Salts cause the interference of ion balance of the cells and impose toxic effects to plants. Biochar can sorb salts and mitigate salt stress to plants through salt sorption, suggesting applications of biochar to mitigate effects of salinity in agricultural, urban and contaminated soils. The high soil CEC caused by the biochar application might restrict the soil salinization.

CEC: The pH of most biochars ranges from neutral to basic and therefore application of biochar can be very suitable for increasing soil pH, which subsequently increases CEC and nutrient retention capacity of soil. Abundance of carboxyl groups on biochar surfaces can increase soil CEC and thereby decrease nutrient leaching. The retention ability of soil for nutrients can be illustrated and supported by the zeta potentials of the biochar. Zeta potential value and sign are related to the surface charge of colloidal particles. In case of negative surface charge, the zeta potential will be negative. Therefore, the incorporation of biochar into acidic soils can increase soil CEC and thus increase the retention ability of Ca^{2+}, Mg^{2+} and K^+. The oxygen-containing functional groups in biochars provide protons through dissociation reactions at high pH and association reactions at low pH, and consequently resist the

change in soil pH.

Effect on Nutrents

Nitrogen: Nitrogen (N) is the essential and major element for crop growth and is highly exposed to volatilization, leaching, and denitrification losses and N transformations. Biochar application has been reported to decrease its losses from soils found a good retention of NO_3^- in soil using various kinds of biochar produced at different temperatures. The increased adsorption of NO_3^- was because of functional groups (aliphatic ether aromatic ring carbonyl), and hydroxyl rather than physical adsorption. A number of mechanisms have been suggested in the reduction of N leaching and retention in soils treated with biochar. These include adsorption, immobilization, and ionic exchange of NO_3^- and NH_4^+ onto biochar. Biochar significantly decreases N_2O emission. The main mechanisms include increase in soil pH, improvement in soil aeration, N immobilization, interaction with soil available organic carbon and N, modification of enzymatic activities, and possibly a toxic effect on microbes responsible for N_2O production. Biochar influences the last step of denitrification and stimulates the conversion of N_2O to N_2, probably due to a liming effect allowing improved exhibition of the nosZ gene.

Phosphorous: Availability of P to plants is promoted by anion exchange capacity of biochar or by cations that interact with P. At low pH, phosphate forms precipitates with Fe^{3+} and Al^{3+}. At high pH, phosphate forms precipitate with Ca^{2+} and Mg^{2+}. Biochar may reduce the formation of phosphate precipitates, and therefore increase availability of P to plants. Synergistic and positive effects of biochar on available P have been observed through increasing water-retention capacity of a sandy soil.

Micronutrients: Biochar application usually increases soil pH, and resultantly micro nutrient availability is also affected. Biochar as such also contains micro elements to some extent as it has been identified that biochars produced by using various biomasses were good source of micronutrients such as Mn, Zn, Cu, Co and Mo.

Biological Properties

Biological N_2 fixation: Biochar application to soils has been reported as an enhancing agent for biological nitrogen fixation (BNF) in legume crops. Different mechanisms of enhanced BNF following biochar application are regarded,

- ✓ Immobilization of N
- ✓ Stimulation of nodule formation
- ✓ Higher supply of bio-available P
- ✓ Increase in soil pH
- ✓ Supply of macro and micro nutrients

Effect on soil micro-organism: The pores of biochar are good sources for sorption and desorption of readily decomposable organic compounds, nitrate, and ammonium, improving the habitat for micro-organisms. Biochar increases pH of acidic soils and enhance soil microbial population in soils. The application of biochar influences soil fungal activity and community structure Arbuscular (AM) and Ectomycorrhizal (EM) fungi, provided a micro-environment for fungal growth and porosity of bioc-

har was the main attributing factor. Probably, microorganisms in the guts of earthworms are more abundant and N-processing enzymes are more active in the presence of biochar. A greater microbial biomass and enzyme activity, therefore, increases N release from organic matter in the gut.

Reduce pollutant organic pollutant: Porosity of biochar greatly influences the retention time of pollutants. The increase in sorption of organic pesticides to biochar in agricultural soils, on one hand, is beneficial since it reduces hazards of pesticide residues, but on the other hand, it can also reduce herbicide efficacy, resulting in the requirement of increased application rates labile organic fraction of biochar may lower pesticide adsorption. Production temperature of biochar also influences the sorption efficiency and in general, the sorption efficiency of biochars is increased with increased production temperature.

Inorganic pollutant: Metal contaminated soils have been remediated by using carbonaceous materials to reduce their leachability and biological availability. Biochar is applied in mine soil to remediate heavy metal (loid)s such as arsenic (As), cadmium (Cd), zinc (Zn) and lead (Pb), and found that the bioavailability of Cd, Zn, Pb was reduced by biochar addition. Biochars are able to form complexes with metal ions on their surfaces and hence reduce bioavailability. Biochar for reducing the risk due to heavy metals and other pollutants may lower over time due to pore blockage by insoluble compounds.

Climate change mitigation: Biochar has been described as a possible means to sequester carbon (C) to mitigate climate change. Biochar counteract climate change problems by the following two key ways. Firstly, by its molecular structure, in which chemically and biologically more stable than the original carbon form, which makes it more difficult to be converted back to CO_2 which means it can store carbon for a long time. Most recently, it is predicted that sustainable biochar systems could amount to net avoided emissions of up to 1.8 Gt CO_2 a year, for total net avoided emissions of 130 Gt CO_2 over 100 years. Secondly, biochar in soil change emissions of other greenhouse gases from soil such as nitrous oxide (N_2O) or methane

Conclusion

Biochar is a stable and efficient soil amendment that improves soil structure, nutrient retention, and moisture availability, while supporting beneficial soil biological activity. Its long persistence in soil makes it effective for long-term soil health improvement and carbon storage. The response to biochar depends on feedstock, production method, soil type, and management practices, highlighting the need for site-specific application. When used judiciously with other nutrient inputs, biochar can enhance soil resilience and contribute to sustainable crop production.

Applications of Carbon Isotope Analysis in Agricultural and Environmental Studies

Prajwala B., Chidanand Gowda M. R. and V. Sahana Patil

Abstract

Carbon isotope analysis has emerged as a powerful tool in agricultural and environmental research for understanding carbon dynamics, plant physiological processes, and ecosystem functioning. Stable carbon isotopes, particularly $\delta^{13}C$, are widely used to distinguish photosynthetic pathways (C_3, C_4, and CAM plants), assess water-use efficiency, and evaluate plant responses to biotic and abiotic stresses. In agricultural systems, carbon isotope techniques contribute to crop improvement, weed ecology studies, nutrient use efficiency assessment, and climate-resilient farming practices. In environmental studies, carbon isotopes aid in tracing carbon sources and sinks, soil organic carbon turnover, land-use change impacts, and biogeochemical cycling. The integration of carbon isotope analysis with modern analytical and modeling approaches has enhanced its application across diverse agroecosystems. This review highlights the principles, methodologies, and key applications of carbon isotope analysis in agricultural and environmental studies, emphasizing its role in advancing sustainable resource management and improving our understanding of carbon-climate interactions.

Introduction

Carbon is a fundamental element governing biological productivity, ecosystem functioning, and global biogeochemical cycles. In both agricultural and environmental sciences, understanding the movement, transformation, and utilization of carbon is critical for addressing contemporary challenges such as food security, land degradation, and climate change. Carbon isotope analysis has emerged as a powerful and reliable approach to investigate carbon dynamics across plant, soil and atmospheric systems. By examining natural variations in carbon isotope ratios, particularly between the stable isotopes ^{12}C and ^{13}C, researchers are able to infer physiological, ecological, and environmental processes that are otherwise difficult to measure directly. Isotopic fractionation occurs during physical, chemical, and biological processes, leading to distinctive carbon isotope signatures (expressed as $\delta^{13}C$ values) in different components of ecosystems. In plants, fractionation during photosynthesis provides a basis for distinguishing photosynthetic pathways and assessing plant responses to environmental conditions. In soils and ecosystems, carbon isotope signatures help trace organic matter sources, turnover rates, and carbon fluxes. With advances in isotope ratio mass spectrometry and analytical precision, carbon isotope analysis has become incre-

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asingly accessible and widely applied. This article provides a comprehensive overview of the principles and applications of carbon isotope analysis in agricultural and environmental studies. Emphasis is placed on its role in plant physiology, crop and weed research, soil carbon dynamics, and environmental monitoring, highlighting its importance for sustainable ecosystem and resource management.

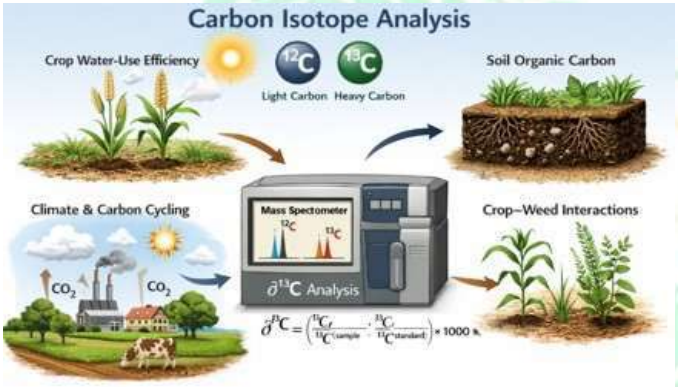
Principles of Carbon Isotope Fractionation

Carbon occurs naturally as two stable isotopes, ^{12}C and ^{13}C, with ^{12}C being more abundant. During biological and physicochemical processes, lighter isotopes are generally favored over heavier ones, resulting in isotopic fractionation. The extent of fractionation depends on the nature of the process and environmental conditions. Carbon isotope composition is commonly expressed as $\delta^{13}C$ values relative to an international standard, allowing comparison across studies. In biological systems, fractionation is most pronounced during photosynthesis, respiration and decomposition. Enzymatic reactions involved in carbon fixation discriminate against ^{13}C to varying degrees, producing characteristic isotope signatures in plant tissues. Similarly, microbial decomposition of organic matter in soils alters $\delta^{13}C$ values, reflecting changes in substrate availability and carbon turnover. Understanding these fractionation mechanisms forms the basis for interpreting carbon isotope data in agricultural and environmental research.

Carbon Isotopes and Photosynthetic Pathways: One of the most widely recognized applications of carbon isotope analysis is the differentiation of photosynthetic pathways. Plants employing the C_3 pathway typically exhibit more negative $\delta^{13}C$ values due to higher discrimination against ^{13}C during carbon fixation by the enzyme Rubisco. In contrast, C_4 plants show less negative $\delta^{13}C$ values as a result of their carbon concentrating mechanism, which reduces isotopic discrimination. CAM plants display intermediate and variable $\delta^{13}C$ values depending on environmental conditions and the degree of CAM expression. This clear distinction has made carbon isotope analysis a valuable tool for identifying plant functional types, studying vegetation composition, and reconstructing past and present plant communities. In agricultural systems, it aids in distinguishing C_3 and C_4 crops and weeds, supporting studies on crop-weed competition, resource use efficiency, and adaptation to climatic variability.

Applications in Crop Physiology and Productivity : Carbon isotope analysis plays an important role in understanding crop physiological responses and productivity under varying environmental conditions. $\delta^{13}C$ values in plant tissues are closely linked to internal CO_2 concentration and stomatal conductance, making them useful indicators of photosynthetic performance. As a result, carbon isotope composition has been widely used as an integrative measure of water-use efficiency (WUE) in crops. In rainfed and drought-prone regions, selection of crop varieties with higher intrinsic water-use efficiency is a key strategy for improving yield stability. Carbon isotope analysis provides a

time-integrated assessment of plant water status, overcoming limitations of instantaneous physiological measurements. It has been applied in breeding programs to screen genotypes for drought tolerance, evaluate irrigation strategies, and assess crop responses to nutrient management practices. Additionally, $\delta^{13}C$ analysis has been used to study carbon allocation patterns within plants, helping to understand source-sink relationships and biomass partitioning. Such insights are valuable for improving crop management and enhancing productivity under changing environmental conditions.



Role in Weed Ecology and Crop-Weed Interactions: Weeds are a major constraint to agricultural productivity, and understanding their ecological strategies is essential for effective management. Carbon isotope analysis offers unique insights into weed biology, particularly in distinguishing photosynthetic pathways and competitive behavior. Many problematic grassy weeds belong to the C_4 group, which often confers higher water- and nitrogen-use efficiency under high temperature and light conditions. By comparing $\delta^{13}C$ values of crops and associated weeds, researchers can assess differential resource use and competitive interactions. Carbon isotope techniques have been used to study niche differentiation, adaptive traits, and ecological plasticity of weed populations across environments. This information supports the development of integrated weed management strategies tailored to specific agroecosystems.

Carbon Isotopes and Water-Use Efficiency: Water scarcity is one of the most pressing challenges in agriculture and ecosystem management. Carbon isotope discrimination is closely linked to transpiration efficiency, making $\delta^{13}C$ a valuable proxy for long-term water-use efficiency. Plants with higher WUE generally exhibit less negative $\delta^{13}C$ values, reflecting reduced stomatal conductance and lower intercellular CO_2 concentration. This relationship has been exploited in studies assessing plant adaptation to drought, irrigation scheduling, and climate variability. In natural ecosystems, carbon isotope analysis helps explain vegetation responses to aridity gradients and changing precipitation patterns. As climate change intensifies water stress in many regions, the use of carbon isotopes for evaluating water-use strategies is likely to become increasingly important.

Soil Organic Carbon Dynamics: Soils represent a major reservoir of terrestrial carbon, and understanding soil organic carbon (SOC) dynamics is critical for climate mitigation and soil health. Carbon isotope analysis is widely used to trace sources of organic matter, estimate carbon turnover rates, and evaluate the impact of land management practices on SOC stocks. Differences in $\delta^{13}C$ values between C_3-

and C_4-derived organic matter allow researchers to track changes in vegetation inputs over time. This approach has been particularly useful in assessing land-use change, crop rotation effects, and residue management practices. Carbon isotope techniques also contribute to studies of soil carbon stabilization mechanisms, microbial processing, and carbon sequestration potential.

Environmental Applications of Carbon Isotope Analysis: Beyond agriculture, carbon isotope analysis has broad applications in environmental studies. It is used to trace carbon sources and sinks at ecosystem and landscape scales, contributing to our understanding of carbon cycling and climate-carbon feedbacks. Isotopic signatures help distinguish between biogenic and anthropogenic carbon sources, assess ecosystem respiration, and monitor changes in carbon fluxes under environmental stress. Carbon isotopes are also employed in studies of land degradation, deforestation, and ecosystem restoration. By providing insights into historical vegetation and carbon dynamics, isotope analysis supports informed decision-making for sustainable land management and conservation planning.

Analytical Techniques and Methodological Advances: The widespread application of carbon isotope analysis has been facilitated by advances in analytical techniques, particularly isotope ratio mass spectrometry (IRMS). Improvements in sample preparation, precision and throughput have expanded the range of materials that can be analyzed, including plant tissues, soils, atmospheric samples and dissolved organic carbon. Coupling isotope analysis with modeling approaches and complementary techniques such as remote sensing has further enhanced its utility. These integrative approaches enable scaling from plot-level measurements to regional and global assessments, strengthening the role of carbon isotope analysis in addressing complex environmental questions.

Limitations and Future Perspectives

- ✓ Interpretation of $\delta^{13}C$ values can be complex because multiple environmental and physiological factors influence isotope discrimination simultaneously.
- ✓ Carbon isotope signals often represent time-integrated responses, which may mask short-term physiological variations.
- ✓ Similar $\delta^{13}C$ values can arise from different processes, leading to potential ambiguity without supporting measurements.
- ✓ Accurate analysis requires specialized instruments such as isotope ratio mass spectrometers, which are expensive and not universally accessible.
- ✓ Sample preparation and handling can introduce analytical errors if standardized protocols are not strictly followed.
- ✓ Soil carbon isotope signatures may be influenced by historical land use, making it difficult to attribute changes to recent management practices.
- ✓ Environmental heterogeneity and spatial variability can limit the extrapolation of isotope results across larger landscapes.

Conclusion

Carbon isotope analysis has proven to be a powerful and versatile tool in agricultural and environmental studies, offering unique insights into carbon dynamics across plant, soil, and ecosystem scales. The use of stable carbon isotopes, particularly $\delta^{13}C$, enables effective differentiation of photosynthetic pathways, assessment of water-use efficiency, evaluation of crop and weed physiological behavior, and tracing of soil organic carbon sources. Its integrative nature provides time-averaged information that is especially valuable under variable climatic and management conditions. Despite certain limitations related to interpretation and analytical requirements, advances in isotope techniques and integration with complementary approaches have significantly enhanced its applicability. Overall, carbon isotope analysis contributes substantially to sustainable agriculture, climate change research, and environmental management, and will continue to play an important role in addressing global challenges related to food security, carbon sequestration, and ecosystem resilience.

AI-Enabled Household Food Systems: Integrating Crop Recommendation, Personalized Nutrition and Smart Diet Planning: Past Evidence and Future Outlook

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Abstract

Artificial Intelligence (AI) and Machine Learning (ML) are increasingly shaping how food is grown, selected, and consumed. This paper explores the integration of agricultural intelligence with nutritional planning to build household food systems that are data-driven, adaptive, and sustainable. It reviews evidence from studies on crop recommendation, AI-assisted diet planning, and agriculture-nutrition linkages, highlighting progress and limitations. The paper also anticipates how such integrated systems may evolve in the next decade under varying conditions of technology adoption, climate stress, and socio-economic change. We conclude with directions for research and policy to strengthen AI-enabled, nutrition-sensitive food systems in India.

Introduction

Food systems at the household level involve choices about what to produce, procure, and consume. While agricultural science guides crop selection, nutrition science informs diet composition; yet these domains have often operated separately. Recent progress in AI and data analytics has enabled models that can predict suitable crops based on soil and climate, or design meal plans tailored to health needs. However, efforts to connect production with nutrition remain limited. This paper examines how computational tools can bridge agriculture and diet planning, offering decision support that aligns farm output with household nutrition.

Integrating AI in Agriculture and Nutrition

In agriculture, machine learning models such as Random Forests, Support Vector Machines, and ensemble techniques have achieved high accuracy in crop recommendation by analyzing soil nutrients, rainfall, and temperature. Studies like Enhancing Agricultural Productivity: A Machine Learning Approach to Crop Recommendations reported accuracies above 99 %, while AgroSense combined soil imaging with nutrient profiling for precise crop selection. Explainable AI (XAI) tools, as seen in AgroXAI, further improve trust by clarifying why a specific crop is advised. Parallel progress has occurred in nutrition informatics. Systems based on generative models and recommendation algorithms now craft diet plans that balance macronutrients and respect user preferences. Research such as Optimizing Nutritional Outcomes: The Role of AI in Personalized Diet Planning demonstrates how computational feedback loops can improve adherence and

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diversity. Despite this progress, most models remain domain-specific either guiding farm production or suggesting meals without linking availability to diet adequacy. Empirical programs in India show the value of connecting these domains. Initiatives such as Farming System for Nutrition demonstrated that integrating crop diversification with nutrition awareness improves household dietary diversity. Yet these were largely manual interventions. Embedding such logic within intelligent digital systems could automate adaptive guidance linking what is feasible to grow with what is healthy to eat.

Data Foundations and Learning Frameworks

Integrated food systems require diverse datasets. Agricultural inputs include soil pH, N-P-K content, rainfall, and remote-sensing indicators, while nutritional inputs cover food composition, household demographics and dietary diversity scores. Combining these enables models that recommend not only profitable crops but also nutrient-dense combinations aligned with local consumption. Supervised learning supports crop prediction; deep neural networks and multimodal fusion allow simultaneous analysis of soil images and structured data. In contrast, AI-based diet planners often rely on constraint optimization or generative approaches. A future direction lies in linking these models through shared variables so that crop recommendation outputs inform meal planning modules, ensuring dietary adequacy from available produce.

Opportunities and Future Outlook

Over the coming decade, rural India may witness gradual integration of such systems. With expanding smartphone access and improved digital infrastructure, AI-based advisory platforms could reach millions of smallholders. Scenario analyses suggest that under moderate adoption, up to one-fifth of rural households could use hybrid crop-nutrition tools by 2030, potentially improving dietary diversity by 15-20 % and yields by over 10 %. Accelerated adoption under strong policy support could double these gains. Yet challenges remain: data quality, interpretability, and affordability will determine scalability. For resilience, models must account for climate variability and regional constraints. Incorporating uncertainty estimation, local calibration, and user feedback loops can enhance reliability. Social inclusion and privacy safeguards are equally essential so that digital food systems serve marginalized groups equitably.

Conclusion

AI offers a transformative pathway to link agriculture and nutrition within household food systems. Current evidence shows maturity in crop recommendation and growing potential in personalized diet planning, but integration is still emerging. The future depends on open data ecosystems, interpretable models, and participatory design. When supported by policy and local capacity, AI-enabled food systems can contribute to sustainable nutrition security, aligning what is grown with what is consumed.

Acknowledgement

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Genome Editing in Crop Improvement: Science, Applications, Regulation and Future Prospects

Shivam Singh, Shivam Singh, Prastuti Bhattacharyya and Prasanna Sarmah

Introduction

Genome editing (GE) has emerged as a revolutionary advancement in plant breeding, offering a level of precision and efficiency that was previously unattainable through traditional methods. Unlike conventional breeding, which relies on crossing plants and laboriously selecting for desired traits over many generations, and classical genetic engineering, which typically involves the random insertion of foreign DNA (transgenesis), genome editing allows for the direct, surgical modification of specific endogenous DNA sequences. This technology is now considered central to addressing the global challenges of food security, climate resilience, and sustainable agriculture. As the world faces a growing population and volatile climate conditions, GE provides a rapid toolkit to develop crops that are more nutrient-dense, hardy, and require fewer chemical inputs.

Historical Evolution of Crop Improvement

The history of crop improvement has transitioned from domestication and mass selection to the scientific rigour of hybrid breeding and mutation breeding in the 20th century. With the integration of molecular markers, breeding for crops was revolutionized (Singha *et al.*, 2024). While the first generation of genetically modified (GM) crops in the 1990s introduced traits like herbicide tolerance, they faced significant limitations, including random gene insertion that could disrupt native plant functions and high regulatory costs due to the presence of foreign DNA. Precision genome editing emerged as a solution to these bottlenecks, enabling researchers to make predictable changes that mimic natural evolutionary processes without the "linkage drag" common in traditional breeding.

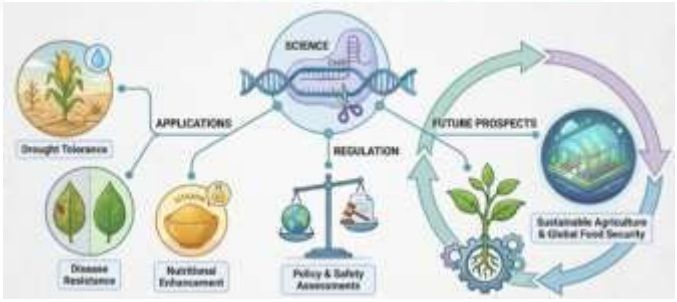


Fig. 1: Integrated framework of genome editing technologies in agriculture

Genome Editing Technologies in Agriculture

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At its molecular core, genome editing utilizes site-directed nucleases to create double-strand breaks (DSBs) at specific genomic locations, which the cell then repairs via natural pathways like Non-Homologous End Joining (NHEJ) or Homology-Directed Repair (HDR) (Singh *et al.*, 2025).

CRISPR-Cas9: The primary tool, utilizing a guide RNA to direct the Cas9 enzyme to a specific DNA target.

CRISPR-Cas12 and Cas13: Cas12 offers alternative targeting requirements (PAM sites), while Cas13 is used specifically for targeting RNA, which is particularly useful for viral resistance.

Base and Prime Editing: These "next-generation" tools allow for precise single-nucleotide changes or "search-and-replace" modifications without creating double-strand breaks, significantly reducing the risk of unintended genomic errors. prime editing employs a programmable Cas nickase fused to a reverse transcriptase, together with a prime-editing guide RNA (pegRNA) that specifies the target site and serves as a template for the intended genome edit (Chen and Liu, 2023).

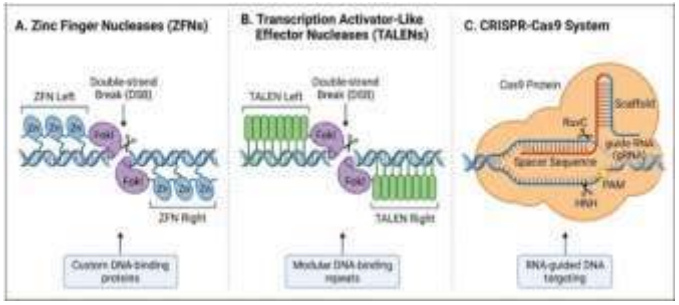


Fig. 2: Key Genome Editing Tools

The technology is often categorized by the type of edit: SDN-1 (gene silencing via small deletions), SDN-2 (small modifications using a template), and SDN-3 (targeted insertion of larger genetic sequences).

Applications of Genome Editing in Crop Improvement

Genome editing is being applied across a vast range of crops and traits:

Yield and Architecture: Modifying genes to optimize grain size in rice or flowering time in maize.

Abiotic Stress Tolerance: Enhancing resistance to drought, heat, and salinity in wheat and soybean.

Biotic Stress Resistance: Creating resistance to bacterial blight in rice and powdery mildew in wheat.

Nutritional Biofortification: Developing high-GABA tomatoes for heart health and biofortified "Golden Rice".

Reduction of Anti-nutritionals: Removing allergens in wheat or toxins in orphan crops like cassava.

Breeding Acceleration: Integrating GE with speed breeding and male sterility systems to produce hybrid seeds more efficiently.

Genome Editing vs. Conventional Breeding and Genetic Engineering

A critical distinction of many genome-edited crops is that they do not contain foreign DNA. Because techniques like SDN-1 produce small mutations that are indistinguishable from those occurring naturally or through traditional mutation breeding, many scientists argue they should not be regulated as strictly as transgenics. GE offers superior precision and speed, reducing the breeding cycle from a decade to just a few years while minimizing off-target genomic risks compared to

chemical mutagenesis.

Regulatory Landscape of Genome-Edited Crops

Global regulations are currently fragmented

United States: Follows a product-based approach where GE crops are often exempt from GMO regulation if the change could have been achieved naturally.

European Union: Historically regulated all GE crops as GMOs, though a new 2024/2025 framework proposes lighter regulations for certain categories.

United Kingdom: Recently passed the Genetic Technology (Precision Breeding) Act to facilitate GE crop commercialization.

China and Japan: China has recently streamlined its GE approval process, while Japan has already approved and marketed the first GE consumer foods (GLP Tracker, 2024; ISAAA, 2024). Regulatory uncertainty can stifle innovation, particularly for small-scale breeders and public research institutions that cannot afford the high costs of GM-style compliance.

Biosafety, Ethical and Environmental Considerations

While highly precise, concerns remain regarding off-target effects, unintended mutations elsewhere in the genome, and their potential impact on food. Environmental concerns include the risk of gene flow to wild relatives and the long-term impact on biodiversity. Ethically, discussions surrounding this technology frequently center on the disparity between scientific risk assessment and public perception.

Socio-Economic Implications

GE has the potential to empower smallholder farmers by providing climate-resilient seeds that reduce reliance on expensive chemical pesticides. However, issues regarding Intellectual Property (IP) and patent concentration among a few large corporations remain a hurdle for equitable global access.

Case Studies and Success Stories

Success stories include the commercialization of the GABA-enriched tomato in Japan and the approval of non-browning potatoes in the US. Furthermore, public initiatives by CGIAR centres are currently developing GE maize and rice tailored specifically for African and Asian regional stresses.

Conclusion

Genome editing is a transformative tool, not a silver bullet, that provides a pathway to a more resilient and sustainable food system. For the technology to reach its full potential, it must be supported by science-based regulation, responsible innovation, and balanced governance that ensures benefits are accessible to all participants in the agricultural value chain.

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Circular Economy and Waste-to-Wealth in Agriculture

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Modern agriculture faces the dual challenge of increasing food production while reducing environmental degradation and resource depletion. Conventional linear agricultural systems follow a "take-use-dispose" model, where inputs such as fertilizers, water, and energy are consumed, and large volumes of waste are generated. Crop residues, animal manure, agro-industrial by-products, and food waste are often treated as liabilities rather than resources. In this context, the concept of the circular economy has gained increasing attention as a sustainable framework that emphasizes resource efficiency, waste reduction, and value creation. Circular economy and waste-to-wealth approaches in agriculture aim to transform agricultural waste into valuable products, thereby enhancing sustainability, profitability, and environmental resilience. A circular economy in agriculture is based on the principle of closing resource loops by reusing, recycling, and regenerating materials within the production system. Instead of discarding waste, circular systems treat it as a resource that can be converted into inputs for agriculture or other sectors. This approach reduces dependency on external inputs, lowers production costs, and minimizes environmental pollution. In agricultural systems, circularity can be achieved by integrating crop production, livestock, fisheries, and agro-processing in a manner that allows by-products from one component to serve as inputs for another. Agricultural waste is generated at multiple stages, including crop production, post-harvest handling, processing, and consumption. Crop residues such as straw, husk, stalks, and leaves constitute a major portion of agricultural waste. In many regions, these residues are burned in fields, leading to air pollution, greenhouse gas emissions, and loss of valuable organic matter. Livestock waste, particularly manure and urine, is another significant resource that is often underutilized or improperly managed, causing water and soil contamination. Additionally, agro-industrial waste from food processing units, such as fruit peels, pulp, and wastewater, presents both environmental challenges and economic opportunities.

Waste-to-wealth strategies focus on converting these waste streams into valuable products such as organic fertilizers, bioenergy, animal feed, and bio-based materials. One of the most widely adopted waste-to-wealth practices in agriculture is composting. Composting transforms organic waste into nutrient-rich compost that improves soil fertility, enhances soil structure, and increases water-holding capacity. The use of compost reduces reliance on chemical fertilizers, lowers input costs, and promotes

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long-term soil health. Vermicomposting, which uses earthworms to decompose organic waste, produces high-quality manure with enhanced nutrient availability and microbial activity. Another important waste-to-wealth pathway is the production of bioenergy from agricultural waste. Crop residues, animal manure, and agro-industrial by-products can be used to generate biogas through anaerobic digestion. Biogas plants convert organic waste into methane-rich gas that can be used for cooking, electricity generation, and heating. The by-product of biogas production, known as digestate, is a nutrient-rich organic fertilizer that can be returned to agricultural fields. This process not only provides renewable energy but also reduces greenhouse gas emissions and improves waste management. Biochar production is an emerging waste-to-wealth technology with significant potential for sustainable agriculture. Biochar is produced by pyrolyzing agricultural biomass under limited oxygen conditions. When applied to soil, biochar improves soil structure, enhances nutrient retention, and increases carbon sequestration. It also helps reduce soil acidity and improves water-holding capacity, making soils more resilient to drought. By converting crop residues into biochar, farmers can reduce residue burning while creating a valuable soil amendment.

Agricultural waste can also be transformed into animal feed and value-added products. Crop by-products such as rice bran, oilseed cakes, and fruit pulp are commonly used as livestock feed ingredients. Advances in processing technologies have enabled the conversion of low-quality residues into nutritionally enhanced feed through fermentation and enrichment processes. In addition, agro-waste is increasingly being used to produce bio-based materials such as biodegradable packaging, bioplastics and natural fibers, contributing to the development of a bio-economy. Circular economy approaches also promote nutrient recycling within agricultural systems. Integrated farming systems that combine crops, livestock, and aquaculture enable efficient recycling of nutrients and energy. For example, livestock manure can be used to fertilize crops, while crop residues can be used as animal feed or bedding. In integrated aquaculture systems, nutrient-rich wastewater from fish ponds can be used for irrigating and fertilizing crops. Such systems reduce waste generation, improve resource efficiency, and enhance farm resilience.

The adoption of circular economy and waste-to-wealth approaches offers multiple environmental benefits. By recycling organic waste, these systems reduce landfill use, prevent air and water pollution, and lower greenhouse gas emissions. Improved waste management also enhances soil health, biodiversity, and ecosystem services. From an economic perspective, waste-to-wealth practices create additional income opportunities for farmers through the sale of compost, biogas, biochar, and value-added products. They also reduce expenditure on fertilizers, energy, and feed, improving farm profitability. Despite their potential, the implementation of circular economy practices in agriculture

faces several challenges. These include lack of awareness among farmers, limited access to technology and infrastructure, high initial investment costs, and inadequate policy support. Small and marginal farmers often face difficulties in adopting waste-to-wealth technologies due to financial and technical constraints. Addressing these challenges requires coordinated efforts from governments, research institutions, private sector, and farmer organizations. Policy interventions play a crucial role in promoting circular agriculture. Supportive policies such as subsidies for biogas plants, incentives for composting and bio-fertilizer production, and regulations discouraging residue burning can accelerate adoption. Capacity building and extension services are essential to educate farmers about the economic and environmental benefits of waste-to-wealth practices. Public–private partnerships and community-based models can further enhance scalability and impact.

In conclusion, circular economy and waste-to-wealth approaches represent a transformative pathway for sustainable agriculture. By converting agricultural waste into valuable resources, these systems reduce environmental pollution, enhance resource efficiency, and create new economic opportunities for farmers. Integrating circular principles into agricultural planning and practice is essential for building resilient, low-carbon, and sustainable food systems. As global agriculture seeks solutions to address climate change, resource scarcity and food security, waste-to-wealth strategies will play an increasingly important role in shaping the future of sustainable farming.

Growing Vegetables Smartly: Types of Vegetable Gardening

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Abstract

Vegetable gardening is an essential part of horticulture, contributing significantly to food and nutritional security, revenue production, and sustainable agriculture. With rising population pressure, limited land resources, fast urbanization, and growing awareness of healthy eating, the need of implementing appropriate vegetable gardening systems has grown exponentially. Horticulturists have classed vegetable gardening into wide varieties over time based on aims, production scale, market orientation, resource availability, and environmental circumstances. This page provides a complete review of the various varieties of vegetable gardening, including their characteristics, applications, and current relevance. The benefits and general significance of vegetable gardening systems are also explored, emphasizing their importance in smart, efficient, and sustainable vegetable production.

Introduction

Vegetables are crucial components of the human diet because they provide vitamins, minerals, dietary fibre, antioxidants, and bioactive chemicals that are required for optimal growth and health maintenance. Vegetable gardening is the growth of vegetable crops using various production strategies to suit home, market, industrial, and nutritional needs. Compared to field crops, vegetable crops are often more intensive, perishable, and management-sensitive, necessitating careful planning and timely operations. Vegetable gardening has been divided into several varieties in order to improve production and resource utilization. These classifications assist farmers, researchers, and extension workers in selecting appropriate gardening systems based on local variables, economic objectives, and consumer needs. Traditional systems such as kitchen, market, and truck gardening coexist with more modern approaches such as protected cultivation, nutrition gardening, terrace gardening, and organic vegetable gardening. Together, these systems provide the foundation of smart vegetable production techniques that address issues such as food security, climate variability, urbanization and environmental sustainability.

Types of Vegetable Gardening

Kitchen Gardening: Kitchen gardening is one of the

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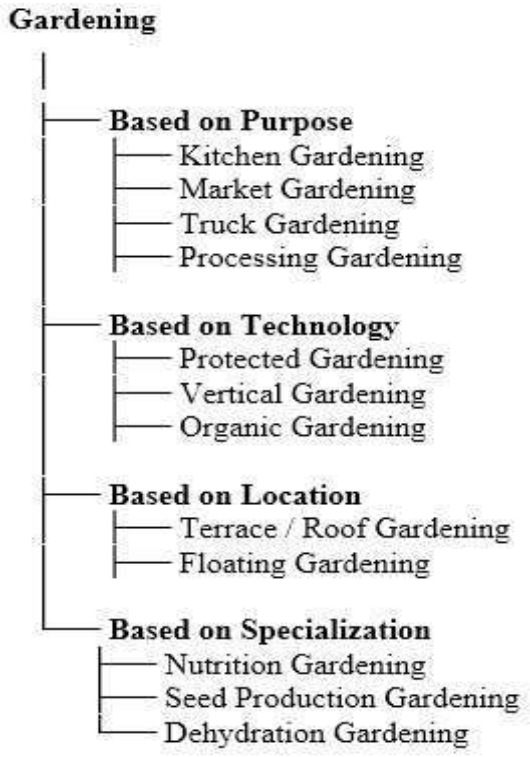
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oldest and most common types of vegetable gardening. Growing veggies in the backyard or near the house to suit a family's daily requirements. The major goal of kitchen gardening is to provide a consistent supply of fresh, nutritious, pesticide-free veggies at a cheap cost. Commonly produced vegetables include leafy greens, tomato, brinjal, chilli, okra, radish, carrot, cucurbits, and legumes. Mixed cropping, intercropping, and succession planting are used to provide year-round availability. Kitchen gardening is a vital aspect of increasing household nutrition, especially for women and children, while also lowering reliance on market veggies.

Marketing Gardening: Market gardening is the intensive growing of vegetables on small to medium-sized plots located near towns and cities. Vegetables grown under this technique are sold directly to local markets, hotels, restaurants, and retail stores. Proximity to markets lowers transportation costs and postharvest losses. Tomatoes, cauliflower, cabbage, spinach, coriander, cucumber, and other fast-growing, high-value vegetables are popular crops. Market gardening involves effective management procedures, including correct irrigation, fertilizer application, pest control, and timely harvesting to fulfill market demand and quality standards.

Truck Gardening: Truck gardening is a large-scale commercial vegetable production strategy that involves growing vegetables in rural locations and transporting them to distant markets. This approach is commonly used where land is reasonably inexpensive and available in large contiguous areas. Vegetables appropriate for truck gardening include potatoes, onions, cabbage, pumpkin, watermelon, and sweet potato. Truck gardening has grown in importance as cold storage facilities and refrigerated transportation have expanded.

Flowchart 1: Classification of Vegetable Gardening



Processing Gardening: Processing gardening is the cultivation of vegetables for use in the processing industry. The produce is canned, frozen, dehydrated, pickled, or processed into products like paste, puree, ketchup, sauces, and soups. Uniformity in size, shape, colour, and maturity is essential in this system. Crops planted widely include tomato, pea, chili, onion, sweet corn, and carrot. Farmers and processing plants must work closely together to ensure timely raw material supply and reduce post-harvest losses.

Forcing Gardening: Forcing gardening is the practice of producing vegetables outside of their typical growing season by altering environmental factors such as temperature, humidity, and lighting. This is accomplished with greenhouses, polyhouses, shade nets, and low tunnels. Forcing conditions are often used to grow vegetables such as tomatoes, cucumbers, capsicum, lettuce, and leafy greens. Although this technique involves a larger initial investment and technical expertise, it allows farmers to harvest vegetables during the off-season and earn higher prices, making it commercially viable.

Floating Gardening: Floating gardening is a unique technology used mostly in waterlogged and flood-prone locations. This approach involves growing vegetables on floating beds made of aquatic weeds, straw, and other organic elements. Crops like cucumbers, green vegetables, and some spices thrive under this system. Floating gardening makes effective use of wetlands and flood-prone areas, creating job opportunities and improving food security in ecologically hard locations.

Vegetable Gardening for Seed Production: This form of vegetable farming focuses on producing high-quality seeds rather than eating veggies. To ensure genetic purity and seed quality, strict adherence to isolation distances, rouging, and seed certification criteria is required. Tomatoes, brinjal, chilli, okra, cucurbits, and cole crops are among the most regularly planted vegetables for seed production. Seed production gardening is critical for expanding the vegetable seed business and providing farmers with access to quality planting material.

Nutrition Gardening: Nutrition gardening is a specific type of kitchen gardening that focuses on preventing malnutrition and micronutrient deficits. It encourages the production of nutrient-dense crops such as leafy greens, orange and yellow vegetables, legumes, and roots and tubers. This technique is frequently used in nutrition-focused development initiatives and makes a substantial contribution to increasing food diversity and nutritional status at the household level.

Terrace and Roof Gardening: Terrace or roof gardening is the process of cultivating vegetables on rooftops using containers, pots, grow bags, or raised beds. It is particularly well-suited to metropolitan locations with limited land availability. This technique not only produces fresh veggies, but it also improves the urban microclimate, lowers building temperatures, and increases aesthetic value. It represents an intelligent adaptation of vegetable growing to urban living.

Vertical Gardening: Vertical gardening involves growing vegetables vertically on trellises, frames, poles, or walls. Climbers and creepers including cucumber, bottle gourd, bitter gourd, beans, and peas are ideal for this system. Vertical gardening optimizes area use, enhances light interception, and lowers disease incidence, making it excellent for tiny and urban gardens.

Organic Vegetable Gardening: Organic vegetable gardening prioritizes the use of organic manures, compost, biofertilizers and biological pest manage-

Table 1: Classification of Gardening based on Purpose and Scale

Type of Gardening	Main Objective	Scale of Operation	Typical Some Vegetable Crops
Kitchen Gardening	Supply of fresh vegetables for household consumption	Backyard/Homestead	Leafy Vegetables, Tomato, Brinjal, Chilli, Radish, Okra, etc.
Market Gardening	Production for sale in the near market	Small to Medium	Tomato, Brinjal, Chilli, Cabbage, Leafy greens, Okra, Cauliflower, etc.
Truck Gardening	Supply of vegetables to distant market	Large	Potato, Onion, Cabbage, Pumpkin, Watermelon, etc.
Processing Gardening	Raw material for processing industries	Medium to Large	Tomato, Potato, Onion, Chilli, Sweet Corn, etc.
Seed Production Gardening	Production of high-quality seed	Medium	Mostly all type Vegetable seeds
Dehydration Gardening	Production of vegetables for drying and dehydration	Medium	Onion, Garlic, Seed spices vegetable

ment approaches above synthetic fertilizers and pesticides. This approach promotes environmental sustainability, soil health, and biodiversity while providing safe and nutritious food. Organic vegetable farming has grown in popularity as consumers desire chemical-free vegetables.

Gardening for Dehydration: Gardening for dehydration focuses on producing veggies that can be dried and dehydrated. Dehydrated veggies have a longer shelf life, require less space, and are easier to transport. Onion, garlic, carrot, spinach, fenugreek, and other leafy crops are frequently cultivated using this approach. High dry matter content and consistent maturity are desired characteristics for dehydration. This form of planting promotes value addition while reducing post-harvest losses.



Fig. 1: General view of a normal Kitchen Gardening

Advantages of Vegetable Gardening

Vegetable growing has several benefits on social, economic, and environmental levels. It assures the consistent availability of fresh and nutritious veggies, which improves nutritional quality and health. Gardening techniques such as kitchen and nutrition gardening cut household food expenditures while increasing self-reliance. Farmers benefit from commercial systems such as market, truck, and processing gardening, which provide work and money. Vegetable gardening benefits the environment by promoting efficient resource use, organic waste recycling, biodiversity conservation, and sustainable land management. Urban gardening systems also help to improve the environment and strengthen climate resilience.

Conclusion

Vegetable gardening systems are clever and adaptive ways to vegetable production under a variety of agro-climatic and socioeconomic settings. From traditional kitchen gardening to modern shielded, vertical, and organic systems, each style of vegetable growing serves a specific function and handles unique obstacles. Understanding and implementing appropriate vegetable farming systems can

increase productivity, profitability, nutritional security and environmental sustainability. In the face of rising population, urbanization, and climate change, vegetable gardening will remain critical to providing healthy diets and sustainable food systems.

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Application of Biofertilizers

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Introduction

Biofertilizers are soil microbe cultures that can be employed as microbial or soil inoculants to increase plant and soil fertility and productivity. Biofertilizers are economical and sustainable plant nutrition sources. A biofertilizer is simply a product that contains living microorganisms that colonize the rhizosphere and stimulate development by increasing the supply or availability of nutrients to the host plant when applied to the soil, seed, or plant surface. Some of the most often used biofertilizers include nitrogen-fixing soil bacteria (*Azotobacter, Rhizobium*), nitrogen-fixing cyanobacteria (*Anabaena*), phosphate-solubilizing bacteria (*Pseudomonas* sp.), and Arbuscular Mycorrhiza (AM) fungus. Phytohormone (auxin)-producing bacteria and cellulolytic microorganisms are also included in biofertilizer formulations. By increasing specific microbial processes, these microbial formulations are used to increase the availability of nutrients in a form that can be digested by plants. An organic fertilizer enhanced with helpful microbes is called a biofertilizer. All organic resources for plant growth that are converted by microbes, plant associations, or interactions into a form that plants may absorb are known as biofertilizers. Biofertilizers are liquid-based or carrier products made of living or dormant microbes (such as bacteria, fungi, algae, and actinomycetes), either alone or in combination, that help fix atmospheric N_2 or solubilizers of various soil nutrients while also producing growth-promoting compounds to increase crop yield and growth (Dineshkumar *et al*., 2018). Microorganisms with unusual roles, such *Azospirillum*, which fixes nitrogen, and P-solubilizing bacteria, are found in biofertilizers. It makes P available to plants by solubilizing it from soil and fertilizer (Saraswati and Sumarno, 2008). In order to get high-quality harvests while lowering pollution, biofertilizers are becoming increasingly important. For the highest seed yield in agriculture, both phosphate and nitrogen fertilizers must be applied. Biofertilizers are formulated in an easy-to use, low-cost carrier substance that can increase plant availability and/or mineral nutrient uptake. A biofertilizer, according to Vessey (2003), is a substance which when applied to seed, plant surfaces (leaves), roots, or soil and promote growth through several approaches and that helps to elevate the supply or accessibility of primary nutrients to the host plant containing living microorganisms that colonize the rhizosphere or the interior of the plant. Biofertilizers should not be confused with green manure, manure, intercrop, or organic supplemented chemical fertilizer.

Biofertilizers: why their need is inevitable?

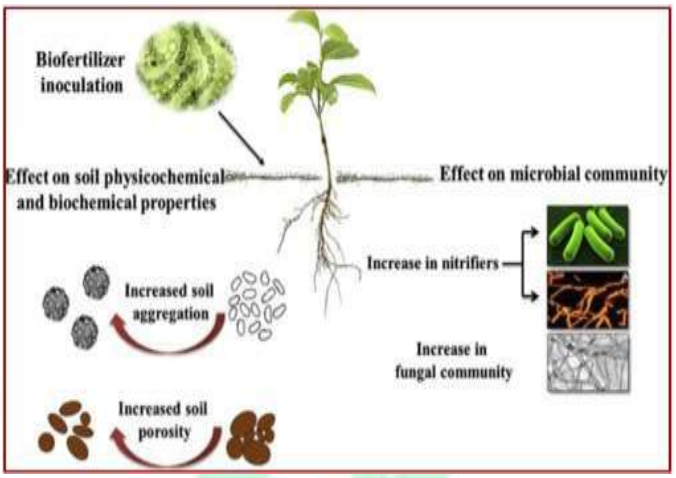
There is little question that the careless use of

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Table 1: Different groups of biofertilizers

Groups	Examples
Nitrogen (N_2) fixing Bio fertilizers	
Free living	*Azotobacter, Clostridium, Anabaena, Nostoc*
Bio Symbiotic	*Rhizobium, Frankia, Anabaena azollae*
Associative-Symbiotic	*Azospirillum*
P-Solubilizing Bio fertilizers	
Bacteria	*Bacillus subtilis* *Pseudomonas striata*
Fungi	*Penicillium* sp., *Aspergillus awamori*
P-Mobilizing Bio fertilizers	
Arbuscular Mycorrhizae	*Glomus*sp., *Gigaspora*sp.
Ectomycorrhiza	*Laccarai sp., Pisolithus sp., Boletus sp., Amanita sp.*
Ericoid Mycorrizha	*Pezizellaericae*
K- solubilizers	
Bacteria	*Frateuria aurantia*
Micronutrient solubilizers (Silicate and Zinc soloubilzers)	
Bacteria	*Bacillus* sp.
Plant Growth Promoting Rhizobacteria	
Bacteria	*Pseudomonas fluorescens*

chemical fertilizers to satisfy the increasing demand for food has contaminated and seriously harmed microbial habitats and beneficial insects. However, the use of excess chemical inputs has decreased soil fertility and increased crop susceptibility to disease (Aktar *et al*., 2009). By 2020, it is projected that in order to meet the target production of 321 million tons of food grain to feed 8 billion people worldwide, 28.8 million tons of nutrients will be needed, but only 21.6 million tons will be available, resulting in a deficit of roughly 7.2 million tons. The globe must undoubtedly increase agricultural output in a sustainable and environmentally friendly manner in order to feed the expanding population with the lack of available nutrients. Therefore, many of the current agricultural practices which include the use of chemical fertilizers, pesticides, herbicides, fungicides and insecticides must unavoidably be reevaluated. Biofertilizers are thought to be a safe substitute for chemical inputs and significantly reduce ecological disturbance in light of the harmful impacts of chemical fertilizers. Biofertilizers are economical, environmentally friendly and significa-ntly increase soil fertility over time.



Nitrogen Fixing Biofertilizers: Nitrogen is the most abundant element in the earth, comprising 78.09 and 79.2% of the atmosphere and soil respectively; sill is the limited element for the plant due to difficulty with its fixation in soil and uptake by the plant roots. Some microbes, either in the associated or non-associated form, help to fix the atmospheric nitrogen in the plant-available form, thus reducing the problem of fixation of N_2, denitrification and leaching loss of this element. The nitrogen-fixing biofertilizers which depend on their association with plants are broadly classified into two types: the symbiotic nitrogen fixers, which can fix the nitrogen when in association with the plant root system; and asymbiotic nitrogen fixer, which can fix nitrogen in soil in a free living state, i.e. they don't require the plant association. The former group includes *Rhizobium* species, *Frankia* species, Cyanobacteria

etc., whereas *Azotobacter chroococcum*, *Beijerinckia mobilis* and *Clostridium* species, free-living cyanobacteria (blue-green algae) etc., are placed in the latter group.

Phosphorous Solubilizing Biofertilizers: Some rhizospheric microorganisms (except mycorrhizal fungi), particularly P-solubilizing bacteria (PSB) and fungi (PSF), can enhance plant P acquisition by directly increasing solubilization of P or by indirect hormone-induced stimulation of plant growth (Richardson *et al*., 2009). The PSB or PSF may mobi lize soil P by the acidification of soil, through the release of enzymes (such as phosphatases and phytases) or the production of carboxylates such as gluconate, citrate and oxalate.

Potassium Solubilizing Biofertilizers: Some rhizobacteria can solubilize the insoluble forms of potassium, which is another essential nutrient necessary for plant growth. The higher bio mass yields due to increased potassium uptake have been observed with *Bacillus edaphicus* (for wheat), *Paenibacillus glucanolyticus* (for black pepper) and *Bacillus mucilaginosus* in coinoculation with the phosphate-solubilizing *Bacillus megaterium* (for eggplant, pepper and cucumber).

Plant Growth Promoting Rhizobacteria (PGPR): Plant Growth Promoting Rhizobacteria (PGPR) The group of bacteria that colonize roots or rhizosphere soil and beneficial to crops are referred to as plant growth promoting rhizobacteria (PGPR). They are also called as microbial pesticides e.g. *Bacillus* spp. and *Pseudomonas fluorescence*. PGPR inoculants currently commercialized that seem to promote growth through at least one mechanism; suppression of plant disease (termed Bio-protectants), improved nutrient acquisition (termed Bio-fertilizers), or phyto-hormone production (termed Bio-stimulants). Species of Pseudomonas and Bacillus can produce as yet not well characterized phyto-hormones or growth regulators that cause crops to have greater amounts of fine roots which have the effect of increasing the absorptive surface of plant roots for uptake of water and nutrients. These PGPR are referred to as Bio-stimulants and the phyto-hormones they produce include indole-acetic acid, cytokinins, gibberellins and inhibitors of ethylene production. *Rhizobacteria* induce resistance through the salicylic acid-dependent SAR pathway, or require jasmonic acid and ethylene perception from the plant for ISR. *Rhizobacteria* belonging to the genera Pseudomonas and Bacillus are well known for their antagonistic effects and their ability to trigger ISR. Resistance-inducing and antagonistic *rhizobacteria* might be useful in formulating new inoculants with combi-nations of different mechanisms of action, leading to a more efficient use for biocontrol strategies to improve cropping systems.

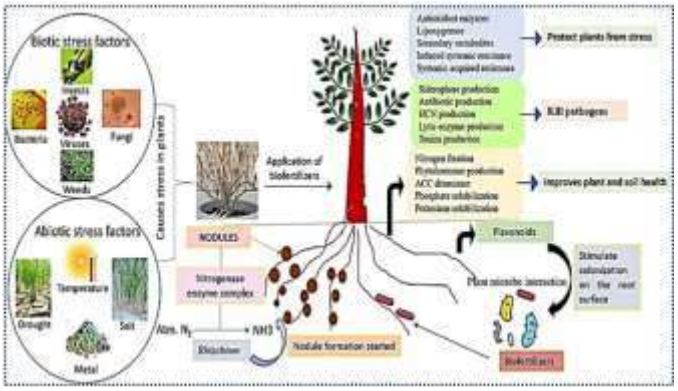
Methods of Application of Biofertilizers

Seed Treatment: Seed treatment is a very effective, economic, and most common method implemented for all types of inoculants (Sethi *et al*., 2014). The seeds are mixed and uniformly coated in a slurry (inoculant mixed with 200 mL of rice kanji) and then shade-dried, before being sown within 24 h.

For liquid biofertilizers, depending upon the quantity of seeds, the coating can be done in either plastic bag (if quantity is small) or bucket (if quantity is large). The seed treatment can be done with two or more bacteria (for instance, nitrogen-fixing bacteria such as Rhizobium, *Azotobacter*, and *Azospirillum* can be taken along with phosphorus-solubilizing microbes), without any antagonistic effect, and provide maximum quantity of each bacterium on individual seed required for better results (Chen, 2006).

Seedling Root Dip: This application is common for plantation crops such as cereals, vegetables, fruits, trees, sugarcane, cotton, grapes, banana, and tobacco where seedling roots are dipped in a water suspension of biofertilizer (nitrogen-fixing *Azotobacter* or *Azospirillum* and phosphorus-solubilizing microbial biofertilizer) for sufficient period of time. The treatment time differs for different crops, for instance, vegetable crops are treated for 20-30 min and paddy for 8-12 h before transplantation.

Soil Application: In this practice, Biofertilizers is applied directly to the soil either alone or in combination. A mixture of phosphate-solubilizing microbial Biofertilizers, cow dung and rock phosphate is kept in shade overnight while maintaining its moisture content at 50%andthen applied to the soil. Some examples of biofertilizers in which soil application is employed are Rhizobium (for leguminous plants or trees) and *Azotobacter* (for tea, coffee, rubber, coconuts, all fruit/agro forestry plants for fuelwood, fodder, fruits, gum, spice, leaves, flowers, nuts, and seeds).



Conclusion

In modern-day agricultural practices, biofertilizers form an important component of sustainable organic farming in terms of a viable alternative of chemical fertilizers that are associated with various environmental hazards. Biofertilizers can fix and make available atmospheric nitrogen in soil and root nodules, solubilize phosphate (from insoluble forms like tricalcium, iron and aluminum phosphates) into available forms, sift phosphates from soil layers, produce hormones and anti-metabolites to uphold root growth, and decompose organic matter for soil mineralization. Biofertilizers technology, which is an inalterable part of sustainable agriculture, has to be appropriate for the social and infrastructural situations of the users, economically feasible and viable, renewable, applicable by all farmers equally, stable in long-term perspective, acceptable by different societal segments, adaptable to existing local conditions and various cultural patterns of society, practically implementable, and productive.

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Horticulture in the City: Urban and Peri-Urban Solutions for Food Security and Environmental Sustainability

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Introduction

Peri-urban areas in India are much too frequently overlooked. They are plagued by environmental degradation, insufficient infra-structure, uncontrolled expansion, and institutional ambiguity. India is home to 16.7% of the world's population despite making up only 2.4% of the planet's total land area (Kumar, 2012). Additionally, the amount of land in India that could be used for cultivation was getting smaller every year. In rural India, land has always been a vital natural resource for producing livelihoods based on agriculture. However, the need for property for residential, commercial, and industrial uses is growing, which encourages a boom in real estate on the outskirts of cities. People lost their farmland, their food and fodder supply, and all the advancements that had been accumulated over the generations as a result of this process. However, the question is whether the property acquired by private parties was used for the intended purpose or if they are holding onto the unbuilt plots in order to benefit greatly after buying them from the farmers at a discount. Future demographic shifts that do not take into account important environmental factors will be disastrous since global washing is causing chaos all over the world. One of the key factors influencing food security is poverty, which is also a major contributor to undernourishment and malnutrition. Urban poverty is linked to both the migration of people from rural to urban regions and the growth of urban areas, as well as the growing distance between the traditional locations for food production rural areas and consumption. Additionally, as a result of global climate change, there is less acreage available for crop production, which provides food for expanding urban and peri-urban populations. The conflict of land use, particularly food crops vs. energy crops, is another challenge facing food security. These scenarios may vary in different parts of the world. Growing urban reliance on rural sources of food as well as agricultural production occurring in urban areas are important components of livelihoods that operate along a rural-urban continuum (Foeken and Uwuour, 2008). Horticultural crops (fruits, veget-ables, potato, tuber crops, mushroom, spices and plantation crops) are rich source of vitamins, minerals, proteins, and carbohydrates etc are referred

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to as protective foods and assume great importance as nutritional security of the people. There are instances that the supply of these produces has not commensurated with the demand resulting in crisis which has been felt by the government from time to time. Promoting Urban and peri-urban horticulture (UPH) for food, nutrition, and environmental services has gained emphasis as a result. Thus, there is also an unplanned transition to urban horticulture, which includes landscape gardening. The creation of sufficient green space is crucial to reducing various environmental problems. Urban green space is made up of natural, semi-natural, and artificial habitats. Urban horticulture and planned landscaping will improve the urban ecosystem and support sustainable livelihoods, even for those with limited resources.

India initiatives for urban and peri-urban horticulture

By 2030, over 40% of Indians will live in urban areas, and by 2050, that number will rise to over 65%. In order to meet the need for fruits, vegetables, flowers, tubers, and aromatic and medicinal plants, horticulture in urban and periurban areas becomes essential. The Government of India has initiated programs for peri-urban vegetable cultivation in recognition of the demand for fresh fruits and vegetables. The Planning Commission established working groups on horticulture for the 12th Plan. These groups discussed issues in sub-groups on urban and peri-urban horticulture and have pushed for concentrated attention on environmental services, health care, and the production of fruits and vegetables.

Urban and Peri-urban horticulture (UPH)-a way forward

Opportunities for urban and peri-urban horticulture are growing in urban areas as the demand for fresh fruits and vegetables rises, leading to a variety of activities. Fresh fruits, vegetables, and flowers may now be obtained through roof and terrace gardening, which also provides environmental benefits. In many developing nations, the production of vegetables has grown in and around cities as an unofficial industry carried out by impoverished and landless city people. The wide variety of horticultural crop species enables increased employment and income, as well as year-round production. Growers have discovered that intense horticulture may be carried out on small plots, effectively utilizing scarce water and land resources. Leafy vegetables provide a quick return to meet a family's daily cash requirements for purchasing food. Leafy vegetables are particularly perishable and post-harvest losses can be reduced significantly when production is located close to consumers. Mushroom centers, which do not need land can be a most promising activities in cities and peri-urban area. Evidently, there is an accelerated production of mushroom production around Delhi. There are new practices to grow cucurbits on the arches created on the pathways, utilising the zero-land for additional production.

Cultivation of fruits, vegetables and flowers: India

has a history of cultivating a broad array of horticultural crops and is lucky to have a diversity of agroclimatic zones. Fruits and vegetables combined account for the largest portion of horticultural produce production (78%). In addition to contributing to the nation's food basket, fruits and vegetables are very profitable crops that are in greater demand in metropolitan areas, where they constitute the most crucial part of a balanced diet. Production of crops and profitability of farmers can be enhanced by encouraging 'off-season' production under protected cultivation in green houses, shade net houses etc for generating income round the year. Fruit crops such as papaya, strawberry annual fruit crops and aonla, pomegranate, bael etc. can be grown with minimum available water conditions in peri-urban areas.

Roof garden in UPH: Due of the restricted space on a home's grounds, roof gardens are a popular alternative in urban and peri-urban settings. The roof of the home and the balcony are the only areas left for garden aficionados, especially in large cities and towns. The site's capacity must be evaluated in order to guarantee the success of a roof garden. To find out about the waterproofing of the flat roof and the strength of the roof structure, professional builders should be engaged. The roof gets incredibly heavy with hundreds of plants, crates, and tons of dirt. Generally, roofs are utilized for growing potted plants like cacti and succulents, chrysanthemums, dahlias, orchids, bougainvillea, roses, seasonal flowers and several kinds of shrubs and herbs. Besides, the vegetable crops such as tomato, brinjal, chillies, beans, leafy vegetables and gourds can also be grown. In a strong roof structure with water-proofing system, the area can be laid out with lawns and herbaceous borders which require at least 30 to 45 cm soil depth. Such planting can be done by placing the soil between the outer wall or the parapet and the wall built on the inner side of the roof.



Terrace gardening in UPH: Terrace gardening typically refers to the space just next to a building. This is an elevated area built on the sides of a hill or around a dwelling building. Since the terrace connects the house to the rest of the outdoor living area, its design must complement the house's layout. Terrace gardening offers seclusion and recreational activities. For landscape gardeners and civil engineers, terrace gardening is a very specialized profession. In addition to planting lawn grasses and other plants, it entails rising ground and building walls, ramps, steps, and paved pathways.

Landscape gardening for environmental services: Plants offer environmental and ecological services along with aesthetic values. Trees and other ornamental plants are crucial to the sequestration of

carbon form atmosphere and play an important role in reducing carbon foot print. As such, trees and other landscape plants serve as an important tool in improving air quality in cities and mitigating potential health effects on human inhabitants. In recent days landscaping concepts have gained popularity into different perspective by introducing ideas like green buildings, greenbelt, green roofs and energy conserving landscape and using ideal plants for air, sound and water, soil pollution mitigation. Parks and urban green spaces impact people's health by providing them with an inexpensive setting for recreation. Over the past 20 years, landscape gardening which encompasses the cultivation and use of garden flowers, turf grass, bedding plants, potted plants, hedges, edges, water gardens, rock gardens, etc. has significantly expanded as a commercial endeavor. Floriculture is no longer just used for religious purposes; it is now a part of modern life, and flower products are used for interior design, floral crafts, floral decorations, and commercial property beautification. As a result, lifestyle floriculture offers a variety of services for projects including the production of decorative plants, cut flowers, grass, and leaves.

Use of wastewater in UPH: Water is one of the Earth's essential natural resources and its scarcity has become a serious global issue due to increased demand driven by population growth and economic progress (Grant *et al*., 2012). Farming communities in peri-urban locations have a tendency to use untreated wastewater for irrigation due to increased competition for scarce water resources. Utilizing wastewater is frequently less expensive for farmers than pumping groundwater to irrigate crops, which requires initial investment and ongoing expenses. Reusing wastewater for irrigation is probably most common in places where there is a shortage of water from other sources for some or all of the year. Another powerful motivation for agricultural reuse is the high concentration of nutrients in wastewater, especially nitrogen and phosphorus, which can boost farming output and hence improve the livelihoods of peri-urban people. There has also been an increased emphasis on a more holistic approach to waste disposal that stresses the benefits of reducing the strength or quantity of waste at source and, where possible, recycling or re-using it close to the point where it is produced. To prevent potential negative impacts on human health and the environment, the importance of wastewater reuse in urban and peri-urban agriculture has to be recognised and clear policy guidelines for reuse need to be established. The most serious problem of using partially treated wastewater, including human and animal wastes, is transmission of gastrointestinal disease. The reuse of wastewater has been increasingly recognized as a vital necessity for sustainable development world-wide (Greenway, 2005). It has been widely practiced as an alternative source of irrigation water in areas where access to safe and abundant freshwater is limited.

Conclusion

Ensuring adequate food supply, environme-

ntal pollution reduction, employment and income generation are some of the important facets of urban and peri urban horticulture (UPH). In the current scenario of changing dietary habits with increasing income, there is a growing demand for horticultural produce. At the same time population pressure in urban and peri-urban area is increasing at accelerated rate with estimate that more than 65 percent people will live in cities and towns by 2050. Urban and peri-urban horticulture is not merely a specialty or side project; it is a crucial component in building resilient, sustainable cities and food systems. When correctly planned and supported, UPH can offer a number of co-benefits, including greater resilience to market and climatic shocks, social inclusion, revenue generation, environmental health, and food and nutrition security. But in order to realize these benefits, real constraints including resource and land pressure, environmental risk, cost, knowledge gaps, and governmental obstacles must be overcome.

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More Vigour through Seed Inviguration in Pulses

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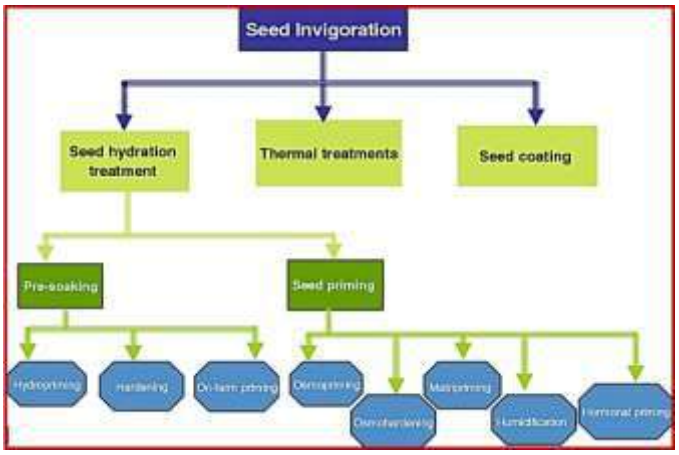
Introduction

Except for those used to produce oil or collected green, pulses are edible seeds from legume plants. It contains foods with substantial nutritional benefits for chronic illnesses, such as faba beans, lentils, chickpeas, peas, and dry beans Known as "Resource pulses," these are brief, intense, and uncommon occurrences of increased resource availability that happen regularly in nature and can have a significant impact on ecological processes at the individual, population, and community levels. The difference between "legumes" and "pulses" is frequently unclear. Plants of the Fabaceae family that produce seeds in pods are known as legumes (Curran, 2012). However, the term "pulses" refers exclusively to the dried edible seeds of these plants, including cowpeas, Bengal gram, pigeon peas, green and black gram, beans, and peas. Notably, soybeans and groundnuts (peanuts) are excluded from the pulse category due to their high fat content. The term "pulses" was first used in the 2020-2025, Dietary Guidelines for Americans, emphasising the necessity of appropriate terminology in establishing a solid research foundation (Yang *et al*., 2008). Protein, fiber, and other vital components are abundant in pulse crops including beans, peas, chickpeas, green grams, pigeon peas, lentils, *etc.* Through nitrogen fixation, they increase soil fertility, which makes them significant for sustainable agriculture. Pulse crops can be genetically modified to increase their nutritional value, which may alleviate micronutrient deficiencies and reduce the risk of chronic illnesses. Due to its inherent capacity to fix atmospheric nitrogen, pulse farming increases soil fertility and lessens the need for expensive synthetic nitrogenous fertilizers, which benefits both farmers and the environment (Robinson *et al*., 2019). Due to its inherent capacity to fix atmospheric nitrogen, pulse farming enhances soil fertility and lessens the need for expensive synthetic nitrogenous fertilizers, which benefits both farmers and the environment. By boosting intakes of iron, zinc, folate and magnesium, among other vitamins and minerals, half a cup of beans or peas can be added to a regular meal to increase its quality. Increasing pulse production can also increase domestic demand, create opportunities for local value-added processing, and provide off-farm jobs and income to rural disadvantaged people, particularly women and young people. Production of pulses is fraught with difficulties, especially in deve-

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loping nations. Women's access to high-value pulse markets and their ability to participate in crop cultivation are frequently restricted by gender inequality. Production is further hampered by social and cultural obstacles such ineffective supply chains, restricted access to resources, and a lack of knowledge about the economic and nutritional advantages of pulses. Particular limitations in India include low yields, bug and pest damage, and a lack of high-quality seeds. The concept of seed invigouration involves both priming and pelleting a relatively new term in the context of seed technology. Seed invigouration encompasses various techniques aimed at enhancing seed quality, particularly for improving germination rates, seedling growth and field performance. These treatments are designed to improve the overall vitality and robustness of seeds, enabling them to perform better under adverse field conditions.

Seed invigouration: During crucial stages of seedling establishment, these treatments aim to reduce the time taken for the seedlings to emerge and shield them from biotic and abiotic influences. Seed invigouration can significantly improve the germination process, seedling growth and field performance of crops, making them especially valuable in modern agriculture, where seed quality and crop establishment are critical factors for achieving high yields and resilience. One important measure of seed quality is seed vigor. It is a quantitative characteristic that affects how well seeds behave after storage, how well they emerge in challenging circumstances, how quickly and uniformly they germinate, and how big their seedlings get. Indeed, a key component of plant growth and agricultural output is seed vigor. The rapidity of germination, the consistency of seedling emergence and the capacity to tolerate environmental stressors like drought, severe temperatures, or disease infections are all components of seed vigor. Techniques for boosting seed quality that concentrate on enhancing field performance, planting value, germinability, and total yield are known as seed invigoration approaches. These techniques mainly aim to improve the cellular and physiological processes of seeds, particularly after storage, so that they can function at their best in the field. To improve seed quality and guarantee effective planting, the choice of seed invigoration treatments is essential. Their applicability varies depending on a number of circumstances, and these treatments are usually customized to the particular crop being grown and the difficulties it encounters.



Seed invigouration techniques

Nowadays, various seed priming techniques have been used widely. Seed priming refers to pre-sowing treatment that helps to improve seed germin-

ation and seedling establishment. The various priming treatments includes, hydropriming (soaking seeds in water to activate physiological processes such as enzyme activation, which helps in breaking dormancy and promote quicker germination), halo priming (seeds are soaked in a solution of inorganic salts, such as potassium nitrate or calcium chloride, which can help to stimulate metabolic activities that enhance germi-nation), osmopriming (seeds are soaked in solutions that contain osmotic agents like polyethylene glycol (PEG) or other organic solutes. These agents reduce water uptake to a controlled level, allowing the seed to begin germination without fully sprouting), thermopriming (seeds are treated with controlled temperatures, either high or low, to break dormancy or to prime them for better germination), solid matrix priming (seeds are mixed with a solid matrix such as vermiculite, peat, or sand. The seeds absorb water from the matrix, promoting hydration without fully soaking them) and bio-priming (soaking seeds in biological compounds, such as beneficial micro-organisms, enzymes, or plant hormones. These bioagents improve seed health, reduce seedborne diseases and enhance seedling vigour) (Ashraf and Foolad, 2005).

Hydro-priming: Priming with water process known as "hydro-priming" involves soaking seeds in water, drying them to dehydrate them, and then planting them the following day. This speeds up the germination process and increases the strength and growth of seedlings. Increased quantity of grains plant^{-1} unit^{-1} area from low vigour seeds on comparison with high vigour seeds and also restored the quality of aged and damaged seeds enhancing the production in field. It also increased germination percentage and seedling emergence which cause productive use of resources (soil, light) to increase the amount of grains. Decrease in seed vigour is an indication of electrolyte leaching due to an increase in membrane permeability.

Osmotic Priming/ Halo Priming: Osmotic Priming or Halo Priming refers to the soaking of Seeds in a solution of inorganic salts. In Osmotic Priming, seeds are soaked in solutions containing chemicals such as Polyethylene glycol (PEG), Potassium nitrate (KNO_3), Sodium chloride (NaCl), Potassium chloride (KCl), Mannitol, Glycerol, Sorbitol. Priming with salt solutions known as Halo priming. Osmotic Priming of seeds helps in the improvement of germination of Seed, Seedling emergence, establishment and final crop yield in salt-affected soils.

Bio-priming: Biopriming of seeds denotes standard tactic for introduction of disease resistance via bio control agents. Priming of seeds with helpful microorganisms and bio control means has been testified more proficiently for the management of diseases and pests as equated to other available methodologies (Prabha *et al.*, 2019). The seed biopriming is a recently adapted method of seed priming. Seed priming is a pre-sowing treatment which leads to a physiological state that allows seed to germinate more proficiently. Numerous instances of biopriming with vari ous biological agents have shown positive impact against a diverse group of

pathogens, such as *Fusarium, Verticillium, Colletotrichum, Rhizoctonia* and *Sclerotium* (Rajput *et al*., 2021).

Impact of seed invigouration on germination parameters and seedling vigour of pulses

Ghassemi-Golezani *et al.* (2008) reported that Seed invigouration treatments significantly improved the germination parameters and seedling vigour in pulses. Hydropriming of lentils resulted in higher seedling emergence in the field, compared to control and seed priming with PEG. Green gram seeds primed in a 450 ppm Zn solution at 25 ± 2 °C for 9 hours produced better germination percentages (98%) and seedling lengths (38 cm), as well as seedling vigour index I (3701) and seedling vigour index II (26.2), according to Mrinali *et al*. (2022). In comparison to control and nano priming of TiO_2 (0.01 %), green gram seed nano priming with TiO_2 (0.02%) produced the highest germination percentage (93.33%), seedling dry weight (0.59 g), and seedling vigor (55.06) as observed by Maroufi *et al*. (2011).

Impact of seed invigouration on growth, yield attributes and yield in pulses

Seed invigouration enhanced the growth attributes, yield attributes and yield of pulse crops. Significant improvement in growth and yield attributes and yields due to Mo seed-coating in common bean and soybean. The number of branches per plant, the number of green leaves per plant (30 DAS and 60 DAS), and the output of dry matter (30 DAS, 60 DAS, and harvest stage) were all greatly impacted by seed invigoration treatments. The seeds primed in $ZnSO_4$ 0.025% for 4 hours plus *Trichoderma viride* seed treatment (10 g kg^{-1} seed at 30 DAS, 60 DAS, and harvest) had the greatest number of branches. The seeds that produced the most dry matter were primed in $ZnSO_4$ at 0.5% for four hours (Raj *et al*., 2020).

Conclusion

Seeds are not always at their most vigorous after harvest, and storage might cause them to further deteriorate. Seed invigoration treatments are essential for improving the quality of seeds because they improve yield, field performance, planting value, and germinability through cellular and physiological restoration. They might then improve the quality of seeds after storage. Furthermore, future research should focus on creating precise, durable, and economical invigoration techniques that are suited to certain pulse genotypes and agroecological circumstances. By doing this, seed invigoration may develop into a key tool for boosting pulse crops' genetic potential and eventually help create a more resilient, fruitful and sustainable agricultural system.

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Okra: The Slimy Superfood

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Introduction

Okra (*Abelmoschus esculentus* L.), belonging to the family Malvaceae, is commonly known as Lady's finger, as well as by several vernacular names, including okra, bhindi, okura, green ginseng, plant Viagra, quimgombo, bamia, gombo, and lai long ma, in the different geographical regions of its cultivation. Okra is believed to have originated near Ethiopia, where it was frequently cultivated by the Egyptians during the 12th century, and thereafter spread throughout the Middle East and North Africa (Lamont, 1999). Okra is an annual shrub that is widely grown in tropical and subtropical climates worldwide. It is a common garden and agricultural crop. It is a widely farmed food crop and is globally known for its palatability. Okra's young green pods are typically eaten as vegetables. Whereas the extract of the pods also functions as a thickening agent in several recipes for soups, as well as sauces, to boost their viscosity. The extensive usage of okra fruit in the pickle industry is another notable use. The polysaccharides included in okra are employed in sweetened frozen foods such as icecreams, as well as bread products, due to their health benefits and longer shelf-lives (Archana *et al*., 2015). Anatomically, the fruits, stem, and leaves of okra are covered with minute soft, hairy structures. Although the flowering of the okra plant is perennial, it is highly dependent on various biotic and abiotic factors. The leaves of okra are polymorphous, characterized by hairy upper and lower surfaces, whereas the petioles are around 15 cm long. The flowers of okra can be easily recognized due to their slight yellowish color with a crimson center. The edible part of okra or its capsule (pod) measures approximately 15-20 cm in length and has a pyramidal-oblong, pentagonal, hispid appearance. Recently, okra has been used not only for its nutritional values but, also, for its nutraceutical and therapeutic properties, owing to the presence of various important bioactive compounds and their associated bioactivities. Okra seeds have been reported to have different protein compositions from cereals and pulses, as their protein ingredients are modified to bear a balance of characteristic amino acids, namely lysine and tryptophan. Thus, owing to their rich content of essential amino acids, okra seeds represent an important constituent of the human diet (Gemede *et al*., 2015). Fresh okra pods comprise roughly 90% water, 2% protein, 7% carbs, and about 3% nutritional fibre. They are rich in vitamins A, C, K, and B complex (particularly folate), as well as

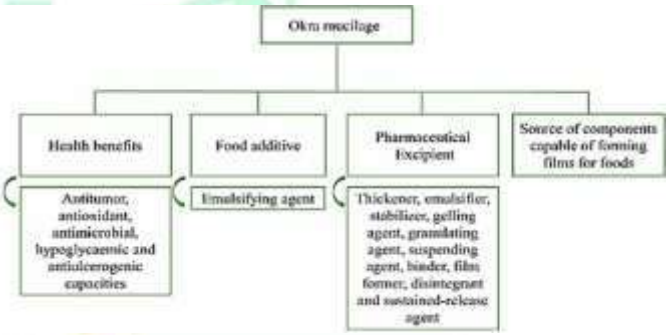
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vital minerals including calcium, magnesium, and potassium. However, okra's mucilage a thick, gel-like substance that forms when pods are chopped or cooked is what makes it magical. Far from being only a kitchen nuisance, this mucilage is a natural source of soluble fibre and complex polysaccharides such as galactose, rhamnose, and glucuronic acid (Adelakun *et al*., 2021).

Beneficial Properties of Okra Mucilage to Health

The search for foods enriched in nutrients and bioactives with properties that help the proper functions of the organism with improvement of the consumers' health reveals the importance of functional foods. In this view, the notion of a "functional food" is related to its nutritional characteristics and to the metabolic and physiological impacts delivering health benefits. In specifically for okra, its mucilage is of vital value for evaluating this vegetable as a potential functional food. Okra mucilage can be consumed in natura and can be considered as a natural functional food itself due to its potential health benefits. Okra mucilage is a mixture of natural polysaccharides, consisting of the monosac charides D-galactose, L-rhamnose, and galacturonic acid associated with proteins and minerals. The polysaccharides from these mucilages demonstrate some important biological activities, such as immunomodulated and anti-inflammatory. Okra mucilage especially has demonstrated functional health properties through in vitro and in vivo studies, such as antitumor, antioxidant, antimicrobial, hypoglycemic, and antiulcerogenic capacities, as well as the ability to bind cholesterol and bile acids, removing toxins from the liver. Gastric irritations are also treated with okra mucilage in traditional medicine. It has certain qualities that stop *Helicobacter pylori* from sticking to stomach tissue. According to Messing *et al.* (2014) findings, there was a correlation between the amount of immature okra fruit aqueous extract and the inhibition of the microorganism's cell membrane proteins binding to their corresponding ligands found in the gastric mucosa.

Beyond the Kitchen: Industrial Applications of Mucilage



Food industry: Technology Emulsifiers are one of the main classes of additives used in the food industry, and they play an important role in the formation and stability of emulsions, including milks, creams, seasonings, desserts, sauces, and beverages. Mucilage serves as a natural thickener, emulsifier, and stabilizer in soups, ice creams, and sauces. Unlike synthetic gums, it is biodegradable and safe for consumption. It can also reduce fat in low-calorie formulations while improving mouth-feel. Datsomor *et al*. (2019) evaluated the replacement of lecithin in chocolate with pectin extracted from okra mucilage and observed that the yield

obtained for formulations containing 25% okra pectin was higher than that of formulation containing only lecithin. This result indicated that the lecithin for okra pectin did not affects the sensory characteristics of the chocolate produced.

Pharmaceutical and biomedical uses: In medicine, okra mucilage acts as a drug carrier, tablet binder, and controlled-release agent. It can be used to encapsulate sensitive compounds, such as probiotics and vitamins, ensuring targeted and sustained release. Research also indicates its potential in wound-healing gels and biodegradable capsules.



Cosmetic and biopolymer applications: Okra's slimy extract is finding a place in the cosmetic industry as a natural moisturizer and hair conditioning agent. Moreover, researchers are experimenting with okra mucilage in bioplastics and eco-friendly films that could replace conventional plastics, aligning with global sustainability goals.

Environmental applications: Recent improvements show that okra mucilage can absorb heavy metals and organic contaminants, making it a green solution for wastewater treatment (Nath *et al*., 2020). This creates a new avenue for the use of a basic vegetable in environmental cleanup projects.

Conclusion

The tale of okra illustrates how creativity can arise from simple. What was formerly written off as "too slimy" is today praised as a source of health-promoting food, eco-friendly materials and bioactive substances. Okra represents the union of sustainability, science, and nutrition as we enter a new era of smart agriculture and green technology. With its mucilage working as a bridge between health and industry, okra stands set to become one of the smart superfoods of the 21st century an icon of how traditional crops may find new significance in a changing world. In fact, keep in mind that slime may be the secret to a more intelligent and health-conscious future the next time you see an okra pod that is slimy.

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Molecular Mechanism of Plant Resistance against Nematodes

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Introduction

The phylum Nematoda represents a staggering biological force, containing the highest number of individual animals on Earth and an immense diversity of species. While the soil is home to many beneficial, free-living species like the model organism *Caenorhabditis elegans*, the subset of nematodes that have adapted to parasitize plants causes global agricultural devastation. The scale of this "battle underground" is best illustrated by its financial impact; plant-parasitic nematode infections are estimated to cause approximately $100 billion in global agricultural losses every year. While chemical nematicides have been used for control, their high cost and extreme environmental toxicity make them increasingly less desirable compared to developing natural host plant resistance (Williamson and Gleason, 2003). Among the most damaging of these pests are two groups of sedentary endoparasites: root-knot nematodes (*Meloidogyne* spp.) and cyst nematodes (*Heterodera* and *Globodera* spp.). These organisms are considered highly sophisticated because they do not simply consume plant tissue; they essentially hijack the plant's physiology to create a permanent home. They possess a specialized feeding structure called a stylet, a hollow, retractable spear used to pierce cell walls and inject secretions from their esophageal glands into the plant. This organ serves as a dual-purpose tool for delivering effector proteins that reprogram the host and for ingesting the resulting cytoplasmic contents (Blaxter *et al*., 1998). Upon entering the root, the infective second-stage juvenile (J2) migrates toward the vascular system. Once there, it signals specific plant cells to enlarge and transform into highly specialized, multinucleate feeding sites: giant cells in the case of root-knot nematodes or syncytia for cyst nematodes. These feeding sites become metabolically hyperactive “sinks” that divert the plant's nutritional resources directly to the developing, now immobile, endoparasite. Throughout this weeks-long process, the nematode must actively evade or suppress the plant's innate immune system to prevent a defensive response. This biological pressure has driven the evolution of Resistance (R) genes in plants, which allow the host to recognize these invaders and initiate a hypersensitive response (HR), a form of localized programmed cell death that starves the parasite before it can reproduce (Williamson and Gleason, 2003).

The Life Cycle of Sedentary Endoparasites

To understand resistance, one must first understand the enemy's life cycle. Both cyst and root-knot nematodes share a similar developmental trajectory.

Invasion: Eggs hatch in the soil as infective second-

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Gene	Host Plant	Targeted Nematodes / Pests	Resistance Spectrum
Mi-1	Tomato	Root-knot nematodes (*M. incognita, M. javanica, M. arenaria*); Potato aphid; Whitefly	Broad-spectrum: Effective against multiple species of nematodes and even hemipteran insects.
Hero A	Tomato	Potato cyst nematodes (*Globodera rostochiensis* and *G. pallida*)	Broad-spectrum: Functions against multiple pathotypes of two different potato cyst nematode species.
Gpa2	Potato	Potato cyst nematode (*G. pallida*)	Narrow-spectrum: Confers resistance only to specific populations/pathotypes of a single species.
Gro1-4	Potato	Potato cyst nematode (*G. rostochiensis*)	Narrow-spectrum: Targeted specifically toward pathotype Ro1.
Hs1	Sugar beet	Sugar beet cyst nematode (*Heterodera schachtii*)	Specific to the sugar beet cyst nematode; the first Nem-R gene ever cloned.

stage juveniles (J2). Using a specialized, hollow spear called a stylet, they pierce plant cell walls and migrate toward the vascular system.

Feeding Site Induction: In response to nematode secretions, plant cells undergo massive reorganization to form highly specialized feeding sites: giant cells (for root-knot nematodes) or syncytia (for cyst nematodes). These multinucleate, metabolically active cells provide the nutrients necessary for the nematode to develop.

Sedentary Phase: Once feeding begins, the nematodes become immobile. Females swell into bulbous shapes and remain nonmotile, while males become vermiform and eventually leave the root to mate.

Reproduction: Egg production typically begins 3-6 weeks post-infection, completing the cycle.

Structural Nature of Nematode Resistance Genes

Plants protect themselves through R-gene-mediated defense, a specific recognition system that triggers a localized hypersensitive response (HR).

The NBS-LRR Class

Most cloned Nem-R genes belong to the NBS-LRR class, characterized by a central nucleotide-binding site (NBS) and a C-terminal leucine-rich repeat (LRR) region (Mitreva *et al*., 2005).

Mi-1 and Hero A: Isolated from tomato, Mi-1 provides broad-spectrum resistance against root-knot nematodes, aphids, and whiteflies. Hero A provides broad resistance against various potato cyst nematode pathotypes.

Gpa2 and Gro1-4: Isolated from potato, these genes offer a narrower range of resistance to specific potato cyst nematode pathotypes.

TIR vs. non-TIR: While Gro1-4 contains an N-terminal Toll-interleukin receptor-like (TIR) domain, Mi-1, Hero A, and Gpa2 belong to the non-TIR subclass.

Extracellular LRR Class

Some genes, like Rhg1 and Rhg4 from soybean, encode proteins with extracellular LRRs, a transmembrane domain, and a cytosolic kinase domain. These structures resemble the rice Xa21 gene and likely act as receptors for extracellular elicitors.

Mechanisms of Resistance and Signalling

The hallmark of nematode resistance is the failure of the pest to establish a functional feeding site. This is often achieved through a hypersensitive response (HR), which involves rapid cell death at the

infection site.

Timing and Localization

The timing of this response varies significantly:

Mi-1.2: Triggers cell death rapidly near the anterior end of the nematode as it attempts to initiate a feeding site.

Hero A: The response occurs *after* the feeding site is induced, leading to its atrophy and resulting in a high ratio of males to females (since males do not require as many nutrients).

Signaling Pathways

Resistance signaling often relies on salicylic acid (SA). For example, when the SA-degrading enzyme nahG is expressed in Mi-1 tomato roots, resistance is lost. Interestingly, while some R-genes require the EDS1 gene for signaling, Mi-mediated nematode resistance does not, suggesting that different Nem-R genes utilize distinct pathways.

The Evolution of Virulence

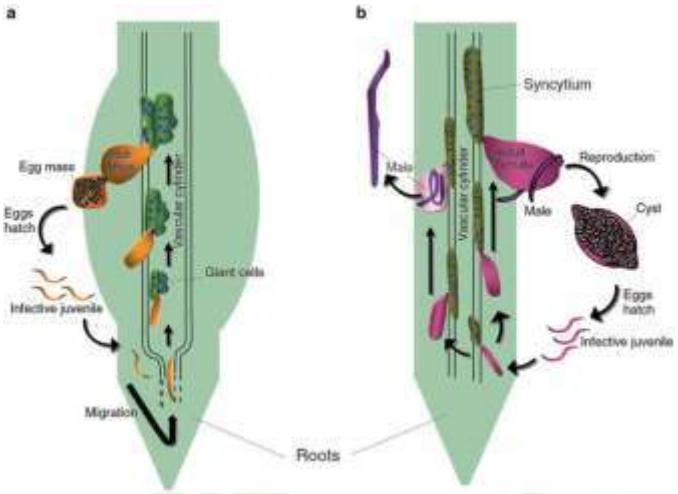
Nematode populations frequently develop virulence the ability to reproduce on hosts carrying specific R-genes. This can occur through the loss or modification of the nematode avirulence (Avr) gene product that the plant normally recognizes (Ernst *et al*., 1992). The search for these *Avr* genes is ongoing but difficult. Because root-knot nematodes often lack sexual reproduction, classical genetic crosses are impossible for many species. However, RNA interference (RNAi) has emerged as a powerful tool, allowing researchers to silence specific nematode genes to observe if they allow the pest to evade plant detection.

Future Perspectives: Transgenic Potential and Challenges

A primary goal of this research is the transfer of Nem-R genes to susceptible crop species. However, interspecific transfer has seen limited success. For instance, Mi-1 confers resistance in tomatoes but fails when moved to tobacco or *Arabidopsis*. This suggests that R-genes require specific "guard" proteins or signaling partners such as the tomato gene Rme-1, that may not be present in distantly related species (Blaxter *et al*., 1998). As genomic sequencing of nematodes like *Meloidogyne hapla* and *Globodera pallida* progresses, our ability to identify the molecular keys to this "battle underground" will only increase, paving the way for more durable and environmentally friendly crop protection (Blaxter *et al*., 1998).

The molecular characterization of plant-nematode interactions has revealed a sophisticated genetic "arms race" where Nem-R genes, such as the NBS-LRR class, trigger localized cell death to starve sedentary parasites. While these natural defenses offer a sustainable alternative to toxic nematicides, the emergence of virulent nematode strains and the complexity of interspecific gene transfer remain significant challenges. Functional tools like RNAi and advancing genomic sequencing of species like *M. hapla* are now essential for identifying the elusive nematode effectors that trigger these host responses. Ultimately, understanding the requirement for specific signalling co-factors like SA and Rme-1 is critical for successfully engineering durable resistan-

ce in diverse crop species. This ongoing research paves the way for a future where agricultural stability is maintained through the precise molecular fortification of the plants themselves.



Life cycle of (a) root-knot nematode and (b) cyst nematode (Abad and Williamson, 2010)

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Lotus Reimagined: A Sacred Bloom Blossoming into Sustainable Business

Deep S. Kuchhadiya, Nataraja K. D. and Ramachandra Naik M.

Introduction

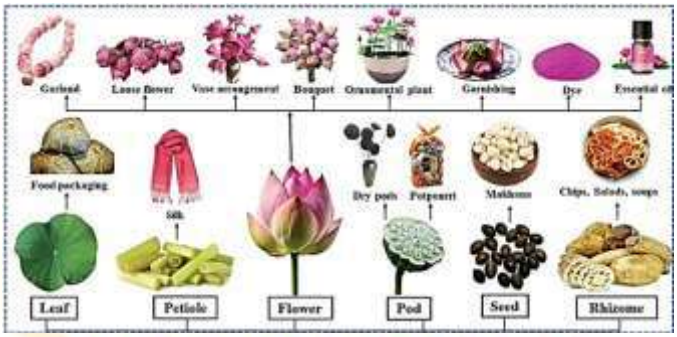
Nelumbo nucifera Gaertn., commonly referred to as Indian-lotus or Sacred lotus, is a member of the Nelumbonaceae family. Nelumbo is a solitary genus comprising two species, *Nelumbo nucifera* Gaertn. and *Nelumbo lutea* Pers. The plant lotus exhibits an extensive native distribution, spanning from central to northern India (Lin *et al*., 2019). Lotus is synonymously called Indian lotus, sacred lotus, Lakshmi lotus, Chinese-waterlily, oriental lotus, etc. A nation's national flower should reflect its culture, history, and legacy. It is intended to strengthen the nation's reputation abroad and contribute to maintaining the values that the country upholds. Lotus is India's national flower. It is a huge, perennial aquatic herb with robust, creeping rhizomes that are yellowish white in color. *Nelumbo nucifera* was given the Sanskrit name "Kamala" in ancient medical literature. There are two varieties: "Pundarika" or "sveta kamala," which have white flowers, and "Rakta Kamala," which have pink or reddish pink blossoms. The plant lotus has become popular because of the richness of biologically active secondary metabolites, notably anthocyanins and flavonols, found in flowers. Although it is native to South-East Asia, lotuses can be found all over the world in semi-tropical areas. Nelumbo may have originated in India, according to European botanist J. Gaertner. The term "Nelumbo," which originates from a location in Sri Lanka, supports this (Wang & Zhang, 2004). Fossils of this ancient flower date back 135 million years. The Puranas and Vedic literature make numerous references to it, notably the Mahabharata's description of a lotus with 1,000 Petals. Its links with several Hindu deities, including the Goddesses Lakshmi, Saraswathi, Kubera, and Vinayaka, underscore its spiritual value. The lotus, which represents eight fortunate symbols, is also highly esteemed in Buddhism and Jainism. Lotuses have long been used to decorate temple ponds for both decorative and religious reasons. Since the seventh century, its structure has served as an inspiration to artists, as seen by Mughal artwork and carvings found in the Ajanta and Ellora caves. Lotus flowers have a huge worldwide market in traditional regions. The sacred lotus is grown commercially for cut flowers in Thailand, Japan, and other South Asian nations. India, China, Vietnam, the Netherlands, Germany, Austria, Norway, Canada, Malaysia, Italy, Switzerland, and Australia are among the major

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nations that export lotus flowers.

Botanical Description

The lotus plant has various edible parts, such as leaves, stalks, flowers, seeds, seed pods, and rhizomes, each with its own significance and applications (Moro *et al*., 2013). The leaves are large, both aerial and floating, orbicular, 20-90 cm in diameter, abruptly acute to form a short tip, petiolate, entire glaucous, non-wettable, strong, cupped in the case of aerial leaves and flat in the case of floating ones, radiately nerved; the fresh leaves are leathery, but when they dry, they become nearly membranous and brittle, with brownish red blotching on the lower surface; the petioles of the aerial leaves are sturdy and erect. Lotus blooms are enormous, solitary, 10-25 cm in diameter, green or blackish green, rigid, sturdy, smooth, and have white, pink, or pinkish white scented peduncles that emerge from the rhizome nodes. They have sheathing at the base and are 1-2 cm long. The blooms, which have several petals and stamens in addition to four sepals, are solitary at the tips of lengthy stems. A slightly cone-shaped torus, 5-10 cm in diameter, with 10-30 carpers sunk into the upper surface, follows them. They are huge, 15-25 cm across, quite spectacular, and colored in various hues of pink. A collection of indehiscent nut-lets is called fruit. Ripe nutlets are roundish or oblong, ovoid, and up to 1.0 cm long by 1.5 cm wide. They have a hard, smooth, brownish or grayish black pericarp that is pedunculated, one-seeded, and somewhat longitudinally striated. The lotus flower, which is prized for its capacity to bloom in dirt without becoming discolored, represents purity and wisdom. This quality has always stood for the noble nature of a gentleman. Although this kind does not prioritize rhizome development and tends to generate substandard rhizomes, lotus blooms are differentiated by their fascinating single, double, or multipetalled blossoms, which enhance their ornamental attractiveness. With up to 1,000 documented varieties worldwide, they display a broad range of colors, including white, pink, yellow, red, and white petals with pink tips, adding to their visual diversity.



Market Potential

Lotus flowers have a huge worldwide market in traditional regions. The sacred lotus is grown professionally for cut flowers in Thailand, Japan, and other South Asian nations (Imsabai *et al*., 2010). India, China, Vietnam, the Netherlands, Germany, Austria, Norway, Canada, Malaysia, Italy, Switzerland, and Australia are among the major nations that export lotus flowers. The lotus extract market, which includes goods made from various lotus plant parts, is expected to grow at a compound annual growth rate (CAGR) of 8.6% from its 2023 valuation of USD 75.56 million to USD 134.62 million by 2030. India leads the world in lotus flower exports with 2,714 shipments, surpassing China with 1,753 shipments

and Vietnam with 605 shipments.

Commercial uses and application of lotus

Nutritional Uses: A very adaptable aquatic plant is the lotus. It has edible qualities in every section. According to reports, all varieties of lotus and their hybrids are edible. Rhizomes are used as a source of water, proteins, and carbs in a variety of Asian foods, including pickles, chips, and boiling meals. Additionally, they are greatly favored while making bread, port patties, and singju, a unique cuisine of vegetable combinations and salads from Manipur. Due to their lengthy shelf life and abundance of vital minerals, lotus seeds provide nutritional advantages. They provide a variety of gastronomic options, including popcorn, cookies, noodles, powdered foods for dry consumption, and bread (Dinkar and Mishra, 2020). The flower stamens are utilized to flavor tea, while the petals are used as garnishes, often floating in soups to add a touch of visual appeal. The detailed mineral and nutritional compositions of various parts of the lotus.

Pharmaceutical Uses: Numerous therapeutic and medical applications of lotuses have been discovered through traditional knowledge. In Ayurvedic traditional medicine, it holds a unique position. Lotus alkaloids, which are found in many parts of the lotus and have numerous potential applications, are mostly composed of 1-benzylisoquinolines, bisbenzyl isoquinolines and aporphines. It has been investigated for possible anticancer effects and used as a diuretic to alleviate inflammation. It is listed as an antidote to some poisons in the lexicon of Indian medicinal herbs. The flowers have been used to cure cholera, diarrhea, and blood problems. Due to their astringent qualities, fruits and seeds help prevent nerve diseases and hyperdipsia.

Textile and Paper Industries: Lotus stems are an important source for textiles and paper industry because of their high cellulose content. It's interesting to note that lotus fibers have cellulose that is comparable to cotton fibers (Pandey *et al*., 2020). The stems that are utilized to obtain fiber must be pink in color and devoid of flowers. Excellent qualities of these fibers include great moisture retention and low fineness. Thirty kilograms of stem can yield about 250 meters of silk thread. Lotus fiber fabrics are lightweight, soft, and fine, which makes them perfect for a variety of textile uses, especially in hygiene items.

Cosmetic Products: A valuable ingredient in many cosmetic products is lotus essential oil. Flowers are a popular choice for perfumes because of their fragrant qualities, which leads to expensive scents. It is widely used in the cosmetics and fragrance industries because to its distinctive perfume and medicinal qualities. Their skin-whitening and anti-wrinkle qualities make them useful as anti-aging products.

Ornamental uses: Lotus cut flowers are utilized in vase arrangements, floral bouquets, and other presentations. Its pods, seeds, and blossoms can all be used in traditional crafts. Lotus can be used in a variety of settings, including as residences, temples, and decorative gardens (Ali, 2003). It can be cultivated as a tiny potted plant, found in ponds and

pools, integrated into fountains, or shown as a special example. In South and Southeast Asia, flowers are especially popular for wedding décor during celebrations and ceremonies like Telangana, India's Bathukamma festival. The flower market makes significant profits as a result of this demand. The lotus is also a great option for water scaping projects because it grows well in lakes, ponds, marshes, and calm, shallow water.

Conclusion

Lotus is grown for its flowers, rhizomes, seedpods, and seeds. It is a diverse bio-resource that can be used in water treatment, medicinal, culinary, ornamental, and cosmetic applications. It has not gotten enough attention despite its potential, and more study is required to fully realize its potential. The goal of research should be to increase yield and weight while optimizing rhizome, flower, and seedpod growth in the shortest amount of time. It's also crucial to extend the flowering season with agronomic techniques or plant growth regulators. As demand increases in both local and international markets, increasing lotus production could give many agricultural communities in India sustainable incomes thanks to the country's abundance of wetlands.

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Disease-Free Crop for a Better Future

Sangita Sahni and Bishun Deo Prasad

Introduction

Agriculture is not only a source of livelihood for millions of farmers but also the foundation of food security and rural development. The success of farming largely depends on the health of crops grown in the field. When crops remain free from diseases, farmers obtain better yields, superior quality produce and higher profits. On the other hand, disease outbreaks can severely damage crops, reduce product-ivity and increase the cost of cultivation. In recent years, plant diseases have become more serious due to changing climatic conditions, irregular rainfall, rising humidity, and continuous cultivation of the same crops. Fungal, bacterial, viral, and nematode diseases affect cereals, pulses, oilseeds, vegetables, fruits, and ornamental crops throughout the country. Under favorable conditions, these diseases spread rapidly and sometimes destroy entire fields within a short period. Therefore, disease-free crop production has become one of the most important requirements for sustainable and profitable agriculture. Healthy crops not only improve farmer income but also contribute to food quality, environmental protection, and national agricultural growth.

Importance of Disease-Free Crops

A healthy crop performs better at every stage of growth. Disease-free plants absorb nutrients efficiently, tolerate environmental stress more effectively, and produce quality harvests. Farmers cultivating healthy crops spend less on pesticides and obtain better market prices.

The major benefits of disease-free crop cultivation include:

- ✓ Higher yield and better crop quality
- ✓ Increased income and reduced production losses
- ✓ Lower expenditure on plant protection chemicals
- ✓ Improved food safety and consumer health
- ✓ Reduced environmental pollution
- ✓ Better soil health and biodiversity
- ✓ Long-term sustainability in agriculture

Thus, maintaining crop health is essential not only for individual farmers but also for the overall agricultural economy.

Why Crop Diseases Occur?

Plant diseases develop when a susceptible crop, a disease-causing organism, and favorable environmental conditions occur together. Several farming practices and environmental factors encou-rage disease development.

Use of Infected Seeds: Poor-quality or infected seeds carry pathogens into the field and initiate dise-

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ase from the early growth stage.

Continuous Cropping: Growing the same crop repeatedly on the same land increases the buildup of disease-causing organisms in the soil.

Excessive Nitrogen Fertilization: Overapplication of nitrogen produces soft plant growth that becomes more vulnerable to diseases.

Waterlogging and Poor Drainage: Excess moisture and standing water create ideal conditions for fungal and bacterial diseases.

Climatic Changes: High humidity, fluctuating temperatures, and irregular rainfall patterns favor rapid multiplication and spread of pathogens.

Poor Field Sanitation: Infected crop residues, weeds, and volunteer plants act as sources of infection for future crops.

Measures for Disease-Free Crop Production

Use Healthy and Certified Seeds: Seed is the foundation of successful farming. Farmers should always use certified, disease-free, and good-quality seeds obtained from reliable sources. Healthy seeds ensure proper germination and reduce the chances of seed-borne diseases. Seed treatment with recommended fungicides or bioagents before sowing protects seedlings from early infection and improves plant establishment.

Grow Resistant Varieties: Cultivating disease-resistant varieties is one of the safest and most economical methods of disease management. Resistant varieties reduce crop losses and minimize dependence on chemical pesticides. Agricultural universities and research institutes have developed many improved varieties resistant to diseases such as rice blast, wheat rust, wilt in pulses, and viral diseases in vegetables.

Follow Crop Rotation: Crop rotation helps break the life cycle of pathogens and reduces disease buildup in the soil. Alternating cereals with legumes, oilseeds, or vegetables improves soil fertility and lowers disease incidence.

Maintain Balanced Nutrition: Balanced nutrient management is essential for healthy crop growth. Excessive fertilizer use, especially nitrogen, often increases disease susceptibility. Application of organic manures, compost, green manure, and bio-fertilizers improves soil structure and enhances beneficial microbial activity, which naturally suppresses harmful pathogens.

Proper Water Management: Proper irrigation management is crucial for disease prevention. Farmers should avoid over-irrigation and ensure proper drainage to prevent water stagnation. Methods such as drip irrigation reduce excess moisture on leaves and minimize disease spread.

Maintain Field Sanitation: Clean cultivation plays an important role in disease management. Diseased plants, infected plant parts, weeds, and crop residues should be removed and destroyed regularly. In horticultural crops, timely pruning of infected branches improves air circulation and reduces disease spread.

Timely Monitoring and Early Diagnosis: Regular field observation helps detect diseases at an early stage. Early diagnosis allows timely control before

severe damage occurs. Farmers should consult agricultural experts, Krishi Vigyan Kendras, or extension personnel whenever unusual symptoms appear in the field.

Adopt Integrated Disease Management

Integrated Disease Management (IDM) combines different disease control methods for effective and environmentally safe crop protection.

Important components of IDM

- ✓ Use of resistant varieties
- ✓ Seed treatment
- ✓ Crop rotation
- ✓ Balanced fertilization
- ✓ Proper irrigation and drainage
- ✓ Biological control agents
- ✓ Need-based chemical application
- ✓ Field sanitation and monitoring

IDM reduces excessive pesticide use and promotes sustainable agriculture.

Promote Biological Control: Biological control agents such as *Trichoderma*, *Pseudomonas*, and *Bacillus* species help suppress plant pathogens naturally. These beneficial microorganisms improve root health and enhance plant resistance. Biological methods are eco-friendly, economical, and safe for humans, animals, and the environment.

Use Chemicals Judiciously: Chemical pesticides should be used only when necessary and according to scientific recommendations. Indiscriminate pesticide use increases production cost and may lead to pesticide resistance and environmental pollution.

Farmers should always

- ✓ Use recommended pesticides and doses
- ✓ Follow proper spray schedules
- ✓ Avoid repeated use of the same chemical
- ✓ Use protective equipment during spraying
- ✓ Follow waiting periods before harvesting

Role of Farmers in Disease Management

Farmers are the first line of defense against crop diseases. Awareness, timely action and adoption of scientific practices are essential for maintaining healthy crops. Farmers should regularly participate in training programs, farmer fairs, and awareness campaigns organized by agricultural institutions. Keeping updated with weather forecasts and disease advisories can also help reduce crop losses. Collective action among neighboring farmers is equally important because many diseases spread rapidly from one field to another.

Contribution of Agricultural Scientists and Institutions

Agricultural scientists and research organizations play a vital role in ensuring disease-free agriculture. Their contributions include:

- ✓ Development of disease-resistant crop varieties
- ✓ Identification and monitoring of emerging diseases
- ✓ Farmer training and awareness programs
- ✓ Promotion of eco-friendly disease management technologies
- ✓ Development of climate-resilient farming practices

The combined efforts of scientists, extension workers, and farmers are essential for sustainable

crop protection.

Future of Healthy Crop Production

Modern agriculture is rapidly adopting advanced technologies for crop health management. Artificial intelligence, remote sensing, drones, mobile-based advisory systems, and precision farming tools are helping farmers identify diseases quickly and manage them more efficiently. Climate-smart agriculture, organic farming, and biological disease management approaches are expected to play a greater role in the future. Promoting environmentally friendly farming methods will help protect natural resources while ensuring food and nutritional security.

Conclusion

Disease-free crop production is the key to profitable, sustainable, and resilient agriculture. Healthy crops provide better yields, superior quality produce, higher farmer income, and safer food for society. Farmers can successfully reduce crop diseases by adopting scientific practices such as the use of healthy seeds, resistant varieties, balanced fertilization, proper irrigation, field sanitation, biological control and integrated disease management. A healthy crop ultimately leads to a healthy farmer, a healthy environment, and a stronger nation. Therefore, promoting disease-free agriculture is not only essential for today's farming but also for securing the future of coming generations.