E-ISSN: 2583-1755

# The Agriculture Magazine

VOLUME-5, ISSUE-11

JUNE 2026

A Monthly Peer Reviewed Magazine for Agriculture and Allied Sciences

https://theagricultureonline.com/

## Editor-in-Chief

**Dr. Vijay Bharti**

Professor (Agronomy)
Water Management Research Centre
Sher-e-Kashmir Universityof Agri. Sciences and Technology of Jammu
(U.T. of J&K)

## Associate Editor

**Dr. Umesh Singh**

Assistant Professor (GPB)
DKS College of Agriculture and Research Station, Alesur
Bhatapara, Chhattisgarh

## International Editor

**Dr. Bisheswar Prasad Yadav**

Director
Directorate of Agricultural Research
Province-2, Parwanipur, Bara
Nepal

## Editorial Board

**Dr. R. K. Singh**

Professor
Department of Agronomy
Institute of Agricultural Sciences
Banaras Hindu University, Varanasi
Uttar Pradesh

**Dr. A. V. Dahiphale**

Agronomist
Central Experimental Station
Wakawali, Dapoli
Ratnagiri, Maharastra

**Dr. Awani Kumar Singh**

Principal Scientist (Horticulture)
Centre for Protected Cultivation Technology (CPCT)
Indian Agricultural Research Institute
New Delhi

**Dr. R. P. Sharma**

Principal Scientist (Soil Science)
ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Bohara Ganeshji Road,
University Road, Udaipur, Rajasthan

**Dr. Sandeep Kumar**

Scientist (Seed Production)
University Seed Farm, Ladhowal
Punjab Agricultural University
Ludhiana

**Dr. Sunil Kumar Verma**

Assistant Professor
Department of Agronomy
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi, Uttar Pradesh

**Dr. Alok Kumar**

Senior Horticulture Officer
National Horticulture Board
Gurugram, Haryana

**Dr. O. P. Garhwal**

Professor
Department of Horticulture
SKNAU, Jobner, Rajasthan

**Dr. Prafulla Pralhadrao G.**

Associate Professor (Seed Pd. Officer)
AICRP-NSP-Breeder Seed Production
Unit, Central Demonstration Farm
Dr. PDKV, Wani Rambhapur
Akola, Maharastra

**Dr. Aniruddh Pratap Singh**

Assistant Professor-cum-Jr.
Scientist
Olericulture and Floriculture
Nalanda College of Horticulture
Noorsarai, Bihar

**Dr. Anuradha Saha**

Chief Scientist (Agronomy)
AICRP (Rice)
Division of Plant Breeding & Genetics
Sher-e-Kashmir Universityof Agri.
Sciences and Technology of Jammu

**Dr. Vikram Kumar**

Scientist-B
Central Silk Board, MESSO
P-3 Seed Station, Rompara
Resubelpara, North Garo Hills
Meghalaya

**Dr. Pravin Kumar Upadhyay**

Scientist
Division of Agronomy
ICAR- Indian Agricultural
Research Institute, New Delhi

**Dr. Vinay Pratap Singh**

Assistant Professor
Department of Plant Physiology
College of Agriculture, Ganj Basoda
JNKVV, Jabalpur

**Dr. A. L. Jat**

Assistant Research Scientist
Division of Agronomy
Oilseed Research Station, SDAU
Sardarkrushinagar, Palanpur
Gujarat

**Dr. Shruti Godara**

Scientist-B, Biotechnology
Forest Research Institute (FRI)
Dehradun, Uttarakhand

**Dr. Devi Lal Bagadi**

Plant Physiologist
AICRP on Arid Zone Fruits
SKN College of Agriculture
Jobner (Rajasthan)

**Dr. Kumari Sunita**

Assistant Professor
Department of Botany
Dean Dayal Upadhyay Gorakhpur
University, Gorakhpur (U.P.)

**Dr. Mukul Kumar**

Assistant Professor-cum-Jr Scientist
Department of Biochemistry & Crop
Physiology, M. B.A.C., Agwanpur
Bihar Agricultural University
Sabour

**Dr. Manish Kumar Singh**

Assistant Professor
Department of Vegetable Science
College of Horticulture,
Banda University of Agriculture and
Technology, Banda (U. P.)

**Dr. Kamlesh Meena**

Subject Matter Specialist
Krishi Vigyan Kendra (ICAR-IIVR)
Deoria, Uttar Pradesh

**Dr. Manoj Kumar Sharma**

Professor
Department of Plant Physiology
SKNAU, Jobner, Rajasthan

**Dr. Sanjeev Kumar**

Agricultural Economist
Department of Economics
and Sociology
College of Basic Sciences & Humanities
Punjab Agricultural University

**Dr. B. L. Dudwal**

Assistant Professor
SKN Agriculture University
Jobner, Jaipur (Rajasthan)

**Dr. Swarnali Duary**

Assistant Professor (Agronomy)
MS Swaminathan School of
Agriculture
Centurion University, Gajapati
Odisha

**Dr. Chenesh Patel**

Department of Entomology
GB Pant University of
Agriculture and Technology
Pantnagar, Uttarakhand

**Dr. Vinod Bhateshwar**

Assistant Professor (LPM)
Department of Agriculture
Vivekananda Global University
Jaipur (Rajasthan)

**Dr. Amit Kumar**

Assistant Professor (Entomology)
GLA University, Mathura
Uttar Pradesh

**Dr. Monalisa Sahoo**

Assistant Professor (Agronomy)
MS Swaminathan School of
Agriculture
Centurion University, Gajapati
Odisha

**Dr. Vikash Kumar**

Assistant Professor (Agronomy)
GLA University, Mathura
Uttar Pradesh

**Gaurav Singh Vishen**

Assistant Professor (Horticulture)
National PG College, Barhalganj
Gorakhpur, Uttar Pradesh

**Mr. Rahul Mishra**

Scientist
ICAR-IISS, Bhopal

**Dr. Arjun Lal Ola**

Assistant Professor (Vegetable Science)
Rani Lakshmi Bai Central
Agricultural University, Jhansi

**Dr. Vijaykumar**

Assistant Professor
Livestock Research and
Information Centre (Deoni)
Karnataka Veterinary, Animal
and Fisheries University, Bidar

**Mr. Avinash Kumar**

Research Scholar
Dr. Rajendra Prasad Central
Agricultural University, Pusa
Bihar

**Ms. Kawaljeet Kaur**

Assistant Professor (Soil Science)
CT Group of Intuitions
Jalandhar, Punjab

**Dr. Rajeev Kumar Srivastava**

Assoc. Professor-cum-Sr. Scientist
Agronomy, Dr. RPCAU, Pusa
Samastipur, Bihar

**Dr. Madhuri Arya**

Assistant Professor - cum - Scientist
PBG, Dr. RPCAU, Pusa, Dholi,
Muzaffarpur, Bihar

**Rahul Kumar**

Executive Officer
Quality Council of India
Ministry of Commerce and Industry

**Dr. Gauri Jairath**

Scientist, Livestock Products Tech.
ICAR-IVRI, Regional Station
Palampur, Himachal Pradesh

**Dr. Sarvan Kumar Khokhar**

Assistant Professor
Department of Agriculture
Sri Guru Teg Bahadur Khalsa
College, Anandpur Sahib Rupnagar,
Punjab

**Sudhir Mishra**

Assistant Professor
National P.G. College, Barhalganj
Gorakhpur, Uttar Pradesh

**Dr. Sanchit Thakur**

Assistant Professor (PBG)
MS Swaminathan School of
Agriculture
Shoolini University, Solan (H.P.)

**Dr. Dharminder**

Associate Professor (Agronomy)
PG College of Agriculture,
Dr. RPCAU, Pusa, Samastipur,
Bihar

**Dr. Mukesh Kumar Meena**

Scientist (SS) (Agril. Economics)
ICAR-IISWC, Dehradun
Uttarakhand

**Dr. Khusboo Raj**

Assistant Professor and Head
(Agril. Extension), National PG
College, DDUGU, Gorakhpur

**Dr. Deepak Gupta**

Assistant Professor (GPB)
SKN College of Agriculture
SKNAU, Jobner, Jaipur

**Abhishek Singh**

Scientist-B
Central Silk Board, MESSO
P-3 Seed Station, Nongpoh,
Meghalaya

## Founder and Managing Editor

**Dr. Kartikeya Choudhary**

Assistant Professor (Agronomy)
School of Agriculture
Galgotias University, Gr. Noida,
Uttar Pradesh

## Co-founder

**Dr. Anoop Kumar Devedee**

Assistant Professor
Division of Agronomy
DDU Gorakhpur University
Gorakhpur, Uttar Pradesh

## Content Editors

**Dr. Mehjabeen**

Department of Soil Science &
Agricultural Chemistry
Bihar Agricultural University
Sabour, Bhagalpur, Bihar

**Ms. Aparnna V.P.**

Department of Dairy Science and
Food Technology
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi, Uttar Pradesh

# Reviewers

| | |
|---|---|
| Dr. Ranjeet Singh Bochalya<br>Division of Agronomy<br>SKUAST-Jammu | Mrs. Manju Netwal<br>Department of Horticulture<br>SKN College of Agriculture, Jobner |
| Dr. Deepak Katkani<br>Mahyco | Mr. Om Prakash Jitarwal<br>Department of Horticulture<br>CCSHAU, Hisar, Haryana |
| Mr. Peeyush Kumar Jayaswal<br>Research Scholar<br>Birsa Agricultural University, Ranchi | Mr. Aakash<br>Research Scholar<br>Institute of Agricultural Sciences, BHU |
| Mr. Gaurav Prakash<br>Department of Soil Science and Agril. Chemistry<br>Agriculture University, Kota | Mr. Shankar Bijarnia<br>Research Scholar<br>SKRAU, Bikaner |
| Dr. Shivam Kumar Singh<br>Department of Horticulture<br>PG College, Ghazipur | Mr. Nitin Yadav<br>Research Scholar<br>Institute of Agricultural Sciences, BHU |
| Mr. Rajkumar Jakhar<br>Research Scholar<br>Institute of Agricultural Sciences, BHU | Mr. Kartik Madankar<br>Research Scholar<br>Institute of Agricultural Sciences, BHU |
| Mr. Mahendra Kumar<br>Research Scholar<br>JNKVV, Jabalpur | Mr. Ayush Bahuguna<br>Assistant Development Officer<br>Department of Horti. and Food Processing, Dehradun |
| DR. Atul Kumar Pachauri<br>Assistant Professor, SAGE University, Bhopal<br>Madhya Pradesh | Mr. Bhagchand Yadav<br>Department of Horticulture<br>SKRAU, Bikaner |
| Mr. Nanu Ram Sharma<br>Department of Entomology<br>SKRAU, Bikaner | Ms. Skikha Jain<br>Research Scholar, Division of Fruit Science<br>Indian Agricultural Research Institute, New Delhi |
| Mr. Dodiya Ravi Kumar Dhirubhai<br>Department of Entomology<br>Anand Agricultural University, Anand, Gujarat | Mr. Suresh Kumar Fagodia<br>Research Scholar, Department of Soil Science and Agricultural Chemistry, SKNAU, Jobner |
| Mr. Kanik Kumar Bansal<br>Research Scholar, Division of Agronomy<br>SKUAST-Jammu | Mr. Vijay Kumar<br>Research Scholar, Division of Agronomy<br>SKUAST-Jammu |
| Shesh Narayan Kumawat<br>AICRP-Weed Management, Division of Agronomy<br>SKUAST-Jammu | Pravallika Sree Rayanoothala<br>Department of Plant Pathology (Agriculture and Allied Sciences), CV Raman Global University, Bubaneswar, Odisha |
| Mr. Veerendra Kumar Patel<br>Research Scholar, Department of Soil Science<br>Mahatma Gandhi Chitrakoot Gramodaya University, Chitrakoot, Satna, Madhya Pradesh | Mr. Vishal Yadav<br>Research Scholar, Department of Extension Education<br>ANDUA&T, Kumarganj, Ayodhya, Uttar Pradesh |
| Anushi<br>Research Scholar, Department of Horticulture (Fruit Science), CSAUAT, Kanpur, Uttar Pradesh | Ganesh Ram<br>Research Scholar, Department of Horticulture,<br>RVSKVV, Gwalior, Madhya Pradesh |
| Mr. Satyabrata Sarangi<br>Research Scholar, Department of Agricultural Entomology, OUAT, Bhubaneswar, Odisha | Dr. Shani Gulaiya<br>Assistant Professor, School of Agriculture, Galgotias University, Greater Noida |

**Volume 5, Issue 11, June 2026**

**Monthly**
**ISSN: 2583-1755**

# The Agriculture Magazine

*A Monthly Peer Reviewed Magazine for Agriculture and Allied Sciences*

https://theagricultureonline.com/

Published by:
**The Agriculture Publication**

18, Keshav Nagar-1, Near Rajasthan Girls College,
Murlipura Scheme, Jaipur-302039
E-mail: info@theagricultureonline.com
Website: theagricultureonline.com

© **Author**

**Disclaimer:** The views expressed in the articles are those of the Authors/contributors and not necessarily of the Editor, editorial board and publisher. Editorial board invites original unpublished articles, case studies and success stories from all functional area of Agriculture and Allied Sciences. Authors/contributors are themselves responsible for any kind of Plagiarism found in their articles and any related issues. Also, it is assumed that the articles have not been published earlier and are not being considered for any other magazine/journal/book.

ISSN: 2583-1755
Volume : 5, Issue : 11
June, 2026
Publication Schedule : Monthly
All Correspondence Should be Address to
The Managing Editor
**Dr. Kartikeya Choudhary**
The Agriculture Magazine

# Our Partners

INDUS FOOD
AGRI-TECH

GriNext
Conference

India
Farm-Tech
AN EXHIBITION ON
FARMING TECHNOLOGY

AGRI
VIETNAM2025

# The Agriculture Magazine

***Volume 5, Issue 11, June 2026***

## CONTENTS


| SI. No. | Titles & Authors | Page No. |
|---|---|---|
| 1. | **Exploring Apple Gourd: Botanical Description and Health Benefits**<br>P. P. Sudharshan, M. Kalirajan and M. Rajasekar | 1-4 |
| 2. | **Medicinal, Agricultural and Production Aspects of Velvet Bean (*Mucuna pruriens*)**<br>Kaameshvaran A., Madhumitha C., Yeshwanth B. and Rajasekar M. | 5-7 |
| 3. | **Mulberry: The Forgotten Superfruit with High Nutritional and Economic Potential**<br>Kumari Madhumala and Karanjeev Kumar | 8-11 |
| 4. | **Drone Technology for Early Crop Disease Detection**<br>Vaibhav Dalvi, Omkar Gupta, Dattavir Deshmukh, Suchita Deshmukh, Gaytri Dhavale and Shivaji Dhule | 12-14 |
| 5. | **The Biology of Carbon Farming: How Tree-Crop Synergy Unlocks Soils Hidden Storage Potential**<br>Bitrus Samuel Gabakau and Kunal Narwal | 15-17 |
| 6. | **Sustainable Fibres, Sustainable Futures: Bamboo-Cotton Textiles and Youth Empowerment**<br>Rubi Pranjana Tamuli, Sangeeta Deo and Ranjana Kumari | 18-21 |
| 7. | **Climate-Smart Rice Cultivation for Sustainable Agriculture**<br>Yazhini Gunasekaran | 22-24 |
| 8. | **Biochar Enhances Soil Sustainability through Evidence-based Mechanisms and Practice**<br>Archika Awasare and Kiran Patel | 25-27 |
| 9. | **Metagenomics and Next-Generation Sequencing in Soil Microbiology**<br>Paghdar Priya P. and Harish V. | 28-31 |
| 10. | **AI-Based Crop Yield Prediction and Smart Irrigation: Emerging Trends in Agribusiness**<br>Devi Lal Jat and Rishab Modi | 32-36 |
| 11. | **Agronomic Innovations: A Pathway to Higher Farm Productivity and Profitability**<br>Laxman Navi, Atheek Ur Rehaman H. M. and Karthik A. N. | 37-41 |
| 12. | **Role of Pathogenesis-Related Proteins and PR-Like Proteins in Plant-Pathogen Interactions**<br>Jesima Barveen U. I., Sumitha S. and Vinodhini A. | 42-45 |
| 13. | **Reform Express in Agriculture & Rural Development: A New Push for Farmer-Centric Governance**<br>Snehalkumar A. Patel, Nital N. Patel, K. S. Shukla and Jatinkumar J. G. | 46-48 |
| 14. | **Carbon Nanodots: Tiny Particles, Mighty Potential for Sustainable Agriculture**<br>Kanishka, Vaibhav R. Chauhan and Rajender Sharma | 49-53 |
| 15. | **Bracing for El Niño 2026: Agricultural Risks and Solutions**<br>H. Uduwawala and B. A. I. S. L. Bandara | 54-58 |
| 16. | **Problematic Soils in Anantapur Region: Challenges and Management**<br>M. Kavitha and B. Usha Sri | 59-61 |
| 17. | **Comparative Assessment of Analytical Instruments Use in Pesticide Residue Laboratories**<br>Ajeet Singh, Ramgopal Dudwal, B. N. Sharma and Hansa K. Jat | 62-65 |
| 18. | **Nutrient Cycling in Agro-Ecosystems: Mechanisms, Benefits and Strategies for Sustainable Agricultural Systems**<br>Komal, Kanik Kumar Bansal and Gurpreet Kaur | 66-68 |
| 19. | **Compost Cow Manure: How to Use Cow Dung as an Organic Manure**<br>Bhavna Sharma, Devshree Panchbhai and Priya Satwadhar | 69-72 |
| 20. | **Newspaper-Wrapped Foods: Invisible Risks to Consumers - Behind a Common Practice**<br>Seuli Saha Roy, P. Kaushik, Anjay and Bhoomika | 73-77 |

# The Agriculture Magazine

***Volume 5, Issue 11, June 2026***


## CONTENTS


| SI. No. | Titles & Authors | Page No. |
|---|---|---|
| 21. | **Emerging Contaminants in Irrigation Water: Implications for Soil Health, Crop Productivity and Food Safety**<br>Ankan Ghosh and Harshita Joshi | 78-82 |
| 22. | **Namo Drone Didi Scheme for Women-Led Smart Agriculture**<br>Sabita Mondal, Arindam Sarkar and Nikhil Kumar | 83-86 |
| 23. | **A Sustainable Approach for Agricultural Waste Management: SAMARTH National Mission**<br>Narendra Yadav and Latika Shrama | 87-89 |
| 24. | **Corn Silk: Nature's Golden Threads of Wellness**<br>Swapna G., Mallikarjun N. and Shivakumar B. S. | 90-93 |
| 25. | **Eco-Friendly Farming Starts with Liquid Biofertilizers**<br>Archika Awasare | 94-99 |
| 26. | **Seed Microbiome Engineering for Crop Establishment**<br>Parkavan D. S., S. Ambika, R. Vedhanayagi and N. Priyadharshini | 100-102 |
| 27. | **Millets on the Rise: Why Ancient Grains are Shaping Modern Agriculture and Food Processing**<br>Karishma Verma | 103-110 |
| 28. | **Pulses for Prosperity: Pathways to a Stronger Pulse Sector in India**<br>M. J. S. L. Naga Durga, Manoj Kumar Dara and V. K. Choudhary | 111-114 |
| 29. | **Biofertilizers: Nature's Solution for Sustainable Agriculture**<br>Manish Raj and Anannya Roy | 115-116 |
| 30. | **Cryopreservation in Vegetable Crops**<br>R. Vedhanayagi, S. Ambika, M. Rajasekar and N. Priyadarshini | 117-119 |
| 31. | **Digital Innovations in Climate-Smart Agriculture**<br>Harshit Doda | 120-125 |
| 32. | **India's Move towards Pulse Sufficient Nation through Mission on Aatmanirbharta in Pulses**<br>Malagouda D. Patil, Amruta P. Barigal, Kumari Basamma and Siddalingareddy | 126-129 |
| 33. | **Sustainable Agriculture Development: Insights from Cow-Based Natural Farming Approach**<br>Ganga Devi, Pramod and J. P. Mishra | 130-132 |
| 34. | **Effect of Various Methods Adopted for Sustainable and Profitable Vegetable Production in Coastal Ecosystems**<br>K. Sha | 133-137 |
| 35. | **Potato Tuber Moth (*Phthorimaea operculella* Z.) Biology and IPM Approaches for Sustainable Potato Cultivation**<br>Prince Gond, Chandan Singh, Nandini Singh and Rutuja Gajanan | 138-141 |
| 36. | **Blue Ports Initiative**<br>Archana R. and Mahiwal Singh | 142-145 |
| 37. | **Flaxseed: A Sustainable Feed Alternative for Livestock**<br>Srashti Dixit | 146-151 |
| 38. | **Cluster Bean (Guar) Cultivation in Rajasthan**<br>Gharsiram and Priya Sharma | 152-154 |
| 39. | **Reproduction in Prokaryotes**<br>Vinodhini A., Jesima Barveen U. and Sumitha S. | 155-157 |
| 40. | **IoT-Based Smart Seed Storage System**<br>Yeshwanth B., Kaameshvaran A. and S. Ambika | 158-161 |

# The Agriculture Magazine

***Volume 5, Issue 11, June 2026***


## CONTENTS


| SI. No. | Titles & Authors | Page No. |
|---|---|---|
| 41. | **Climate Change Effects on Vegetable Seed Production and Viability**<br>Kaameshvaran A., Yeshwanth B. and S. Ambika | 162-165 |
| 42. | **High-Performance Liquid Chromatography: Principles, Instrumentation and Applications**<br>Akanksha | 166-168 |
| 43. | **Jeeraphool Rice: Reviving a Tribal Heritage through GI Recognition, Value Addition and Biodiversity Conservation**<br>Manoj Kumar Dara, Praveen Kumar Verma and M. J. S. L. Naga Durga | 169-174 |
| 44. | **Sea Buck Thorn: A Nutritional and Medicinal Powerhouse**<br>Anjali H. Patel, Sandip D. Ninama and Sunil K. Patel | 175-179 |
| 45. | **Microplastics and their Impact on Insect Biodiversity: A Hidden Threat to Ecosystem Sustainability**<br>Priyanka K. | 180-183 |
| 46. | **Black Gold Beneath Our Feet: The Role of Soil Organic Carbon in Productive Soils**<br>CH. Mounika, K. Sannihitha and M. Divya Tejaswini | 184-186 |
| 47. | **Ebola Virus Disease: A Global Public Health Threat**<br>Bhoomika, Anjay, Seuli Saha Roy, P. Kaushik and Vivek Kumar Naik | 187-189 |
| 48. | **Economic Impact of Insect Pests on Tomato Cultivation and their Management**<br>Raman Sankar, Premika Ramasamy, Lakshmanan Sankar, Selvaprabu Palanivel and Ajay Raja Anandhan | 190-192 |
| 49. | **Green Synthesis of Nanoparticles in Plant Stress Management and Growth Promotion**<br>P. V. S. Ramunaidu, Dharminder and Sunil Kumar | 193-197 |
| 50. | **Precision Pollination Technique for Vegetable**<br>Indulekshmi S., S. Ambika, S. Parvathy and D. S. Parkavan | 198-200 |
| 51. | **A Comparative Analysis of Agricultural Practices: India vs. the Czech Republic**<br>Debdipta Dolai | 201-203 |
| 52. | **From Farm to Plate: Can India Make Healthy Eating Affordable?**<br>Malavika Kashyap | 204-207 |
| 53. | **Nanotechnology in Soil Science: Transforming Nutrient and Soil Management**<br>Sharwan Lal Yadav | 208-211 |
| 54. | **Carbon Farming: Sustainable Agriculture for Climate Change Mitigation**<br>Shubham Singh | 212-215 |
| 55. | **Climate-Smart Agriculture: Building Resilient Cropping Systems for the Future**<br>Shubham Singh | 216-219 |
| 56. | **Cover Cropping: A Sustainable Strategy for Soil and Crop Management**<br>Shubham Singh | 220-223 |
| 57. | **Integrated Farming Systems: Diversifying Agriculture for Sustainability and Profitability**<br>Shubham Singh | 224-227 |
| 58. | **Smart Irrigation Technologies: Enhancing Water Use Efficiency in Agriculture**<br>Shubham Singh | 228-231 |
| 59. | **Biochar for Soil Improvement and Sustainable Crop Production**<br>Sharwan Lal Yadav | 232-235 |
| 60. | **Conservation Agriculture and Soil Health**<br>Sharwan Lal Yadav | 236-239 |

# The Agriculture Magazine

***Volume 5, Issue 11, June 2026***


## CONTENTS


| SI. No. | Titles & Authors | Page No. |
|---|---|---|
| 61. | **Natural Farming: Revitalizing Soil Health for Sustainable Agriculture**<br>Sharwan Lal Yadav | 240-243 |
| 62. | **Precision Nutrient Management: Enhancing Fertilizer Use Efficiency for Sustainable Agriculture**<br>Sharwan Lal Yadav | 244-248 |
| 63. | **Artificial Intelligence in Soil Science: Revolutionizing Soil Management and Decision-Making**<br>Vishal Kumar | 249-252 |
| 64. | **Digital Soil Mapping: Transforming Soil Assessment and Land Management**<br>Vishal Kumar | 253-256 |
| 65. | **Microplastics in Agricultural Soils: Emerging Challenges for Soil Health**<br>Vishal Kumar | 257-260 |
| 66. | **Regenerative Agriculture: Restoring Soil Health and Ecosystem Resilience**<br>Vishal Kumar | 261-264 |
| 67. | **Soil Carbon Sequestration: A Natural Solution for Climate Change Mitigation**<br>Vishal Kumar | 265-268 |
| 68. | **Identification of Suitable Linseed Varieties for Mid Hill Ecosystem**<br>Badapmain Makdoh, Letngam Touthang, Ampee Tasung and Rajesh Khan | 269-270 |
| 69. | **Requirement of Pulse Crops**<br>Namha Y. P., Kalal P. H. and Prajapati A. S. | 271-273 |
| 70. | **Artificial Intelligence as a Catalyst for Fruit Crop Production: Emerging Opportunities and Applications**<br>P. Swarnalatha and Potnuru Santosh Kumar | 274-277 |
| 71. | **Revolutionizing Food Safety: Sensor Technology in Spoilage Detection and Microbiological Assessment**<br>Judy Lalthanmawii, Rathod Rohit Kailasrao and Jainam Patel Nanubhai | 278-282 |
| 72. | **Climate Resilient Agriculture: Farming for a Changing Climate**<br>Nayana H. N., Shruthi G. S., Supriya M. E. and Dayanandanaik S. | 283-286 |
| 73. | **3D Food Printing Technologies and their Potential**<br>Lad P. A., V. P. Kad and G. M. Chavan | 287-293 |
| 74. | **Carbon Farming: An Emerging Strategy for Sustainable Crop Production and Climate Change Adaptation**<br>Anil Jakhar, Priyanka Choudhary, Rahul Jakhar and Nirmal Choudhary | 294-297 |
| 75. | **Regenerative Agriculture: A Sustainable Solution for Soil Degradation**<br>Muneshwar Prasad Mandal | 298-299 |
| 76. | **RNA Interference (RNAi): A Natural Mechanism of Gene Silencing**<br>Vishal D. Pawar and Kishor T. Thakare | 300-303 |
| 77. | **Strategies to Restore Soil Health for Sustainable Production**<br>S. Teja, V. Boomika, S. S Masaye, A. I. Patel and J. Devika | 304-307 |
| 78. | **Role of Marker-Assisted Selection in Pest Resistance**<br>Manisha Patel and Radheshyam Ramkrishna Dhole | 308-311 |
| 79. | **Genomic Selection Approaches in Crop for Pest Resistance Breeding**<br>Manisha Patel and Radheshyam Ramkrishna Dhole | 312-315 |
| 80. | **Application of RNA Interference Technology in Plant Breeding for Insect Pest Suppression**<br>Manisha Patel and Radheshyam Ramkrishna Dhole | 316-319 |

# The Agriculture Magazine

***Volume 5, Issue 11, June 2026***


## CONTENTS


| SI. No. | Titles & Authors | Page No. |
|---|---|---|
| 81. | **Breeding Climate-Resilient Crops with Pest Resistance Traits**<br>Manisha Patel and Radheshyam Ramkrishna Dhole | 320-323 |
| 82. | **The Nutritional Powerhouse: Exploring the Benefits of Black Rice**<br>Gurpreet Kaur, Kanik Kumar Bansal and Komal | 324-327 |
| 83. | **Urban Fruit Gardening and Terrace Orchards: Bringing Nature Back to City Life**<br>G. Bhrijavasi and P. Vinaya Kumar Reddy | 328-330 |
| 84. | **Precision Irrigation Scheduling: A Pathway to Higher Water Use Efficiency in Rice-Wheat Cropping**<br>Navjot Kaur and Neha Kumawat | 331-334 |
| 85. | **Transcriptomics: A New Era of Vegetable Crop Improvement**<br>Teja S., S. S. Masaye and A. I. Patel | 335-338 |
| 86. | **Chemical Diversity and Medicinal Potential of Millipede Defensive Secretions**<br>Yashwant Patne and Ravi Barde | 339-344 |
| 87. | **Jammu & Kashmir's Rural Innovation: Defining Agritech- Entrepreneurship-Scope, Challenges & Opportunities**<br>Tabasum Mushtaq, Mushtaq Ahmad Lone and Jameel Ahmad Khan | 345-350 |



https://theagricultureonline.com/

# Exploring Apple Gourd: Botanical Description and Health Benefits

**P. P. Sudharshan, M. Kalirajan and M. Rajasekar**

## Introduction

Apple gourd (*Praecitrullus fistulosus*) locally known as round gourd, tinda or Indian baby pumpkin is a favourite cucurbit vegetable grown extensively in India and some other South Asian countries. Valued for its tender fruits, mild flavour and excellent nutritional qualities. The crop is well adapted to tropical and sub-tropical climates and can be successfully grown in open fields, kitchen gardens and in protected cultivation systems. Apple gourd fruits are a good source of water, dietary fibre, vitamins and minerals and are a great part of a healthy diet. Regular consumption can aid hydration, digestion and general wellbeing. The soft fruits are often used in many culinary dishes such as curries, stir fries and stuffed vegetable dishes. Apple gourd is short duration crop having good market demand and attractive economic returns from agriculture point of view. It is adaptable to different environmental conditions and shows good response to improved cultivation practices which makes it a preferred choice of vegetable growers. Apple gourd is gaining its importance as a nutritious, profitable and versatile vegetable crop due to growing consumer awareness about healthy eating and sustainable farming.

## Scientific classification

Kingdom: Plantae

Order: Cucurbitales

Family: Cucurbitaceae

Genus: Praecitrullus

Species: *P. fistulosus*

## Botanical Description

Apple gourd is an annual, warm-season vegetable crop characterized by a vigorous creeping or trailing vine grow up to a height 3 m long.

**Seed:** Seeds are cream-coloured to pale yellow, flat, oval and smooth. They are enclosed within the fleshy pulp of the fruit. Mature seeds possess a hard seed coat and retain viability for several years under proper storage conditions.

**Leaves:** The leaves are simple, alternate, petiolate and broadly cordate to orbicular in shape. They possess 3-5 shallow lobes with serrated margins. Leaves are dark green, photosynthetically active and arranged alternately along the stem. The petiole is long and cylindrical structure. The leaf measures from 8-15 cm length.

**Flower:** Apple gourd is monoecious, producing separate male and female flowers on the same plant. The flowers are solitary, bright yellow and axillary.

**P. P. Sudharshan and M. Kalirajan**
M.Sc. Scholar, Department of Vegetable Science, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu

**M. Rajasekar**
Assistant Professor, Department of Vegetable Science, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu

Male flowers are more numerous and borne on long stalks, while female have an inferior ovary at the base. Pollination is mainly carried out by bees and other insects.

**Fruit:** The fruit is a round to slightly flattened pepo, light green in color with a smooth, tender rind. It contains soft white flesh and numerous seeds. Fruits are harvested at the immature stage for vegetable use and typically measure 5-10 cm in diameter.

## Value-added products of Apple Gourd

Apple gourd (tinda) can be processed into several value-added products to enhance shelf life, market value and consumer acceptance.

### Fresh and Culinary Products

- ✓ Frozen apple gourd slices
- ✓ Apple gourd curry mix
- ✓ Dehydrated apple gourd flakes

### Commercial Products

- ✓ Apple gourd pickle
- ✓ Dried chips
- ✓ Dehydrated apple gourd powder

### Health and Functional Products

- ✓ Apple gourd juice
- ✓ Vegetable smoothie blends
- ✓ Dietary fiber supplements

### Convenience Products

- ✓ Apple gourd-based soup
- ✓ Vegetable cutlets and patties
- ✓ Extruded snack products

**Nutritional Value:** Nutritional value of Apple gourd (*Praecitrullus fistulosus)* per 100 g is given in Table 1 (Source: Yadav *et al*., 2015).

**Table 1: Nutritional value of Apple gourd**

| | |
|---|---|
| Carbohydrates | 12.5 (g) |
| Energy | 15-21 kcal |
| Protein | 2.0 (g) |
| Fat | 3.9 (g) |
| Fibre | 0.6 (g) |
| Calcium | 66.3 (mg) |
| Iron | 1.03 (mg) |
| Magnesium | 28.1 (mg) |
| Vitamin C | 27.5 (mg) |
| Thiamine ($B_1$) | 0.04 (mg) |
| Riboflavin ($B_2$) | 0.08 (mg) |
| Niacin ($B_3$) | 0.3 (mg) |

### Health benefits

**Promotes Hydration:** Apple gourd contains approximately 94% water, which helps maintain body hydration, regulate body temperature and support normal physiological functions.

**Supports Digestive Health:** The dietary fibre present in apple gourd aids digestion, promotes regular bowel movements and helps prevent constipation.

**Aids Weight Management:** Being low in calories (about 21 Kcal per 100 g) and high in water content, apple gourd is an excellent food for weight-control and calorie-conscious diets.

**Rich in Antioxidants:** Apple gourd contains vitamin C and carotenoids, which help neutralize free radicals, reduce oxidative stress and protect cells from damage.

**Supports Heart Health:** The presence of potassium helps regulate blood pressure, maintain electrolyte balance and support normal cardiovascular function.

**Enhances Immune Function:** Vitamin C contributes to improved immune response and helps the body defend against infections and diseases.

**Beneficial for Diabetic Diets:** Its low calorie and moderate carbohydrate content make apple gourd a suitable vegetable for inclusion in balanced diabetic meal plans.

**Supports Bone Health:** Apple gourd provides minerals such as calcium, phosphorus and magnesium, which are important for maintaining healthy bones and teeth.

**Improves Skin Health:** The antioxidant vitamins present in the fruit help support healthy skin by reducing oxidative damage and promoting tissue repair.

## Conclusion

Apple gourd (*Praecitrullus fistulosus*) is a nutritious and versatile cucurbit vegetable crop, which is appreciated for its tender fruits, high water content and rich nutritional composition. Easy to cultivate, adjustable to different agro-climatic conditions and gives good economic return to the farmers. Its fruits are low in calories and are an excellent source of vitamins, minerals, dietary fibre and antioxidants that are beneficial to human health and well being. Besides fresh consumption, apple gourd has an immense potential for value addition in the form of pickles, dehydrated products, powders, soups and other processed foods. Apple gourd (*Lagenaria siceraria*) is an important vegetable crop for sustainable agriculture, food security and nutritional improvement because of its nutritional, medicinal and commercial importance.

## References

Longvah, T., Ananthan, R., Bhaskarachary, K. and Venkaiah, K. (2017). Indian food composition tables (IFCT 2017). National Institute of Nutrition, Indian Council of Medical Research.

National Institute of Nutrition. (2024). Dietary guidelines for Indians: A manual. Indian Council of Medical Research-National Institute of Nutrition.

Kumar, S., Singh, B. and Sharma, A. (2020). Nutritional quality and health benefits of cucurbitaceous vegetables. *International Journal of Vegetable Science*, 26(5): 420-432.

Mageshwaran, V., Sangeetha, P. and Karthikeyan, R. (2021). Advances in processing and value addition of vegetable crops for enhanced nutritional security. *Journal of Food Processing and Preservation*, 45(8): e15632.

United States Department of Agriculture, Agricultural Research Service. (2025). *FoodData Central*. Retrieved from https://fdc.nal.usda.gov

Yadav, R. K. and Ram, H. H. (2015). Nutritional and medicinal value of tinda (*Praecitrullus fistulosus*). In: Cucurbit Research and Development. New Delhi: Indian Agricultural Research Institute.

# Medicinal, Agricultural and Production Aspects of Velvet Bean (*Mucuna pruriens*)

**Kaameshvaran A., Madhumitha C., Yeshwanth B. and Rajasekar M.**

## Introduction

Velvet Beans are consumed as a vital part of daily living by indigenous tribes around the world. It is still used as a replacement for

coffee in Central America and as a main stay in some Guatemalan regions' traditional cuisines. Additionally, the beans are quite well-liked in India and Southeast Asia. Actually, *Mucuna Pruriens* is used in almost every tropical culture on the planet, whether as food, medicine, or decoration. However, when consumed as food, the velvet beans go through a unique process that eliminates a lot of their psychoactive ingredients because high dosages can have unintended consequences. The *Mucuna pruriens* plant's velvet beans are a good source of protein for vegetarians because they are high in amino acids even without these substances. Most regions of the tropics are home to the twining annual leguminous vine known as velvet bean (*Mucuna pruriens* var. *utilis*), or simply Mucuna. It only grows during the rainy season and dies when the winter season arrives. It features long, robust twining stems that, depending on growing conditions, can reach a length of two to three meters, as well as big trifoliate leaves, or leaves with three leaflets.

**Other Names of Velvet Bean:** Kaunch or Kevanch (Hindi), Poonaikali (Tamil), Nasukunni (Kannada), Naikorana (Malayalam), and Dulagondi (Telugu)

**Plant Description:** Among the 100 species of climbing vines and shrubs in the Leguminosae family is genus Mucuna. The word “mucunã” is the source of the genus name. In the tropics, *Mucuna pruriens* is a common fodder plant. The long tendrils of this annual climbing shrub can reach a length of more than 15 meters. Most of it is covered with delicate hairs, but it almost completely loses its hair as it ages. The extract of M. in methanol. Pruriens demonstrated anti-Xanthomonas action. Additionally, it exhibited strong antifungal action against other plants and fungus like *Fusarium oxysporum* also harming fungus. *Mucuna pruriens* root and seed extracts have a strong capacity to prevent the development of dangerous bacteria and fungus, which makes them potential natural remedies for human ailments as well as flora. Additionally, studies on *Mucuna pruriens* leaves have revealed noteworthy antibacterial action by the inhibition of certain microbes.

**Common names:** Cowitch, Cowhage, Velvet Bean, Cow-itch, Buffalo bean, velvet bean, mucuna, nescafe, pode mico, fava-coceira, cabeca-de-frade,

**Kaameshvaran A., Madhumitha C., Yeshwanth B. and Rajasekar M.**
Department of Vegetable Science, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu

cowage, cowhage, cow-itch, Bengal bean, Mauritius bean, itchy bean, krame, picapica, chiporro, buffalo bean.

**Medicinal Uses:** The velvet bean is a great fertilizer, but it has many additional uses. It has been utilized globally for both human and animal consumption as food and medicine. Velvet Bean (*Mucuna pruriens*) is a traditional plant that has been used for centuries in the traditional medicine, particularly Ayurveda, to promote men's health and vitality. One of its most famous advantages is that it can help to promote testosterone production by natural means. The seeds of the velvet bean have L-DOPA, which aids in enhancing levels of dopamine in your own brain. Dopamine not only lifts one's mood, but also helps stimulate the release of hormones that tell the body to produce more testosterone. This plant can be beneficial for men with low testosterone levels or those suffering from fertility problems by boosting hormone levels, increasing sperm count and improving sexual health. It is also a potent antioxidant that guards the testicles and sperm cells from damage due to stress or toxins. Most people who take velvet bean report increased energy, mood and libido signs of healthy testosterone function. Being a natural herb, velvet bean is most widely featured in food supplements for men's reproductive health. It's necessary to use it in a limited form, as too much L-DOPA can cause undesirable side effects like nausea or restlessness. When used properly, velvet bean naturally helps support a balance of hormones, fertility, and general male health.

**Antimicrobial activity:** Uses of the solvents such as Extracts from *Mucuna pruriens* roots and seeds, such as petroleum and hexane, have been tested against a number of harmful bacteria, such as *Staphylococcus, Bacillus subtilis, Escherichia coli, and Pseudomonas aeruginosa, Klebsiella pneumonia* with *E. coli. Notably, Bacillus* showed a clear zone of inhibition of about 18 mm. These extracts use selective toxicity to target DNA and RNA synthesis, which prevents the bacteria from growing and multiplying. *M. pruriens'* methanolic extract demonstrated efficacy against *Xanthomonas campestris*. With the exception of *Candida albicans*, all studied microorganisms were inhibited in growth to varied degrees by the methanol extract. Strong antibacterial activity was shown against *Proteus mirabilis* NCIB 67, *B. subtilis* NCTC 8263, *E. coli* NCTC 10418, *S. aureus* NCTC 6571, and *Bacillus aeruginosa* ATCC 10145. To identify the active ingredients causing the antibacterial action, more research is advised.

**Antivenom property:** It has been examined whether the seed extract from *M. pruriens* can mitigate the effects of venom from some snakes, such as kraits and cobras. The extract assisted in neutralizing the poisons when administered to rats prior to their exposure to cobra venom. Minimizing negative consequences such as organ damage and death. *Mucuna pruriens* extract stopped the liver and heart from being harmed when rats were given cobra venom injections. Other organs were unaffected by the venom. In vitro experiments demonstrated that

*Mucuna pruriens* extract could lessen the negative effects of cobra and krait venom, demonstrating its capacity to shield creatures from the venom of snake bites.

**Anti-diabetic activity:** The use of complementary medicine has increased dramatically in recent years, and the WHO has advised assessing the potential of plants as potent medicinal agents, especially in areas where access to current drugs is limited. There is notable antidiabetic action in the aqueous extract of *Mucuna pruriens* seeds. The aqueous extract dramatically lowered blood sugar levels in rats with high blood sugar, which is brought on by streptozotocin. Oral administration consequently, within two hours of ingesting the extract, blood sugar levels in normal rats decreased from approximately 127 mg% to 75 mg% following a glucose load. After 21 days of daily therapy, blood sugar levels in rats given streptozotocin decreased from about 250 mg% to 90 mg%. According to the study, one of the main causes of *Mucuna pruriens* seeds' antidiabetic effects may be their high dietary fiber content.

## Production Technology of Velvet Bean

**Climate:** The velvet bean grows in hot, humid climates with extended growing seasons and between 650 and 2,500 mm of annual precipitation. Long dry spells won't harm it, especially if it's established early in the growth season.

**Soil:** A variety of soil types, including sandy soils that are generally unproductive, are suitable for velvet bean growth.

## Cultivation Practices

**Land preparation:** The crop does not need a lot of land preparation because of its big seeds.

**Fertilizer and lime requirements:** To promote nodulation and effective fertilizer utilization, 500-700 kg $ha^{-1}$ of lime preferably dolomitic lime should be applied to sandy soils.

**Harvesting time and yield estimates:** Typically, mucuna is only picked once during the growing season, at 50% booting, for hay production. Usually, its blossoms are hidden beneath the leaf canopy. Short days and cooler nighttime temperatures (21$^{o}$C ) cause flowering to begin in early March. Farmers prefer to harvest it when the pods are dry and mature because of its high grain feeding value and abundant seeding potential. Together with the pods, they can next collect the leftover leaves.

## References

Athiba, A. (2025). Medicinal Uses of *Mucuna Pruriens*-Velvet Beans: A Review of its Therapeutic Potential. *International Research Journal of Modernization in Engineering Technology and Science*, 7(01): 3453-3457.

Lucia Raffaella, *et al.* (2012). The Magic Velvet Bean of *Mucuna pruriens*. Lampariello *Journal of Tradtional and Complementary Medicine*, p. 331.

Antiparkinson Murali, Dhanasekaran, K., Tharakan, B. and Bala V. Manyam. (2006). *Phytotherapy Research*, p. 6

# Mulberry: The Forgotten Superfruit with High Nutritional and Economic Potential

**Kumari Madhumala and Karanjeev Kumar**

## Introduction

Mulberry (*Morus* spp.) is traditionally known as the primary food source of silkworms, but in recent years its delicious and highly nutritious fruits have attracted considerable attention from farmers, consumers, and food-processing industries. Rich in vitamins, minerals, antioxidants, and anthocyanins, mulberry fruits are increasingly recognized as a valuable functional food. With proper cultivation practices, mulberry can become a profitable fruit crop for small and marginal farmers.

**A Fruit with a Rich History:** Mulberry has been cultivated for thousands of years across Asia, Europe, and North America. Ancient civilizations valued the fruit not only for its pleasant taste but also for its medicinal properties. In traditional systems of medicine, mulberry fruits were used to improve blood circulation, enhance immunity, and support overall well-being.India is home to several species of mulberry, including white mulberry (*Morus alba*), black mulberry (*Morus nigra*), and red mulberry (*Morus rubra*). While the leaves gained prominence because of their importance in silk production, the fruits remained largely confined to home gardens and local markets.

Today, changing consumer prefer-ences and grow-ing awareness about healthy foods are creating new opportunities for this neglected fruit crop.

**Nature's Colourful Gift:** Mulberry fruits resemble elongated berries and undergo a fascinating transformation during ripening. Initially green, they gradually turn pink, red, and finally deep purple or black depending on the variety. The attractive colour of ripe mulberries is not merely aesthetic. It is due to the presence of anthocyanins, powerful antioxidant pigments that help protect human cells from oxidative stress. These natural compounds are also responsible for the fruit's increasing popularity among nutritionists and food processors. A fully ripe mulberry offers a unique blend of sweetness and mild acidity, making it enjoyable as a fresh fruit as well as a processed product.

**A Nutritional Powerhouse:** Despite its small size, mulberry is exceptionally rich in nutrients. The fruits contain appreciable quantities of vitamin C, iron, potassium, calcium, dietary fibre, and various bioactive compounds. Researchers have reported that mulberry fruits are abundant in:

- ✓ Anthocyanins
- ✓ Flavonoids
- ✓ Phenolic compounds
- ✓ Resveratrol

**Kumari Madhumala and Karanjeev Kumar**
Department of Horticulture (Fruit Science), Nalanda College of Horticulture, Noorsarai, Nalanda, Bihar

- ✓ Natural sugars
- ✓ Organic acids

These compounds are associated with numerous health-promoting effects, including antioxidant, anti-inflammatory, anti-diabetic and cardioprotective activities. In an era where consumers actively seek foods that offer health benefits beyond basic nutrition, mulberry fits perfectly into the category of functional foods.

**Climate Requirement:** Mulberry is highly adaptable and can be cultivated under a wide range of climatic conditions. The crop grows successfully in tropical, subtropical, and temperate regions. However, warm and moderately humid conditions favor vigorous growth and fruit production. An optimum temperature range of 24-30°C is considered ideal for vegetative growth and fruit development. The plant can tolerate moderate drought but performs best under adequate soil moisture.

**Soil Requirement:** Mulberry thrives in fertile, deep, well-drained loamy soils rich in organic matter. Sandy loam to clay loam soils with good water-holding capacity are considered ideal. The optimum soil pH ranges between 6.2 and 7.5. Waterlogged and highly saline soils should be avoided, as they adversely affect root growth and fruit yield.

**Selection of Varieties:** The choice of variety plays an important role in determining fruit quality and yield. Some promising fruit-bearing mulberry varieties include:

- ✓ White Mulberry (*Morus alba*)
- ✓ Black Mulberry (*Morus nigra*)
- ✓ Red Mulberry (*Morus rubra*)
- ✓ Kokuso varieties
- ✓ Local superior genotypes with large and sweet fruits

Farmers should select varieties based on local climatic conditions, fruit quality and market demand.

**Propagation**

Mulberry can be propagated through:

**Hardwood Cuttings:** This is the most common and economical method.

- ✓ Select healthy shoots of 8-12 months age.
- ✓ Prepare cuttings of 18-22 cm length containing 3-4 buds.
- ✓ Plant cuttings in nursery beds during winter or early spring.

**Other Methods:** Air layering, Ground layering, Grafting, Tissue culture. Vegetative propagation ensures true-to-type plants and early fruiting.

**Land Preparation:** The field should be thoroughly ploughed 2-3 times to obtain a fine tilth. All weeds, stones, and crop residues should be removed. Before planting, incorporate 15-20 tonnes of well-decomposed farmyard manure per hectare into the soil to improve fertility and soil structure.

**Planting:** Planting is generally carried out during the monsoon season.

**Spacing:** For fruit production:

- ✓ 4 m × 4 m spacing under normal conditions
- ✓ 5 m × 5 m spacing for vigorous varieties

This spacing allows proper canopy development, sunlight penetration, and convenient orchard operations.

**Pit Preparation:** Dig pits of 60 cm × 60 cm × 60 cm. Fill the pits with: Topsoil, 15-20 kg FYM, 1 kg vermicompost, 100 g neem cake. Plant the saplings and irrigate immediately after planting.

**Nutrient Management:** Mulberry responds well to organic and inorganic fertilizers.

**Organic Manure**

Apply: 15-20 kg FYM per plant annually. Organic manures improve soil health, microbial activity, and fruit quality.

**Fertilizer Schedule:** For bearing trees:

- ✓ Nitrogen (N): 150-200 g $tree^{-1}$ $year^{-1}$
- ✓ Phosphorus ($P_2O_5$): 100 g $tree^{-1}$ $year^{-1}$
- ✓ Potassium ($K_2O$): 100-150 g $tree^{-1}$ $year^{-1}$

The fertilizers should be applied in two equal splits:

- ✓ Before flowering
- ✓ After fruit harvest

Micronutrients such as zinc and boron may be applied if deficiencies are observed.

**Irrigation Management:** Young plants require regular irrigation for establishment.

**Irrigation Frequency**

Summer: Every 7-10 days

Winter: Every 15-20 days

Rainy season: As required

Drip irrigation is highly recommended because it:

- ✓ Saves water
- ✓ Improves nutrient-use efficiency
- ✓ Enhances fruit yield and quality

Mulching around the tree basin further conserves soil moisture.

**Training and Pruning:** Proper training and pruning are essential for maintaining tree shape and improving fruit production.

**Training:** Maintain a single stem up to 60-80 cm height and allow 3-4 primary branches to develop.

**Pruning:** After harvest:

- ✓ Remove dead, diseased and crossing branches.
- ✓ Thin over crowded shoots.
- ✓ Maintain an open canopy for better light penetration.

Annual pruning encourages new shoot emergence, where most fruiting occurs.

**Weed Management:** Keep the orchard weed-free, particularly during the first three years. Methods include: Manual weeding, Mulching, Inter-cultivation, Cover crops. Organic mulches such as straw, dry leaves, and crop residues effectively suppress weeds and conserve moisture.

**Flowering and Fruiting:** Mulberry flowers are generally produced during spring. Fruit development occurs rapidly, and harvesting usually begins 4-6 weeks after flowering. Depending on the variety and climate, harvesting may continue for several weeks.

**Harvesting:** Mulberry fruits are highly delicate and should be harvested carefully. Harvest fruits when: Fully coloured, Soft, Sweet, Easily detachable from the stalk. Harvesting is usually carried out manually during the early morning hours. Frequent picking at 2-3-day intervals ensure better fruit quality.

**Yield:** A well-managed mulberry orchard starts bearing fruits within 2-3 years after planting. Average fruit yield: Young orchard: 3-5 tonnes $ha^{-1}$, Mature orchard: 8-12 tonnes $ha^{-1}$.

Superior varieties under intensive management can produce even higher yields.

**Post-Harvest Management:** Mulberry fruits are highly perishable and should be marketed or processed immediately after harvest. Value-added products include: Juice, Squash, Syrup, Jam, Jelly, Wine, Vinegar, Ice cream and dried mulberries. Processing helps reduce post-harvest losses and increases profitability.

## Conclusion

Mulberry possesses immense potential as an underutilized fruit crop. Its adaptability, nutritional richness, medicinal value, and suitability for value addition make it an attractive option for diversification in fruit production systems. By adopting scientific cultivation practices and developing efficient marketing channels, mulberry can emerge as a profitable fruit crop for the future while contributing to nutritional security and rural livelihoods.

# Drone Technology for Early Crop Disease Detection

**Vaibhav Dalvi, Omkar Gupta, Dattavir Deshmukh, Suchita Deshmukh, Gaytri Dhavale and Shivaji Dhule**

## Introduction

Drone technology is playing an important role in modern agriculture by helping farmers monitor crop health and detect diseases at an early stage. Traditional methods of crop inspection require more labour, time, and cost, whereas drones can quickly survey large agricultural fields with high accuracy. These drones are equipped with advanced technologies such as RGB cameras, thermal sensors, multispectral sensors, GPS systems, and imaging tools that capture real-time data and images of crops. By analysing these images, farmers can identify unhealthy plants, nutrient deficiencies, water stress, and disease symptoms before they spread across the field. Early disease detection helps farmers take timely preventive measures, reducing crop losses and improving crop productivity. Drone technology also supports precision farming by reducing excessive use of pesticides, fertilizers, and water resources. In recent years, the use of agricultural drones has increased due to their efficiency, speed, and ability to improve decision-making in farming practices. Although challenges such as high cost, limited battery life, and weather dependency exist, drone technology has become a valuable tool for sustainable agriculture and smart farming systems.

## Key Components of Early Crop Diseases Detection System

**Drone Frame:** The drone frame is the main body that supports all components such as motors, sensors, cameras, and batteries. It is designed to be lightweight and durable for stable flight.

**Propellers and Motors:** Motors rotate the propellers to lift and control the drone. These components help the drone fly smoothly over agricultural fields for monitoring crops.

**Flight Controller:** The flight controller acts as the brain of the drone. It controls flight movement, balance, navigation, and communication between different components.

**GPS System:** The GPS system helps the drone navigate accurately and map agricultural fields. It enables precise monitoring and automatic flight paths.

**RGB Camera:** RGB cameras capture normal color images of crops. These images help identify visible disease symptoms, damaged plants, and crop conditions.

**Multispectral Sensors:** Multispectral sensors capture images using different light wavelengths. They help detect crop stress, nutrient deficiencies, and diseases that are not visible to the human eye.

**Vaibhav Dalvi, Omkar Gupta, Dattavir Deshmukh, Suchita Deshmukh, Gaytri Dhavale and Shivaji Dhule**
College of Agricultural Engineering and Technology (CAET), VNMKV, Parbhani, Maharashtra

Fig.1 Real-Time Crop Monitoring using Drone

**Battery System:** The battery supplies power to the drone and its sensors. Battery capacity determines the drone's flight time and operational efficiency.

**Communication System:** This system transfers data and images from the drone to the ground station or mobile device for analysis and monitoring.

**Data Processing Software:** Software analyses images and sensor data collected by the drone. It helps farmers identify diseased areas and make accurate farming decisions.

**Ground Control Station:** The ground control station is used to operate and monitor the drone during flight. It allows users to plan routes, view live images, and control drone functions.

**Spraying Mechanism (Optional):** Some agricultural drones are equipped with spraying systems to apply pesticides or fertilizers directly to infected crop areas.

Fig. 2: Spraying Plant Protection Agent using Drone

## Working Principle

Drone technology works on the principle of remote sensing and image analysis. The drone flies over the agricultural field using GPS navigation and captures real-time images and data through RGB cameras, thermal cameras, and multispectral sensors. These sensors detect changes in crop color, temperature, moisture, and plant health. Diseased or stressed plants show different patterns compared to healthy plants. The collected data is transmitted to a computer or ground control station, where special software analyses the images and identifies infected crop areas. Based on the analysis, farmers can take early corrective actions such as pesticide spraying, irrigation management, and nutrient application. This working principle helps in early disease detection, reduces crop losses, and improves agricultural productivity through precision farming.

Drone technology for early crop disease detection works through a systematic process of field monitoring, data collection, image analysis, and decision-making. The complete working process is explained below:

**Field Planning:** The process begins with planning the drone flight using GPS and mapping software. The operator defines the agricultural field area, flight path, altitude, and speed to ensure proper coverage of crops.

**Drone Take-off and Field Survey:** The drone takes off and flies over the crop field at a fixed height. It follows the planned route automatically or manually while continuously monitoring the crops.

**Detection of Disease Symptoms:** Diseased or stressed plants show changes in leaf color, temperature, moisture level or Growth pattern. The sensors identify these abnormal changes, which may not be visible to the human eye at an early stage.

**Image Processing and Analysis:** Special software processes the collected data using image analysis and artificial intelligence techniques. The software compares healthy and unhealthy crop patterns and identifies infected areas.

**Disease Identification:** The analysed data helps detect crop diseases early before they spread widely in the field. The software generates maps and reports showing affected crop areas.

**Decision Making:** Based on the results, farmers can take proper corrective actions such as pesticide spraying, irrigation management, fertilizer application and removal of infected plants. Some agricultural drones are also equipped with spraying systems that apply pesticides only to infected areas. This reduces chemical usage and saves resources.

**Monitoring and Follow-Up:** After treatment, drones are again used to monitor crop recovery and ensure proper disease control. Continuous monitoring improves crop health and productivity.

## Conclusion

Drone technology for early crop disease detection is an advanced and effective solution in modern agriculture. It helps farmers monitor crop health, detect diseases at an early stage, and take timely corrective actions. By using cameras, sensors, and image analysis, drones improve crop management, reduce crop losses, and increase agricultural productivity. This technology saves time, labor, water, fertilizers, and pesticides through precision farming practices. Although there are some limitations such as high cost and weather dependency, the benefits of drone technology are highly valuable for sustainable agriculture. In the future, drone technology will play an important role in smart farming and improving food production efficiency.

## References

Chin, R., Catal, C. and Kassahun, A. (2023). Plant disease detection using drones in precision agriculture. *Precision Agriculture*, 24: 1663-1682.

Lajurkar, M., Barve, A., Waghmare, S., Karande, R., Kharbade, S., Bagde, A. and Sathe, S. (2025). Applications of Drone for Crop Disease Detection and Monitoring: A Review. *Asian Research Journal of Agriculture*. https://doi.org/10.9734/arja/2025/v18i1638.

Shahi, T., Xu, C., Neupane, A. and Guo, W. (2023). Recent Advances in Crop Disease Detection Using UAV and Deep Learning Techniques. *Remote Sensing*, 15: 2450.

# The Biology of Carbon Farming: How Tree-Crop Synergy Unlocks Soils Hidden Storage Potential

**Bitrus Samuel Gabakau and Kunal Narwal**


## Abstract

This review investigates the function of agroforestry-based carbon farming in promoting soil organic carbon sequestration and alleviating climate change through the synergy of tree crops. Soil is one of the largest terrestrial carbon reservoirs, containing significantly more carbon than the atmosphere, which makes its conservation and restoration essential for global climate regulation. The review emphasizes how the integration of deep-rooted trees with crops enhances carbon storage, nutrient cycling, microbial activity, soil structure, and ecosystem resilience. Special focus is placed on root niche partitioning, where trees access deeper soil layers while crops utilize topsoil resources, thus minimizing competition and augmenting subsoil carbon inputs. The article also addresses nutrient pumping, a mechanism by which deep-rooted trees retrieve leached nutrients and redistribute them to surface soils via litter fall and root exudates. Furthermore, the review explores the rhizosphere priming effect and its impact on long-term carbon stability. Evidence from isotopic labeling studies indicates that deep roots can enhance the decomposition of ancient soil organic matter, highlighting both the potential benefits and challenges associated with subsoil carbon sequestration. In summary, the review asserts that appropriate species selection, minimized soil disturbance, and ongoing subsoil monitoring are crucial for the successful operation of agroforestry systems as sustainable and resilient net carbon sinks. Furthermore, these integrated systems contribute to sustainable agriculture, better water retention, conservation of biodiversity, and long-term global productivity.

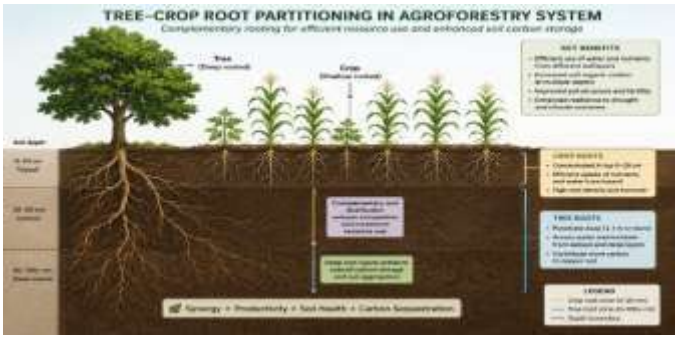

## Introduction

The intensifying climate crisis, fueled by human-induced greenhouse gas emissions, has placed soil carbon sequestration at the forefront of natural climate solutions. The Intergovernmental Panel on Climate Change reports that human activities have already caused an increase of approximately 1.1°C in global temperatures compared to pre-industrial levels, prompting international agreements like the Paris Agreement to seek voluntary emissions reductions among countries (Sharma *et al.*, 2025). Among the various terrestrial carbon reservoirs, soil is the largest, containing about 75% of the carbon stored on land (Bagnall *et al*., 2024). Soil organic carbon (SOC) sequestration, which is the process of transferring atmospheric $CO_2$ to soil organic matter for long-term stabilization, provides numerous ecological co-benefits beyond climate mitigation, such as improved soil quality, sustainable food production and enhanced water security.

**Bitrus Samuel Gabakau and Kunal Narwal**
Sanskaram University, Jhajjar, Haryana

Agroforestry, the integration of woody perennials with crops or livestock on the same land unit, has gained acknowledgment for its ability to boost soil carbon sequestration while fostering sustainable land management (Sharma *et al*., 2025). These systems facilitate carbon sequestration through various mechanisms: accumulation of aboveground biomass, storage of root carbon, and enhancement of soil organic matter (Das, 2024). The synergistic benefits of combining trees with crops extend beyond carbon storage, encompassing improved soil fertility, increased microbial activity and enhanced ecosystem resilience to climatic extremes such as droughts and soil erosion (Sharma *et al.*, 2025). Roots and their exudates serve as crucial carbon sources for deeper soil layers, with arboreal elements in integrated systems significantly contributing more soil organic carbon (SOC) at depth than herbaceous vegetation (Garrett *et al.*, 2024). However, this review explore how tree crop synergy unlock soil hidden potential.

**Root Niche Partitioning:** Root niche partitioning is all about how root systems of different plant species are arranged in space and time, allowing them to gather resources while keeping competition at bay. This is especially noticeable in tree-crop systems, where trees usually develop deep roots that reach into the subsoil, while crops focus their roots in the topsoil (Sharma *et al*., 2025). These deep roots can tap into nutrients that have leached down past the reach of regular crop roots, bringing them back up to the surface through processes like litterfall and root exudation (Bagnall *et al*., 2024). This process, often referred to as "nutrient pumping," helps minimize nutrient loss and keeps productivity high even with reduced fertilizer use.




## The Priming Paradox and Subsoil Carbon

The combination of trees and crops brings fresh carbon into the deeper layers of soil, while this new carbon could help with carbon storage, it might also speed up the breakdown of older, often ancient, soil organic matter (SOM). This interesting situation, known as the rhizosphere priming effect (RPE), is crucial for figuring out if tree-crop systems act as carbon sinks or sources (Perveen *et al*., 2014). This paradox is especially pronounced in subsoil, where organic matter has been around for thousands of years, findings reveals that various environmental and biological factors indicate fresh root inputs suddenly disturb (Fontaine *et al*., 2007).

## Deep Root Priming

The rhizosphere priming effect is all about how the presence of living roots can either speed up or slow down the breakdown of soil organic matter (SOM) when they release easily accessible carbon (Perveen *et al.*, 2014). Fontaine *et al.* (2007) found that roots reaching down to 80 cm deep triggered the mineralization of soil carbon that was around 15,000 years old. Interestingly, when they adjusted for root

biomass, the rhizosphere priming effect was consistent across all soil depths, suggesting that deep carbon is just as susceptible to priming as surface carbon, even though it seems more stable (Fontaine *et al.*, 2007).

## Conclusion

Tree crop synergy in agroforestry can substantially increase soil carbon by integrating deep-rooted trees with shallow arable crops, boosting subsoil carbon inputs, soil nutrient cycling, including soil structure while ensuring co-benefits for productivity and resilience. However, increased root inputs may activate rhizosphere priming that accelerates old-soil decomposition, so long-term sequestration requires proper species selection, less soil disturbance, and management that enhance organo-mineral stabilization. However, monitoring of subsoil carbon are needed to ensure these systems become net, robust carbon sinks.

## References

Bagnall, D. K., Morgan, C. L. S. and McBratney, A. B. (2024). Deep soil organic carbon: A review. CABI Reviews. https://doi.org/10.1079/cabireviews.2024.0024

Das, D. K. (2024). Impact of agroforestry on soil fertility and soil carbon: A review. *Indian Journal of Agroforestry*, 26(3). https://epubs.icar.org.in/index.php/IJA/article/view/16293

Garrett, L. G., Byers, A. K., Wigley, K., Heckman, K. A., Hatten, J. A. and Wakelin, S. A. (2024). Lifting the profile of deep forest soil carbon. *Soil Systems*, 8(4): 105.

Fontaine, S., Barot, S., Barré, P., Bdioui, N., Mary, B. and Rumpel, C. (2007). Stability of organic carbon in deep soil layers controlled by fresh carbon supply. *Nature*, 450: 277-280.

Perveen, N., Barot, S., Alvarez, G., Klumpp, K., Martin, R., Rapaport, A., Herfurth, D., Louault, F. and Fontaine, S. (2014). Priming effect and microbial diversity in ecosystem functioning and response to global change: A modeling approach. *Soil Biology and Biochemistry*, 78: 169-178.

Sharma, P., Jetawat, R. P. S., Mohapatra, R., Saikanth, D., Ranjith, R., Singh, B. V. and Kumar, S. (2025). Synergistic effects of agroforestry on carbon sequestration and climate adaptation: A comprehensive review. *Asian Journal of Soil Science and Plant Nutrition*, 11(1): 454-471.

# Sustainable Fibres, Sustainable Futures: Bamboo-Cotton Textiles and Youth Empowerment

**Rubi Pranjana Tamuli, Sangeeta Deo and Ranjana Kumari**

## Introduction to the Textile Landscape

India's textile industry represents a unique blend of cultural heritage, technological progress, and economic importance. As one of the country's largest employment-generating sectors, it supports rural livelihoods, preserves traditional craftsmanship, and makes a significant contribution to industrial growth. In recent years, the industry has undergone notable changes driven by sustainability concerns, advancements in material science, and the growing need to equip young people with skills suited to emerging industries. Within this evolving environment, natural fibres are gaining renewed attention not only as traditional resources but also as valuable materials for sustainable production and livelihood enhancement.

Among these developments, bamboo-cotton blended textiles have emerged as an innovative example of sustainable textile advancement. They illustrate how locally available resources and traditional knowledge can be adapted to meet modern performance requirements and global market expectations. By combining natural fibre innovation with activewear and contemporary apparel, bamboo-cotton textiles create opportunities for value addition employment generation, and skill development, particularly in bamboo-rich regions such as Northeast India.

## Natural Fibres in India: The Growing Importance of Bamboo-Cotton Blends

India possesses a rich variety of natural fibres, including cotton, jute, silk, ramie, and banana fibre, all of which contribute significantly to the nation's textile sector. Among these, bamboo has attracted increasing interest from researchers and industry professionals due to its rapid growth, relatively low environmental impact, and desirable fibre properties. While bamboo has long been used in traditional crafts and construction, its transformation into textile fibre represents a significant advancement in sustainable material development.

When blended with cotton, bamboo's textile potential expands considerably. Bamboo fibres provide softness, excellent moisture absorption, and

**Rubi Pranjana Tamuli**
Asssistant Professor, Department of Apparel and Textile Science, College of Community Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar

**Sangeeta Deo**
Professor, Department of Apparel and Textile Science, College of Community Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar

**Ranjana Kumari**
Technical Worker, All India Coordinated Research Project, Women-in-Agriculture, College of Community Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar

natural antibacterial characteristics, whereas cotton contributes strength, durability, and broad consumer acceptance. Together, they create a balanced fibre blend that offers both comfort and performance. Furthermore, because both fibres are biodegradable and bamboo cultivation generally requires fewer resources, bamboo-cotton blends align well with the principles of environmentally responsible textile production.

## Properties, Applications, and Market Potential

**Properties of Bamboo-Cotton Blended Textiles:** The performance of bamboo-cotton fabrics depends largely on fibre composition, yarn characteristics, and fabric structure. Research and experimental studies indicate that these blends possess greater moisture absorption and faster drying capabilities than conventional cotton fabrics. Such moisture-management properties are especially valuable in garments intended for active use and prolonged wear, particularly in India's warm and humid climatic conditions. In addition, bamboo-cotton fabrics offer enhanced breathability and thermal comfort, making them highly suitable for activewear, athleisure, and everyday performance clothing. Their natural antibacterial and odour-resistant qualities are particularly attractive in the growing wellness and fitness apparel market. Bamboo fibres contribute a soft and smooth texture, while cotton ensures dimensional stability, durability, and structural support. Importantly, many of these benefits can be achieved without extensive chemical treatments, helping maintain the environmental credentials of the fabric. Another significant advantage is biodegradability. As concerns regarding textile waste continue to increase, bamboo-cotton blends present an environmentally responsible alternative that supports sustainable consumption and production practices within the global fashion industry.

**Applications in Contemporary Apparel and Active wear:** Bamboo-cotton blended textiles are versatile and can be used across numerous apparel categories. Recent product developments demonstrate their suitability for unisex active wear, including T-shirts, polo shirts, track jackets, tank tops, and performance shorts. These applications align closely with the rapidly expanding athleisure market, where consumers seek garments that combine functionality, comfort, and everyday style. Beyond performance benefits, bamboo-cotton fabrics also provide opportunities for cultural expression. Traditional Assamese motifs, such as the kingkhap design, can be incorporated into contemporary garments through handloom weaving and self-jacquard techniques. This integration not only enhances aesthetic appeal but also helps preserve and promote indigenous textile traditions. As a result, bamboo-cotton activewear serves not only as functional clothing but also as a medium for cultural storytelling, a feature that resonates strongly with consumers interested in sustainable and ethically produced fashion.

**Market Potential and Opportunities for Youth:** Demand for sustainable textiles and performance-oriented apparel continues to grow in both domestic and international markets. This trend is influenced by

increasing health awareness, changing lifestyles, and rising concern for environmental sustainability. Younger consumers, in particular, are increasingly drawn to products that reflect ethical production practices, transparency and ecological responsibility. Within this market context, bamboo-cotton textiles hold a unique position. They offer many of the performance advantages associated with synthetic materials while maintaining the environmental benefits of natural fibres. From an economic perspective, bamboo-cotton activewear is well suited to decentralised and value-added production systems that can support small enterprises and handloom clusters, especially in bamboo-rich regions such as Assam. Youth participation in areas such as textile design, product development, material innovation, garment manufacturing, branding, and digital marketing can create new pathways for employment and entrepreneurship. The widespread availability of e-commerce platforms and digital communication channels further enables young entrepreneurs to access broader consumer markets, including specialised international segments interested in sustainable products. In addition, sustainable and handcrafted activewear often commands premium market value compared to mass-produced alter-natives. Strong narratives centred on cultural heritage, environmental responsibility, and material authenticity can enhance brand identity and build consumer trust. Consequently, bamboo-cotton textiles offer promising opportunities for livelihood diversification and long-term economic resilience.

**Entrepreneurship, Skill Development and Capacity Building:** The incorporation of bamboo-cotton textile innovation into youth-focused entrepreneurial initiatives supports broader objectives related to employment generation, skill enhancement, and inclusive economic development. Training in areas such as fibre processing, weaving technology, apparel manufacturing, quality assessment, design innovation, and digital marketing equips young individuals with skills that are increasingly valuable in modern textile industries. Institutional support through training programmes, incubation centres, research initiatives, and supportive policy measures can further strengthen entrepreneurial capabilities and industry readiness. By linking traditional weaving expertise with contemporary market demands, bamboo-cotton textiles encourage the exchange of knowledge across generations while promoting innovation and creativity. Such capacity-building efforts contribute not only to sustainable income generation but also to the preservation and continued relevance of India's rich textile heritage in an increasingly competitive global marketplace.

## Conclusion

Bamboo-cotton blended textiles represent a promising avenue for sustainable textile development and youth empowerment. Their favourable material properties, adaptability across diverse apparel categories, and growing acceptance among consumers underscore their increasing relevance within India's evolving textile industry. More importantly, the promotion and wider adoption of

bamboo-cotton textiles align closely with national priorities related to sustainability, skill development, and economic self-reliance. By supporting natural fibre innovation, strengthening regional economies, and creating meaningful opportunities for young entrepreneurs, bamboo-cotton blends can contribute significantly to the development of a resilient, inclusive, and future-oriented textile sector.

# Climate-Smart Rice Cultivation for Sustainable Agriculture

**Yazhini Gunasekaran**


## Abstract

Climate change poses a serious threat to global rice production through rising temperatures, irregular rainfall, and increased pest incidence. Climate-smart rice cultivation offers sustainable solutions by integrating resource-efficient and adaptive farming practices. This article highlights key strategies such as alternate wetting and drying, use of climate-resilient varieties, soil health management, and integrated pest management. These approaches aim to enhance productivity while reducing greenhouse gas emissions and conserving natural resources. Adoption of modern technologies and crop diversification further strengthens resilience against climatic stresses. Climate-smart practices not only improve yield stability but also support environmental sustainability and farmer livelihoods. The approach is essential for ensuring food security in the face of climate variability and long-term ecological challenges.


## Introduction

Rice is one of the most important cereal crops in the world, serving as the primary food source for more than half of the global population. In countries like India, rice cultivation is deeply linked with food security, rural employment, and economic stability. However, the sustainability of rice production is increasingly threatened by climate change. Rising global temperatures, erratic monsoon patterns, increased frequency of droughts and floods, and the emergence of new pests and diseases are significantly affecting rice yields. Traditional rice cultivation practices, particularly continuous flooding, excessive use of chemical fertilizers, and monocropping, contribute to environmental degradation. These practices not only lead to inefficient use of natural resources but also increase greenhouse gas emissions such as methane and nitrous oxide, which further aggravate climate change. Climate-smart rice cultivation has emerged as a holistic approach to address these challenges. It is based on three main objectives: increasing agricultural productivity, enhancing resilience to climate change, and reducing greenhouse gas emissions wherever possible. This approach integrates improved agronomic practices, advanced technologies, and sustainable resource management strategies.

In the context of a growing population and shrinking natural resources, there is an urgent need to transform conventional rice farming into a more sustainable and climate-resilient system. Climate-smart practices offer a pathway to achieve this transformation while ensuring long-term food security and environmental sustainability.

**Yazhini Gunasekaran**
Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu

**Water Management Practices:** Water scarcity is becoming a major constraint in rice cultivation, particularly in regions dependent on monsoon rainfall. Traditional flooding methods require large quantities of water and contribute significantly to methane emissions. Alternate Wetting and Drying (AWD) is an effective water-saving technique in which irrigation is applied only after the field has dried to a certain level. This method reduces water use by 25-30% (Zhang, 2025) and lowers methane emissions without affecting yield. Other practices such as direct-seeded rice (DSR) also help reduce water consumption by eliminating the need for puddling and transplanting. Efficient irrigation scheduling and the use of field water tubes further improve water management and ensure optimal crop growth.

**Climate-Resilient Rice Varieties:** The development of stress-tolerant rice varieties is a key component of climate-smart agriculture. These varieties are designed to withstand adverse environmental conditions such as drought, submergence, salinity, and high temperatures. For example, drought-tolerant varieties require less water and can survive dry spells, while flood-tolerant varieties can remain submerged for extended periods. Salinity-tolerant varieties are particularly useful in coastal regions where soil salinity is increasing due to sea water intrusion. Adoption of these improved varieties reduces the risk of crop failure and ensures stable production under changing climatic conditions.

**Soil Health Management:** Soil health plays a crucial role in sustaining rice productivity. Continuous use of chemical fertilizers without organic inputs leads to soil degradation, reduced fertility, and declining yields. Climate-smart practices emphasize integrated nutrient management, which combines organic and inorganic fertilizers. The use of farmyard manure, compost, crop residues, and green manure improves soil structure, enhances microbial activity, and increases nutrient availability. Conservation tillage practices help reduce soil erosion and maintain soil moisture. Additionally, site-specific nutrient management ensures that fertilizers are applied in the right quantity and at the right time, improving efficiency and reducing environmental pollution.

**Integrated Pest and Disease Management:** Climate change has altered pest and disease dynamics, leading to increased infestations and crop losses. Warmer temperatures and high humidity create favorable conditions for pests and pathogens. Integrated Pest Management (IPM) is a sustainable approach that combines biological, cultural, and chemical methods to control pests. This includes the use of pest-resistant varieties, biological control agents, crop rotation, and timely monitoring of pest populations. Judicious use of pesticides is encouraged only when necessary, reducing environmental contamination and protecting beneficial organisms.

**Mechanization and Smart Technologies:** Modern technologies are playing a vital role in climate-smart rice cultivation. Mechanization reduces labor dependency and increases operational efficiency.

Laser land leveling ensures uniform distribution of water across the field, minimizing wastage. Drones and sensors are increasingly being used for crop monitoring, nutrient management, and pest detection. Mobile-based applications and weather forecasting systems provide real-time information to farmers, enabling them to make timely decisions regarding planting, irrigation, and harvesting. Precision agriculture techniques help optimize input use and improve productivity.

**Crop Diversification and Cropping Systems:** Continuous monocropping of rice can lead to soil nutrient depletion and increased pest problems. Crop diversification involves growing different crops in rotation or in combination with rice (Gunasekaran *et al.,* 2021). Incorporating legumes such as pulses improves soil fertility through nitrogen fixation. Crop rotation also helps break pest and disease cycles and enhances farm income by providing multiple sources of revenue. Diversified cropping systems increase resilience against climate risks and reduce dependency on a single crop.

**Greenhouse Gas Mitigation:** Rice cultivation is a significant source of methane emissions due to anaerobic conditions in flooded fields. Climate-smart practices aim to reduce these emissions through improved water and nutrient management. Techniques such as AWD, use of organic amendments, and optimized fertilizer application reduce methane and nitrous oxide emissions. These practices contribute to climate change mitigation while maintaining productivity.

## Conclusion

Climate-smart rice cultivation provides a comprehensive approach to tackle the challenges of climate change while ensuring sustainable agricultural production. By integrating improved water management, resilient crop varieties, soil health practices, and modern technologies, farmers can enhance productivity and reduce environmental impact. The adoption of these practices not only improves farm resilience but also contributes to global efforts in mitigating climate change. Promoting climate-smart agriculture through policy support, research, and farmer participation is essential for ensuring long-term food security and sustainability.

## References

Zhang, D. (2025). Impact of Alternate Wetting and Drying (AWD) Irrigation on Rice Yield and Greenhouse Gas Emissions. *Field Crop*, 8.

Gunasekaran, Y., Kaliappan, S. B. and S. P. (2021). Developing soil quality indices for different crop rotations of deltaic inceptisol regions of India. *Communications in Soil Science and Plant Analysis*, 52(12): 1363-1376.

# Biochar Enhances Soil Sustainability through Evidence-based Mechanisms and Practice

**Archika Awasare and Kiran Patel**


## Abstract

Biochar, a multifaceted soil amendment, is rigorously characterised to assess its potential for pollutant removal and its diverse applications. Environmental impact prediction becomes more precise through structural and elemental analyses. The buoyancy in the field of agricultural science was initially a blessing in disguise, but has recently been found to have detrimental consequences. Beyond environmental contamination, the challenges of climate change, fossil fuel depletion, and excessive land degradation have come to the fore. Pollutants such as heavy metals pose a substantial threat due to their persistence in soil and inevitable toxicity to organisms. Considerable efforts have therefore been made to remediate contaminated soils. Biochar possesses a large surface area, strong carbon-sequestration capacity, and abundant nutrient content, with additional potential for bio-oil and syngas production. Consequently, biochar can reduce the bioavailability of pollutants, particularly heavy metals, in soil, contribute to climate-change mitigation through carbon sequestration, and offset fossil-fuel use via bio-oil and syngas production. Further, biochar enhances soil productivity, which can support food security.


## Introduction

Globally, biochar, a multipurpose carbonaceous material, is being utilized to enhance soil fertility, alongside improved plant growth and development under both normal and stress conditions. It improves water retention, fosters nutrient absorption, and promotes microbial activity, thereby creating a fertile environment that supports sustainable and resilient agriculture. Biochar also acts as a carbon sink, contributing to long-term carbon sequestration and mitigating climate-change impacts. A major advantage of biochar is its facilitation of adsorption through highly porous structures and diverse functional groups. Understanding the factors involved in biochar formation that determine its characteristics and adsorptive capacity is essential for ensuring its viability in terms of plant productivity and soil health, particularly the biological activity of soils. From the late eighteenth century onwards, rapid industrialisation transformed socio-economic life, first in Europe and later worldwide. While technological advances increased productivity and comfort, they also produced significant externalities most notably climate change and pollution from heavy metals. Climate change has already affected the planet substantially, and no environmental sphere has remained immune to heavy-metal contamination. Once released, heavy metals are transported across

**Archika Awasare and Kiran Patel**
Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur, Madhya Pradesh

air, water, and soil and can persist for long periods. These toxic metals adversely affect plants and animals and degrade ecosystems. It is therefore necessary to pursue remediation strategies that both minimise heavy-metal damage and contribute to climate-change mitigation. Biochar is a carbonaceous product often carbon-neutral or even carbon-negative, obtained via the thermochemical conversion of biomass under oxygen-limited conditions (pyrolysis). The physical and chemical characteristics of biochar vary with pyrolysis temperature and feedstock type. Biochar can reduce the bioavailability and leachability of heavy metals in contaminated soils, improve overall soil quality, and markedly decrease heavy-metal uptake by crops. Furthermore, it can be produced from a wide range of biomass, thereby reducing waste. Recent work highlights its capacity to contribute to climate-change mitigation, produce biofuel, and enhance soil productivity. Accordingly, the application of biochar offers a promising approach not only for remediating contaminated soils but also for addressing climate change, fossil-fuel depletion, and food-security concerns.

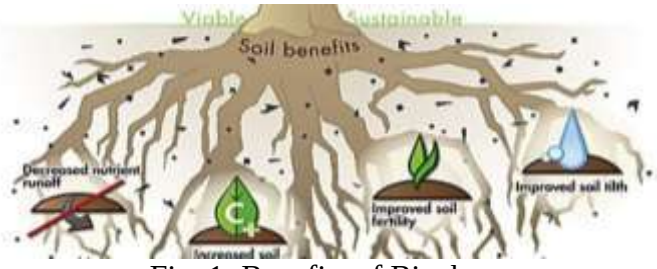



Fig. 1: Benefits of Biochar

## Mechanisms Used for the Containment of Pollutants by Biochar

Carbonaceous materials have long been employed as sorbents for contaminants in soil and water. For biochar, the principal mechanisms include:

**Sorption (Adsorption/Partitioning):** Sorption of organic and inorganic contaminants onto biochar is a key pathway. High surface area, microporosity, pH, and ionic strength influence sorption. Biochar produced at higher pyrolysis temperatures often exhibits greater sorption efficiency for organic-contaminant remediation in soils and water. Adsorption is particularly significant for metallic contaminants.

**Hydrogen-Bond Formation:** Polar compounds are adsorbed via hydrogen bonds with oxygen-containing surface functional groups on biochar (e.g., carboxyl, hydroxyl, phenolic). In contrast, non-polar compounds associate with hydrophobic sites where hydrogen bonding between water and oxygenated groups is absent.

**Electrostatic Attraction/Repulsion:** Interactions between positively charged (cationic) organic contaminants and negatively charged biochar surfaces can immobilise pollutants. Electrostatic outer-sphere complexation may occur through metal exchange with $K^+$ and $Na^+$ present in the biochar.

**Diffusion into Biochar Phases:** Non-ionic compounds can diffuse into both the non-carbonised and carbonised fractions of biochar, providing an effective sorption mechanism.

**Formation of Surface Complexes:** Cations form surface complexes with active functional groups (e.g., -COOH and -OH) on biochar.

Generally, metals with smaller ionic radii exhibit greater adsorption capacities.

**Precipitation and Co-precipitation:** Certain metals (e.g., Pb) can form stable precipitates (such as lead-phosphate-silicates) within or on biochar. Co-precipitation and inner-sphere complexation between metals and the organic matter/mineral oxides in biochar further contribute to immobilisation.

# Metagenomics and Next-Generation Sequencing in Soil Microbiology

**Paghdar Priya P. and Harish V.**


## Abstract

In essence, soil microbiology is the study of microorganisms in soil ecosystems and how they function, their diversity and interactions. These functions include nutrient cycling, organic matter decomposition and other processes that contribute to soil quality. Nevertheless, using traditional approaches of culture based techniques results in only a fraction of the microbial diversity being revealed, hence leaving the true diversity of the ecosystem largely unstudied. Metagenomics is therefore a promising approach that studies microorganisms without culturing them, since it directly examines the genomes of microorganisms. The advent of metagenomics together with Next-Generation Sequencing (NGS) has opened doors to rapid, high quality, and affordable sequencing of microbial DNA that leads to better insight about the microbial diversity and functions within soils. NGS technologies have greatly revolutionized the study of soil microbes since many new species have been discovered due to increased resolution and the ability to study larger samples. Such applications range from sustainable agriculture where soils are made more fertile by microbial action to bioremediation and climate change management through carbon cycling.


## Introduction

Soils form a rich ecosystem for various microorganisms which play important roles in the nutrient cycle and plant productivity (Jansson and Hofmockel, 2018; Fierer, 2017). Conventional approaches based on culture techniques only account for a limited number of microorganisms (Handelsman, 2004; Torsvik and Øvreås, 2002). Metagenomics can provide insights on microbial diversity through DNA sequencing without cultivating the microbes (Thomas *et al*., 2012; Gilbert and Dupont, 2011). NGS further improves this approach with its ability to sequence DNA rapidly and in large quantities (Shokralla *et al*., 2012; Metzker, 2010). The use of these approaches allows us to understand the contribution of microorganisms to the nutrient cycle and stress tolerance (Delgad Baquerizo *et al*., 2018; Banerjee *et al*., 2019). Their combination facilitates sustainable agriculture and environmental monitoring (Prosser, 2015; Singh *et al*., 2009). In summary, these approaches have revolutionized the field of soil microbiology, making it relevant.

**Metagenomics in Soil Microbiology:** Metagenomics involves the study of genetic information obtained from the soil without the use of cultures. It helps reveal important aspects related to microbial diversity and functionality (Handelsman, 2004; Thomas *et al*., 2012). Metagenomics is especially valuable as compared to the traditional techniques because it is possible to conduct studies of the whole

**Paghdar Priya P. and Harish V.**
Department of Agricultural Microbiology, B. A. College of Agriculture, AAU, Anand, Gujarat

microbial communities in their original environments (Gilbert and Dupont, 2011). Two types are typically used the shotgun technique (that is designed to analyze all the DNA fragments) and amplicon sequencing, such as 16S rRNA sequencing (Sharpton, 2014; Caporaso *et al*., 2012). The first method is more useful for comprehensive functional profiling, while the second one helps to estimate community structure without spending too much money (Quince *et al*., 2017). The main benefit of metagenomics is the absence of necessity to grow microorganisms. It makes it possible to identify and analyze previously unculturable species (Torsvik and Øvreås, 2002). It has revealed tremendous numbers of new microbes and metabolic pathways (Delmont *et al*., 2015).

**Role of NGS Technologies:** The Next Generation Sequensing (NGS) approach is fundamental in soil microbiology as it enables fast and efficient microbial genome sequencing (Metzker, 2010; Shokralla *et al*., 2012). Sequencing technologies like Illumina, PacBio, and Oxford Nanopore are used in soil metagenomic studies (Quail *et al*., 2012; Rhoads and Au, 2015). Illumina offers highly accurate short reads, and the PacBio and Nanopore sequencing provide long reads for effective genome assemblies (Goodwin *et al*., 2016). NGS provides massive high throughput sequencing, which facilitates in depth profiling of microbial populations (Shokralla *et al*., 2012). It also offers increased speed and efficiency than previous sequencing techniques (Metzker, 2010). High throughput sequence data is subjected to extensive bioinformatics analysis in order to derive taxonomic and functional information about the organisms being studied (Scholz *et al*., 2012). Therefore, NGS plays an important role in soil metagenomic studies.

**Application in soil:** Metagenomics and NGS have been instrumental in expanding our understanding of soil ecosystems by aiding in the comprehensive analysis of microbes. In microbial diversity studies, these techniques have provided knowledge on the enormous range of microorganisms that exist both in terms of taxonomic and functional diversity (Fierer, 2017; Delgado Baquerizo *et al*., 2018). In the study of soil fertility and agriculture, they assist in improving nutrient management and production through plant microbes interactions (Singh *et al*., 2009; Prosser, 2015). When applied in bioremediation, these tools aid in identifying the microbes responsible for breaking down contaminants in contaminated soil environments (Mason *et al*., 2014; Bell *et al*., 2014).

Figure: Flow chart explaining integrated process of metagenomics and next-generation sequencing in the exploration of the microbes existing in soil. It includes sampling, genome sequencing, computation, ecology, agriculture improvement, pollutant degradation, and carbon dynamics

Finally, they play a role in climate change research by unraveling microbial contribu-tions to the global carbon cycle and greenhouse gases regulation (Jansson and Hofmockel, 2018; Crowther *et al*., 2016).

**Challenges:** Despite current difficulties, Metagenomics and Next-Generation Sequencing techniques have a promising future in soil microbiology. In the coming years, efforts will be made to develop these approaches, which are likely to improve sequencing and decrease its cost, making these techniques more affordable globally. Artificial intelligence algorithms and machine learning will facilitate the process of analyzing big bioinformatics data. Global microbial databases will enable researchers to identify soil microorganisms that remain unidentified at present. Improved long read sequencing techniques will facilitate genome assembly and function elucidation. Implementation of standardized protocols concerning sample collection and data analysis will make results from various studies more comparable. Combined usage of several "omics" methods like metagenomics, transcriptomics, and proteomics will facilitate functional analysis. Such developments will facilitate precision agriculture by optimizing soil management techniques and increasing crop yields. Furthermore, their potential for application in bioremediation and environmental monitoring will become stronger.

## Conclusion

In summary, Metagenomics and Next-Generation Sequencing have revolutionized soil microbiology through comprehensive profiling of microbial populations. They provide insights into the hidden biodiversity and capabilities that conventional techniques cannot uncover. The use cases in agriculture, environmental remediation, and climate change research underscore their significance in sustainable soil management practices. While there are some technical limitations to address, ongoing progress is enhancing their effectiveness and feasibility. In the future, their incorporation with sophisticated computational models will offer more profound insights into soil systems.

## References

Banerjee, S., Schlaeppi, K. and Van Der Heijden, M. G. (2019). Keystone taxa as drivers of microbiome structure and functioning. *Nature Reviews Microbiology*, 16(9): 567.

Bell, T. H., Yergeau, E., Martineau, C., Juck, D., Whyte, L. G. and Greer, C. W. (2011). Identification of nitrogen-incorporating bacteria in petroleum-contaminated arctic soils by using [15N] DNA-based stable isotope probing and pyrosequencing. *Applied and Environmental Microbiology*, 77(12): 4163-4171.

Fierer, N. (2017). Embracing the unknown: disentangling the complexities of the soil microbiome. *Nature Reviews Microbiology*, 15(10): 579-590.

Gilbert, J. A. and Dupont, C. L. (2011). Microbial metagenomics: beyond the genome. *Annual Review of Marine Science*, 3(1): 347-371.

Caporaso, J. G., Lauber, C. L., Walters, W. A., Berg-Lyons, D., Huntley, J., Fierer, N., ... and Knight, R. (2012). Ultra-high-throughput microbial community analysis on the Illumina HiSeq and MiSeq platforms. *The ISME Journal*, 6(8): 1621-1624.

Crowther, T. W., Todd-Brown, K. E., Rowe, C. W., Wieder, W. R., Carey, J. C., Machmuller, M. B., ... and Bradford, M. A. (2016). Quantifying global soil carbon losses in response to warming. *Nature*, 540(7631): 104-108.

Delgado-Baquerizo, M., Oliverio, A. M., Brewer, T. E., Benavent-González, A., Eldridge, D. J., Bardgett, R. D., ... and Fierer, N. (2018). A global atlas of the dominant bacteria found in soil. *Science*, 359(6373): 320-325.

Delmont, T. O., Robe, P., Cecillon, S., Clark, I. M., Constancias, F., Simonet, P., ... and Vogel, T. M. (2011). Accessing the soil metagenome for studies of microbial diversity. *Applied and Environmental Microbiology*, 77(4): 1315-1324.

Handelsman, J. (2004). Metagenomics: application of genomics to uncultured microorganisms. *Microbiology and Molecular Biology Reviews*, 68(4): 669-685.

Singh, B. K., Bardgett, R. D., Smith, P. and Reay, D. S. (2010). Microorganisms and climate change: terrestrial feedbacks and mitigation options. *Nature Reviews Microbiology,* 8(11) : 779-790.

Jansson, J. K. and Hofmockel, K. S. (2018). The soil microbiome from metagenomics to metaphenomics. *Current Opinion in Microbiology*, 43: 162-168.

Mason, O. U., Hazen, T. C., Borglin, S., Chain, P. S., Dubinsky, E. A., Fortney, J. L., ... and Jansson, J. K. (2012). Metagenome, metatranscriptome and single-cell sequencing reveal microbial response to Deepwater Horizon oil spill. *The ISME Journal*, 6(9): 1715-1727.

Metzker, M. L. (2010). Sequencing technologies the next generation. *Nature Reviews on Genetics*, 11(1): 31-46.

Next-generation Sequencing Technologies for Environmental DNA Research. *Molecular Ecology*, 21(8): 1794-1805.

Prosser, J. I. (2015). Dispersing misconceptions and identifying opportunities for the use of'omics' in soil microbial ecology. *Nature Reviews Microbiology*, 13(7): 439-446.

Quince, C., Walker, A. W., Simpson, J. T., Loman, N. J. and Segata, N. (2017). Shotgun metagenomics from sampling to analysis. *Nature Biotechnology*, 35(9): 833-844.

Sharpton, T. J. (2014). An introduction to the analysis of shotgun metagenomic data. *Frontiers in Plant Science*, 5: 209.

Thomas, T., Gilbert, J. and Meyer, F. (2012). Metagenomics-a guide from sampling to data analysis. *Microbial Informatics and Experimentation*, 2(1): 3.

# AI-Based Crop Yield Prediction and Smart Irrigation: Emerging Trends in Agribusiness

**Devi Lal Jat and Rishab Modi**


## Abstract

Artificial Intelligence (AI) is transforming modern agriculture by improving productivity, resource-use efficiency, and decision-making. Growing population pressure, climate variability, and water scarcity have increased the need for smart agricultural solutions. Technologies such as Machine Learning (ML), Internet of Things (IoT), remote sensing, and predictive analytics are widely used for crop yield prediction and smart irrigation management. Research indicates that AI-based models can achieve over 90% prediction accuracy while reducing irrigation water use by 20-30%. AI supports precision farming and climate-smart agriculture, contributing to sustainable agricultural development and food security.


## Introduction

Agriculture faces major challenges including climate change, declining water resources, soil degradation, and increasing food demand. The global population is expected to reach nearly 9.7 billion by 2050, requiring significant increases in food production. Traditional farming methods often rely on experience-based decisions, which may be ineffective under changing environmental conditions. Artificial Intelligence offers data-driven solutions by analyzing large agricultural datasets and providing accurate recommendations. AI applications in agriculture include crop yield prediction, smart irrigation, pest and disease detection, soil analysis, fertilizer management, and market forecasting. The rapid growth of IoT, cloud computing, and remote sensing technologies has accelerated AI adoption in agriculture.

## Concept of Artificial Intelligence in Agriculture

Agriculture is one of the most important sectors of the global economy and plays a critical role in ensuring food security and rural livelihoods. However, modern agriculture faces several challenges such as climate change, irregular rainfall, declining soil fertility, pest attacks, labor shortages, and inefficient resource management. Traditional farming practices often depend on farmer experience and manual observations, which may not provide accurate predictions or efficient decision-making. Artificial Intelligence (AI) offers innovative solutions by analyzing large datasets collected from weather stations, soil sensors, satellite imagery, drones and agricultural databases. AI technologies enable predictive analytics, automation, and intellig-

**Devi Lal Jat**
Assistant Professor, Department of Agricultural Economics, RNT College of Agriculture, Kapasan, Chittorgarh, Rajasthan
**Rishab Modi**
B.Sc. (Hons.) Agriculture Student, RNT College of Agriculture, Kapasan, Chittorgarh, Rajasthan

ent resource management, helping farmers improve efficiency and productivity.

### Important AI technologies used in agriculture

- ✓ Machine Learning (ML)
- ✓ Deep Learning (DL)
- ✓ Internet of Things (IoT)
- ✓ Remote Sensing and GIS
- ✓ Computer Vision
- ✓ Robotics and Automation

### AI-Based Crop Yield Prediction

Crop yield prediction is considered one of the most valuable applications of Artificial Intelligence in agriculture. Accurate forecasting of crop production helps farmers, agribusiness companies, policymakers, food industries, and insurance firms make effective economic and management decisions. Traditional crop forecasting methods often rely on field surveys and historical averages, which may not account for sudden climatic variations or soil conditions. AI-based systems provide a more scientific and data-driven approach by analyzing multiple variables simultaneously.

The major data sources used in AI-based crop prediction include

- ✓ Historical crop production records
- ✓ Temperature and rainfall data
- ✓ Soil fertility and moisture levels
- ✓ Fertilizer and pesticide application
- ✓ Crop growth stages
- ✓ Satellite imagery and NDVI data
- ✓ Weather forecasting information
- ✓ Pest and disease incidence reports

Machine learning algorithms such as Random Forest, Decision Trees, Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Deep Learning models are widely used for crop yield prediction. These algorithms identify hidden relationships between environmental factors and crop performance.

### Research Findings and Statistical Evidence

Crop yield prediction is one of the most significant applications of AI in agriculture. Accurate yield forecasting helps farmers, agribusiness firms, insurance companies, and policymakers make better production and marketing decisions. Machine learning algorithms such as Random Forest, Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Gradient Boosting are commonly used for yield prediction. These models can analyze large agricultural datasets and identify patterns that are difficult for humans to recognize. A systematic review of 184 research studies conducted between 2017 and 2024 concluded that AI-based crop prediction models significantly outperform conventional statistical methods. Research conducted across 37 countries achieved an $R^2$ value of 0.94, indicating high prediction reliability. A practical AI system trained using more than 200,000 agricultural records achieved approximately 91% prediction accuracy under real farming conditions. Studies also indicate that AI systems can reduce forecasting errors by 15-25% compared to traditional approaches. The use of remote sensing and satellite imagery further improves crop yield prediction accuracy by enabling

real-time crop monitoring.

## AI in Smart Irrigation Systems

Agriculture consumes nearly 70% of the world's freshwater resources, making efficient water management essential for sustainable farming. In countries like India, irregular monsoon rainfall and groundwater depletion have increased the need for smart irrigation technologies. Traditional irrigation systems often lead to excessive water usage, nutrient leaching, and reduced irrigation efficiency. Artificial Intelligence-based smart irrigation systems use real-time environmental data and automated decision-making tools to optimize water usage.

These systems commonly use:

- ✓ Soil moisture sensors
- ✓ Weather forecasting systems
- ✓ IoT-enabled devices
- ✓ Satellite monitoring
- ✓ Automated irrigation controllers
- ✓ Crop water requirement models

Research studies indicate that AI-driven irrigation systems can reduce water usage by 20-30% while maintaining optimum soil moisture levels. In greenhouse farming systems, AI-based irrigation has shown improvements in crop quality, water productivity and fertilizer efficiency.

Smart irrigation systems are increasingly being adopted in:

- ✓ Precision farming
- ✓ Greenhouse cultivation
- ✓ Commercial horticulture
- ✓ Drip irrigation systems
- ✓ Drought-prone agricultural regions

The integration of AI with cloud computing and mobile applications also allows farmers to monitor irrigation systems remotely.

## Integration of AI with Remote Sensing and IoT

AI algorithms process this information to analyze crop conditions, soil health, pest infestations, and vegetation growth. Normalized Difference Vegetation Index (NDVI) imagery is commonly used in precision agriculture to evaluate crop health and biomass development. AI-powered systems can identify nutrient deficiencies, water stress, and disease symptoms before visible damage occurs.

IoT devices continuously collect environmental data such as:

- ✓ Soil moisture
- ✓ Temperature
- ✓ Humidity
- ✓ Rainfall
- ✓ Wind speed
- ✓ Nutrient levels
- ✓ Light intensity

This data is transmitted to cloud-based AI systems for real-time analysis and recommendations. The integration of AI, IoT, and remote sensing provides several advantages:

- ✓ Real-time crop monitoring
- ✓ Improved resource efficiency
- ✓ Early pest and disease detection
- ✓ Better irrigation management
- ✓ Reduced labor dependency
- ✓ Improved yield forecasting

Drone-based agricultural monitoring systems are becoming increasingly popular because they provide high-resolution field imagery and rapid data collection over large farming areas. Several agricultural technology companies are currently developing AI-powered farm management platforms that combine sensor networks, weather forecasting, and predictive analytics to support precision farming.

## Benefits of AI in Agriculture

Modern AI systems combine remote sensing technologies, drones, and IoT sensors to monitor agricultural fields in real time. Satellite imagery and NDVI analysis help assess crop health, detect disease outbreaks, and estimate biomass production.

IoT devices continuously collect environmental data such as:

- ✓ Soil temperature
- ✓ Soil moisture
- ✓ Humidity
- ✓ Rainfall
- ✓ Nutrient levels

AI systems analyze these datasets to provide automated recommendations regarding irrigation, fertilization, and crop management.

## Challenges and Limitations

Despite significant benefits, AI adoption in agriculture faces several challenges:

- ✓ High implementation and maintenance costs
- ✓ Limited digital infrastructure in rural areas
- ✓ Lack of technical knowledge among farmers
- ✓ Dependence on high-quality data
- ✓ Privacy and data security concerns
- ✓ Limited access to advanced technologies by small farmers

Poor-quality data can reduce prediction accuracy and affect decision-making efficiency. Government support and farmer training programs are necessary to overcome these limitations.

## Future Prospects of AI in Agribusiness

The future of Artificial Intelligence in agriculture is highly promising and is expected to play a major role in achieving sustainable and climate-resilient farming systems. Rapid advancements in robotics, drone technology, machine learning, and precision farming are accelerating the adoption of AI-based agricultural solutions worldwide.

Future agricultural systems may include:

- ✓ Fully automated smart farms
- ✓ Autonomous tractors and robotic harvesters
- ✓ AI-based disease diagnosis systems
- ✓ Drone-assisted crop monitoring
- ✓ AI-powered agricultural advisory platforms
- ✓ Climate-smart irrigation systems

## Blockchain-enabled supply chain management

Artificial Intelligence can also support food traceability and quality control by improving supply chain transparency. The integration of AI with big data analytics will help governments and policymakers predict food shortages, monitor climate impacts, and improve agricultural planning. In India, government initiatives such as Digital Agriculture Mission, Smart Farming Projects, and AI-based startups are promoting technology adoption in rural

areas.

Several Indian startups are already using AI technologies for:

- ✓ Crop disease identification
- ✓ Soil testing
- ✓ Market price prediction
- ✓ Drone-based spraying
- ✓ Precision irrigation
- ✓ Farm advisory services

According to industry projections, AI adoption in agriculture is expected to increase substantially over the next decade as technologies become more affordable and accessible. Universities and agricultural research institutions are also conducting research on AI-driven sustainable farming systems to improve food security and climate resilience.

## Conclusion

The future of AI in agriculture is highly promising. Advancements in robotics, drone technologies, autonomous tractors, precision farming systems, and climate-smart agriculture are expected to accelerate AI adoption.

Future developments may include:

- ✓ Fully automated farms
- ✓ AI-based pest and disease diagnosis
- ✓ Robotic harvesting systems
- ✓ Real-time crop monitoring using drones
- ✓ AI-powered agricultural advisory systems

The integration of AI with blockchain technology may also improve supply chain transparency and food traceability.

## References

Jabed, M. A. and Murad, M. A. A. (2024). Crop yield prediction using machine learning and deep learning approaches. *Heliyon*.

Shashi, S. (2024). AI-driven crop yield prediction for sustainable agriculture. *International Journal of Scientific Research.*

Klerkx, L., Jakku, E. and Labarthe, P. (2019). A review of digital agriculture. *Agricultural Systems*, 169: 1-12.

Wolfert, S., Ge, L., Verdouw, C. and Bogaardt, M. (2017). Big data in smart farming. *Agricultural Systems*, 153: 69-80.

Zhang, Q. and Pierce, F. J. (2013). Agricultural automation: Fundamentals and practices. CRC Press.

Bassine, F. Z., *et al*. (2023). Machine learning and IoT in agriculture. *Agricultural Systems*.

# Agronomic Innovations: A Pathway to Higher Farm Productivity and Profitability

**Laxman Navi, Atheek Ur Rehaman H. M. and Karthik A. N.**


## Abstract

Agriculture is facing increasing challenges due to rising production costs, declining natural resources, labor shortages and climate change, all of which affect farm profitability and sustainability. Agronomic innovations offer practical and scientific solutions to address these challenges by improving resource-use efficiency, enhancing crop productivity and reducing production costs. The importance of modern agronomic interventions such as precision nutrient management, water-saving technologies, conservation agriculture, improved crop varieties, integrated weed management, crop diversification, integrated pest and disease management, farm mechanization, climate-smart agriculture and integrated farming systems. These innovations help optimize the use of land, water, nutrients and labor while improving resilience to climatic and market uncertainties. The role of farmer training, extension services and emerging digital technologies in accelerating the adoption of improved practices. By integrating scientific knowledge with sustainable resource management, agronomic innovations can significantly enhance farm productivity, profitability and environmental sustainability. Widespread adoption of these technologies will play a crucial role in ensuring food security, improving farmers' livelihoods and promoting sustainable agricultural development in the future.


## Introduction

Agriculture remains the backbone of the Indian economy, providing livelihoods to millions of farming families. However, increasing production costs, declining soil fertility, water scarcity, labor shortages and the impacts of climate change have made farming less profitable in many regions. Farmers today face the challenge of producing more food from limited resources while ensuring environmental sustainability.

In this context, agronomic innovations offer practical solutions to enhance productivity, reduce input costs and improve farm profitability. Agronomic innovations refer to improved crop management practices, modern technologies, resource-conservation techniques and scientific interventions that increase the efficiency of agricultural production systems. These innovations help farmers maximize returns from every unit of land, water, labor and capital invested in farming. By adopting suitable agronomic practices


**Laxman Navi**
Technical Assistant, AICRP on Sugarcane, Agricultural Research Station, Sankeshwar, Karnataka

**Atheek Ur Rehaman H. M.**
Scientist (Agronomy), AICRP on Pigeonpea, ZARS, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka

**Karthik A. N.**
Research Scholar, Department of Agronomy, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka

farmers can achieve higher yields, better quality produce and increased income while conserving natural resources.

## Importance of Agronomic Innovations

Agronomic innovations play a crucial role in modern agriculture by:

- ✓ Increasing crop productivity and resource-use efficiency
- ✓ Reducing production costs through efficient input management
- ✓ Enhancing resilience to droughts, floods, and climate variability
- ✓ Improving soil health and environmental sustainability
- ✓ Increasing profitability and livelihood security of farmers
- ✓ Promoting sustainable intensification of agriculture

The adoption of innovative agronomic practices is becoming increasingly important to meet the growing food demand while ensuring economic viability and environmental protection.

**Precision Nutrient Management:** Balanced and efficient nutrient management is one of the most effective ways to improve farm profitability. Excessive or imbalanced fertilizer application not only increases production costs but also leads to nutrient losses and environmental pollution. Precision nutrient management involves applying the right nutrient source at the right rate, right time and right place. Soil testing helps farmers understand nutrient deficiencies and optimize fertilizer application. Site-specific nutrient management enables efficient utilization of fertilizers, resulting in higher crop yields and reduced input costs. The use of organic manures, compost, biofertilizers and green manures further improves soil fertility and nutrient availability. Integrated Nutrient Management (INM), which combines organic and inorganic nutrient sources, enhances nutrient-use efficiency and sustains long-term productivity.

**Water-Saving Technologies:** Water scarcity is becoming a major constraint in agriculture. Efficient water management practices can significantly improve crop productivity and profitability. Micro-irrigation systems such as drip and sprinkler irrigation deliver water directly to the root zone, minimizing losses due to evaporation and runoff. These systems improve water-use efficiency and reduce labor requirements. Mulching with crop residues, plastic sheets or organic materials conserves soil moisture, suppresses weeds and improves soil health. Rainwater harvesting structures help store excess rainfall for supplemental irrigation during dry periods. Deficit irrigation and alternate wetting and drying techniques in crops such as rice can save substantial amounts of water without significantly affecting yields. Such practices reduce irrigation costs and enhance water productivity.

**Conservation Agriculture:** Conservation agriculture is a sustainable farming approach based on minimum soil disturbance, permanent soil cover and crop diversification. It helps reduce soil erosion, improve soil health and increase resource-use efficiency. Zero tillage and reduced tillage practices reduce fuel consumption and labor costs while maintaining soil structure. Crop residue retention enhances soil organic matter and improves moisture conservation. Conservation agriculture improves soil biological activity and nutrient cycling, resulting in better crop growth and long-term productivity. Farmers adopting conservation agriculture often experience lower production costs and higher profitability.

**Improved Crop Varieties:** The selection of suitable crop varieties is critical for maximizing farm income. Modern high-yielding varieties and hybrids possess superior traits such as: Higher yield potential, Resistance to pests and diseases, Tolerance to drought and heat stress, better nutrient-use efficiency and improved quality characteristics. Climate-resilient varieties are particularly important in regions prone to weather uncertainties. The use of certified seeds ensures better germination, uniform crop establishment and enhanced productivity.

**Integrated Weed Management:** Weeds compete with crops for nutrients, water, sunlight and space, causing significant yield losses. Effective weed management is essential for improving crop productivity and profitability. Integrated Weed Management (IWM) combines cultural, mechanical, biological and chemical methods to control weeds efficiently. Practices such as crop rotation, optimum plant population, mulching and timely herbicide application help reduce weed infestation. The adoption of pre-emergence and post-emergence herbicides, when used judiciously, minimizes labor costs and increases crop yields. Integrated approaches ensure sustainable weed control while reducing environmental risks.

**Crop Diversification and Cropping Systems:** Dependence on a single crop increases production risks and income fluctuations. Crop diversification helps farmers spread risks and improve overall farm profitability. Introducing pulses, oilseeds, vegetables, fodder crops and horticultural crops into existing farming systems enhances income opportunities. Intercropping systems, particularly involving legumes, improve resource utilization and soil fertility. Diversified cropping systems improve resilience against market and climatic uncertainties. They also provide multiple sources of income throughout the year.

**Integrated Pest and Disease Management**

Pests and diseases can cause severe economic losses if not managed properly. Integrated Pest Management (IPM) combines preventive, cultural, biological and chemical measures to minimize pest damage. Regular field monitoring helps detect pest infestations at an early stage. Biological control agents, pheromone traps, light traps and resistant varieties reduce dependence on chemical pesticides. The judicious use of pesticides based on economic threshold levels helps reduce production costs and

environmental contamination. Effective pest management enhances crop quality and market value.

**Mechanization and Smart Farming:** Farm mechanization improves operational efficiency and reduces labor dependency. The use of modern machinery such as seed drills, planters, power weeders, harvesters and threshers enable timely farm operations. Precision agriculture technologies, including GPS, sensors, drones and remote sensing tools, provide valuable information for crop management. These technologies help optimize the use of inputs and improve decision-making. Digital agriculture platforms offer weather forecasts, market information and advisory services, enabling farmers to make informed management decisions.

**Climate-Smart Agriculture:** Climate change poses significant challenges to agricultural production. Climate-smart agricultural practices help farmers adapt to changing weather patterns while maintaining productivity and profitability. Key climate-smart practices include: Drought-tolerant crop varieties, efficient water management, Crop diversification, Agroforestry systems, Conservation agriculture, integrated nutrient and pest management. These practices enhance resilience to climate variability and reduce production risks.

**Integrated Farming Systems:** Integrated Farming Systems (IFS) combine crops, livestock, poultry, fisheries, horticulture and other enterprises within a single farm. This approach improves resource recycling and income diversification. Crop residues can be used as animal feed, while livestock manure can be utilized as organic fertilizer. Such integration reduces external input requirements and improves farm sustainability. Integrated farming provides year-round employment and income opportunities, making farming more resilient and profitable.

## Role of Farmer Training and Extension Services

The successful adoption of agronomic innovations depends on effective knowledge dissemination. Farmer training programs, demonstrations, field days and extension services help create awareness about improved technologies. Agricultural universities, Krishi Vigyan Kendras (KVKs), research institutions and extension agencies play a crucial role in transferring technology from laboratories to farmers' fields. Continuous capacity building enables farmers to adopt innovations effectively and maximize benefits.

## Future Prospects

The future of agriculture lies in the integration of scientific knowledge, modern technologies and sustainable resource management practices. Innovations such as artificial intelligence, machine learning, drone technology, Internet of Things (IoT) and precision farming will further transform agricultural production systems. Policies promoting climate-smart agriculture, digital agriculture and resource conservation will accelerate the adoption of agronomic innovations. Farmers who embrace these technologies will be better positioned to improve productivity, reduce costs and enhance profitability.

## Conclusion

Enhancing farm profitability is essential for

ensuring the economic well-being of farming communities and the sustainability of agriculture. Agronomic innovations provide practical and effective solutions for increasing productivity, improving resource-use efficiency, reducing production costs and mitigating climatic risks. Practices such as precision nutrient management, water-saving technologies, conservation agriculture, crop diversification, integrated pest management, mechanization and integrated farming systems can significantly improve farm income. The widespread adoption of these innovations, supported by research, extension services and policy interventions, will pave the way for a more productive, profitable and sustainable agricultural sector.

## References

Kaur, A., Singh, G., Menon, S. and Kumari, K. (2024). Integrated weed management: A comprehensive review of conventional, non-conventional, and emerging strategies for sustainable agriculture. *Journal of Advances in Biology & Biotechnology*, 27(8): 156-167.

Parihar, C. M., Jat, H. S., Jat, S. L., Kakraliya, S. K. and Nayak, H. S. (2020). Precision nutrient management for higher nutrient use efficiency and farm profitability in irrigated cereal-based cropping systems. *Indian Journal of Fertilisers*, 16(10): 1000-1014.

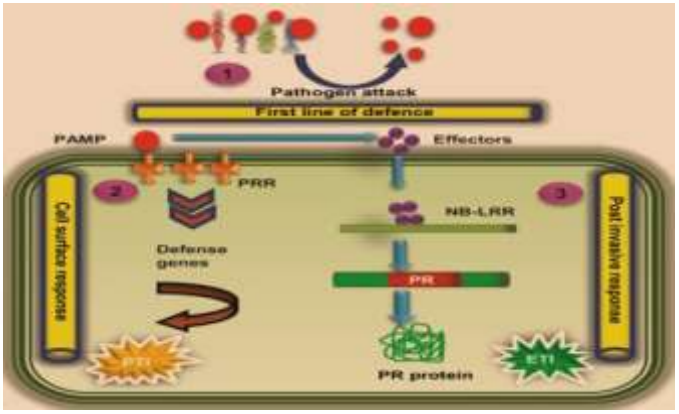
Sethi, R. R., Jena, S. K., Renuka Rani, B. and Jamanal, S. K. (2022). Advanced water management technology for enhancing agricultural productivity. ICAR-Indian Institute of Water Management (ICAR-IIWM), Bhubaneswar & National Institute of Agricultural Extension Management (MANAGE), Hyderabad, India.

Sivaraman, K., Thankamani, C. K. and Srinivasan, V. (2023). Crop diversification: cropping/system approach for enhancing farmers' income. In Handbook of spices in India: 75 years of research and development (pp. 3847-3926). Singapore: Springer Nature Singapore.

# Role of Pathogenesis-Related Proteins and PR-Like Proteins in Plant-Pathogen Interactions

**Jesima Barveen U. I., Sumitha S. and Vinodhini A.**

Due to their immobility, plants are continuously exposed to a range of environmental stressors, including disease outbreaks. Despite this limitation, plants have evolved a highly developed defense system that enables them to recognize and respond to invasive microorganisms. Using this technique, plants are able to recognize conserved molecular patterns on pathogens and initiate fundamental immune responses. If this response is not enough to stop the infection, plants activate a second, more concentrated defensive layer called effector-triggered immunity (ETI).When plant resistance proteins identify pathogen-derived effector molecules, ETI is triggered, producing a quick and potent defense response that frequently results in disease resistance. Plant defense depends on both induced and constitutive (pre-existing) systems. Plants produce and accumulate a variety of defense related proteins near the infection site during the initial stages of infection. Numerous of these proteins exhibit antibacterial activity and promote the development of physical barriers in the cell wall, such as lignin. In order to stop the spread of pathogens, plants might occasionally trigger a hypersensitive reaction in which infected cells quickly die. Plant immunity is mostly dependent on pathogenesis-related (PR) proteins, which are defense related proteins. These proteins play a major role in resistance against bacteria, fungi, viruses, and other pathogens. They are created in reaction to pathogen attack.




Source: Joshi *et al.*, 2021

## Enzymatic PR Proteins in Plant Defense

**PR-1 Family Structure:** Small, acidic proteins have conserved cysteine residues.

**Function:** The exact biochemical function remains unclear. Possess a variety of antifungal and antibacterial qualities. Cause damage to fungal cell membranes and prevent spore germination. For example, tobacco PR-1a and Arabidopsis PR-1.

**PR-2 Family (β-1,3-Glucanases)**

**Structure:** Hydrolytic enzymes break the β-1,3-glucan connections in fungal cell walls.

**Function:** Fungal cell walls are weakened by the breakdown of β-glucans. Release oligosaccharides that trigger additional defense mechanisms.

**Jesima Barveen U. I., Sumitha S. and Vinodhini A.**
M.Sc. Scholar, Department of Plant Pathology, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu Tamil Nadu

| Family | Pfam | Activity | Functions |
|---|---|---|---|
| PR1 | PF00188 | Immune signaling, Lipid-binding | Antimicrobial, Abundant induced protein in the apoplast |
| PR2 | PF00332 | b-1,3-glucanase | Antimicrobial, Cellwall degradation |
| PR3<br>PR4<br>PR8<br>PR11 | PF00182<br>PF00967<br>PF00704<br>PF00704 | Chitinase (GH19) Chitin binding Chitinase (GH18) | Antimicrobial, cell wall degradation. |
| PR5 | PF00314 | Thaumatin/ Osmotin/ Zeamatin-like | Antifungal, Glucan binding, Plasma membrane permeability, Anti-freeze activity |
| PR6 | PF00280 | Protease inhibitor | Nematocidal, Insecticidal, Synergistic with PR13 |
| PR7 | PF00082 | Subtilisin-like endoprotease | Antifungal, Phytocytokine signaling |
| PR9 | PF00141 | Heme-containing peroxidase | Lignin-forming peroxidase |
| PR10 | PF00407 | Ribonuclease-like,large hydrophobic cavity | Antimicrobial, Cytoplasmic protein. |
| PR12 | PF00304 | Plant defensin | Antimicrobial, Induction of ion efflux |
| PR13 | PF00321 | Thionin | Antimicrobial, Membrane permeating, Synergistic with PR14 |
| PR14 | PF00234 | Non-specific lipid-transfer protein Protease inhibitor Seed storage | Antimicrobial |
| PR15<br>PR16 | PF00190<br>PF00190 | Oxalate oxidase-like | Antimicrobial. ROS generation. Germin, Cupin family |
| PR17 | PF04450 | Putative aminopeptidase | Poorly characterized |

Some are also involved in the production of pollen and seeds.

**Location:** Vacuole or apoplast.

**PR-3 family- Chitinases Class I, II, IV, V and VI**

**Structure:** Have a chitin-binding domain and a catalytic domain.

**Function:** In fungal walls, hydrolyze chitin poly-mers (β-1,4 linkages). Generate defense pathway-signaling chitin oligosaccharides. It Found in a variety of plant species, including rice, tomatoes, and tobacco.

**PR-4 Family -Hevein-like proteins**

**Structure:** Hevein is a small protein with a chitin-binding domain that resembles rubber tree latex.

**Function:** By binding chitin, it inhibits the growth of fungi. Have characteristics similar to both chitinase and lysozyme. One example is tobacco "win" proteins, which are created by wounds.

**PR-5 family or Thaumatin-like proteins**

**Structure:** Similar to thaumatin, a sweet-tasting protein from *Thaumatococcus daniellii*.

**Function:** The permeability of fungal membranes permits the outflow of cell contents. Antiviral, antifungal, and anti-oomycete characteristics. It is capable of binding β-glucans and inhibiting fungal enzymes.

**Induction:** Using salicylic acid, ethylene, and pathogen attack.

**PR-6 Family-Proteinase Inhibitors**

**Structure:** Prevent pathogens and insects from using their serine or cysteine proteases.

**Function:** Prevent the breakdown of host proteins by pathogen enzymes. It Prevent herbivory by blocking the digestive enzymes in insects' stomachs. Tomato trypsin inhibitor and potato inhibitor II are two examples.

**PR-7 Family (Endoproteinases)**

**Structure:** Metalloproteinases (need metal ions such as $Zn^{2+}$).

**Function:** Release signal peptides by breaking down

host or pathogen proteins. Take part in defense signaling and cell wall modification. Tomato P69 protein, for instance.

**PR-8 Family or Class III Chitinases**

**Structure:** Acidic chitinases differ in sequence from PR-3.

**Function:** Antifungal; hydrolyzes chitin.

**PR-9 Family-Peroxidase**

**Structure:** Heme-containing enzymes.

**Function:** Encourage the production of lignin and suberin, which strengthen cell walls, by oxidizing phenolics. Create reactive oxygen species (ROS) to fight microorganisms. Participate in the hypersensitive reaction (HR).One such is tobacco anionic peroxidase.

**PR-10 Family or Ribonuclease-like proteins**

**Function:** It Destroy pathogen RNA to prevent viruses from spreading. Link small molecules to signaling, such as flavonoids and phytohormones. For example, the Bet v. 1 allergen is present in birch pollen.

**PR-11 Family (Acidic Type, Class I Chitinases)**

**Function:** Like PR-3 and PR-8, but with a different isoelectric point and localization.

**Function:** Protect against fungal infections by hydrolyzing chitin. Salicylic acid and pathogen infection are the inducers.

**Family PR-12 (Defensins)**

**Function:** Creation channels to damage fungal plasma membranes. Prevent spore germination and hyphal growth. Some exhibit insecticidal and antibacterial properties.

**Thionins in the PR-13 family**

**Function:** Insert into microbial membranes to cause lysis. Toxic to fungi and bacteria.

**Location:** Cell walls and vacuoles. For example, α- and β-thionins are found in wheat and barley.

**LTPs, or lipid-transfer proteins, belong to the PR-14 family**

**Function:** Move phospholipids from one membrane to another. Cuticle-reinforcing, antifungal, and antibacterial functions. Take part in stress tolerance and signaling. Barley LTP1 is one example.

**PR-15 Family (GLPs or germin-like proteins)**

**Function:** Produce hydrogen peroxide ($H_2O_2$) for defensive signaling and lignification. Strengthen the cell wall when a pathogen invades. One example is barley germin.

**PR-16 Family (GLP-related Germin-like Proteins)**

**Function:** Like PR-15, these proteins may not have enzymatic activity but serve as structural defense or signaling proteins.

**PR-17 Family**

**Function:** Thought to possess antifungal properties. It might be involved in systemic signaling. PR-17C from tobacco is one example.

**Pathogen-Derived PR-Like Proteins**

PR proteins were once thought to be defensive chemicals produced from plants. Recent research, however, has shown that many plant diseases also create PR-like proteins, which are proteins that resemble plant PR proteins. These pathogen-derived proteins frequently function as virulence factors that

weaken host defenses and encourage infection.The most researched PR-like proteins are PR1-like proteins. These proteins have been found in nematodes, oomycetes, and fungi and are members of the CAP protein family. Pathogen proteins that resemble PR1.

# Reform Express in Agriculture & Rural Development: A New Push for Farmer-Centric Governance

**Snehalkumar A. Patel, Nital N. Patel, K. S. Shukla and Jatinkumar J. G.**

**Abstract**

India's agriculture sector is undergoing a major administrative transformation through the "Reform Express" initiative launched under the leadership of Shivraj Singh Chouhan and the vision of Narendra Modi. The initiative aims to replace slow, paperwork-based governance with a transparent, technology-driven, and farmer-centric system. Earlier challenges such as delayed benefit delivery, weak monitoring, manual processing, and slow grievance redressal reduced the effectiveness of agricultural welfare programs. The new reforms focus on AI-enabled governance, digital monitoring, faster complaint resolution, verification of financial assistance, and improved farmer awareness. These measures are expected to enhance transparency, reduce corruption, strengthen accountability, and improve service delivery in rural areas. The "Reform Express" represents a significant step toward modernizing agricultural governance and supporting the vision of a digitally empowered and farmer-friendly rural India.

## Introduction

Union Agriculture and Rural Development Minister Shivraj Singh Chouhan has emphasized that governance should move beyond paperwork and create direct impact in people's lives. Under the vision of Prime Minister Narendra Modi, the Ministry has launched a faster and more accountable "Reform Express" aimed at improving agricultural administration, grievance redressal, and delivery of benefits to farmers and rural citizens. The reforms focus on transparency, digital monitoring, AI-enabled governance, faster disposal of cases, and ensuring that government schemes reach beneficiaries without delays or corruption (Press Information Bureau). India's agriculture sector remains the backbone of the rural economy, contributing significantly to employment, food security, and economic stability. In recent years, the government has focused on transforming agriculture through digital governance, infrastructure development, farmer welfare schemes, and technology-driven reforms. The latest "Reform Express" initiative reflects a shift from traditional file-based administration to result-oriented governance. The aim is to make agricultural and rural development systems more responsive, transparent, and farmer-friendly (Press Information Bureau).

## Old System and its Limitations

**Snehalkumar A. Patel and Nital N. Patel**
Scientist, Krishi Vigyan Kendra, Navsari Agricultural University, Navsari, Gujarat
**K. S. Shukla and Jatinkumar J. G.**
Assistant Professor, NMCA, Navsari Agricultural University, Navsari, Gujarat

Earlier administrative systems in agriculture and rural development faced several operational challenges:

**Delay in Delivery of Benefits:** Farmers often had to visit multiple offices repeatedly to receive subsidies, compensation, or scheme benefits.

**Weak Monitoring Mechanisms:** There was limited verification of whether financial assistance actually reached the intended beneficiaries.

**Manual and Paper-Based Governance:** Heavy dependence on files and physical approvals slowed decision-making and created inefficiencies.

**Slow Disposal of Complaints and Court Cases:** Grievance redressal mechanisms were often time-consuming, affecting trust in governance systems.

**Limited Awareness among Farmers:** Many farmers remained unaware of available schemes and support programs due to weak outreach systems.

These limitations reduced the effectiveness of welfare programs and delayed the pace of rural development.

**Why these Reforms were needed**

The reforms became necessary because Indian agriculture is undergoing rapid transform-ation. Farmers today require timely services, digital access, transparent governance, and faster financial support. Several national priorities also demanded administrative modernization:

- ✓ Increasing farmer income
- ✓ Enhancing efficiency in subsidy delivery
- ✓ Promoting digital agriculture
- ✓ Reducing corruption and leakages
- ✓ Improving accountability in rural governance
- ✓ Ensuring inclusive development in villages

The government has also recognized that technology such as Artificial Intelligence, digital platforms, and direct monitoring can significantly improve service delivery.

**New Reform Express: Key Changes Introduced**

**Governance Beyond Files:** The Minister stressed that administration should create visible impact in citizens' lives instead of remaining limited to paperwork.

**Dedicated Monitoring Teams:** Special teams have been formed to monitor complaints and ensure faster resolution of farmers' grievances.

**Verification of Financial Assistance:** Officials have been instructed to verify through telephone and digital systems whether beneficiaries actually received funds.

**Use of AI and Digital Technologies:** The ministry is promoting AI-enabled governance and digital monitoring systems to improve transparency and efficiency.

**Faster Resolution of Court Cases:** Departments have been directed to accelerate disposal of pending legal matters related to agriculture and rural development.

**Increased Farmer Awareness:** The government plans to strengthen awareness campaigns so that farmers can better access schemes and benefits.

**Focus on Accountability:** The reform model aims to establish measurable outcomes and citizen-centric governance in rural administration.

## Expected Impact of the Reforms

The "Reform Express" initiative is expected to bring several long-term benefits:

- ✓ Faster delivery of agricultural schemes
- ✓ Greater transparency in fund transfer
- ✓ Reduced corruption and leakages
- ✓ Improved trust between farmers and administration
- ✓ Better grievance redressal systems
- ✓ Stronger digital agriculture ecosystem
- ✓ Enhanced efficiency in rural governance

The reforms also align with India's broader vision of "Viksit Bharat 2047," where agriculture modernization and rural prosperity are central priorities (PM India).

## Conclusion

The new reform initiative in agriculture and rural development represents a significant administrative shift toward technology-driven, accountable, and citizen-focused governance. By integrating AI, digital monitoring, faster grievance systems, and direct beneficiary verification, the government aims to make rural administration more effective and transparent. If implemented efficiently, the "Reform Express" can strengthen farmer confidence, improve service delivery, and accelerate the transformation of India's rural economy.

## References

PIB Press Release - Reform Express in Agriculture & Rural Development.

PM India - Reform Momentum and Governance Vision.

# Carbon Nanodots: Tiny Particles, Mighty Potential for Sustainable Agriculture

**Kanishka, Vaibhav R. Chauhan and Rajender Sharma**


## Abstract

Carbon Nanodots (CNDs) are a novel class of fluorescent carbon nanomaterials with a diameter generally below 10 nm. Their remarkable characteristics, such as small size, high water solubility, biocompatibility, photostability, and ease of surface functionalization, make them highly suitable for agricultural applications. CNDs are synthesized by both top-down and bottom-up approaches and can be derived from natural, low-cost precursors including fruit peels. Research has demonstrated that CNDs promote seed germination, seedling vigour, water and nutrient uptake, photosynthesis efficiency, and stress tolerance in diverse crop species. Their eco-friendly and non-toxic nature positions them as promising next-generation nano-biostimulants for sustainable crop production.


## Introduction

Agriculture worldwide faces mounting pressure to increase productivity while minimising environmental degradation. In this context, nanotechnology has opened promising avenues through the development of nanomaterials that can interact with plants at a cellular level. Among these, Carbon Nanodots (CNDs) have attracted considerable research attention owing to their unique combination of physical, chemical, and biological properties. Carbon Nanodots, often abbreviated as CNDs, C-dots, or GQDs (Graphene Quantum Dots, a related variant), are zero-dimensional carbon nanoparticles generally ranging from 1 to 10 nanometres in diameter. They were first discovered accidentally in 2004 during the purification of single-walled carbon nanotubes (Xu *et al.*, 2004). Since then, they have evolved into one of the most widely studied classes of nanomaterials worldwide.

## What are Carbon Nanodots (CNDs)?

CNDs consist primarily of carbon atoms arranged in a $sp^2$-hybridised graphitic core, surrounded by a shell rich in functional groups such as hydroxyl (-OH), carboxyl (-COOH), and amine (-NH2) groups. These surface groups are not merely decoration - they are the key to CNDs' remarkable versatility, enabling them to interact with biological molecules, bind nutrients, and be chemically tailored for specific applications.

## Unique Properties of Carbon Nanodots


**Kanishka**
Department of Seed Science and Technology, College of Horticulture, Dr. YSP UHF, Nauni, Solan, Himachal Pradesh
**Vaibhav R. Chauhan**
Department of Fruit Science, College of Horticulture, Dr. YSP UHF, Nauni, Solan, Himachal Pradesh
**Rajender Sharma**
Department of Vegetable Science, College of Horticulture, Dr. YSP UHF, Nauni, Solan, Himachal Pradesh

What makes CNDs so special? The answer lies in a constellation of properties that, taken together, create a material almost tailor-made for biological and agricultural use:

**Bright Fluorescence:** CNDs emit strong, tuneable fluorescence - meaning they can glow in different colours (blue, green, yellow, red) depending on their size and surface chemistry when exposed to light. This makes them valuable as biosensors and imaging agents for detecting plant stress or disease (Sun *et al*., 2006).

**Water Solubility:** Unlike many nanoparticles that clump together or refuse to dissolve in water, CNDs disperse readily, making them easy to apply as foliar sprays or root-zone drench solutions.

**Biocompatibility and Low Toxicity:** Research findings consistently indicate that CNDs, particularly those obtained from renewable natural sources, are highly biocompatible and exhibit negligible toxicity to plants, soil microorganisms, and animal systems under normal application levels.

**Rich Surface Chemistry:** The abundance of functional groups on their surface allows CNDs to be loaded with nutrients, pesticides, or growth regulators and released in a controlled, targeted manner.

**Photocatalytic Activity:** CNDs can harvest light energy and generate reactive species that can stimulate plant metabolism, similar to how photosynthesis captures sunlight.

**Stability:** CNDs are resistant to photobleaching (they do not fade easily in light), making them reliable for long-term monitoring applications.

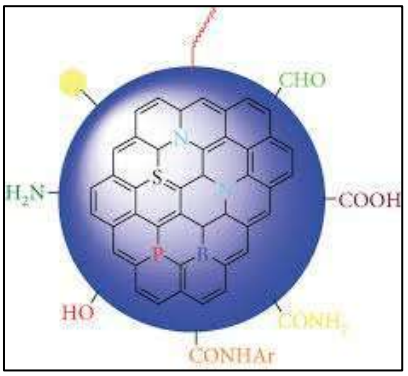



Fig. 1: Structure of carbon nanodot

## How are Carbon Nanodots Synthesized?

One of the most appealing features of CNDs is how simple and inexpensive it can be to make them. There are two broad approaches:

**Top-down methods:** Breaking down larger carbon structures (such as graphite, carbon black, or even charcoal) into nanoscale fragments using techniques like laser ablation, arc discharge, or chemical oxidation.

**Bottom-up methods:** Building CNDs up from small molecular precursors through hydrothermal synthesis, microwave treatment, or pyrolysis. This is where it gets especially exciting for agriculture - researchers have successfully synthesised CNDs from agricultural waste materials such as sugarcane bagasse, rice husk, neem leaves, coconut shell, banana peel, orange peel, wheat straw, and even cow dung. This circular-economy approach adds an extra layer of sustainability to the technology. Hydrothermal synthesis essentially heating the raw material with water in a closed vessel at moderate temperatures (around 120-200°C for a few hours) is particularly popular because it is straightforward, affordable, and produces CNDs with excellent

fluorescence properties.

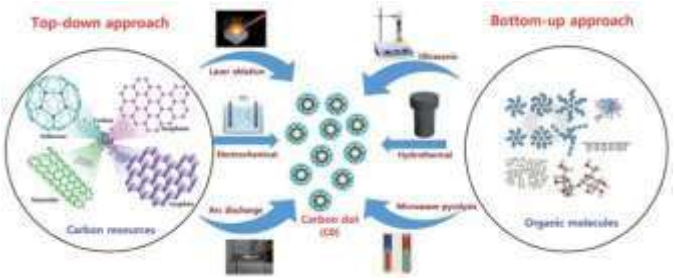



Fig. 2: Synthesis of carbon nanodots

## How CNDs Influence Plant Growth

**Uptake, Translocation and Accumulation in Plants:** Plant uptake of CNDs is well-documented through advanced imaging techniques. Their small size (< 10 nm) allows passive movement through seed coat pores and intercellular spaces, after which they cluster in cotyledonary tissues and accelerate germination. Once inside the root, CNDs bind to vascular bundle surfaces and ride the transpiration stream upward through the xylem, reaching stems and leaf mesophyll within days. In mung bean, fluorescent CND signals were traceable in every major tissue - root, stem, cotyledon, and leaf vein - within five days of exposure (Li *et al*., 2016). This whole-plant mobility means a single application at the root zone delivers systemic benefit.

**Enhancement of Photosynthesis:** CNDs boost photosynthetic output via two parallel routes. First, their UV-to-blue photoluminescence converts otherwise unutilised solar energy into wavelengths chlorophyll can directly absorb, raising light-use efficiency without any chemical input. Second, CND degradation inside plant cells - driven by endogenous peroxidases and hydrogen peroxide - yields growth-promoting hormone analogues and $CO_2$ that re-enters the Calvin cycle as an additional carbon substrate. The net enzymatic result is a consistent elevation of Rubisco activity (up to 42% in mung bean) and faster carbohydrate accumulation (Wang *et al.*, 2018).

**Improvement in Nutrient Assimilation:** The polar surface groups (-OH, -COOH) of CNDs function as ion chelators, binding $K^+$, $Ca^{2+}$, $Mg^{2+}$, $Fe^{3+}$, $Zn^{2+}$, $Mn^{2+}$, and $Cu^{2+}$ near root surfaces and raising their local bioavailability for uptake. Water absorption is simultaneously enhanced: CND-primed mung bean seeds imbibed 34.9% more moisture than unprimed controls, shortening the time to germination and improving early seedling establishment (Wang *et al*., 2018). Because mineral ion transport in roots is hydraulically driven, the water-uptake and nutrient-uptake benefits are mutually reinforcing.

**Stimulation of Biological Nitrogen Fixation:** CNDs can directly amplify the capacity of soil nitrogen-fixing bacteria. In *Azotobacter chroococcum*, a concentration of 4 mg $mL^{-1}$ CNDs altered the secondary structure of nitrogenase and accelerated its electron transfer kinetics, resulting in a 158% gain in nitrogenase activity (Wang *et al.*, 2018). This translates to more atmospheric $N_2$ converted to plant-available ammonium, reducing the crop's dependence on synthetic nitrogenous inputs a benefit with both economic and environmental significance.

**Enhanced Reactive Oxygen Species (ROS) Scavenging:** CNDs act as antioxidants, neutralising harmful reactive oxygen species that accumulate under stress conditions. Through the suppression of

reactive oxygen species-induced damage, CNDs contribute to the maintenance of cellular homeostasis and enhance plant resilience against environmental and biological stresses, including drought, salinity, and pathogen pressure.

**Hormonal Signalling:** CNDs interact with phytohormone biosynthesis pathways, upregulating gibberellins and auxins that control cell elongation and root growth.

**Ion Channel Modulation:** CNDs influence the uptake of essential ions ($K^+$, $Ca^{2+}$, $NO^{3-}$) through root cell membranes, improving nutrient absorption efficiency.

**Gene Expression Regulation:** Evidence suggests that CNDs can trigger the upregulation of genes involved in cellular protection mechanisms, including antioxidant systems and heat shock responses, thereby enhancing the plant's capacity to cope with biotic and abiotic stresses.

## Advantages over Conventional Inputs

When compared with traditional agricultural inputs, CNDs offer several compelling advantages. Unlike synthetic fertilizers, CND-based nano-fertilizers release nutrients slowly, reducing losses and pollution. Unlike chemical pesticides, CND biosensors enable early detection without spraying chemicals. Unlike metal-based nanoparticles (silver, titanium dioxide), CNDs derived from carbon especially from organic waste carry a far lower ecotoxicological risk. CNDs are also cost-competitive when made from waste biomass, making them accessible to smallholder farmers if production is scaled appropriately. Their water solubility means they can be applied through existing irrigation and spraying equipment without any modification. Finally, because many CND precursors are agricultural by-products, their production actually valorises waste, converting a disposal problem into an economic opportunity.

## Conclusion

Carbon Nanodots represent a scientifically robust and practically promising addition to the toolkit of sustainable agriculture. The unique combination of biological compatibility, ecological safety, and natural degradability makes carbon nanodots a more sustainable alternative to many metal-containing nanomaterials. CNDs are readily absorbed by seeds and roots, translocated through vascular tissues, and exert wide-ranging agronomic benefits from accelerating germination and boosting photosynthesis to enhancing stress tolerance and promoting biological nitrogen fixation across a diverse range of crop species. The lack of reported toxic impacts and residue accumulation in edible plant tissues highlights the potential of CNDs as a safe nanomaterial for sustainable food and agricultural systems. With scalable synthesis routes available from agricultural waste materials such as fruit peels, CNDs offer a cost-effective and green nanotechnology solution. As research advances, CNDs are poised to emerge as next-generation nano-fertilisers and nano-biostimulants that contribute meaningfully to food security and environmental sustainability in modern agriculture.

## References

Li, W., Zheng, Y., Zhang, H., Liu, Z., Su, W., Chen, S., Liu, Y., Zhuang, J. and Lei, B. (2016). Phytotoxicity, uptake, and translocation of fluorescent carbon dots in mung bean plants. *ACS Applied Materials & Interfaces*, 8(31): 19939-19945.

Sun, Y. P., Zhou, B., Lin, Y., Wang, W., Fernando, K. S., Pathak, P., Meziani, M.J., Harruff, B.A., Wang, X., Wang, H. and Luo, P. G. and Xie, S. Y. (2006). Quantum-sized carbon dots for bright and colorful photoluminescence. *Journal of the American Chemical Society*, 128(24): 7756-7757.

Wang, H., Li, H., Zhang, M., Song, Y., Huang, J., Huang, H., Shao, M., Liu, Y. and Kang, Z. (2018). Carbon dots enhance the nitrogen fixation activity of *Azotobacter chroococcum* *ACS Applied Materials & Interfaces*, 10(19): 16308-16314.

Wang, H., Zhang, M., Song, Y., Li, H., Huang, H., Shao, M., Liu, Y. and Kang, Z. (2018). Carbon dots promote the growth and photosynthesis of mung bean sprouts. *Carbon*, 136: 94-102.

Xu, X., Ray, R., Gu, Y., Ploehn, H. J., Gearheart, L., Raker, K., and Scrivens, W. A. (2004). Electrophoretic analysis and purification of fluorescent single-walled carbon nanotube fragments. *Journal of the American Chemical Society*, 126(40): 12736-12737.

# Bracing for El Niño 2026: Agricultural Risks and Solutions

**H. Uduwawala and B. A. I. S. L. Bandara**

## Introduction

Something unusual is happening beneath the surface of the Pacific Ocean. Since early 2026, an enormous mass of warm water, known to climate scientists as a Kelvin wave, has been racing eastward toward South America, triggering alarm bells in weather agencies around the world. The US National Oceanic and Atmospheric Administration (NOAA) now estimates an 82% probability that El Niño will develop between May and July 2026, with the event expected to persist well into 2027. What makes this particularly concerning is its projected intensity. Some European climate models suggest that the Ocean Niño Index (ONI) could exceed 3°C above normal, a threshold reached only once in recorded history, in January 1878. For farmers, food security specialists, and agricultural policymakers, this is far from background noise. El Niño events have historically reshaped rainfall patterns, triggered droughts, intensified heat waves, and disrupted planting seasons across the tropics and subtropics. A "super" event of the scale currently being forecast could rival some of the most severe agricultural disruptions of the modern era. This article examines what the 2026 El Niño could mean for global agriculture, identifies the crops and regions facing the greatest risks, and explores what farmers and policymakers can do right now to protect food production and livelihoods.

**Understanding El Niño and Its Agricultural Relevance:** El Niño occurs when trade winds weaken across the equatorial Pacific, allowing warm surface waters to accumulate in the central and eastern parts of the ocean. This sets off a chain of teleconnections, atmospheric connections that influence temperature and rainfall patterns far beyond the Pacific region. The World Meteorological Organization reports that land surface temperatures are likely to remain above normal across most of the world during the May-July season, with particularly strong signals over southern North America, Central America, the Caribbean, Europe, and northern Africa. The agricultural impacts of El Niño are far from uniform. Hotter and drier conditions are expected across South Asia, Southeast Asia, southern Africa, and Australia, while parts of South America and East Africa are likely to experience above-average rainfall. This creates a challenging combination of drought and flooding that can place simultaneous pressure on food systems. El Niño events typically persist for 9 to 12 months. Climate change is making the situation even more concerning. The frequency and intensity of ENSO events have increased since the second half of the 20$^{th}$ century, and current projections indicate that this trend is likely to continue.

**H. Uduwawala and B. A. I. S. L. Bandara**
Department of Plant Sciences, Faculty of Agriculture, Rajarata University of Sri Lanka

## Impact on Global Crop Production

**Yield Losses by Commodity:** The most comprehensive global assessment of El Niño's impact on crop production comes from a study by Iizumi *et al*., (2014), published in Nature Communications. Drawing on yield data from approximately 12,000 political units worldwide, the researchers found that El Niño negatively affects harvested areas across 22-24% of global cropland and significantly reduces average global yields of several key staple crops. Wheat yields decline by 1.32%, rice by 1.33%, and maize by as much as 4.3%. Soybean, however, is a notable exception. Global soybean yields tend to increase by 2.1-5.4% during El Niño years because the United States and Brazil, which dominate global production, often experience cooler and wetter growing conditions that support higher yields. Rice deserves particular attention because it remains the primary staple food for more than half of the world's population. At the same time, it carries the highest probability (6.6%) of simultaneous yield losses across multiple countries during El Niño years. This means production shortfalls frequently occur in several major rice-producing nations at once, amplifying pressure on global supplies and increasing the risk of food market disruptions (Cao *et al*., 2023). Further evidence comes from research by the Alliance of Bioversity International and CIAT (2024), which found that rice production declined during each of the three El Niño events recorded since 2000. The study also identified nighttime heat waves during the growing season as the most damaging agro-climatic factor, highlighting the growing vulnerability of rice systems to rising temperatures.

**Regional Agricultural Hotspots:** The 2023-24 El Niño, one of the five strongest on record, saw sea surface temperatures about 2°C above average and has become a recent and sobering reference point for understanding agricultural impacts. In southern Africa, 11 out of 13 recorded El Niño seasons have been linked to below-normal maize yields in Zimbabwe. In West Africa, the 2023 event delayed the onset of rainfall across the Sahel, which disrupted the sowing of key staple crops such as millet, sorghum, and groundnuts. Satellite-based NDVI (Normalized Difference Vegetation Index) data also recorded significant vegetation losses during the critical growing season, highlighting the scale of agricultural stress. In Latin America, more than 800,000 rural people across Bolivia, Colombia, Peru, and Venezuela were exposed to drought conditions, with resulting harvest declines contributing to food insecurity that is expected to persist into 2025. In South and Southeast Asia, El Niño typically weakens the monsoon system, often described as India's “real finance minister” because of its deep influence on agricultural output and the wider economy. When the monsoon weakens, irrigation availability declines and production of rice, cotton, and pulses are put under strain across countries including India, Indonesia, the Philippines, and Vietnam. A stronger El Niño event in 2026 is widely expected to further suppress monsoon rainfall and intensify these pressures.

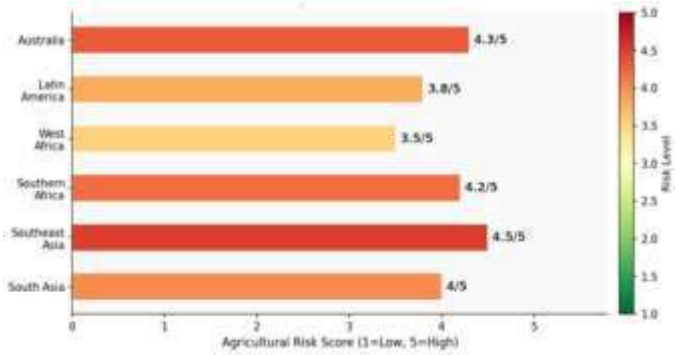



Fig. 1: Regional Agricultural Risk Severity during El Nino Events

## Strategies to Protect Agriculture from El Niño

**Drought Tolerant Crop Varieties:** Deploying drought-adapted crop varieties is one of the most reliable first lines of defence against climate stress. Agricultural research institutions have developed varieties that can withstand water deficits through three main mechanisms: drought tolerance, which allows crops to function under low tissue water potential; drought avoidance, which helps maintain tissue moisture despite limited soil water; and drought escape, which enables faster growth so plants complete critical stages before severe drought conditions set in. To be effective, these varieties need to be distributed through regional seed systems and government subsidy programmes before the growing season begins. Priority should be given to certified drought-tolerant seeds to ensure farmers have timely access to resilient planting material. At the same time, indigenous seed varieties, which are often overlooked in formal agricultural systems, have demonstrated strong resilience under local stress conditions. Integrating these traditional varieties alongside modern improved crops can strengthen overall adaptability and provide farmers with a broader buffer against unpredictable rainfall patterns.

**Precision Irrigation and Water Management:** Efficient water use becomes critical when rainfall fails. Drip and sprinkler irrigation systems can reduce agricultural water consumption by 30-50% compared to conventional flood irrigation while still maintaining or even improving yields. At the farm level, rainwater harvesting, farm ponds, and small-scale reservoirs help extend water availability through dry spells and provide farmers with more flexibility during periods of water stress. At a broader scale, integrated water resource management plays an equally important role. This approach coordinates upstream and downstream water users and protects watershed vegetation, creating a systemic buffer that individual farm-level solutions alone cannot achieve.

**Soil Health and Conservation Agriculture:** Well-managed soils retain moisture for longer periods, support stronger root development, and recover more quickly from heat stress. Climate-smart practices such as no-till farming, cover cropping, mulching, and the application of biochar help reduce crop water stress under drought conditions. Soil organic matter plays a particularly important role in this process. Even a 1% increase in soil organic matter allows soils to hold an additional 20 litres of water per cubic metre, highlighting the long-term value of investing in soil health.

**Crop Diversification and Intercropping:** Monocultures are particularly fragile in the face of climate shocks. Growing multiple crop varieties or species

within a single season provides a form of yield insurance, since if one crop fails under drought conditions, another may still produce. Intercropping systems that combine compatible crops can also improve soil moisture retention and help reduce pest pressure, making the overall system more resilient. Climate-smart agriculture frameworks increasingly recommend blending traditional knowledge of crop diversification with modern agronomic tools to strengthen food system resilience under increasing climate variability.

**Early Warning Systems and Planting Calendar Adjustment:** ENSO forecasts today provide months of advance warning. Seasonal forecasts are essential for guiding preparedness actions in climate-sensitive sectors such as agriculture, water resource management, energy, and health. ENSO-based crop yield forecasting models can predict yields 1-12 months in advance for 32-42% of global harvested areas, depending on the crop type. This early warning capacity gives farmers and policymakers a critical window to prepare for potential impacts. Farmers who adjust planting dates, switch crop varieties, and secure water storage before dry conditions arrive consistently experience lower losses than those who do not.

**Financial Instruments and Policy Response:** Technical adaptation requires strong enabling institutions. Index-based agricultural insurance, which pays out based on rainfall or weather indices rather than individual farm-level assessments, offers an affordable way to protect farmers against climate-related shocks. The overall impact of El Niño is likely to depend on both the intensity of the event and the adaptive capacity of farmers, particularly their ability to switch to drought-resistant crops. Strengthening this adaptive capacity is therefore central to reducing losses. Governments and international donors are encouraged to activate contingency plans early. This includes pre-positioning food reserves, fast-tracking input subsidies for drought-adapted crop varieties, and coordinating early humanitarian responses in the most food-insecure regions.

## Conclusion

The 2026 El Niño is shaping up to be one of the most powerful climate events in living memory. With NOAA placing an 82% probability on its formation by mid-year, European models projecting a 100% probability of super El Niño conditions by November, and Pacific Ocean temperatures rising toward levels not recorded since 1877, the threat to global agriculture is both real and immediate. History shows that El Niño repeatedly reduces rice and wheat yields, drives food price inflation, and pushes vulnerable farming communities into crisis. Yet this is not a story without agency. The research literature is clear: drought-tolerant varieties, precision irrigation, soil conservation, crop diversification, and strong early warning systems all significantly reduce exposure to the worst outcomes. In most vulnerable regions, planting decisions for the 2026-27 season have not yet been finalised. Seed systems can still be diversified, irrigation infrastructure can still be repaired, and early warning messages are

already available. The worst of El Niño's agricultural impact is not inevitable, but avoiding it requires treating forecasts not as background noise, but as a call to action. Farmers, agronomists, policymakers, and development organisations that act now, before conditions deteriorate, will be best positioned to protect harvests, safeguard livelihoods and strengthen food security through what is likely to be a highly challenging agricultural year ahead.

## References

Alliance Bioversity International - CIAT. (2023). As El Niño Wanes, Food Security Pain Remains. https://alliancebioversityciat.org/stories/el-nino-wanes-food-security-pain-remains

Iizumi, T., Luo, J.-J., Challinor, A. J., Sakurai, G., Yokozawa, M., Sakuma, H., Brown, M. E. and Yamagata, T. (2014). Impacts of El Niño Southern Oscillation on the global yields of major crops. *Nature Communications*, 5(1).

Cao, J., Zhang, Z., Tao, F., Chen, Y., Luo, X. and Xie, J. (2023). Forecasting global crop yields based on El Nino Southern Oscillation early signals. *Agricultural Systems*, 205: 103564.

NOAA Climate Prediction Center. (2026). ENSO Diagnostic Discussion. National Weather Service. https://www.cpc.ncep.noaa.gov

Zero Carbon Analytics. (2026). Are we heading towards a Super El Niño in 2026? https://zerocarbon-analytics.org

# Problematic Soils in Anantapur Region: Challenges and Management

M. Kavitha and B. Usha Sri

## Introduction

Anantapur district, located in the Rayalaseema region of Andhra Pradesh, is one of the most drought-prone areas in India. The district experiences a semi-arid climate characterized by low and erratic rainfall, high temperatures, and frequent droughts. Agriculture is the primary livelihood, but productivity is constrained by poor soil conditions and water scarcity. Among the various agricultural challenges, problematic soils, particularly saline and alkaline (sodic) soils, adversely affect crop growth and soil productivity. These soils occupy a relatively small area but have a significant impact on agricultural sustainability and farm income.

## What are Problematic Soils?

Problematic soils are soils with physical or chemical properties that restrict plant growth and reduce agricultural productivity. The major problematic soils in Anantapur are saline soils and alkaline (sodic) soils.

**Saline Soils:** Saline soils contain excessive concentrations of soluble salts such as:

- ✓ Sodium chloride (NaCl)
- ✓ Calcium chloride ($CaCl_2$)
- ✓ Magnesium sulphate ($MgSO_4$)
- ✓ Sodium sulphate ($Na_2SO_4$)

Generally, saline soils have:

- ✓ Electrical Conductivity (EC) > 4 dS $m^{-1}$
- ✓ pH less than 8.5
- ✓ Exchangeable Sodium Percentage (ESP) less than 15

## Characteristics

- ✓ White salt crust on the soil surface
- ✓ Poor seed germination
- ✓ Stunted crop growth
- ✓ Reduced water absorption by roots
- ✓ Wilting even when soil appears moist

## Causes of Salinity

**Low Rainfall:** Insufficient rainfall fails to wash salts below the root zone.

**High Evaporation:** Intense summer temperatures draw water upward through capillary action, leaving salts behind.

**Saline Groundwater Irrigation:** Continuous use of poor-quality groundwater contributes to salt accumulation.

**Poor Drainage:** Improper drainage prevents removal of excess salts.

## Alkaline (Sodic) Soils

Sodic soils contain excessive exchangeable sodium ions on soil colloids.

Generally, sodic soils have:

- ✓ pH greater than 8.5
- ✓ ESP greater than 15
- ✓ Poor soil structure

## Characteristics

M. Kavitha and B. Usha Sri
Assistant Professor (Soil Science), Sri Krishnadevaraya College of Agricultural Sciences, Ananthapuramu, Andhra Pradesh

- ✓ Hard and compact soil
- ✓ Surface crust formation
- ✓ Poor infiltration rate
- ✓ Poor aeration
- ✓ Reduced nutrient availability

**Causes**

**Sodium Accumulation:** Excess sodium replaces calcium and magnesium on soil particles.

**Inadequate Drainage:** Poor drainage encourages sodium build-up.

Semi-Arid Climate: High evaporation and low rainfall accelerate sodicity development.

**Factors Responsible for Problematic Soils**

**Low and Erratic Rainfall:** Anantapur receives one of the lowest rainfalls in Andhra Pradesh. Due to inadequate rainfall:

- ✓ Salts are not leached from the root zone.
- ✓ Salt concentration gradually increases.
- ✓ Soil moisture remains low.

**High Temperature and Evaporation:** Summer temperatures often exceed 40°C. Effects include:

- ✓ Increased evaporation losses
- ✓ Upward movement of dissolved salts
- ✓ Salt deposition near the surface

**Soil Characteristics:** The district's red soils have:

- ✓ Low clay content
- ✓ Low cation exchange capacity
- ✓ Poor moisture retention

These conditions make the soils more vulnerable to degradation.

**Irrigation Water Quality:** Many farmers depend on groundwater irrigation. Problems include:

- ✓ High salinity levels in groundwater
- ✓ Excess sodium content
- ✓ Long-term deterioration of soil structure

**Effects of Problematic Soils on Agriculture**

**Crop Production Losses:** Problematic soils reduce agricultural productivity through:

- ✓ Poor Germination
- ✓ High salt concentration inhibits seed emergence.
- ✓ Reduced Water Uptake
- ✓ Plants experience physiological drought even when water is available.

**Nutrient Imbalance:** Availability of essential nutrients decreases:

- ✓ Nitrogen
- ✓ Phosphorus
- ✓ Zinc
- ✓ Iron
- ✓ Root Growth Restriction

Compacted soils limit root penetration and nutrient absorption.

**Yield Reduction:** Farmers often experience significant yield losses in sensitive crops.

**Management Practices**

- ✓ Leaching of salts
- ✓ Application of gypsum
- ✓ Addition of organic matter
- ✓ Proper drainage management
- ✓ Rainwater harvesting
- ✓ Cultivation of salt-tolerant crops such as sorghum, pearl millet, cotton, barley and sun-flower

## Conclusion

Problematic soils, particularly saline and sodic soils, pose a major challenge to sustainable agriculture in Anantapur district. Scientific soil reclamation practices such as gypsum application, organic matter incorporation, efficient drainage, and cultivation of salt-tolerant crops can significantly improve soil productivity and sustainability.

## References

Acharya N. G. Ranga Agricultural University (ANGRAU).

Indian Council of Agricultural Research (ICAR).

Krishi Vigyan Kendra, Kalyandurg.

National Bureau of Soil Survey and Land Use Planning (NBSS&LUP).

Central Soil Salinity Research Institute (CSSRI).

# Comparative Assessment of Analytical Instruments Use in Pesticide Residue Laboratories

**Ajeet Singh, Ramgopal Dudwal, B. N. Sharma and Hansa K. Jat**

## Introduction

Chromatographic techniques are essential analytical tools used for the separation, identification and quantification of chemical compounds in various fields, including agriculture, environmental science, pharmaceuticals, food safety, and pesticide residue analysis. Over time, chromatography has evolved from conventional methods such as High-Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC) to advanced hyphenated techniques like Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) and Gas Chromatography-Tandem Mass Spectrometry (GC-MS/MS).

HPLC (High-Performance Liquid Chromatography) is widely used for the analysis of non-volatile, thermally unstable, and polar compounds. It offers good separation efficiency and quantitative accuracy for a wide range of analyses.

UHPLC (Ultra-High-Performance Liquid Chromatography) is an advanced form of HPLC that utilizes smaller particle-size columns and higher operating pressures. It provides faster analysis, higher resolution and improved sensitivity compared to conventional HPLC. LC-MS/MS (Liquid Chromatography-Tandem Mass Spectrometry) combines the separation capability of liquid chromatography with the high sensitivity and selectivity of tandem mass spectrometry. It is considered the gold standard for the determination of pesticide residues, veterinary drugs, mycotoxins, and pharmaceutical contaminants at trace levels.

GC (Gas Chromatography) is primarily used for volatile and semi-volatile compounds. It provides excellent separation efficiency but requires analyses to be thermally stable and volatile.

GC-MS (Gas Chromatography-Mass Spectrometry) integrates GC with mass spectrometric detection, enabling both separation and structural identification of compounds. It is extensively used for environmental monitoring, forensic investigations and pesticide residue analysis.

GC-MS/MS (Gas Chromatography-Tandem Mass Spectrometry) represents a further advancement, offering superior sensitivity, selectivity, and confirmation capabilities. It minimizes matrix interference and enables reliable detection of trace-level contaminants in complex samples.

**Ajeet Singh**
Assistant Professor, Department of Soil Science & Agril. Chemistry, RARI (SKNAU, Jobner), Durgapura, Jaipur, Rajasthan
**Ramgopal Dudwal**
Young Professional, Department of Entomology, RARI (SKNAU, Jobner), Durgapura, Jaipur, Rajasthan
**B. N. Sharma and Hansa K. Jat**
Assistant Professor, Department of Entomology, RARI (SKNAU, Jobner), Durgapura, Jaipur, Rajasthan

## Comparative Study of HPLC and GC

| Parameter | HPLC (High-Performance Liquid Chromatography) | GC (Gas Chromatography) |
|---|---|---|
| Principle | Separation based on interaction between analyses, liquid mobile phase, and stationary phase | Separation based on volatility and interaction with stationary phase in a gaseous mobile phase |
| Mobile Phase | Liquid solvent(s) | Inert carrier gas (He, $N_2$, $H_2$) |
| Sample Type | Non-volatile, polar, thermally unstable compounds | Volatile, thermally stable compounds |
| Operating Temperature | Usually ambient to moderate temperatures | High temperatures (up to 350°C or more) |
| Column Type | Packed columns containing stationary phase particles | Capillary or packed columns coated with stationary phase |
| Detector Examples | UV-Vis, PDA, Fluorescence, RI, MS | FID, ECD, TCD, NPD, MS |
| Sample Preparation | Often requires filtration and dilution | May require extraction and derivatization |
| Analysis Time | Moderate (5-60 min) | Generally faster (5–30 min) |
| Sensitivity | High, especially with MS detectors | Very high, especially with ECD and MS |
| Solvent Consumption | High | Very low |
| Cost of Operation | Higher due to solvent use | Lower solvent cost, but requires carrier gas |
| Applications | Pharmaceuticals, bio-molecules, pesticides, food additives, organic acids | Pesticides, volatile organic compounds (VOCs), hydrocarbons, flavors, solvents |

## Comparative Study of UHPLC and GC-MS

| Parameter | UHPLC (Ultra High-Performance Liquid Chromatography) | GC-MS (Gas Chromatography-Mass Spectrometry) |
|---|---|---|
| Principle | Separation of compounds in liquid phase using high pressure and chromatographic columns | Separation of volatile compounds in gas phase followed by mass spectrometric detection |
| Sample Type | Polar, non-volatile, thermally unstable compounds | Volatile, semi-volatile, thermally stable compounds |
| Mobile Phase | Liquid solvents (water, methanol, acetonitrile, etc.) | Inert carrier gas (helium, nitrogen, hydrogen) |
| Operating Temperature | Generally ambient to moderate temperatures | High temperatures (up to 350°C or more) |
| Detection | UV, PDA, Fluorescence, MS, MS/MS | Mass Spectrometer (MS) |
| Sensitivity | High sensitivity, especially when coupled with MS/MS | Very high sensitivity and selectivity |
| Analysis Time | Fast (typically 2-20 min) | Moderate (10-60 min) |
| Resolution | Very high due to small particle size columns | High chromatographic resolution |
| Sample Preparation | Usually simple filtration/extraction | Often requires derivatization for polar compounds |
| Compounds Analyzed | Pesticides, pharmaceuticals, amino acids, proteins, plant metabolites | Pesticides, VOCs, hydrocarbons, environmental pollutants |
| Quantification | Excellent for non-volatile compounds | Excellent for volatile and semi-volatile compounds |
| Instrument Cost | High | High |
| Maintenance Cost | Moderate to high | High |
| Applications in Pesticide Residue Analysis | Suitable for polar and thermally labile pesticides | Suitable for volatile and semi-volatile pesticides |

The selection of an appropriate chromatographic technique depends on the physicochemical properties of the analyses, required detection limits, sample matrix complexity, and regulatory requirements. In recent years, LC-MS/MS and GC-MS/MS have become the preferred techniques for multi-residue pesticide analysis due to their exceptional sensitivity, accuracy and compliance with international standards. This comparative study aims to evaluate the principles, instrumentation, advantages, limitations, and applications of HPLC, UHPLC, LC-MS/MS, GC, GC-MS, and GC-MS/MS, highlighting their suitability for modern analytical and pesticide residue laboratories.

### Advantages of HPLC

- ✓ Suitable for thermally unstable compounds.
- ✓ Can analyze high-molecular-weight compounds.
- ✓ Wide applicability in pharmaceutical and biological samples.
- ✓ No need to volatilize analyses.

### Advantages of GC

- ✓ Excellent separation efficiency.
- ✓ Faster analysis for volatile compounds.
- ✓ High sensitivity and reproducibility.
- ✓ Lower solvent consumption.

### Applications in Pesticide Residue Analysis

- ✓ HPLC/LC-based methods are preferred for polar and thermally unstable pesticides such as carbamates, neonicotinoids, and many modern pesticides.
- ✓ GC-based methods are preferred for volatile and semi-volatile pesticides such as organochlorines, organophosphates, and pyrethroids.

### Advantages of UHPLC

- ✓ Rapid analysis with high throughput.
- ✓ Excellent separation efficiency.
- ✓ Suitable for polar and thermally unstable compounds.
- ✓ Lower solvent consumption compared to conve-ntional HPLC.
- ✓ Easily coupled with MS/MS for multi-residue analysis.

### Advantages of GC-MS

- ✓ Highly sensitive and selective.
- ✓ Provides structural identification through mass spectra.
- ✓ Ideal for volatile and semi-volatile compounds.
- ✓ Widely accepted for pesticide residue and environmental analysis.

### Limitations

### UHPLC

- ✓ Less suitable for highly volatile compounds.
- ✓ Expensive columns and high-pressure systems.

### GC-MS

- ✓ Not suitable for non-volatile and thermally unstable compounds.
- ✓ Derivatization may be required for polar analyses.

### Advantages of LC-MS/MS

- ✓ Suitable for a wide range of polar and thermally labile compounds.
- ✓ Minimal sample derivatization.
- ✓ Excellent sensitivity and selectivity.
- ✓ Ideal for multi-residue pesticide analysis.

### Advantages of GC-MS/MS

- ✓ Superior separation of volatile compounds.
- ✓ Highly reproducible mass spectra.
- ✓ Lower matrix effects.
- ✓ Excellent for environmental contaminants and volatile pesticides.

### Limitations

### LC-MS/MS

- ✓ Higher matrix effects.
- ✓ More expensive maintenance.
- ✓ Mobile phase purity is critical.

### GC-MS/MS

- ✓ Limited to volatile and thermally stable compo-unds.

**Comparative Study of LC-MS/MS and GC-MS/MS**

| Parameter | LC-MS/MS (Liquid Chromatography-Tandem Mass Spectrometry) | GC-MS/MS (Gas Chromatography-Tandem Mass Spectrometry) |
|---|---|---|
| Principle | Separation of compounds in liquid phase followed by MS/MS detection | Separation of compounds in gas phase followed by MS/MS detection |
| Sample Type | Polar, non-volatile, thermally unstable compounds | Volatile, semi-volatile, thermally stable compounds |
| Mobile Phase | Liquid solvents (water, methanol, acetonitrile) | Inert carrier gas (helium, nitrogen, hydrogen) |
| Operating Temperature | Generally low temperatures | High temperatures required for vaporization |
| Derivatization | Usually not required | Often required for polar compounds |
| Sensitivity | Very high for polar pesticides, pharmaceuticals, mycotoxins | Very high for volatile pesticides and organic pollutants |
| Analysis Time | Moderate | Faster for volatile compounds |
| Sample Preparation | Simple for most analytes | More complex if derivatization is needed |
| Matrix Effects | More susceptible to ion suppression/enhancement | Less matrix interference |
| Cost | High instrument and maintenance cost | High but generally lower operating cost than LC-MS/MS |
| Common Ionization Source | Electrospray Ionization (ESI), APCI | Electron Ionization (EI), Chemical Ionization (CI) |
| Applications | Pesticide residues, antibiotics, hormones, veterinary drugs, mycotoxins | Organochlorine pesticides, pyrethroids, PCBs, PAHs, VOCs |

- ✓ Derivatization may be required.
- ✓ High-temperature operation can degrade some analytes.

## Applications in Pesticide Residue Analysis

**LC-MS/MS:** Commonly used for:

- ✓ Neonicotinoids
- ✓ Carbamates
- ✓ Triazoles
- ✓ Sulfonylurea herbicides
- ✓ Antibiotic residues

**GC-MS/MS:** Commonly used for:

- ✓ Organochlorines
- ✓ Organophosphates
- ✓ Synthetic pyrethroids
- ✓ PAHs
- ✓ Volatile organic compounds

## Conclusion

- ✓ HPLC/UHPLC: Suitable for routine chromatographic analysis.
- ✓ LC-MS/MS: Essential for analysis of polar and thermally unstable pesticide residues.
- ✓ GC-MS/MS: Essential for volatile and semi-volatile pesticide residues at trace levels.
- ✓ LC-MS/MS and GC-MS/MS together provide the most comprehensive, sensitive, and internationally accepted platform for multi-residue pesticide analysis in food, soil, water, and agricultural commodities.

# Nutrient Cycling in Agro-Ecosystems: Mechanisms, Benefits and Strategies for Sustainable Agricultural Systems

**Komal, Kanik Kumar Bansal and Gurpreet Kaur**


## Abstract

Nutrient cycling is a fundamental ecological process that regulates the movement and transformation of nutrients within agro-ecosystems. Efficient nutrient cycling improves soil fertility, enhances crop productivity, reduces nutrient losses, and promotes environmental sustainability. However, intensive agricultural practices such as excessive fertilizer application, monocropping, and residue burning have disrupted natural nutrient cycles, resulting in soil degradation and environmental pollution. Sustainable practices including crop rotation, cover cropping, integrated nutrient management, residue retention, and precision agriculture help restore nutrient balance and improve nutrient use efficiency. This article reviews major nutrient cycling processes, the role of soil microorganisms, environmental benefits, challenges, and future prospects for sustainable agricultural systems.


## Introduction

Sustainable agricultural production depends on the continuous recycling of nutrients within the soil-plant-microbe system. Nutrient cycling involves the transfer and transformation of essential elements such as nitrogen (N), phosphorus (P), and potassium (K) through biological, chemical, and physical processes. In natural ecosystems, nutrient cycling maintains ecological balance through decomposition and biological interactions. Modern farming systems often disrupt these cycles through intensive cultivation and excessive fertilizer use. Therefore, improving nutrient cycling has become a key strategy for enhancing agricultural sustainability and environmental protection.

## Importance of Nutrient Cycling

Nutrient cycling ensures the continuous availability of essential nutrients for plant growth. Efficient cycling improves soil fertility, increases nutrient use efficiency, reduces dependence on synthetic fertilizers, enhances crop productivity, and minimizes environmental pollution. It also contributes to improved soil biological activity and resilience against climate variability.

## Major Nutrient Cycling Processes

**Nitrogen Cycle:** The nitrogen cycle includes mineralization, nitrification, denitrification, biological nitrogen fixation, immobilization, and volatilization. These processes regulate nitrogen availability and influence crop productivity. Proper management reduces nitrogen losses and improves nutrient uptake.

**Ajeet Singh**
Faculty of Agriculture, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab

**Phosphorus and Potassium Cycling:** Phosphorus and potassium cycle through weathering, decomposition, microbial activity and plant uptake. Phosphorus availability is often limited due to soil fixation, whereas potassium availability depends on mineral weathering and soil reserves. Soil microorganisms and mycorrhizal fungi enhance nutrient availability.

**Role of Soil Microorganisms:** Microorganisms are essential drivers of nutrient cycling. They decompose organic matter, mineralize nutrients, fix atmospheric nitrogen, solubilize phosphorus, and improve soil structure.

**Table 1: Major Soil Organisms and Functions**

| Organism | Function |
|---|---|
| *Rhizobium spp.* | Biological nitrogen fixation |
| *Azotobacter spp.* | Free-living nitrogen fixation |
| Mycorrhizal fungi | Enhanced phosphorus uptake |
| Decomposer fungi | Organic matter decomposition |
| Earthworms | Nutrient recycling and soil aeration |

**Sustainable Practices for Enhancing Nutrient Cycling:** Crop rotation improves nutrient balance and contributes biologically fixed nitrogen through legumes. Cover crops reduce nutrient leaching, increase soil organic matter, and improve soil structure. Integrated Nutrient Management (INM) combines organic and inorganic nutrient sources to maintain soil fertility and productivity. Crop residue retention returns nutrients to the soil while improving microbial activity and moisture conservation. Precision agriculture uses sensors, GPS, drones, and satellite technologies to optimize fertilizer application and increase nutrient use efficiency.

**Environmental Benefits:** Efficient nutrient cycling improves soil organic matter, aggregation, and water-holding capacity. It reduces nitrate leaching, runoff and eutrophication of water bodies. Sustainable nutrient management also lowers greenhouse gas emissions, promotes carbon sequestration, and strengthens climate resilience.

## Challenges and Future Prospects

Despite its benefits, adoption of nutrient cycling practices faces economic, technical, and institutional constraints, including limited farmer awareness, inadequate extension services and insufficient policy support. Future agricultural systems are expected to increasingly utilize biofertilizers, microbial inoculants, artificial intelligence-based nutrient management, precision farming technologies and climate-smart agricultural practices to improve sustainability.

## Conclusion

Nutrient cycling forms the foundation of sustainable agro-ecosystems by maintaining soil fertility, improving crop productivity, and reducing environmental impacts. Practices such as crop rotation, cover cropping, integrated nutrient management, residue retention, and precision agriculture enhance nutrient recycling and nutrient use efficiency. Wider adoption of these approaches can support long-term food security, environmental sustainability, and climate resilience.

## References

Briones, M. J. I. and Schmidt, O. (2017). Conventional tillage decreases the abundance and biomass of earthworms and alters their community structure: A global meta-analysis. *Global Change Biology*, 23(10): 4396-4419.

Chivenge, P., Saito, K., Bunquin, M. A., Sharma, S., and Dobermann, A. (2021). Co-benefits of nutrient management tailored to smallholder agriculture. *Global Food Security*, 30: 100570.

Garba, I. I., Bell, L. W. and Williams, A. (2022). Cover crop legacy impacts on soil water and nitrogen dynamics, and on subsequent crop yields in drylands: A meta-analysis. *Agronomy for Sustainable Development*, 42(34).

Hassan, M. U., Aamer, M., Mahmood, A., *et al.* (2022). Management strategies to mitigate $N_2O$ emissions in agriculture. *Life*, 12(3): 439.

Ladha, J. K., Peoples, M. B., Reddy, P. M., *et al.* (2022). Biological nitrogen fixation and prospects for ecological intensification in cereal-based cropping systems. *Field Crops Research*, 286: 108541.

Nouri, A., Lukas, S., Singh, S., Singh, S. and Machado, S. (2022). When do cover crops reduce nitrate leaching? A global meta-analysis. *Global Change Biology*, 28(15): 4736-4749.

Rockström, J., Gupta, J., Qin, D., *et al.* (2023). Safe and just Earth system boundaries. *Nature*, 619(7968): 102-111.

# Compost Cow Manure: How to Use Cow Dung as an Organic Manure

**Bhavna Sharma, Devshree Panchbhai and Priya Satwadhar**


## Abstract

Cow dung has been utilized in agriculture for centuries as a valuable source of plant nutrients and organic matter. In recent years, growing concerns regarding soil degradation, declining soil fertility, and excessive dependence on chemical fertilizers have renewed interest in composted cow manure as a sustainable organic fertilizer. Composting converts fresh cow dung into a stable, pathogen-free, and nutrient-rich soil amendment that enhances soil fertility, improves soil structure, increases water-holding capacity, and promotes beneficial microbial activity. Properly composted cow manure not only supplies essential nutrients to crops but also contributes to long-term soil health and environmental sustainability. This article discusses the composition of cow dung, the composting process, benefits of composted cow manure, comparison with chemical fertilizers, and recommendations for its use in crop production.


## Introduction

Organic manures play a crucial role in sustainable agriculture by maintaining soil fertility and reducing dependence on synthetic fertilizers. Among the various organic resources available to farmers, cow dung remains one of the most abundant and widely utilized materials. As a by-product of livestock farming, cow dung contains organic matter, essential plant nutrients, and a diverse population of microorganisms that contribute to soil health. Fresh cow dung, however, is not ideal for direct application because it may contain pathogens, weed seeds, and unstable organic compounds that can negatively affect plant growth. Composting transforms raw cow dung into a safer and more effective organic fertilizer through controlled microbial decomposition. The resulting compost provides balanced nutrition, improves soil properties, and supports sustainable crop production.

## Nutrient composition of cow dung

Cow dung contains both macro- and micro-nutrients essential for plant growth. Although nutrient composition varies depending on animal diet, age, and management practices, composted cow manure are given in Table 1. In addition to these nutrients, cow manure supplies trace elements such


**Bhavna Sharma**
Assistant Professor, Department of Plant Pathology, School of Agricultural Sciences, G. H. Raisoni University, Saikheda, Madhya Pradesh

**Devshree Panchbhai**
Assistant Professor, Department of Animal and Dairy Science, School of Agricultural Sciences, G. H. Raisoni University, Saikheda, Madhya Pradesh

**Priya Satwadhar**
Assistant Professor, Department of Soil Science and Agricultural Chemistry, School of Agricultural Sciences, G. H. Raisoni University, Saikheda, Madhya Pradesh

as zinc, iron, manganese, boron, and copper, which are important for plant metabolism and growth.

**Table 1: Nutrient content in cow dung**

| Nutrient | Typical Content (%) |
|---|---|
| Organic Matter | 20-30 |
| Nitrogen (N) | 0.5-1.5 |
| Phosphorus ($P_2O_5$) | 0.2-0.8 |
| Potassium ($K_2O$) | 0.5-1.0 |
| Calcium | 0.3-0.8 |
| Magnesium | 0.1-0.3 |

## Why Compost Cow Dung?

Composting is a biological process in which microorganisms decompose organic materials under controlled aerobic conditions. During composting, complex organic compounds are converted into stable humus-like substances. The major advantages of composting cow dung include:

- ✓ Elimination of harmful pathogens and parasites.
- ✓ Destruction of weed seeds.
- ✓ Reduction of unpleasant odors.
- ✓ Stabilization of nutrients.
- ✓ Improved nutrient availability.
- ✓ Reduction of ammonia toxicity.
- ✓ Production of a safe and environmentally friendly fertilizer.

## Method of composting cow manure

### Materials required

- ✓ Fresh cow dung
- ✓ Dry crop residues, straw, or dry leaves
- ✓ Water
- ✓ Composting pit or heap

### Composting procedure

- ✓ Select a well-drained location protected from excessive rainfall.
- ✓ Prepare alternate layers of cow dung and carbon-rich materials such as straw or dry leaves.
- ✓ Maintain an approximate carbon-to-nitrogen ratio of 25-30:1.
- ✓ Adjust moisture content to 50-60%.
- ✓ Construct a pile approximately 1-1.5 m high.
- ✓ Turn the compost every two to three weeks to maintain aeration.
- ✓ Maintain temperatures between 55 and 65°C during active decomposition.
- ✓ Allow the compost to mature for 8-16 weeks until it becomes dark brown, crumbly, and odorless.

### Indicators of mature compost

- ✓ Dark brown to black color
- ✓ Earthy smell
- ✓ Crumbly texture
- ✓ Temperature similar to ambient conditions
- ✓ Absence of recognizable feed or bedding materials

## Benefits of Composted Cow Manure

**Improvement of Soil Physical Properties:** The organic matter present in composted cow manure promotes aggregation of soil particles and improves soil structure. Enhanced aggregation increases soil porosity, improves aeration, facilitates root growth, and enhances water infiltration. Organic matter also increases the soil's water-holding capacity, helping crops withstand short periods of drought.

**Improvement of Soil Chemical Properties:** Composted cow manure supplies nitrogen, phosphorus, potassium, and several micronutrients in a slow-release form. It also increases the cation exchange capacity of soils, improving nutrient retention and

reducing nutrient losses through leaching. In acidic soils, long-term application may help moderate soil pH and improve nutrient availability.

**Enhancement of Soil Biological Activity:** Cow manure compost serves as a food source for beneficial microorganisms. Increased microbial activity enhances nutrient cycling, decomposition of organic residues, and formation of stable humus. Beneficial microorganisms also contribute to disease suppression and improved root health.

**Environmental Benefits:** The utilization of cow dung through composting converts livestock waste into a valuable agricultural input. Composting reduces environmental pollution, minimizes nutrient runoff, recycles farm wastes, and contributes to carbon sequestration in agricultural soils. By partially replacing chemical fertilizers, composted manure also supports environmentally sustainable farming systems.

## Comparison from chemical fertilizers

### Composted cow manure versus chemical fertilizers

| Parameter | Composted Cow Manure | Chemical Fertilizers |
|---|---|---|
| Nutrient Release | Slow and sustained | Rapid |
| Organic Matter | High | Absent |
| Soil Structure Improvement | Significant | Minimal |
| Microbial Activity | Enhanced | Limited |
| Environmental Impact | Low | Can contribute to pollution if misused |
| Long-term Soil Health | Improves | May decline with excessive use |

Although chemical fertilizers provide nutrients quickly, composted cow manure improves overall soil health and contributes to long-term agricultural sustainability. The best results are often obtained through integrated nutrient management combining both organic and inorganic nutrient sources.

## Application of Composted Cow Manure

**Field crops:** Apply 5-10 t $ha^{-1}$ during land preparation and incorporate into the soil two to three weeks before sowing.

**Vegetable crops:** Apply 2-5 kg $m^{-2}$ of bed area before planting.

**Fruit trees:** Apply 10-25 kg compost per tree annually depending on tree age and canopy size.

**Nursery and Potting mixtures:** Mix compost, soil, and sand in a ratio of 1:1:1 for raising healthy seedlings.

## Precautions

- ✓ Avoid direct application of fresh cow dung to growing crops.
- ✓ Use only well-composted manure.
- ✓ Do not apply excessive quantities.
- ✓ Store compost under covered conditions to prevent nutrient losses.
- ✓ Maintain proper composting conditions to ensure pathogen destruction.
- ✓ Follow recommended pre-harvest intervals for edible crops.

## Conclusion

Composted cow manure is an effective organic fertilizer that enhances soil fertility, improves soil physical and biological properties, and supports sustainable crop production. Through proper composting, fresh cow dung can be transfor-

med into a stable, nutrient-rich amendment that provides long-term benefits to agricultural soils. Regular use of composted cow manure, either alone or in combination with chemical fertilizers, can improve crop productivity while promoting environmental sustainability and soil health.

## References

FAO. Plant Nutrition for Food Security. FAO Fertilizer and Plant Nutrition Bulletin No. 16.

FAO. Organic Manure and Soil Fertility Management Guidelines.

Misra, R. V. and Hesse, P. R. Organic Manure Management. FAO/UNDP.

Bernal, M. P., Alburquerque, J. A. and Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment.

Hargreaves, J. C., Adl, M. S. and Warman, P. R. (2008). A review of the use of composted animal manures in agriculture.

Edmeades, D. C. (2003). The long-term effects of manures and fertilizers on soil productivity and quality.

# Newspaper-Wrapped Foods: Invisible Risks to Consumers - Behind a Common Practice

**Seuli Saha Roy, P. Kaushik, Anjay and Bhoomika**

## Introduction

Have you ever bought a hot samosa wrapped in a newspaper, carried vegetables home in old newsprint, or seen snacks served on sheets torn from yesterday's newspaper? For many people, this is a familiar sight. The use of newspapers for wrapping, storing, and serving food has been a common practice for decades, especially in street food stalls, local markets, sweet shops, in trains - specially "Jhal Muri" and even some households. The newspaper packaging may appear convenient, economical, and environmentally friendly, but it conceals several health hazards. Most consumers are not aware about the fact that newspapers are not designed for direct food contact. The inks, dyes, adhesives, chemicals, and contaminants present in newspapers can migrate into food and eventually enter the human body. In the current era, food safety awareness grows worldwide, and health experts and regulatory agencies have increasingly discouraged this practice. The next time you enjoy a newspaper-wrapped snack, it may be worth asking: What else am I consuming besides food?

## Newspapers: Not for Food Packaging

Newspapers are manufactured for reading and information dissemination, not for packaging food. During printing and production, newspapers come into contact with numerous chemical substances, including inks, pigments, solvents, oils, and adhesives. Moreover, newspapers pass through multiple stages of handling before reaching consumers. These are touched by printing workers, distributors, vendors, and readers, which make it vulnerable to contamination by dust, dirt, microorganisms and environmental pollutants. Unlike food-grade pack-aging materials, newspapers are not produced under conditions that ensure food safety. Therefore, its direct contact with food poses significant risks.

Fig. 1: Showing the common practice of using newspaper as food wrapper

**Risks associated with Printing Inks:** Printing inks are one of the greatest health concerns.

Modern printing inks contain various substances such as: Mineral oils, Petroleum-based

**Seuli Saha Roy, P. Kaushik, Anjay and Bhoomika**
Department of Veterinary Public Health & Epidemiology, Bihar Veterinary College, Bihar Animal Sciences University, Patna, Bihar

hydrocarbons, Pigments and colorants, Solvents, Plasticizers Preservatives, Heavy metals in some printing formulations when food comes into contact with newspaper, especially hot, oily, acidic, or moist food, these chemicals can migrate from the paper into the food. This process is known as chemical migration and has been documented in several food packaging studies. Even small amounts of transferred chemicals can contribute to cumulative exposure over a prolonged period.

**Hot and Oily Foods are at Greater Risk:** Street foods and fried snacks are particularly susceptible to contamination. Examples include:

- ✓ Samosas
- ✓ Pakoras
- ✓ Kachoris
- ✓ Jalebis
- ✓ Bread pakoras
- ✓ Fried fish
- ✓ Chips
- ✓ Cutlets
- ✓ Parathas

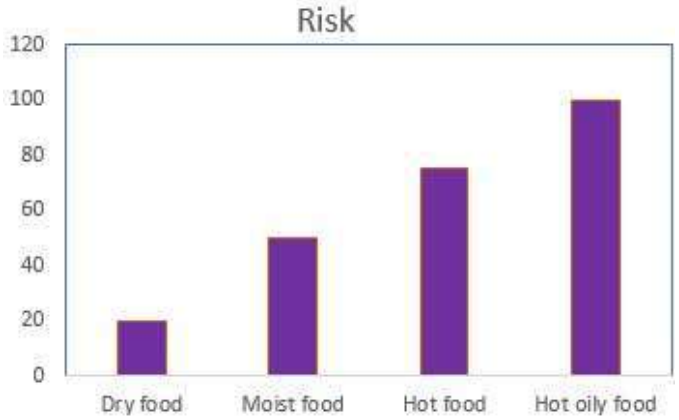



Fig. 2: Hot and oily foods facilitate the leaching of chemicals from newspaper ink into food

The heat from freshly cooked food softens printing ink, and oil acts as a solvent that facilitates transfer into food. Consequently, hot and oily foods, are more likely to be contaminated.

## Hidden Chemical Contaminants in Newspapers

**Mineral Oils:** Mineral oils are widely used in printing inks. Research has shown that mineral oil hydrocarbons can migrate from paper packaging into food products. Some fractions may accumulate in human tissues and organs due to chronic exposure.

**Heavy Metals:** Printing inks may contain trace amounts of heavy metals such as lead, cadmium, chromium, cobalt, etc. These metals are toxic even at low concentrations and can accumulate in the body over time.

**Volatile Organic Compounds:** Printing processes may involve volatile organic compounds, which can leave residues in newspapers. Prolonged exposure to such compounds is associated with adverse health effects.

**Chemical Additives:** Various stabilizers, resins, and additives used in printing and paper production can also contaminate food upon direct contact.

## Health Risks Associated with Newspaper-Wrapped Foods

**Cancer Risk:** Printing inks and mineral oils contain carcinogenic substances. Repeated ingestion of contaminated food may increase the risk of certain cancers.

**Effect on Liver and Kidney:** Chronic exposure to contaminants from newspaper inks may cause additional stress on these organs and potentially impair with its function.

**Neurological Effects in Children:** Children consume many foods commonly sold in newspaper packaging or wrapping, including snacks and sweets. Because their body weight is lower and their organs are still developing, they are more susceptible to chemical contaminants than adults. Heavy metals such as lead present in newspaper ink can adversely affect the nervous system of children. Exposure to lead is linked to reduced cognitive performance, learning difficulties, behavioral problems, and impaired neurological development

**Hormonal and Reproductive Effects:** Some chemicals found in newspapers can act as endocrine-disrupting compounds, interfere with hormonal balance, and potentially affect reproductive health.

**Microbial Contamination: An Overlooked Danger:** Newspapers can also carry microorganisms and are capable of contaminating food. From printing press to consumer, newspapers may be exposed to dust, soil, airborne microbes, dirty surfaces or floor and human handling. As a result, newspapers may harbour bacteria, protozoa, fungi, and other spores of microorganisms, which can contaminate food and lead to foodborne illnesses. This risk becomes particularly important when newspapers are used to wrap ready-to-eat foods.

**Recycled Paper: Additional Concerns**

Many newspapers are produced from recycled paper. However, recycled paper may contain residues from previously printed materials, adhesives, dyes, industrial chemicals, and contaminants. Recycling is beneficial for waste reduction, but recycled newspapers are generally unsuitable for direct food contact unless specifically processed and certified as food-grade material.

**Food Safety Regulations and Official Warnings**

Food safety authorities worldwide discourage the use of newspapers for food packaging. In India, the Food Safety and Standards Authority of India (FSSAI) has specifically warned food vendors, restaurants, and consumers against wrapping food in newspapers. According to FSSAI, printing inks contain bioactive materials that may contaminate food and pose health risks. The authority has emphasized that newspapers should never be used for packaging, serving, or storing food.

**Why the Practice Continues**

Despite repeated warnings, newspaper packaging remains common because it is:

- ✓ Cheap
- ✓ Easily available
- ✓ Convenient
- ✓ Perceived as recyclable
- ✓ Deeply ingrained in traditional practices

Many vendors are not aware of the associated risks, while consumers often overlook the issue because the effects are not immediately visible.

**Safe Alternatives to Newspaper Packaging**

**Food-Grade Paper:** Specially manufactured food-grade paper is designed to prevent chemical leaching and is suitable for direct food contact.

**Butter Paper and Parchment Paper:** These materials are widely used for bakery products, sandwiches, and snacks.

**Food-Grade Containers:** Reusable or disposable food-grade containers offer superior protection against contamination.

**Stainless Steel Utensils:** For household storage and serving, stainless steel remains one of the safest options.

**Biodegradable Packaging:** Eco-friendly alternatives made from plant fibers, bagasse, bamboo, or other biodegradable materials provide both safety and sustainability.

**Traditional Natural Packaging:** In many regions, banana leaves, palash leaves, Sal leaves, and similar natural materials continue to serve as safe and environmentally friendly food packaging alternatives.

## What Consumers can do

Consumers can help reduce risks by:

- ✓ Refusing newspaper-wrapped foods.
- ✓ Asking vendors to use food-grade packaging.
- ✓ Carrying reusable containers when purchasing food.
- ✓ Spreading awareness among family and friends.
- ✓ Supporting businesses that follow food safety practices.

## The Role of Food Vendors

Food vendors play a crucial role in protecting public health. They should:

- ✓ Avoid newspaper packaging completely.
- ✓ Use certified food-grade materials.
- ✓ Educate workers about food safety.
- ✓ Follow regulatory guidelines.
- ✓ Maintain hygienic handling and storage practices.

## Conclusion

The practice of wrapping food in newspapers may seem harmless, but scientific evidence suggests otherwise. Newspapers can transfer harmful chemicals, mineral oils, heavy metals, and microbial contaminants to food, particularly when the food is hot, oily, or moist. These contaminants may contribute to a wide range of health hazards, which may include neurological disorders, organ damage, hormonal disturbances, and potentially increase cancer risk. Food safety begins long before food is served on the plate. Choosing safe packaging materials is a simple yet important step toward the safeguard of public health. The Awareness among consumers and food vendors can gradually reduce the widespread use of newspapers for food packaging.

*A newspaper is meant for reading not for wrapping the food we eat.*

## References

European Food Safety Authority (EFSA). Scientific Opinion on Mineral Oil Hydrocarbons in Food. *EFSA Journal*, 2012.

World Health Organization (WHO). *Food Safety: Key Facts*. Geneva, Switzerland.

Food Safety and Standards Authority of India (FSSAI). *Advisory on Use of Newspapers for Packing, Serving and Storing Food Items*, 2016.

Biedermann, M. and Grob, K. (2010). Migration of mineral oil from printed paperboard into foods. *Food Additives & Contaminants*, 27(12): 1811-1821.

Robertson, G. L. (2016). Food Packaging: Principles and Practice (4th Ed.). CRC Press.

# Emerging Contaminants in Irrigation Water: Implications for Soil Health, Crop Productivity and Food Safety

**Ankan Ghosh and Harshita Joshi**


## Abstract

The growing demand for irrigation water and the increasing reuse of treated wastewater in agriculture have raised serious concerns regarding the presence of emerging contaminants in agricultural ecosystems. These contaminants include pharmaceuticals, personal care products, pesticides, endocrine-disrupting chemicals, microplastics, and industrial pollutants that are often not completely removed during conventional wastewater treatment processes. Continuous use of contaminated irrigation water can negatively influence soil quality by altering its physical, chemical, and biological properties, ultimately affecting soil fertility and microbial activity. In addition, several contaminants can be absorbed by crops and transferred into edible plant parts, posing potential risks to food safety and human health. Long-term exposure to such pollutants through contaminated food may lead to various health disorders, including hormonal imbalance, organ damage, and antibiotic resistance. The article also highlights the major sources and pathways through which these contaminants enter agricultural systems, such as domestic sewage, industrial discharge, agricultural runoff, and reclaimed wastewater. Furthermore, it discusses the importance of monitoring, advanced detection methods, sustainable irrigation practices, phytoremediation, and proper wastewater management strategies to reduce contaminant accumulation in soils and crops. Addressing these challenges is essential for maintaining sustainable agriculture, protecting environmental health, and ensuring safe food production in the future.


## Introduction

Watering is important in increasing food production and securing food safety, especially in developing countries. During the last century, there have been significant advancements in irrigation that have led to increased food production, double cropping, and reduced dependence on rainfall (Schoengold and Zilberman, 2007). Nevertheless, due to increased demand for water resources owing to population growth, climate change, and water scarcity, there has been an increase in the use of alternative sources of water in irrigation like treated wastewater (Ungureanu *et al.*, 2020). One major environmental problem related to the reuse of wastewater for agricultural purposes includes the appearance of emerging contaminants in irrigation water. Emerging contaminants refer to pharmaceuticals, personal care products, plasticisers, surfactants,


**Ankan Ghosh**
B.Sc. (Hons.) Agriculture Student, Brainware University, Barasat, Kolkata, West Bengal

**Harshita Joshi**
M.Sc. Scholar (Horticulture), Kumaun University, Nainital, Uttarakhand

pesticides and other organic pollutants whose removal from wastewater treatment processes remains ineffective. They may accumulate in soil, affect the biological processes taking place in it, reduce the yield, and eventually get into the food chain through crop uptake (Calderón-Preciado *et al.*, 2011). Continuous irrigation using contaminated water may lead to the degradation of soil and pose serious threats to human beings and their food security. Thus, knowing about the nature and effects of such emerging contaminants is extremely important.

## Emerging Contaminants in Irrigation Water

### Definition of Emerging Contaminants

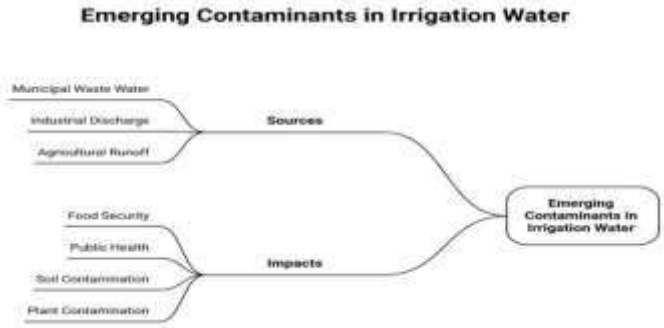
The emerging contaminants (ECs) consist of a variety of contaminants that include pharmaceuticals, personal care products (PPCPs), industrial compounds, pesticides, endocrine-disrupting chemicals and microplastics. Such pollutants are produced by both domestic, industrial, and agricultural activities and are being detected at an increasing rate in water sources used for irrigation purposes. Unlike traditional pollutants, several ECs are not completely removed in sewage treatment plants (Sauvé and Desrosiers, 2014).

### Why Emerging Contaminants are a Growing Concern

There is an increase in the application of treated wastewater in irrigation, which has contributed to the increased presence of ECs in agricultural production systems. Such pollutants may accumulate in the soil, affect microbial life, reduce soil fertility, and affect crop growth. Furthermore, due to their persistence and mobility in the environment, they make them challenging to manage. New contaminants are continually discovered owing to improvements in analytical techniques (Sauvé and Desrosiers, 2014).

### Occurrence of Emerging Contaminants in Irrigation Water

Irrigation water has been identified as one of the major sources of pollutant transport to agricultural ecosystems. Municipal waste water, industrial discharge, and agricultural runoff serve an important part in the contamination of irrigation water by pathogens, heavy metals, pharmaceuticals, and organic micropollutants. Continued use of contaminated water could lead to high concentrations of pollutants in soils and plants, thus posing a serious threat to food security and public health (Mcheik *et al.*, 2022).




### Types of Emerging Contaminants

**Pharmaceuticals and Personal Care Products (PPCPs):** The PPCPs include antibiotics, painkillers, cosmetics, and disinfectants that end up in the irrigation water due to contamination by sewage or wastewater. The antibiotics create problems as they affect microbial functions within the soil and incre-

ase the development of antibiotic-resistant micro-organisms. Metformin, tramadol and benzophenone-3 have been discovered within plants irrigated by such water (Gregorio-Lozano *et al*., 2022).

**Pesticides and Decomposition Products:** Current agricultural practices utilize a variety of pesticides, herbicides, and fungicides as a way of increasing crop yield. Unfortunately, the overuse of the substances creates their accumulation in soil and water systems. Most of the pesticides carry carcinogens and toxic compounds that harm soil microorganisms and plants' quality (Dabrowski, 2015).

**Endocrine Disrupting Compounds (EDCs):** The Endocrine Disrupting Compounds are chemicals used in personal care products, cleaning agents, plastics, and various industrial items. The EDCs affect the endocrine function of humans and animals and accumulate through the process of irrigation of the agricultural soils and plants (Bofill, 2023).

**Microplastics and Nanoplastics:** Microplastics and nanoplastics are being found more frequently in freshwater environments and agricultural soils. These particles can change soil characteristics, influence plant development, and enter the food chain via crop absorption. The significant long-term effects on the environment and health continue to be a crucial issue (Mcheik *et al.*, 2022).

**Sources and Pathways of Emerging Contaminants**

**Residential and Urban Sewage:** The sewage from residences consists of pharmaceuticals, bacteria, and persistent pollutants such as PFAS in irrigation systems. Inadequate treatment of residential sewage contributes to its environmental spread (Abbaszadegan *et al*., 2024).

**Industrial Sewage:** Sewage from industries, especially textile manufacturing, is characterised by heavy metals including cadmium, copper, and iron. Such pollutants contaminate irrigation waters as well as reduce soil fertility (Uslu *et al*., 2021).

**Farming Activities:** Fertilisers, pesticides, manure, and antibiotics contained in farming wastewater are considered key sources of contamination of ECs. Repeated application of contaminated manure leads to the emergence of antibiotic resistance (Mahale and Sharma, 2023).

**Wastewater Utilised for Irrigation:** The application of treated wastewater in irrigation is increasing due to the scarcity of freshwater resources. However, its continued use can cause salt, metal, and organic contamination of the soil (Zainurin *et al.*, 2021).

**Effects of Emerging Contaminants on Soil Health**

**Effects on Soil Physical and Chemical Properties:** Continuous irrigation with contaminated water changes the soil's pH levels, soil salinity, and soil nutrient balance. The solubility of heavy metals is high in acidic soils, increasing their movement through soil and toxicity levels (Madjar and Scăeteanu, 2020).

**Effects on Soil Microbial Communities:** Contaminants have negative impacts on microbial respiretion in soils, enzymes, and other nutrient cycles, such as nitrogen conversion cycles. This reduction in mic-

robial diversity will eventually decrease soil fertility levels (Snow *et al*., 2019).

**Development of Antibiotic Resistance in Soils:** Soil irrigation using contaminated water or polluted fertilisers creates an environment for the development of antimicrobial resistance genes in soils. This will foster the development of antibiotic resistance in soils (Mahale and Sharma, 2023).

**Implications on Agriculture Development and Production**

**Pollutant Absorption and Transport in Plants:** Pollutants enter plants through the roots and are then transported to edible organs. Perfluoroalkyl and polyfluoroalkyl substances and different mobile pollutants have shown significant transport abilities into vegetables and grains (Shen *et al.*, 2023).

**Physiological and Chemical Effects of Contaminants on Plants:** Metals and contaminants inhibit photosynthetic activity, enzyme mechanisms, and plant metabolism. Pollution with arsenic for example has considerable effects on rice productivity (Heikens, 2006).

**Implications on Agricultural Productivity and Quality:** The presence of contaminants lowers germination rates, growth, and overall productivity of plants. Arsenic contamination and high concentrations of metals significantly reduce agricultural production and the quality of crops (Ahsan and Del Valls, 2018).

**Food Safety and Human Health Implications**

**Bioaccumulation in Agricultural Crops:** Vegetables and cereal crops have the capacity to bioaccumulate pollutants from the irrigation water and contaminated soil. Such substances may enter the food chain and affect human health (Ahsan and Del Valls, 2018).

**Consequences of Pollutant Exposure on Human Health:** Prolonged exposure to pollutants such as arsenic and cadmium may cause such health issues as skin diseases, kidney damage, heart disorders, neurotoxicity, and even cancer (Madjar and Scăeteanu, 2020).

**Harmful Effects of Exposure to ECs on Human Health:** Protracted intake of ECs through contaminated food is associated with reproductive problems, hormonal imbalance, diabetes, and other health-related complications (Mwegoha and Kihampa, 2010).

**Detection, Monitoring and Management Strategies**

Highly sensitive techniques, such as QuEC hERS extraction and liquid chromatography, are utilised to detect low concentrations of contaminants (Gregorio-Lozano *et al.*, 2022). It is imperative to control contamination accumulation in agricultural systems using effective wastewater treatment techniques, phytoremediation, alternative irrigation systems, and strict policy enforcement (Shi *et al.*, 2023).

**References**

Schoengold, K. and Zilberman, D. (2007). The economics of water, irrigation and development. *Handbook of Agricultural Economics*, 3: 2933-2977.

Calderón-Preciado, D., Matamoros, V. and Bayona, J. M. (2011). Occurrence and potential crop uptake of emerging contaminants and related compounds in an agricultural irrigation network. *Science of the Total Environment*, 412: 14-19.

Ungureanu, N., Vlăduț, V. and Voicu, G. (2020). Water scarcity and wastewater reuse in crop irrigation. *Sustainability*, 12(21): 9055.

Abbaszadegan, M., *et al*. (2024). Wastewater reuse and emerging contaminants in agriculture. *Environmental Research*, 241: 117654.

Ahsan, D. A. and Del Valls, T. A. (2018). Impact of arsenic contamination on crop productivity and food safety. *Environmental Pollution*, 240: 784-792.

Bofill, J. (2023). Endocrine disrupting chemicals in agricultural environments. *Science of the Total Environment*, 856: 159023.

Dabrowski, J. M. (2015). Pesticide contamination and environmental risks in agriculture. *Water SA*, 41(3): 345-356.

Gregorio-Lozano, S., *et al.* (2022). Monitoring of pharmaceuticals and personal care products in crops irrigated with reclaimed water. *Journal of Hazardous Materials*, 435: 128987.

Mwegoha, W. J. S. and Kihampa, C. (2010). Heavy metal contamination in agricultural soils and health implications. *African Journal of Environmental Science and Technology*, 4 (11): 763-769.

Heikens, A. (2006). Arsenic contamination in irrigation water and its effects on crops. *Agriculture, Ecosystems & Environment*, 113(1-4): 1-14.

Mahale, J. and Sharma, N. (2023). Emerging contaminants and antimicrobial resistance in agricultural soils. *Environmental Monitoring and Assessment*, 195: 1124.

Madjar, R. M. and Scăeteanu, G. V. (2020). Heavy metal contamination in agricultural soils and food safety risks. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 20(1): 345-352.

Mcheik, A., *et al.* (2022). Irrigation water contamination and risks to food safety. *Foods*, 11(9): 1321.

Sauvé, S. and Desrosiers, M. (2014). A review of what is an emerging contaminant. *Chemistry Central Journal*, 8(1): 15.

Shen, D., et al. (2023). Uptake and translocation of PFAS in crops irrigated with reclaimed water. *Environmental Science & Technology*, 57(4): 1542-1551.

Shi, Q., *et al.* (2023). Sustainable irrigation strategies for reducing contaminant accumulation in crops. *Agricultural Water Management*, 278: 108139.

Snow, D. D., *et al.* (2019). Impact of emerging contaminants on soil microbial processes. *Environmental Toxicology and Chemistry*, 38(5): 1021-1030.

# Namo Drone Didi Scheme for Women-Led Smart Agriculture

Sabita Mondal, Arindam Sarkar and Nikhil Kumar

## Introduction

Indian agriculture is slowly embracing modern technologies. However, a large section of our farmers continues to depend on traditional practices. These traditional practices are usually labour-intensive and less efficient. On the other hand, Indian rural women, who are the lifeblood of agricultural activities, lacks access to advanced agricultural tools and income-generating opportunities. In order to address these challenges, the Government of India in the year 2024, has introduced the Namo Drone Didi Scheme. Namo Drone Didi Scheme is an innovative initiative that connects technology with women empowerment. The scheme represents a forward-looking approach to making agriculture more efficient. Moreover, it also aims creating new livelihood avenues for women in rural areas.

## About the Scheme

The Namo Drone Didi Scheme was launched in 2024. Its primary aim is providing drone technology to women Self-Help Groups (SHGs) members. The scheme is designed to train rural women in operating agricultural drones. It aims to impart trainings like skill development in spraying fertilizers and pesticides using drones. Central government agencies in collaboration with agricultural institutions and local bodies are the implementing agencies. The primary objective of the scheme is to promote precision farming. Empowering women economically and socially is also a major objective of this scheme by equipping women with modern skills and tools. The scheme seeks to transform them into service providers who can assist farmers and manage a sustainable livelihood.

## Key Features of the Scheme

Capacity building is one of the most significant aspects of the Namo Drone Didi Scheme. Women members are selected from Self Help Groups. Afterwards, they are provided with structured training. It enables them to operate drones efficiently and safely. The scheme also helps the SHGs to procure drones. It offers financial assistance and subsidies to the members so that they can procure it without facing heavy financial constraints. Secondly, it also trains women to use drones to provide agricultural services to farmers on a rental basis. Thus, promoting a service-based model. It creates a steady source of income for the beneficiaries and ensures better utilization of the technology. Moreover, the use of drones ensures judicial application of inputs. It reduces manual labour and minimizes

**Sabita Mondal and Arindam Sarkar**
Department of Agricultural Extension, Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal
**Nikhil Kumar**
Department of Extension Education, Bihar Agricultural University, Sabour, Bhagalpur, Bihar

health risks associated with exposure to chemicals. It therefore, make the farming practices harmless and more sustainable.

## Benefits and Impact

The Namo Drone Didi Scheme brings a range of benefits that goes beyond individual beneficiaries to the larger agricultural community. The availability of drone services ensures timely and uniform application of fertilizers and pesticides. This improves crop health and productivity. It also reduces dependency on manual labour. Thus, reducing operational costs and saving time during peak agricultural seasons. For rural women, the scheme serves as a powerful means of economic empowerment. Women by becoming trained drone operators, gain access to a new and dignified source of income. This enhances their financial independence in the society. It also improves their decision-making ability within the household. Such participation over time, helps in narrowing the gender differences in agriculture. It ensures larger inclusion of women in technology-driven activities. Additionally, the scheme promotes precise input usage in farming. It minimizes environmental pollution and reduces heavy chemical application. Thus, contributes to sustainable agriculture.

## Eligibility Criteria

The scheme primarily targets women Self-Help Groups members. Identity proof and bank account linkage are the basic requirements for their eligibility. Whereas, participation in group activities is essential for selection as beneficiary. Benefits of the scheme are extended collectively to these groups and not to the individuals alone. The SHGs thus, must be properly registered and actively functioning. Precisely the SHGs, that are engaged in agriculture and allied activities. It gives preference to women who are from rural backgrounds and willing to undergo training. Also eager to actively participate in providing drone-based services. The inclusive nature of the scheme encourages and ensures participation of women from economically weaker sections. Thus, promoting equitable access to opportunities to them.

## How to Apply

The application process is designed to be accessible and community-oriented under the Namo Drone Didi Scheme. Interested women can express their willingness to participate, by approaching local agricultural offices, district authorities, or SHG federations through their Self-Help Groups. The concerned departments guide the SHGs through the necessary procedures. It informs the process and guidelines for registration, verification, and selection for training under this scheme. After selection, beneficiaries are enrolled in training programs. The training is conducted by recognized institutions. Where the trainees get opportunity to learn drone operation and its maintenance. Financial assistance for procuring drones is aided through government support. This assistance is often in association with banks or other implementing agencies. The involvement of local administrative bodies makes the application process smooth. The scheme focuses to

reach the eligible beneficiaries effectively.

## Success Stories

Under Namo Drone Didi Scheme, in several pilot regions, women who had negligible prior experience of advanced technology are now confidently operating drones. They are also providing drone related services to the farmers in their villages. They are popularly referred to as "Drone Didis". Thus, gaining name and respect within their communities. They are also able to earn a stable income. In areas where labour shortages are a common challenge, their work has also assisted the farmers to adopt modern practices effectively. Such initiative proves that the right combination of training, support, and opportunity can transform lives. It also encourages others to come forward. Thus, early experiences from different parts of the country shows the promising potential of the Namo Drone Didi Scheme.

## Challenges and Limitations

The scheme does face few challenges in its implementation, despite its innovative approach. Limited awareness and initial reluctance among rural women in remote and marginalized regions, often prevent them to participate. Further, lack of confidence and low exposure among the eligible beneficiaries hinders the adoption of drone technology. In rural areas these facilities are still in its primitive stage of development. The lack of availability of technical support and maintenance services for drones adds further concern. Moreover, ensuring timely financial assistance is very crucial for its adoption. Scheme's success depends upon the effective coordination among different implementing agencies.

## Suggestions

There is a need to strengthen the awareness campaigns at the grassroots level. This will maximize the impact of the Namo Drone Didi Scheme. It will encourage more women to come forward and participate. Further, training expansion, monitoring and continuous support may help to build confidence among the beneficiaries. Better access to repair and maintenance services in rural areas will ensure the success of the scheme. Moreover, integration of the scheme with other agricultural and rural development programs can enhance both its reach to people and effectiveness in functioning. Whereas, encouraging partnerships with private players will ensure smooth and efficient operation. A collaboration with technology providers may also bring innovation into the system.

## Conclusion

With constant efforts and effective implementation, this scheme, can bring a transformative change in rural India. It has the merit to stand as a remarkable initiative. It blends technological advancement with social empowerment by placing modern tools in the hands of rural women. It can promote agriculture, make it more productive, inclusive and sustainable. Thus, the scheme fosters agricultural efficiency. It also opens up new pathways for livelihood and self-reliance.

## References

Guidelines. 5. India.gov.in. (2024). Namo Drone Didi Scheme

Klita, B., Dutta, B. and Rajkumar, A. (2025). Namo Drone Didi: Women Piloting India's Agricultural Future.

Ministry of Rural Development. (2024). Centre Launches Namo Drone Didi Scheme.

# A Sustainable Approach for Agricultural Waste Management: SAMARTH National Mission

**Narendra Yadav and Latika Shrama**

Agriculture is the backbone of the Indian economy and generates a huge quantity of crop residues every year. After harvesting crops such as paddy, wheat, maize, sugarcane, and cotton, large amounts of agricultural residues remain in the fields. In many parts of India, especially northern states, farmers burn these residues to quickly prepare land for the next crop season. This practice, known as stubble burning, has become a major environmental concern because it causes severe air pollution, smog formation, greenhouse gas emissions, and health-related problems. To address this issue, the Government of India launched the SAMARTH Mission (Sustainable Agrarian Mission on use of Agri-Residue in Thermal Power Plants) on 12 July 2021 under the Ministry of Power. The mission aims to utilize agricultural residues as biomass fuel in coal-based thermal power plants. It promotes biomass co-firing technology, where biomass pellets are mixed with coal for electricity generation. The mission supports sustainable agriculture, cleaner energy production, and environmental protection.

According to official estimates, India generates nearly 750 million metric tonnes (MMT) of biomass annually. Approximately 97,000 MT biomass had been co-fired in thermal power plants by March 2023. Co-firing of 97,000 MT biomass helped reduce more than 1.2 lakh metric tonnes of $CO_2$ emissions. Procurement contracts for more than 11 lakh MT biomass pellets were awarded. The number of thermal power plants adopting biomass co-firing increased from 7 plants to 35 plants within a short period. A substantial quantity of this biomass remains unused or is burnt openly in fields. The SAMARTH Mission was introduced to convert this agricultural waste into a useful energy resource and reduce dependence on fossil fuels.

## Objectives of SAMARTH Mission

The SAMARTH Mission was launched with several important objectives related to agriculture, environment, and energy sustainability.

**Reduction in Stubble Burning:** One of the primary objectives of the mission is to reduce open-field burning of crop residues. Stubble burning releases harmful gases and particulate matter into the atmosphere, contributing significantly to air pollution. By creating a market for crop residues, the mission

**Narendra Yadav**
Research Scholar, Department of Agricultural Economics, MPUAT, Udaipur, Rajasthan
**Latika Shrama**
Professor, Department of Agricultural Economics, MPUAT, Udaipur, Rajasthan

encourages farmers to sell agricultural waste instead of burning it.

**Promotion of Biomass Co-firing:** The mission promotes the use of biomass pellets in coal-based thermal power plants. Biomass pellets made from crop residues are mixed with coal during electricity generation. The Government of India has mandated thermal power plants to use 5-10 per cent biomass pellets with coal. This reduces coal consumption and promotes cleaner power generation.

**Reduction in Carbon Emissions:** Thermal power plants are major sources of greenhouse gas emissions. Biomass co-firing reduces carbon dioxide emissions and helps India move toward its climate change mitigation goals.

**Additional Income for Farmers:** Crop residues, which were previously considered waste, become a valuable economic resource under the SAMARTH Mission. Farmers can earn additional income by selling paddy straw and other residues to biomass pellet manufacturers.

**Promotion of Renewable Energy:** Biomass is a renewable source of energy. The mission supports India's transition toward sustainable and renewable energy systems by increasing biomass utilization in the power sector.

## Need for the SAMARTH Mission

The mission became necessary due to increasing environmental and energy-related challenges in India.

**Air Pollution from Crop Residue Burning:** Every year, stubble burning in states like Punjab, Haryana, and Uttar Pradesh causes severe air pollution in North India, including Delhi NCR. Burning crop residues releases smoke, particulate matter, carbon monoxide, methane, and other harmful gases into the atmosphere.

**Heavy Dependence on Coal:** India's thermal power sector depends heavily on coal for electricity generation. Coal combustion contributes significantly to carbon emissions and environmental degradation. Biomass co-firing provides a cleaner alternative by partially replacing coal with agricultural biomass.

**Poor Crop Residue Management:** Large quantities of agricultural residues remain unused due to lack of proper management systems. The mission provides a scientific mechanism for converting agricultural waste into energy resources.

**Need for Sustainable Agricultural Practices:** Sustainable residue management is essential for maintaining soil health and environmental sustainability. The SAMARTH Mission promotes integrated approaches for agricultural waste utilization and clean energy generation.

## Key Features of SAMARTH Mission

The mission includes several important features for effective implementation.

**Biomass Co-firing in Thermal Power Plants:** Under the mission, biomass pellets are blended with coal in thermal power plants for electricity generation. Co-firing helps reduce fossil fuel consumption and lowers carbon emissions.

**Biomass Pellet Manufacturing:** Agricultural resid-

ues such as paddy straw, cotton stalks, mustard residues, and sugarcane trash are converted into biomass pellets and briquettes. These pellets are easier to transport, store, and utilize in thermal power plants.

**Institutional Framework:** The Government established a dedicated Mission Directorate and Steering Committee under the Ministry of Power for monitoring and implementation of the mission. Coordination is maintained among ministries, thermal power plants, research institutions, and state governments.

**Research and Development:** The mission promotes research on advanced biomass combustion technologies, pellet manufacturing systems, and emission reduction methods to improve efficiency and sustainability.

**Participation of Farmers and Industries:** Farmers, biomass aggregators, transporters, pellet manufacturers and industries are actively involved in the biomass supply chain created under the mission.

## Benefits of SAMARTH Mission

The SAMARTH Mission provides environmental, economic and energy-related benefits.

| Environmental Benefits | Economic Benefits | Energy Benefits |
|---|---|---|
| Reduction in Air Pollution | Additional Farmer Income | Reduced Coal Consumption |
| Reduction in Greenhouse Gas Emissions | Employment Generation | Promotion of Renewable Energy |
| Improvement in Soil Health | Rural Industrial Development | Cleaner Power Generation |

## Conclusion

The SAMARTH National Mission is an innovative and sustainable initiative that connects agriculture, environment and energy sectors.

Launched in 2021, the mission provides an effective solution to the growing problem of crop residue burning in India. By promoting biomass co-firing in thermal power plants, the mission helps reduce air pollution, lower carbon emissions, improve renewable energy utilization, and create additional livelihood opportunities for farmers. The successful implementation of the SAMARTH Mission can contribute significantly toward sustainable agricultural development, cleaner energy production, rural employment generation and environmental protection in India.

# Corn Silk: Nature's Golden Threads of Wellness

**Swapna G., Mallikarjun N. and Shivakumar B. S.**

## Introduction

Corn silk, the silky thread-like structures that emerge from the top of an ear of corn (*Zea mays*), is a natural byproduct of maize cultivation with a long history of use in traditional medicine. These fine strands play a crucial role in pollination and are rich in various bioactive compounds that contribute to their medicinal value. For centuries, corn silk has been used in many cultures to treat urinary tract disorders, kidney-related ailments, and inflammatory conditions. Its natural diuretic properties help promote urine production, support urinary health, and assist in the removal of toxins from the body. In recent years, scientific research has increasingly focused on corn silk due to its potential antioxidant, anti-inflammatory, antimicrobial and health-promoting effects. Corn silk contains a variety of beneficial nutrients and phytochemicals, including vitamins, minerals, flavonoids, and phenolic compounds. These constituents contribute to its therapeutic potential and make it a promising ingredient for herbal teas, dietary supplements, and functional foods.

The functional properties of corn silk are comparable to those of various cereal flours, making its incorporation into commonly consumed food products convenient for enhancing their nutritional value. Studies have reported that corn silk possesses superior nutritional and antioxidant characteristics compared to conventional cereals such as wheat and rice. Due to its high protein and dietary fiber content, corn silk has significant potential for use in the development of value-added functional foods (Rita Singh *et al*., 2024). Although corn silk is generally considered an agricultural waste byproduct and is often discarded, it is a rich source of essential nutrients, including carbohydrates, proteins, vitamins and minerals. In addition, it contains bioactive components such as resins, mucilage, dietary fiber, polyphenols, and flavonoids, which contribute to its antioxidant and health-promoting properties (Vijitha and Saranya, 2017). These attributes highlight the potential of corn silk as a sustainable and nutritious ingredient for food and health-related applications (Prashant *et al.*, 2022)

## Health Benefits and Medicinal Properties of Corn Silk

**High Blood Pressure Treatment:** Corn silk possesses diuretic properties, which help eliminate excess fluids and sodium from the body, potentially lowering blood pressure. It contains chemicals that may inhibit the action of the angiotensin-converting enzyme (ACE), leading to a reduction in blood pressure levels.

**Diabetes Management:** Corn silk tea has been shown to elevate insulin levels in diabetic individuals

aiding in the stabilization of blood sugar levels and preventing significant fluctuations throug-hout the day. Maintaining stable blood sugar levels is crucial for reducing the risk of complications associated with diabetes.

**Cholesterol Regulation:** Preliminary studies suggest that corn silk extract may help lower total cholesterol and LDL (bad cholesterol) levels while increasing HDL (good cholesterol) levels. This could contribute to better cardiovascular health and a reduced risk of heart disease and stroke.

**Anti-Inflammatory Effects:** Corn silk tea may serve as a natural remedy for inflammatory conditions, including arthritis and gout, offering relief from swelling and discomfort in the joints.

**Antioxidant Properties:** Rich in flavonoids, corn silk acts as a powerful antioxidant, combating oxidative stress and free radical damage. This may help reduce the risk of various diseases, including inflammation-related conditions, cancer, diabetes, and heart disease.

**Eye Pressure Relief:** Research indicates that corn silk extract may help reduce intraocular pressure in hypertensive patients, potentially benefiting those at risk for glaucoma.

**Urinary System Support:** Corn silk has demons-trated diuretic, uricosuric, and antilithiatic effects, meaning it may support kidney health, alleviate conditions like cystitis and nephritis, and aid in the treatment of kidney stones.

## Functional and Therapeutic Applications of Corn Silk for Human Health

**Corn Silk Soup:** In some Asian traditional practices, corn silk is incorporated into soups for its nutritional and medicinal benefits. Fresh corn silk is tied into small bundles and simmered with corn kernels, ginger, garlic, and vegetable broth. This preparation provides antioxidants and may help support digestion while reducing inflammation.

**Corn Silk Tea:** Corn silk tea is one of the most common traditional preparations. It can be prepared by boiling 1-2 tablespoons of fresh or dried corn silk in 2 cups (approximately 500 mL) of water for 10-15 minutes. After straining, the tea may be consumed warm. Traditionally, it has been used to support kidney function, promote urine production, and reduce inflammation.

**Corn Silk Lemon Water:** A refreshing beverage can be prepared by simmering 1 tablespoon of corn silk in 1 liter of water for several minutes. After cooling, lemon juice and fresh mint leaves may be added for flavor. This drink is commonly consumed for hydration, detoxification, and support of urinary tract health.

**Corn Silk Tincture:** A corn silk tincture can be prepared by soaking dried corn silk in alcohol, such as vodka, for approximately 4-6 weeks in a sealed container. The resulting extract is typically used in small, diluted amounts. Traditionally, corn silk tinctures have been utilized to support urinary tract health, manage fluid retention and assist in maint-aining healthy blood pressure levels. Use should be undertaken with appropriate professional guidance.

## Precautions & Contraindications of corn silk use

**Patients with Kidney Disorders or Hypokalemia:** The diuretic action of corn silk may increase potassium excretion through urine. This may worsen hypokalemia (low potassium levels) and could pose risks for individuals with chronic kidney disease or impaired kidney function. Medical supervision is recommended before use in such cases.

**Pregnant and Breastfeeding Women:** Corn silk should be avoided during pregnancy because of its mild diuretic effects and potential influence on uterine activity. Additionally, there is insufficient scientific evidence regarding its safety during breast-feeding. Therefore, pregnant and lactating women should consult a healthcare professional before using corn silk products.

**Individuals Taking Diuretic or Blood Pressure Medications:** Corn silk possesses natural diuretic and antihypertensive properties. When used alongside prescribed diuretics or blood pressure medications, it may enhance their effects, potentially leading to excessive fluid loss, electrolyte imbalances, or abnormally low blood pressure (hypotension).

**People Taking Anticoagulants or Those with Bleeding Disorders:** Corn silk contains vitamin K and various bioactive compounds that may influence blood clotting mechanisms. Individuals taking anticoagulant medications, such as Warfarin, or those with bleeding disorders should use corn silk cautiously and seek medical advice before consumption.

**Individuals with Corn Allergies:** People who are allergic to corn or corn-derived products may experience allergic reactions to corn silk. Symptoms may include skin irritation, itching, swelling, or other hypersensitivity reactions. Such individuals should avoid corn silk products.

## Emerging Applications of Corn Silk in Functional and Health-Promoting Foods

**Herbal Teas and Infusions:** Corn silk has been traditionally consumed as a herbal tea due to its diuretic, detoxifying and kidney-supporting properties. When prepared as an infusion, it provides a mild flavor while delivering bioactive compounds such as maysin, luteolin, and other flavonoids that exhibit antioxidant and nephroprotective activities. In countries such as China, Korea, and Indonesia, corn silk tea is widely marketed as a functional beverage that may support kidney health, reduce water retention, and help maintain healthy blood pressure levels. This application aligns with the growing preference for natural, plant-based, and caffeine-free beverages.

**Functional Beverages:** Beyond traditional teas, corn silk extracts can be incorporated into ready-to-drink functional beverages formulated to promote hydration, detoxification, and metabolic wellness. The antioxidant compounds present in corn silk may help reduce oxidative deterioration, thereby improving product stability and shelf life. Furthermore, combining corn silk extract with ingredients such as lemon, ginger, honey, or green tea can enhance flavor, nutritional value, and potential synergistic health benefits, making it suitable for wellness drinks and sports beverages.

**Bakery and Snack Fortification:** Corn silk powder and extracts can be incorporated into bakery products such as bread, cookies, cakes, muffins, and biscuits, as well as snack products including cereal bars and extruded snacks. The addition of corn silk enhances dietary fiber content, antioxidant activity, and overall nutritional quality.

**Extract Powders and Nutraceutical Capsules:** Standardized corn silk extracts are increasingly being developed in powder and capsule forms for use in the nutraceutical industry. These products are often standardized based on flavonoid or polysaccharide content to ensure consistent quality and bioactivity. Such formulations provide a convenient means of delivering the health benefits of corn silk and may be targeted toward supporting blood glucose regulation, urinary tract health, kidney function and antioxidant supplementation. Encapsulation also helps protect sensitive bioactive compounds from degradation, thereby improving stability and shelf life.

## Conclusion and Future Perspectives

Corn silk, once considered a low-value agricultural by-product, has emerged as a valuable natural resource with significant potential in the fields of functional foods, nutraceuticals, and sustainable food innovation. In conclusion, corn silk represents a promising and sustainable functional ingredient with broad applications in food, pharmaceutical and nutraceutical industries. Continued scientific investigation and technological advancement will play a crucial role in unlocking its full potential and facilitating its successful integration into future health-oriented and environmentally sustainable products. Despite its considerable potential, the commercial application of corn silk remains at an early stage of development. Further research is required to optimize extraction and processing techniques, improve the stability and bioavailability of its bioactive compounds, and establish standardized quality control measures. In addition, comprehensive toxicological evaluations and well-designed clinical studies are necessary to determine its long-term safety, efficacy, and appropriate dosage levels for human consumption.

## References

Rita, S. R., Akanksha, S. and Apurva. (2024). Exploring Nutritional and Functional Properties of Corn silk. *International Journal of Current Advanced Research*, 13(7): 3171-3176.

Vijitha, T. P. and Saranya, D. (2017). Corn Silk- A Medicinal Boon. *International Journal of ChemTech Research*, 10(10): 129-137.

Prashant, S. P., Palak, J. and Nishita, N. (2022). Corn Silk- A Natural Therapy for Curing Diseases and ots Benefits. *International Research Journal of Engineering and Technology*, 09 (9): 2395-0072.

# Eco-Friendly Farming Starts with Liquid Biofertilizers

**Archika Awasare**


## Abstract

In 2026, the global agriculture is facing challenges of the increasing effects of climate change, soil erosion, and the need for sustainable food production. Chemical fertilizers have increased crop yields over the years but also lower soil fertility, increase acidity, kill beneficial microorganisms and pollute water systems. Liquid biofertilizers have become an alternative revolution and ecofriendly. Unlike the chemical alternatives they enhance soil biodiversity, promote beneficial microbes and do not come with the shelf life and transport problems of carrier based products. Liquid biofertilizers have a minimum shelf life of one year and are safe for workers, compatible with drip irrigation and are made from waste materials such as rice husks thus converting disposal costs into assets. They are a foundation of sustainable agriculture with reported benefit-cost ratios of >2.0 and increased yields in many crops.


## Introduction

The agriculture industry around the globe is now confronted with new challenges in 2026 due to climate change, soil erosion, and an increase in the need for sustainable food production. Chemical fertilizers have been used to increase yields but proved to be harmful to the environment, as they decrease soil fertility, cause soil acidity, kill micro-organisms, and pollute the water system. Liquid biofertilizers have come as a game-changing alternative for farmers to use in sustainable agriculture. Unlike chemically-based fertilizers, liquid biofertilizers improve the biodiversity of soil, improve soil health, and ensure the return of beneficial microbes. In addition, liquid biofertilizers help circumvent the problems associated with carrier-based products such as low shelf life and transportation problems. Liquid biofertilizers have a minimum shelf life of one year, are not harmful to the workers in any way, and are easily adaptable to drip irrigation systems. In addition, advances in technology now permit their production through the use of waste materials such as rice husks and process water, thus turning disposal cost into valuable assets. Benefit-cost ratio above 2.0 and increased yields are some of the benefits demonstrated for many crop species in the literature.

**Liquid Biofertilizers:** Liquid biofertilizers are an effective and modern alternative to carrier-based formulations. They are also called flowable or aqueous suspensions because they are in liquid form and can be easily applied. These are mainly based on broth culture, mineral and organic oils, oil-in-water, and polymer-based suspensions.

**Archika Awasare**
Research Scholar, Department of Soil Science and Agricultural Chemistry JNKVV, Jabalpur, Madhya Pradesh

Generally, they contain 10-40% microorganisms, 1-3% suspending agents, 1-5% dispersants, 3-8% surfactants, and 35-65% carrier liquids (such as water or oil). This composition helps maintain the microorganisms alive and active for longer periods, thereby providing better nutrition to crops and increasing soil fertility. Liquid biofertilizers should contain special cell protectants that assist in the formation of cysts and dormant spores. They are considered more suitable than solid inoculants because they have a shelf life of 1.5 to 2 years, are free from contamination, do not require sticky substances, and can be easily used with modern equipment. Additionally, they can tolerate high temperatures up to 45°C, are simple to handle and apply, can be easily mixed with components that encourage microbial growth, and can be readily applied to seeds and soil.The carrier used in liquid biofertilizers should be cheap, easily available, non-toxic and simple to handle. Further-more, the carrier's pH should be suitable, water-holding capacity should be high, and its physical and chemical properties should be uniform to promote microbial growth. Although liquid biofertilizers have a longer storage period, microorganisms can sometimes be affected due to starvation, lack of oxygen, and adverse environmental conditions, which may cause an excessive reduction in microbial count. Liquid biofertilizers can reduce the use of chemical fertilizers by approximately 15-40%. Moreover, their volume is about 10% less than that of solid biofertilizers, requiring less storage space.

Picture 1: Acknowledgment: AI-generated

## Liquid Biofertilizers: A Boon for Farmers

Liquid biofertilizers are highly beneficial for farmers. They are a much cheaper alternative to chemical fertilizers (such as Urea and DAP), reducing fertilizer expenses by 25 to 30 percent. Their use increases both the number and length of crop roots, which strengthens the plant and enables it to absorb more nutrients from the soil. These biofertilizers improve soil health by making it crumbly and fertile. The beneficial bacteria present in them pull free nitrogen from the air and supply it to the plants. At the same time, they also solubilize the fixed phosphorus (from DAP) lying in the fields for years and make it available to the plants. In drought conditions, they help protect the crop and also provide protection against diseases by increasing the population of beneficial soil insects. This directly impacts crop quality grains gain luster, and yield weight increases, fetching better prices in the market. The best part is that their use is extremely easy. Farmers can apply them to the field through drip irrigation, dissolve them in water and spray, or also use them for seed treatment. Low cost, easy application, and better yield liquid biofertilizers are a complete solution for farmers.

## Methods of Application of Liquid Biofertilizers

There are four main methods of using liquid biofertilizers in fields: Seed Treatment, Root Dipping, Soil Application and Application with Irrigation Water.

Picture 2: Acknowledgment: AI-generated.

**Seed Treatment:** This is the most common and effective method for all types of inoculants. For each kilogram of seeds, 5-6 ml of liquid biofertilizer should be mixed with an equal amount of 10% starch solution or 10% jaggery solution in a plastic bag and applied evenly to the seeds. Press the bag for at least 2 minutes or until all seeds are uniformly wet. Then open the bag, fill it with air, and dry slowly in the shade for 20-30 minutes while gently shaking. Another option is to take a large quantity of seeds in a bucket and mix the inoculant by hand. Seed treatment can be done with Rhizobium, Azotobacter, Azospirillum, and PSM (Phosphate Solubilizing Microorganisms), and treatment with any two or more of these bacteria can be done without any adverse effects. Most importantly, seeds should be coated with an outer layer of Rhizobium, Azotobacter, Azospirillum, and PSM vaccine.

**Root Dipping:** This method is used for applying liquid biofertilizers like Azospirillum/PSM in paddy and vegetable crops. In a portion of the field, 250-300 ml of liquid biofertilizer inoculant should be mixed with 5-10 liters of water, and the roots of the seedlings should be dipped in this solution for at least half an hour before transplanting.

**Soil Application:** For one acre of main field, 250-300 ml of liquid inoculant of each bacterium can be used. Before use, all inoculants should be dissolved in 10-15 liters of water and mixed with 200 kg of cow dung manure powder, vermicompost, or other compost, and left overnight. This mixture should be applied at the time of sowing or transplanting, especially below the seed surface in the beds. Immediately after application of microbial inoculants in tropical soils, combined inoculation of liquid Azospirillum + Rhizobium + Azotobacter showed better response on all parameters such as leaf number, height, shoot length, root length and biochemical components like chlorophyll, carbohydrate, protein, and carotenoid content.

**Foliar Spray and Fertigation:** Liquid biofertilizers can also be applied through spraying or fertigation (mixing fertilizer with irrigation water). Since liquid biofertilizers are usually concentrated, it is necessary to dilute them with water before field application to avoid burning the fertilizer. During fertigation, the biofertilizer is mixed with water and other micronutrients in a tank. The irrigation sprinkler/ sprayer/ piping delivers it to specific plants. Fertigation is commonly used in greenhouses or shade nets. Farmers can use liquid inoculants with drip irrigation systems in their main fields by adding 250-300 ml of each bacterium per acre into a drip tank and releasing

**Table 1: Liquid Biofertilizers**

| Liquid Biofertilizer Name | Type /Function | Main Crops / Usage |
|---|---|---|
| Rhizobium (Liquid) | Nitrogen-fixing bacteria | Leguminous crops (Chickpea, Pea, Groundnut, Soybean, Lentil) |
| Azotobacter (Liquid) | Free-living nitrogen-fixing bacteria | Non-leguminous field crops (Wheat, Maize, Mustard, Cotton, Vegetables) |
| Azospirillum (Liquid) | Nitrogen fixation by associative symbiosis | Cereal crops (Paddy/Rice, Sorghum, Sugarcane, Maize, Pearl millet/Coarse grains) |
| P.S.B. (Phosphate Solubilizing Bacteria) | Phosphorus solubilizing (e.g., Pseudomonas striata) | All crops (Cereals, Pulses, Oilseeds, Vegetables) |
| K.S.B. (Potash Solubilizing Bacteria) | Potash solubilizing (e.g., *Bacillus* species) | All crops, especially in potash-deficient soils |
| Mycorrhiza (V.A.M.) Liquid | Arbuscular mycorrhizal fungi | Horticultural crops, Fruits, Vegetables, Oilseeds |
| Z.S.B. (Zinc Solubilizing Bacteria) | Micronutrient solubilizing | All crops in zinc-deficient soils |
| Acetobacter (Liquid) | Nitrogen-fixing bacteria | Sugarcane only |

it within 10-15 days of transplanting/sowing.

**Liquid Biofertilizers:** Specific liquid biofertilizers for various crops have been developed by the Microorganism Research and Production Center for Liquid Biofertilizers. Their objective is to increase soil fertility and enhance crop yield.

**Liquid Biofertilizer: Rhizobium**

Rhizobium is a highly effective liquid biofertilizer, developed specifically for leguminous crops (such as Chickpea, Pea, Mung bean, Urad bean, Soybean, etc.). Rhizobium provides key benefits for crop production. Through nitrogen fixation, it forms nodules on plant roots in the soil, thereby making atmospheric nitrogen available to the plants. This leads to significant fertilizer saving, as its use saves approximately 40-50 kg of nitrogen per hectare. Additionally, it promotes higher yield; scientific experiments have observed that its proper use increases crop yield by 15-20%.

**Method of Application:** It is mainly used for seed treatment. A dosage of 100 ml of liquid biofertilizer is sufficient for 10 kg of seeds. To apply, spread the seeds on a clean tarpaulin or sack, sprinkle the liquid fertilizer over them, and mix gently with hands so that a layer coats the seeds. Finally, dry the treated seeds in the shade and sow them immediately after drying.

**Plant Growth Promoting Biofertilizer Aceto-bacter (only for sugarcane crop)**

**Method of Application:** For seed treatment, 100 ml of liquid biofertilizer is sufficient for 10 kg of seeds or sugarcane setts. For planting seedlings, mix 500 ml of biofertilizer in 30 liters of water, dip the roots of the seedlings for 10 minutes, and then plant them. Through drip irrigation, it can also be applied at the rate of 1000 ml (1 liter) per acre.

**Important Precautions:** Wear gloves on your hands while using and keep the bottle away from your face. Store it in a cool place away from direct sunlight and heat. Do not mix it with any chemical fertilizer, insecticide, or herbicide. Maintain a gap of at least one week between the use of chemicals and the application of this biofertilizer.

**Liquid Biofertilizer: Azotobacter**

This common soil bacterium promotes seed germination. Increasing soil fertility and ensuring nutrient availability is one of the effective ways to enhance crop yields. Organic matter present in the

soil is the most important factor for the growth of this bacterium. Lack of organic matter in the soil creates an obstacle for its growth and nitrogen fixation capacity.

**Seed Treatment Method:** 100 ml of liquid biofertilizer is sufficient for 10 kg of seeds. Make a heap of seeds on a clean tarpaulin or sack, add the recommended amount of liquid biofertilizer, and mix well so that each seed is properly coated. Perform seed treatment in the shade. Sow the treated seeds as soon as possible.

**Method of Application:** Use 1000 ml per acre through drip irrigation. For planting seedlings, dissolve 500 ml of biofertilizer in 15 liters of water; this is sufficient for one acre. Dip the roots of the seedlings for 10 minutes and then transplant.

**Soil Treatment:** Mix 1.5 to 2 liters of liquid-based culture thoroughly with 10 to 15 kg of well-decomposed cow dung manure or 50-100 kg of compost/vermicompost, and then evenly spread and incorporate it into the soil for one acre.

**Liquid Fertilizer: Azospirillum (For All Crops)**

Azospirillum bacteria have the ability to colonize plant roots and fix atmospheric nitrogen. A close associative relationship is considered to exist between higher plant systems and Azospirillum. It is considered helpful in enhancing the plant's resistance to biotic and abiotic stress by producing plant hormones, especially indole-3-acetic acid. Along with sorghum, maize, finger millet, pearl millet, and other small coarse grains, these bacteria are also associated with fodder grasses. These root-colonizing bacteria are not limited to the root surface; rather, a large number of them also penetrate the root tissues and maintain hormonal co-existence with the plant.

**Method of Application:** 100 ml of liquid biofertilizer is sufficient for 10 kg of seeds. Make a heap of seeds on a clean tarpaulin or sack, add the recommended amount of seeds and liquid biofertilizer, and mix well so that each seed is properly coated with the liquid biofertilizer. Perform seed treatment in the shade. Sow the treated seeds as soon as possible. Use 1000 ml per acre through drip irrigation. For planting seedlings, dissolve 500 ml of biofertilizer in 15 liters of water; this is sufficient for one acre. Dip the roots of the seedlings for 10 minutes.

**Plant Growth Promoting Biofertilizer**

Pseudomonas (Specifically *Pseudomonas fluorescens*) Pseudomonas is one of the most extensively studied and widely used Plant Growth-Promoting Rhizobacteria (PGPR) in modern sustainable agriculture. Unlike some other nitrogen-fixing bacteria, Pseudomonas acts as a multi-functional agent acting partly as a fertilizer, partly as a protector (protective shield), and partly as a growth catalyst.

**Seed Treatment Method:** 100 ml of liquid biofertilizer is sufficient for 10 kg of seeds. Make a heap of seeds on a clean tarpaulin or sack, mix with the recommended quantity of seeds and liquid biofertilizer so that each seed is properly coated with the liquid biofertilizer. Perform seed treatment in the shade. Sow the treated seeds as soon as possible.

**Method of Application:** Use 1.5-2 liters per acre through drip irrigation. Dissolve 1.5 to 2 liters of liquid-based culture in 10 to 15 liters of water, mix with 50-100 kg of compost/vermicompost, and leave it to enhance the activity of the bacteria. Spray this mixture in the field before sowing/transplanting and incorporate it into the soil. For foliar spray, spray at the rate of 2 liters per acre.

## Conclusion

Ecological Farming begins with Liquid Biofertilizers In this way, it is evident that the utilization of liquid biofertilizers is not optional; instead, it has become a necessity for sustainable agriculture. The impact of the excessive application of chemical fertilizers on our soil due to the Green Revolution may be restored effectively with the help of these microorganisms. Because of their characteristics of having a long shelf life, the ability to survive under high-temperature conditions, and non-contaminating nature, they have proved to be more evolved as compared to traditional fertilizers. Not only do they rejuvenate soil health by enriching its carbon content and soil fertility, but they also make a direct impact on farmers' earnings by lowering the cost of cultivation. The only way towards ecological sustainability is the wide use of liquid biofertilizers.

# Seed Microbiome Engineering for Crop Establishment

**Parkavan D. S., S. Ambika, R. Vedhanayagi and N. Priyadharshini**

## Introduction

Seed microbiome plays a critical role in germination, nutrient uptake and stress tolerance. Seed microbiome is a method were seeds interact with microbes like bacteria, fungi, cyanobacteria through biopriming, coating, etc. The study of the seeds is known as seed science. Recent research results are shows that the seed treatment with microbes improves nutrient uptake, stress tolerance, hormonal regulation which also exhibit symbiotic releationship between the plants and the microbes. Nowadays the study of seed microbiome plays an important role in efficient crop establishment.

**Seed Microbiome:** The process of inhabitation of microorganisms like bacteria, fungi and viruses with seeds is known as seed microbiome. It plays a critical role in plant growth, development, germination and health. The beneficial microorganisms and plant growth promoting bacteria can be for seed microbiome process. It has proved that these microbiome have the ability to transmit from parent plants that can be influenced by the genotype of host, plant development stages and environmental conditions.

**Benefits of Seed Microbiome:** Seed microbes plays a major and critical role in plant growth, development and productivity. These microbes boost germination, biomass, seedling vigor and stress tolerance. *Spirulina platensis* is a cyanobacteria that enhances photosynthetic capacity of seedlings by upregulating cholorophyll synthesis genes under cadmium stress. A study shows that the germination frequency of mung bean seeds in enhanced when cultured with domestic soil. In rice, maize, wheat and tomato the crop growth and yield in enhanced by using seed endophytic bacteria. The phytohormones like IAA, cytokinin and gibberellins produced by microbes increases root growth, plant development and biomass. IAA producing bacteria promotes cell elongation and lateral root growth in seedlings of maize and wheat. Some of these beneficial bacteria help in mobilizing and solubility of plant nutrients like phosphorus, potassium and zinc which makes plants to uptake more available nutrients. Some microbes helps in reducing the disease and pest attack by inhibiting the harmful microorganisms. It also plays other important roles like stress management, pest resilience, plant establishment, an alternative for chemical fertilizers, conservation of ecology, etc.

**Impact of Seed Microbiome in Vegetable Crops:** Seed microbiome plays an important role in physiological and ecological function of plants that influence germination, establishment of seeds and plant development. It also contributes in mobilizati-

**Parkavan D. S., S. Ambika, R. Vedhanayagi and N. Priyadharshini**
SRM College of Agricultural Sciences, SRM Institute of Science and Technology Baburayanpettai, Chengalpattu, Tamil Nadu

on of nutrients, regulation of phytohormones, suppressing diseases, mitigating stress, etc. It's primary role is seed germination where during the imbibition process these microorganisms stimulate the enzymetic activities involve in metabolism reserve such as protease and amylase that helps in breakdown of carbohydrates and protein stored in seeds to initiate embryo growth. Some bacterias like Bacillus and *Pseudomonas spp*, produce phyto-hormones like gibberellins and IAA promote germination and radicle growth. These microbes also enhances the seedling vigour and architecture of the root development. These priming technology improves the resistant to early stage infections and damping off of seedlings and also reduces the use of chemicals.

## Seed Microbiome Procedure

**Limitations:** Field performance is not always reliable because the microbes will work well in labs and it may not perform the same in farming conditions. It is due to the changes in weather, soil, and moisture. Beneficial microbes struggle more to survive because they have to compete with other strong native soil microorganisms. Combining multiple microbes is difficult because they may not work well together and their effectiveness can change under stress. Different crops and varieties respond differently, so single microbial treatment may not suit all plants. Keeping microbes alive during storage is very challenging, mostly in hot and humid conditions. There are more concerns about the safety and environmental impact. The correct way about how microbes interact with plants is still not fully understood. Production and supplying of these microbes at low cost and large scale is still difficult, especially for small farmers.

## Conclusion

Seed microbiome engineering is one of the sustainable method to improve germination and early plant growth development in vegetable crops. It also plays major role in plants by improving nutrient availability, regulating hormones, protecting against diseases, and increasing stress tolerance like drought resistance. Some other techniques like bioprimming, microbial consortia and seed coatings help in managing these beneficial microorganisms and it ensures uniform germination, faster early growth, and better crop establishment. It also improves nutrient use efficiency, climate resilience, and natural plant defense systems during early development stage. Some of the major challenges in seed microbiome include maintaining microbial survival, ensuring compatibility with different crops and achieving consistent field performance. Future improvements depend on advanced research tools like omics technologies, systems biology, and microbe-focused

**Seed microbiome engineering of major vegetable crops**

| Vegetable crop | Engineering approach | Microbes used | Functional mechanisms | Observation |
|---|---|---|---|---|
| Tomato | Biopriming | *Bacillus subtilis*, *Pseudomonas fluorescens* | phosphate solubiization, IAA production | Increased germination %, enhanced root length, |
| Brinjal | Seed treatment | *Pseudomoas spp*, *Trichoderma spp* | ISR activation, pathogen suppression | Soil borne diseases are reduced, seedling establishment increased |
| Chilli | Biopriming | *Trichoderma harzianum*, *Bacillus spp* | enzyme secretion, activation of antioxidants | Improved vigour index, enhanced stress tolerance |
| Okra | Biopriming | PGPR consortia | Nutrient mobilization, ACC deaminase activity | Increased germination rate, improved early growth |
| Cucumber | Microbial consortium | *Bacillus amyloliquefaciens*, *Pseudomonas spp* | Siderophore production, nitrogen fixation | Improved root structure, increased biomass in salinity |

plant breeding. Overall seed microbiome may help in sustainable growth and development of plants in the emerging era.

## References


Berg, G., Rybakova, D., Fischer, D., Cernava, T., Vergès, M. C. C., Charles, T., ... and Schloter, M. (2020). Microbiome definition re-visited: old concepts and new challenges. *Microbiome*, 8(1): 103.

Nelson, E. B. (2018). The seed microbiome: origins, interactions and impacts. *Plant and Soil*, 422 (1): 7-34.

Compant, S., Samad, A., Faist, H. and Sessitsch, A. (2019). A review on the plant microbiome: ecology, functions, and emerging trends in microbial application. *Journal of Advanced Research*, 19: 29-37.

Truyens, S., Weyens, N., Cuypers, A. and Vangronsveld, J. (2015). Bacterial seed endophytes: genera, vertical transmission and interaction with plants. *Environmental Microbiology Reports*, 7(1): 40-50.

# Millets on the Rise: Why Ancient Grains are Shaping Modern Agriculture and Food Processing

**Karishma Verma**


## Abstract

Millets, among the oldest cultivated cereal crops in human history, are experiencing a remarkable global resurgence owing to their outstanding nutritional profiles, environmental resilience, and suitability for diverse food processing applications. These small-seeded grasses, classified into major and minor varieties, have sustained populations in arid and semi-arid regions of Asia and Africa for millennia and are now being recognized as critical tools for addressing contemporary challenges related to food security, climate change, and diet-related chronic diseases. The United Nations' declaration of 2023 as the International Year of Millets has further catalysed global interest in millet research, cultivation, and processing. This article examines the agronomic significance, nutritional composition, health benefits, and processing transformations associated with millets, drawing on recent Scopus-indexed research. The evidence strongly supports the positioning of millets as indispensable components of sustainable modern agriculture and innovative food systems.


## Introduction

The global food system today faces a convergence of challenges, including rapid population growth, escalating climate change impacts, persistent malnutrition, and a rising burden of non-communicable diseases. Against this backdrop, millets have re-emerged as strategically important crops that were long overlooked in favour of high-yielding staples such as wheat and rice introduced during the Green Revolution. Millets are small-seeded grasses belonging to the Poaceae family and are broadly categorised into major millets, which include pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), and sorghum (*Sorghum bicolor*) and minor millets, including foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), barnyard millet (*Echinochloa spp.*), kodo millet (*Paspalum scrobiculatum*) and proso millet (*Panicum miliaceum*) (Sharma *et al*., 2024). These crops are widely cultivated across marginal and degraded lands and have the capacity to thrive under harsh environmental conditions, including drought, high temperatures, and nutrient-poor soils, where conventional cereals are unable to perform adequately (Sharma *et al*., 2024). According to Gowda *et al.* (2022), billions of people worldwide are currently experiencing food insecurity and malnutrition, and the United Nations has set a global target to end hunger by 2030, yet achieving that target remains distant owing to the combined effects of climate

**Karishma Verma**
College of Food Technology, K. K. Wagh, Nashik, Maharashtra

change, population growth and economic slow-downs. Millets, described as nutri-cereals, are abundant sources of essential macronutrients and micronutrients, including carbohydrates, proteins, dietary fibre, lipids, and phytochemicals, which position them as powerful nutritional allies in this ongoing fight against food insecurity (Gowda *et al.*, 2022). Furthermore, their inherent drought tolerance, low input requirements, and short crop cycle render them particularly valuable for smallholder farmers cultivating in resource-limited environments.

(https://kitchenkathukutty.wordpress.com/2015/04/26/millets/)

Khan *et al*. (2025) noted that millets are gaining renewed interest as commonly underexplored foods with niche potential to address multiple intersecting issues in food, health, and sustainability. Their rich nutritional profiles, low glycemic index, high dietary fibre content, and significant bioactive compound content make them suitable for individuals managing diabetes, metabolic diseases, and digestive disorders (Khan *et al.*, 2025). The breadth of evidence now available from food science, agronomy and nutrition sciences makes a compelling case for the systematic integration of millets into both modern agricultural strategies and food processing industries. The following sections trace this evidence from field to food system, covering millet diversity, agronomic advantages, nutritional attributes, health implications, processing technologies and emerging challenges.

**Millet Diversity and Global Agricultural Significance:** Millets represent a diverse group of crops adapted to a wide range of climatic and soil conditions, making them among the most geographically versatile cereal crops on the planet. Globally, millet crops are cultivated on 718 lakh hectares, with India alone accounting for 138 lakh hectares (Sharma *et al.*, 2024). The 2022 global production reached 304.8 lakh metric tons, with India contributing 120 lakh metric tons, equivalent to approximately 39% of the world total, followed by Nigeria with 11% and China with 9% (Sharma *et al.*, 2024). These figures reflect a renewed global momentum in millet agriculture, particularly as policy frameworks and research programmes increasingly prioritise these crops in the context of food system resilience.

Yousaf *et al*. (2021) observed that millet production has been steadily increasing in recent decades to meet the dietary requirements of a growing global population, and that millets are an excellent source of all essential nutrients including protein, carbohydrates, fat, minerals, vitamins, and bioactive compounds. Their cultivation practices are also diverse and adaptive, as millets are incorporated into various cropping systems including rotation,

intercropping, relay cropping, mixed cropping, and strip cropping with pulses, cereals, vegetables, and oilseeds (Sharma *et al*., 2024). This versatility makes them important contributors not only to household food security but also to broader agroecological stability and rural incomes. Mukherjee *et al.* (2025) pointed out that millets flourish across a wide range of climatic and soil conditions, particularly in marginal and degraded lands, exhibiting remarkable resilience to various environmental stresses. Their ability to thrive under challenging conditions with minimal water and fertility requirements makes them an invaluable resource for sustainable agriculture, especially in drought-prone areas and soils affected by acidity, salinity or aluminium toxicity (Mukherjee *et al.*, 2025). Due to these characteristics, millets have been aptly termed as miracle grains.

**Agronomic Resilience and Climate Adaptation:** One of the most compelling arguments for the wider adoption of millets lies in their superior agronomic resilience to climate change-induced stresses. As $C_4$ plants, millets possess enhanced photosynthetic efficiency and recognised low carbon and water footprints, and they exhibit strong adaptability to diverse ecological conditions, enabling them to thrive across arid, semi-arid, subtropical, and tropical climates (Mukherjee *et al.*, 2025). Unlike rice, wheat, and maize, which together account for nearly 80% of global food consumption and require intensive inputs while remaining highly vulnerable to climatic fluctuations, millets can sustain their productivity under conditions that would devastate conventional staples.

Sharma *et al.* (2024) detailed that the peculiar phenotypic traits of millets, such as their small leaf areas, thickened cell walls, dense root systems, and short life cycles, contribute directly to their stress tolerance. The large root length and decreased shoot length observed in little millet stimulate drought resistance, while the large or dense root hairs and high root biomass of foxtail millet similarly improve its ability to withstand water deficit conditions (Sharma *et al.*, 2024). These physiological adaptations collectively enable millets to be cultivated across a diverse altitude range, from 60 to 3,500 metres above sea level, and even on marginal lands where other crops struggle to survive (Mukherjee *et al.*, 2025).

Millet cultivation also contributes positively to environmental sustainability beyond mere climate resilience. Sharma *et al.* (2024) noted that millet crops contribute to reducing carbon emissions, sequestering carbon, and mitigating climate change effects due to their lower fertiliser input and harvesting machine requirements. The cultivation of millets plays a critical role in reducing soil loss, improving soil fertility, and supporting biodiversity conservation, all of which are essential attributes for sustainable land management in an era of accelerating ecological degradation (Sharma *et al*., 2024). Gowda *et al*. (2022) further noted that millets can thrive in less productive soil conditions compared to other cereal crops, which allows farmers in resource-scarce environments to achieve viable yields without heavy reliance on costly agrochemical inputs.

**Nutritional Composition of Millets:** The nutritional attributes of millets constitute a strong scientific basis for their inclusion in modern diets and food formulations. Millets are rich in dietary fibre, proteins, essential vitamins, and minerals including iron, calcium, and magnesium, as well as a wide array of bioactive compounds such as flavonoids, phenolic acids, and carotenoids (Sharma *et al*., 2024). Yousaf *et al.* (2021) confirmed that millets are an excellent source of all essential nutrients, including protein, carbohydrates, fat, minerals, vitamins, and bioactive compounds, and that their nutrient-rich profile positions them as a viable and superior alternative to major cereals. Khan *et al*. (2025) provided a comprehensive account of millet nutritional composition, highlighting that millets are highly nutritious and health-promoting foods characterised by their rich nutrient profiles, low glycemic index, high dietary fibre, and significant bioactive compound content. Among minerals, finger millet is particularly notable for its exceptionally high calcium content, which has significant implications for the prevention of osteoporosis and the support of bone health, especially in populations with limited access to dairy products (Mukherjee *et al.*, 2025). Pearl millet, on the other hand, is recognised for its high iron and zinc content, making it a key resource in the fight against micronutrient deficiency, which affects more than two billion people globally (Gowda *et al*., 2022). The protein quality of millets is also noteworthy. Yousaf *et al.* (2021) reported that millets are an excellent source of all essential nutrients, including protein, carbohydrates, fat, minerals, vitamins, and bioactive compounds and their bioactive peptides, xylooligosaccharides, and phenolic compounds add significant nutritive value and provide protection against various degenerative diseases. Furthermore, the gluten-free nature of millets makes them a highly suitable dietary option for individuals with celiac disease or gluten intolerance, a segment of the global population that is increasingly seeking wheat alternatives (Khan *et al.*, 2025). The plentiful polyunsaturated fatty acids present in millet oil are also beneficial in the management of chronic heart diseases, further broadening the health appeal of these crops (Yousaf *et al*., 2021).

**Health Benefits and Disease Prevention:** The health-promoting properties of millets extend well beyond their macronutrient and micronutrient content, encompassing a broad spectrum of functional bioactivities that have attracted significant scientific attention. Khan *et al.* (2025) established that millets are functional foods with the potential to promote sustainable agriculture and enhance health because of their high fibre content, antioxidant capacity, and anti-inflammatory properties, and that they are particularly valuable in supporting blood glucose regulation and metabolic health. Their low glycemic index is a key characteristic, as it enables a slower and more sustained release of glucose into the bloodstream, which is beneficial for individuals managing diabetes and metabolic syndrome. Mukherjee *et al.* (2025) reported that millets are rich

sources of essential macronutrients, micronutrients, dietary fibres, essential amino acids, minerals, anti-oxidants, trace elements, proteins, lipids, and carbohydrates. These compounds collectively confer protective effects against a range of chronic and non-communicable diseases. Finger millet, in particular, has been associated with the ability to tackle lifestyle disorders, chronic diseases, and nervous system dysfunction due to the elevated presence of calcium, iron, and essential amino acids (Mukherjee *et al*., 2025). The health benefits extend to cardiovascular protection through lipid regulation, gut health promotion through prebiotic dietary fibre, and potential anticarcinogenic activity through antioxi-dant phenolics. Gowda *et al.* (2022) highlighted that nutritionally, millet grains provide significant amounts of energy, dietary fibre, calcium, iron, zinc, lipids, and quality proteins, offering sustenance and food security to vulnerable communities. These properties are particularly important for women and children, who are disproportionately affected by micronutrient deficiencies in low-income settings. In addition, millets have in-built tolerance-related characteristics that further make them a dependable dietary resource even as climatic variability reduces the availability of other food crops (Gowda *et al*., 2022). The convergence of nutritional richness with agronomic reliability makes millets uniquely positioned to address both food quantity and food quality challenges simultaneously.

## Processing Technologies and Nutritional Changes

Food processing plays a decisive role in determining the final nutritional value, palatability, digestibility, and shelf life of millet-based products. A broad spectrum of processing techniques is applied to millets, ranging from traditional primary methods to advanced modern technologies. Gowda *et al*. (2022) categorised primary processing techniques as including dehulling, soaking, germination, roasting, drying, polishing, and milling, which are carried out to make millets fit for human consumption. Secondary processing methods such as fermenting, parboiling, cooking, puffing, popping, malting, baking, flaking, and extrusion are subsequently employed to develop value-added processed food products. Among the various traditional techniques, germination and fermentation have emerged as particularly effective in enhancing millet nutrition. Gowda *et al*. (2022) concluded that germination and fermentation showed a positive improvement in the overall nutritional characteristics of millets, whereas excessive dehulling, polishing, and milling resulted in a reduction of dietary fibre and micronutrients. Yousaf *et al*. (2021) supported this finding, noting that processing methods, with the exception of cooking, generally improved starch and protein digestibility in millets. These processes achieve their effects by breaking down complex starches into simpler soluble sugars, reducing antinutritional factors, and increasing the bioavailability of minerals and amino acids. Khan *et al*. (2025) confirmed that fermentation, soaking, and sprouting reduce anti-nutrients while boosting nutrient bioavailability, and that these methods are valuable tools for the food

industry to enhance the nutritional quality of millet-based products. At the same time, challenges persist in millet product development, particularly with regard to texture, shelf life, and consumer appeal. These limitations underscore the importance of continued research in optimising processing parameters to retain the maximum nutritional potential of millets while simultaneously meeting the sensory and functional requirements of modern consumers (Khan *et al.,* 2025). Gowda *et al.* (2022) similarly emphasised that understanding the changes occuring in the nutrient value of millets due to processing can help the food industry, researchers, and consumers select suitable processing techniques to optimise nutrient value and increase bioavailability.

**Antinutritional Factors and their Management:**

Despite their impressive nutritional attributes, millets are known to contain antinutritional factors that can compromise the bioavailability of their beneficial compounds. These factors include phytates, oxalates, tannins, trypsin inhibitors, and polyphenols, which can bind essential minerals, inhibit digestive enzymes, and reduce the absorption of key nutrients when millets are consumed in raw or minimally processed forms (Khan *et al.,* 2025). Yousaf *et al.* (2021) noted that processing is essential in millets as it enhances the nutritional bioavailability, organoleptic properties, and simultaneously reduces the antinutritional factors that would otherwise limit the dietary value of these grains. Yousaf *et al*. (2021) reported that dehulling millet grains beyond 30% leads to a substantial loss of dietary fibre, indicating that while removal of the outer hull reduces antinutrients, it must be conducted with careful calibration to preserve intact fibre fractions. Fermentation, on the other hand, is more targeted and beneficial in its effects. Gowda *et al*. (2022) highlighted that germination and fermentation are effective in reducing antinutritional factors while simultaneously improving nutrient content, thus representing a preferred processing approach for the development of nutritious millet-based foods. Khan *et al*. (2025) emphasised that despite the existence of strategies to manage antinutritional factors, challenges remain in terms of developing processing methods that are both effective and economically feasible for smallholder farmers and small-scale processors. Research directed at combining multiple processing steps, such as soaking followed by fermentation or germination followed by roasting, offers promising avenues for reducing antinutrients more comprehensively while simultaneously enhancing sensory attributes. These combined processing approaches represent an important frontier in millet food technology that can bridge traditional practices with modern nutritional science.

**Value-added millet products & market potential:**

The transformation of raw millets into value-added food products is a critical step in ensuring their wider market acceptance and mainstreaming into global food systems. Yousaf *et al*. (2021) documented that millets are processed into a wide range of food products including malted, cooked, fermented,

roasted and puffed preparations, and that their immense popularity in tribal communities extends to use in snacks, bread, puddings, and beverages, which also hold important cultural significance in many societies. As consumer preferences increasingly shift towards healthier, functional, and minimally processed foods, the market opportunity for millet-based products has expanded substantially. Sharma *et al*. (2024) identified that millets are versatile in value-added foods such as gluten-free flour, snacks, and fermented foods, and that their multiple functional properties have been recognised across the food and beverage industry, including in the production of weaning foods, health bars, breakfast cereals, noodles, cookies, and traditional fermented beverages. The development of such products is supported by the functional characteristics of millets, which include good water absorption capacity, emulsification properties, and gelation behaviour, all of which are desirable from a food technology standpoint. Gowda *et al*. (2022) noted that functional characteristics of millets are useful for designing special foods and value-added products, and that technology interventions are required to motivate both farmers and food manufacturers to adopt millets more widely. Mukherjee *et al*. (2025) further pointed out that the millet industry has significant potential to contribute to rural employment, household incomes, and national economies, particularly in developing countries where millet cultivation is traditionally embedded in agricultural systems. The economic opportunity presented by the global health food trend, combined with the 2023 International Year of Millets policy push, has created a favourable environment for investment in millet processing infrastructure, research and development, and market expansion. Khan *et al*. (2025) underscored that research is the key to promoting millets as a modern dietary staple, and that continued innovation in processing, packaging, and product development will be decisive in expanding the consumer base for millet-based foods beyond traditional markets.

## Conclusion

Millets represent a convergence of agronomic resilience, nutritional richness, and food processing versatility that makes them uniquely suited to the demands of modern agriculture and food systems. Their drought tolerance, climate adaptability and low environmental footprint address the urgent need for sustainable crop production in an era of accelerating climate change. Simultaneously, their exceptional nutrient profiles, functional bioactive compounds, and suitability for diverse processing applications position them as powerful instruments for combating malnutrition, managing chronic disease, and meeting the growing consumer demand for healthy, gluten-free, and minimally processed foods. The convergence of scientific evidence, global policy support, and consumer interest signals that the resurgence of millets is not a temporary trend but a structural shift in how humanity approaches food, agriculture, and nutrition security. Sustained investment in research, processing technology, and inclusive value chains will be essential to realising

the full potential of these ancient grains in the modern world.

## References


Gowda, N. A. N., Siliveru, K., Prasad, P. V. V., Bhatt, Y., Netravati, B. P. and Gurikar, C. (2022). Modern processing of Indian millets: A perspective on changes in nutritional properties. *Foods*, 11(4): 499.

Khan, T., Islam, R. U. and Azad, A. A. (2025). Millets: A comprehensive review of nutritional, antinutritional, health, and processing aspects. *Food Research International*, 203: Article 115784.

Mukherjee, B., Jha, R. K., Sattar, A., Dutta, S., Bhattacharya, U., Samanta, S., Huirem, B., Singh, S. K., Das, S. and Bal, S. K. (2025). Harnessing the potential of millets for climate-resilient and sustainable agriculture. *Frontiers in Plant Science*, 16: 1574699.

Sharma, A., Ceasar, S. A., Pandey, H., Devadas, V. S., Kesavan, A. K., Heisnam, P., Vashishth, A., Misra, V. and Mall, A. K. (2024). Millets: Nutrient-rich and climate-resilient crops for sustainable agriculture and diverse culinary applications. *Food Research International*, 196: Article 115177.

Singh, S. M. and Rao, P. S. (2024). Modern and conventional processing technologies and their impact on the quality of different millets. *Food Science and Biotechnology*, 33(8): 1791-1812.

Yousaf, L., Hou, D., Liaqat, H. and Shen, Q. (2021). Millet: A review of its nutritional and functional changes during processing. *Food Research International*, 142: Article 110197.

# Pulses for Prosperity: Pathways to a Stronger Pulse Sector in India

M. J. S. L. Naga Durga, Manoj Kumar Dara and V. K. Choudhary

## Introduction

Pulses occupy a unique position in Indian agriculture. Often referred to as the "Poor man's protein," they serve as an affordable and essential source of dietary protein for millions of households. Beyond their nutritional significance, pulses contribute to soil fertility through biological nitrogen fixation, improve cropping system sustainability, and play a crucial role in climate-resilient agriculture. India is the world's largest producer, consumer, and importer of pulses. This apparent contradiction reflects one of the most intriguing paradoxes in Indian agriculture. While the country has made remarkable progress in increasing pulse production over the past decade, domestic demand continues to outpace supply, resulting in periodic shortages and dependence on imports from countries such as Canada, Australia, Mozambique, and Myanmar. As concerns about nutritional security, climate change, and sustainable agriculture gain prominence, the pulse sector is receiving renewed policy attention. Building a stronger pulse sector is no longer only about increasing production; it is also about enhancing farmer profitability, improving resource-use efficiency, strengthening food security, and reducing import dependence.

## The Current Scenario: Why Pulses Are Back in the Spotlight

Pulses have returned to the centre of India's agricultural and food policy discussions. In recent years, domestic demand for pulses has continued to rise due to population growth, increasing health awareness, and greater emphasis on balanced diets. However, production growth has not always kept pace with consumption requirements. Consequently, India has periodically relied on imports of tur (pigeon pea), urad (black gram), and masur (lentil) to stabilize domestic supplies and control price volatility. India has witnessed significant improvements in pulse production over the last decade. Production has increased considerably due to expanded area coverage, adoption of improved varieties, enhanced policy support, and targeted government interventions. The country has achieved notable success in crops such as chickpea, pigeon pea, mung bean, and lentil. However, production gains have not completely eliminated supply-demand gaps. Population growth, changing dietary preferences, increasing health awareness, and rising incomes continue to drive demand for pulses. Consequently, India periodically resorts to imports to stabilize domestic supplies and prices.

**M. J. S. L. Naga Durga and Manoj Kumar Dara**
Research Scholar, Department of Agricultural Economics, CoA, IGKV, Raipur, Chhattisgarh
**V. K. Choudhary**
Professor, Department of Agricultural Economics, CoA, IGKV, Raipur, Chhattisgarh

The challenge is not merely one of production volume. Significant regional disparities in productivity persist across states. Many pulse-growing regions continue to experience lower yields compared to global standards. Furthermore, fluctuations in production due to weather variability often contribute to market instability. This situation highlights the need for a more comprehensive approach that addresses productivity, profitability, risk management and market development simultaneously. The paradox has been demonstrated below.

Fig. 1: Infographics illustrating Pulse Paradox of India (The figure is an original conceptual illustration prepared by the authors to synthesize information from the reviewed literature).

## Why Pulses Matter more than Ever

Pulses are central to India's food and nutrition security. With a large proportion of the population relying on plant-based diets, pulses provide an affordable source of protein, dietary fibre, vitamins, and minerals. Their importance is further underscored by rising concerns regarding protein deficiency and malnutrition among vulnerable populations. From an environmental perspective, pulses offer several advantages. Unlike many crops, pulse plants fix atmospheric nitrogen through symbiotic bacteria, reducing the need for synthetic nitrogen fertilizers. This lowers production costs, improves soil health, and contributes to sustainable agricultural systems. Pulses also fit well into crop diversification strategies. They require relatively less water than many cereal crops and can perform reasonably well under rainfed conditions. As climate variability increases, pulses can contribute to the development of more resilient farming systems.

Fig. 2: Infographics Illustrating the Multifaceted Benefits of Pulses in Indian Agriculture (The figure is an original conceptual illustration prepared by the authors to synthesize information from the reviewed literature).

## Why does the Pulse Gap Persist?

Several structural and institutional factors continue to constrain the growth of the pulse sector.

**Low Productivity Levels:** Despite improvements, average pulse yields in India remain below those achieved in several leading pulse-producing countries. Yield gaps arise due to limited adoption of improved technologies, inadequate access to quality seeds, suboptimal input use, and exposure to biotic

and abiotic stresses.

**Dependence on Rainfed Agriculture:** A substantial proportion of pulse cultivation occurs under rainfed conditions. As a result, pulse production remains highly vulnerable to erratic rainfall, droughts, and other climate-related shocks. Weather uncertainty can significantly affect both yields and farmer incomes.

**Market and Price Volatility:** Pulse markets often experience substantial price fluctuations. During years of bumper production, prices may fall sharply, discouraging farmers from expanding pulse cultivation in subsequent seasons. Conversely, production shortfalls can lead to sharp price increases, affecting consumers.

**Limited Procurement Infrastructure:** Although MSP support exists for major pulse crops, procurement operations remain uneven across regions. Many farmers continue to face difficulties accessing assured procurement mechanisms, reducing the effectiveness of price support policies.

**Pest and Disease Challenges:** Pulse crops are susceptible to several pests and diseases that can significantly reduce yields. Climate change may further intensify pest pressures and increase production risks.

## Building a Stronger Pulse Sector: The Way Forward

Strengthening India's pulse sector requires a balanced strategy that focuses on productivity, resilience, and market development. Bridging yield gaps through improved varieties, quality seeds, better nutrient management, and effective pest control can significantly enhance production. At the same time, the promotion of drought-tolerant and climate-resilient varieties will be essential in addressing increasing weather uncertainties. Efforts must also focus on strengthening procurement systems, improving market intelligence, and expanding value chains to reduce price volatility and improve farmer confidence. Integrating pulses into cereal-dominated farming systems can enhance soil health and diversify farm incomes, while Farmer Producer Organizations (FPOs) can improve collective marketing and market access. Furthermore, investments in processing, branding and value-added pulse products can create new income opportunities and stimulate consumer demand. Together, these measures can help build a more productive, profitable, and resilient pulse sector for the future.

## Conclusion

Pulses occupy a strategic position at the intersection of nutrition, sustainability and agricultural development. The challenge is no longer simply producing more pulses but creating an ecosystem that enables farmers to cultivate pulses profitably, sustainably, and with reduced risk. A stronger pulse sector can contribute to improved nutritional outcomes, reduced import dependence, healthier soils, and more resilient farming systems. Through sustained efforts in research, market development, climate adaptation, and institutional support, pulses can emerge as a powerful driver of both farmer prosperity and national food security.

**Table 1: Government Support for Pulse Development**

| Programme/Policy | Period | Key Features | Purpose |
|---|---|---|---|
| Technology Mission on Oilseeds and Pulses (TMOP) | 1986-87 (Pulses component added subsequently) | Technology dissemination, improved varieties, extension support, production enhancement measures | First major national effort to improve pulse productivity and reduce import dependence. |
| Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPOM) | 2004-05 to 2010-11 | State-specific interventions, seed distribution, demonstrations, input support and flexibility in implementation | Address regional constraints and improve pulse production through decentralized planning. |
| National Food Security Mission (NFSM)-Pulses | 2007-08 onwards | Cluster demonstrations, improved seed distribution, integrated nutrient management, plant protection and farmer training | Increase pulse production and bridge widening demand-supply gaps. |
| Accelerated Pulses Production Programme (A3P) | 2010-11 onwards (under NFSM) | Large-scale demonstrations using improved production technologies and best management practices | Accelerate productivity growth in major pulse-growing districts. |
| Seed Hub Programme for Pulses | 2016-17 onwards | Seed multiplication through ICAR institutes and State Agricultural Universities, promotion of improved varieties | Improve availability of quality seed and enhance varietal replacement rates. |
| Buffer Stock Creation for Pulses | 2015-16 onwards | Government procurement and maintenance of strategic pulse reserves through NAFED and other agencies | Stabilize prices, improve availability and manage supply shocks. |
| Pradhan Mantri Annadata Aay SanraksHan Abhiyan (PM-AASHA) | 2018 onwards | Price Support Scheme (PSS), Price Deficiency Payment Scheme (PDPS) and private procurement support | Strengthen MSP operations and provide better price assurance to pulse growers. |

In an era characterized by climate uncertainty and evolving dietary needs, strengthening India's pulse sector is not merely an agricultural priority, it is a strategic investment in the country's future.

## References


Tripathi, A. K. (2019). Feeling the Pulse: Towards Production Expansion of Pulses in India. *Journal of Asian and African Studies*, 54(6): 894-912.

Kumar, R. and Raju, K.V. (2018). Leveraging Policies for Self Sufficiency in Pulses in India. *Indian Journal of Human Development*, 12(2): 191-206.

Government of India. (2024). *Agricultural Statistics at a Glance 2024*. Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, New Delhi.

Pooniya, V., Choudhary, A. K., Dass, A., Bana, R. S., Rana, K. S., Rana, D. S., Tyagi, V. K. and Puniya, M. M. (2015). Improved Crop Management Practices for Sustainable Pulse Production: An Indian Perspective. *The Indian Journal of Agricultural Sciences*, 85(6).

Government of India. (2024). *Pocket Book of Agricultural Statistics 2024*. Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, New Delhi.

Government of India. (2024). *Agricultural Marketing Information System and MSP Reports*. Commission for Agricultural Costs and Prices (CACP), Ministry of Agriculture and Farmers Welfare, New Delhi.

# Biofertilizers: Nature's Solution for Sustainable Agriculture

**Manish Raj and Anannya Roy**

## Introduction

Biofertilizers are the products containing one or more carrier based living species of micro-organisms which have the ability to mobilize nutritionally important elements from non-usable to usable forms through biological process such as nitrogen fixation and phosphate solubilization or mobilization. They are environmental-friendly and cost-effective supplement to fertilizers and organic manure. Biofertilizers play a significant role in improving nutrient availability to crop plants. They are considered as one of the components of INPS.

## Types of biofertilizer

- ✓ Nitrogen fixing
- ✓ Phosphorus solubilizing
- ✓ Organic matter decomposers

## Nitrogen fixing biofertilizers

**Rhizobium:** Rhizobium inoculants are the most important biofertilizers because of their nitrogen fixing ability. Rhizobium is gram negative bacteria which leaves in root nodules of legumes through symbiotic association.

**Azotobacter:** It is an aerobic chemo heterotrophic and free-living bacterium; hence it works better non-symbiotically in the root rhizosphere of crops like wheat rice, sorghum and vegetables like onion, brinjal and tomato in the presence of adequate organic matter.

**Frankia:** It shows symbiotic association with trees and shrubs and fix atmospheric nitrogen.

**Azolla:** It is a free-floating water fern and fixes atmospheric nitrogen in symbiotic association with blue green algae.

## Phosphorus Solubilizing Biofertilizers

**Phosphate Solubilizing Bacteria (PSB):** Phosphorus is one of the essential nutrients required for plant growth, but a large portion of phosphorus present in soil remains unavailable to plants. Phosphate Solubilizing Bacteria convert insoluble forms of phosphorus into soluble forms through the secretion of organic acids and enzymes. They help in improving root development, flowering, fruit formation, and overall crop productivity.

**Phosphate Solubilizing Fungi (PSF):** Certain fungi such as *Aspergillus* and *Penicillium* species are efficient in dissolving unavailable phosphorus compounds in the soil. They increase phosphorus availability to plants and contribute to sustainable crop production.

**Potassium Solubilizing Biofertilizers (KSB):** Potassium is another major nutrient essential for plant growth and development. Potassium Solubilizing

**Manish Raj**
M.Sc. Scholar, Department of Soil Science and Agricultural Chemistry, CAU, Imphal
**Anannya Roy**
B.Sc. (Hons.) Agriculture Student, SDSUV, Uttarakhand

Bacteria release potassium from insoluble mineral sources presents in the soil. They improve plant resistance against drought, diseases, and environmental stress while enhancing crop quality and yield.

**Organic Matter Decomposers**

***Trichoderma:*** *Trichoderma* is a beneficial fungus that decomposes organic residues and improves soil health. It also acts as a biocontrol agent by suppressing several harmful soil-borne plant pathogens. It promotes healthy root growth and enhances nutrient uptake.

**Cellulolytic Microorganisms:** These microorganisms break down plant residues, crop waste, and other organic materials into simpler compounds. This process increases the availability of nutrients and improves soil structure and fertility.

**Benefits of Biofertilizers**

- ✓ Increase the availability and uptake of essential nutrients.
- ✓ Improve soil fertility and microbial activity.
- ✓ Reduce dependence on chemical fertilizers.
- ✓ Promote better root growth and plant development.
- ✓ Improve crop yield and quality.
- ✓ Enhance plant tolerance against environmental stresses.
- ✓ Maintain ecological balance and protect the environment.
- ✓ Provide a cost-effective and sustainable solution for farmers.

**Method of Application**

**Seed Treatment:** Biofertilizers are coated on seeds before sowing to ensure early root colonization and better nutrient availability.

**Seedling Root Dip:** Seedlings are dipped in a biofertilizer solution before transplanting, which promotes healthy root establishment.

**Soil Application:** Biofertilizers can be mixed with compost or farmyard manure and applied directly to the soil.

**Precautions while using Biofertilizers**

- ✓ Store biofertilizers in a cool and dry place away from direct sunlight.
- ✓ Use the products before their expiry date.
- ✓ Avoid mixing biofertilizers with chemical pesticides or fungicides during application.
- ✓ Apply recommended doses as per crop requirement.
- ✓ Ensure adequate soil moisture for better microbial activity.

**Conclusion**

Biofertilizers are a key component of sustainable agriculture. They not only improve nutrient availability and soil health but also reduce environmental pollution caused by excessive use of chemical fertilizers. Adoption of biofertilizers by farmers can lead to higher productivity, lower cultivation costs, and long-term preservation of soil fertility. Integrating biofertilizers with balanced nutrient management practices is an effective approach toward eco-friendly and profitable farming.

# Cryopreservation in Vegetable Crops

R. Vedhanayagi, S. Ambika, M. Rajasekar and N. Priyadarshini

## Introduction

The cryopreservation is used in vegetable crops to store all kind of propagule which are not stored in dry method as seed. This importantly focused on non-seed producing crops such as tubers and asexually propagated plants. This method is more benefitting one for long term storage. Cryopreservation is one of the techniques to preserve the plant parts or plant organs stored in -196°C to stop the metabolic activity, compared to field genebank cryopreservation can be stored for long term condition. Vegetable crops like potato, Ginger, garlic, ivy guard, tapioca etc. Some sensitive seed or recalcitrant seed are not able to store in dry conditions which are stored through freezing conditions that halt the metabolic process and are stored. Cryopreservation eliminates the pathogens and seed borne disease this helps researcher from cleaning. Environmental degradation will disturb ecosystems and reduces biodiversity. In situ conservation can't fully protect plant genetic resources. It needs to be joind with ex situ methods that store biological material under controlled conditions, with this option to reintroduce it into the wild later. Traditional ex situ approaches like seed banks and clonal collections, new technologies now play major role in plant biodiversity conservation. It helps to collect, multiply, and conserve plant germplasm.

## Need for Cryopreservation in Vegetable Crops

- ✓ Long term conservation of genotypes
- ✓ Conservation of rare and endangered plants
- ✓ Reduces maintenance cost
- ✓ Protecting from pest and disease
- ✓ Vegetatively propagated plant part can easily preserve
- ✓ Easily maintain genetic stability
- ✓ Helps for crop improvement
- ✓ Highly helps for biotechnology and research perpose
- ✓ Helps for future food production and sustain-ability

## Different Plant Material used for Cryopres-ervation in Vegetable Crops

In cryopreservation different plant parts are stored according to the purpose and plant the propagule varies.

- ✓ Pollen grain for hybridization
- ✓ Seeds
- ✓ Embryos both zygotic and somatic embryo are used for conservation
- ✓ Shoot tip and apical meristem that maintain genetic stability
- ✓ Cell suspension and callus cultures used for both

**R. Vedhanayagi, S. Ambika, M. Rajasekar and N. Priyadarshini**
SRM College of Agricultural Sciences, SRM Institute of Science and Technology Baburayanpettai, Chengalpattu, Tamil Nadu

biotechnology and genetic improvement

- ✓ Nodal and axillary buds as vegetatively propagated crops
- ✓ Protoplast in advanced tissue culture example crops like in garlic the shoot tip and clove, potato shoot tip and clove, onion embryo and seed are preserved, tomato the seed and pollen were used, brinjal shoot tip and callus culture as conserved in cryopreservation.

## Step Involved In Cryopreservation

STEP 1: Selection of mother plant (healthy and disease-free plan material were selected)

Step 2: Pretreatment for cold tolerance

Step 3: Addition of cryoprotectant

Step 4 Dehydration process

Step 5: Freezing with liquid nitrogen

Step 6: Storing as long term conservation

Step 7: Thawing to avoid ice crystal formation

Step 8: Removal of cryoprotectant from the material

Step 9: Recovery and regeneration into healthy plant

## Different Method of Cryopreservation

- ✓ Slow freezing method is plant material are slowly cooled in control rate before storing in liquid nitrogen. These reduce ice crystal formation; it is suitable for all type of crops including reduce the cellular damage.
- ✓ Rapid freezing method is selected material has directly dipped in liquid nitrogen for faster freezing prevent large ice crystals formation. This consumes less time and quick method.
- ✓ Vitrification method here the high concentration cryoprotective solution were treated and cooled at faster rate. It is effective in shoot tip culture method and meristem method. This turns toxic when prolonged for long time.
- ✓ Encapsulation-vitrification method here explant were encapsulated with alginate beads, dehydrated and finally frozen in liquid nitrogen. This method improves the survival rate.
- ✓ Droplet vitrification method here the explant were placed in small droplet of cryoprotectant solution on aluminum foil strip and directly immersed in liquid nitrogen which fasten the cooling process. This requires careful handling.
- ✓ Cryo-plat method here the plant were fixed in plate than treated on cryoprotectant and frozen rapidly.

## Advantages of Cryopreservation

- ✓ Plant materials are preserved for many years with viability
- ✓ The plant has its original genetic character
- ✓ Vegetatively propagated plant is stored effect-ively
- ✓ The ultra-low temperature prevents from pst and disease
- ✓ Cryopreservation needs less maintenance
- ✓ Used for breeding and research program
- ✓ Successful regeneration and healthy plant after thawing

## Disadvantages of Cryopreservation

- ✓ High initial cost due to expensive equipment
- ✓ Skilled labor was needed for
- ✓ Toxicity of cryoprotectant
- ✓ Time consuming standardization

- ✓ Depend on continuous liquid nitrogen supply

## Conclusion

Cryopreservation is highly suitable method for long term conservation for vegetable genetic resource and maintain stability, disease free plants. This mostly reliable for rare and endangered species and also vegetatively propagated plants. The advancement in biotechnology and cryogenic technics which is more precious for sustainable agriculture and preservation of vegetable crops.

## References

Ruta, C., Lambardi, M. and Ozudogru, E. A. (2020). Biobanking of vegetable genetic resources by in vitro conservation and cryopreservation. *Biodiversity and Conservation*, 29(13): 3495-3532.

Kaviani, B. and Kulus, D. (2022). Cryopreservation of endangered ornamental plants and fruit crops from tropical and subtropical regions. *Biology*, 11(6): 847.

Romadanova, N., Kushnarenko, S. and Karasholakova, L. (2017). Development of a common PVS2 vitrification method for cryopreservation of several fruit and vegetable crops. *In Vitro Cellular & Developmental Biology-Plant*, 53(4): 382-393.

# Digital Innovations in Climate-Smart Agriculture

**Harshit Doda**


## Abstract

Climate change poses significant challenges to global agriculture through rising temperatures, water scarcity, soil degradation, and increasing climatic variability. Climate-Smart Agriculture (CSA) has emerged as a sustainable approach to enhance productivity, strengthen resilience, and reduce environmental impacts. This article examines recent advances in digital and biological innovations that are transforming climate-smart agricultural systems. Emerging technologies such as artificial intelligence, machine learning, remote sensing, precision irrigation, and digital soil intelligence are improving resource-use efficiency, climate-risk management, and agricultural decision-making. Studies demonstrate that these technologies can optimize irrigation and nutrient management, improve water productivity, enhance soil carbon sequestration, and support climate adaptation. In addition, conservation agriculture and microbial biofertilizers are contributing to sustainable intensification by improving soil health and crop resilience. The integration of technological innovation, farmer participation, and supportive institutional frameworks offers a promising pathway toward productive, resilient, and environmentally sustainable agricultural systems capable of addressing future food security challenges under changing climatic conditions.


## Introduction

Agriculture is increasingly confronted by the challenges of climate change, including rising temperatures, erratic rainfall patterns, water scarcity, soil degradation, declining biodiversity and increasing greenhouse gas emissions. These interconnected challenges threaten global food security and the livelihoods of millions of farmers. According to recent research, innovative climate-smart approaches are becoming essential for sustaining agricultural productivity while simultaneously enhancing resilience and environmental sustainability (Mandour *et al.*, 2025; Huang *et al.*, 2026). Climate-Smart Agriculture (CSA) has emerged as a transformative framework that integrates three key objectives: increasing agricultural productivity, strengthening adaptation to climate variability, and reducing environmental impacts (Wijeratne et al., 2026). Recent advances in artificial intelligence (AI), machine learning (ML), remote sensing, precision irrigation, digital soil intelligence, conservation agriculture, and bio-based technologies are rapidly transforming agricultural systems worldwide (Zhang *et al.*, 2026; Ray *et al.*, 2026; Shi *et al.*, 2026).

Studies conducted across Asia, Africa, Europe and the Americas demonstrate that digital innovations can optimize resource use, improve climate-risk management, enhance soil health,

**Harshit Doda**
Assistant Professor, School of Agriculture, Galgotias University, Greater Noida, Uttar Pradesh

increase water-use efficiency and strengthen agricultural resilience under changing climatic conditions (Hasbi *et al*., 2026; Onah *et al*., 2026; Novais *et al*., 2026). At the same time, farmer-centered adaptation frameworks, conservation practices and microbial technologies are providing complementary pathways for sustainable intensification and climate adaptation (Robles *et al*., 2026; Gutierrez *et al*., 2026; Zhang *et al*., 2026).

This article explores how emerging digital and biological innovations are reshaping climate-smart agriculture and discusses their potential to build resilient, productive and sustainable agricultural systems for the future.

## Artificial Intelligence: The Brain behind Climate-Smart Agriculture

Artificial intelligence is revolutionizing agricultural decision-making by enabling precise resource management and climate adaptation.

Zhang *et al.* (2026) developed a machine-learning optimization framework integrating Partial Least Squares Regression, Random Forests, and Genetic Algorithms to optimize irrigation, nitrogen application, and planting density in maize production systems in China. Their study demonstrated yield increases exceeding 20%, water productivity improvements above 31%, and economic gains exceeding 15%, while simultaneously reducing irrigation and nitrogen inputs. Similarly, Ray *et al.* (2026) applied ensemble machine-learning models, including ExtraTrees, LightGBM, and CatBoost, to predict soil organic carbon responses to biochar application. Their model achieved an impressive prediction accuracy ($R^2$ = 0.86), identifying biochar rate, crop type, soil type, and pH as key determinants of carbon sequestration.

In rice production systems, Dar *et al.* (2026) employed Bayesian Neural Networks and Support Vector Machines to forecast production under climate change. Their findings showed that renewable energy technologies and AI-based forecasting could help offset the negative impacts of rising temperatures and greenhouse gas emissions. Furthermore, Mandour *et al.* (2025) highlighted that AI-powered tools such as computer vision, IoT sensor networks, climate forecasting models and deep learning systems are transforming climate-smart agriculture through real-time monitoring, stress detection, yield prediction, and precision management.

**Table 1: Artificial Intelligence Applications in Climate-Smart Agriculture**

| Study | Technology Used | Key Contribution |
|---|---|---|
| Zhang *et al.* (2026) | RF-GA Optimization Framework | Yield ↑ >20%; WP ↑ >31% |
| Ray *et al.* (2026) | Ensemble ML (CatBoost, LightGBM) | SOC prediction ($R^2$ = 0.86) |
| Dar *et al.* (2026) | Bayesian Neural Networks | Climate-smart rice forecasting |
| Mandour *et al.* (2025) | AI, IoT, Deep Learning | Precision agriculture and adaptation |

## Precision Water Management under Climate Change

Water scarcity is among the most serious threats to global agricultural sustainability. Precision irrigation technologies are helping farmers maximize water productivity while maintaining crop yields. Hasbi *et al.* (2026) evaluated a semi-automated drip

irrigation system powered by solar and grid electricity in cassava production under rainfed conditions in Indonesia. The technology increased tuber yield by 42.4% and improved water-use efficiency by 34%, while supplemental irrigation represented only 2.84% of total water inputs. Likewise, Zhang *et al*. (2026) demonstrated that AI-assisted irrigation optimization significantly improved maize productivity while reducing water use. These findings underscore the role of smart irrigation technologies in addressing water scarcity and enhancing resilience to drought. As climate variability intensifies, digital irrigation systems are expected to become increasingly important for sustainable crop production in water-limited environments.

**Remote Sensing and Digital Climate Intelligence:**

Remote sensing and geospatial technologies are expanding the scope of climate-smart agriculture beyond individual farms to regional and national scales. Shi *et al*. (2026) combined remote sensing, XGBoost, neural networks, and explainable AI techniques to forecast biomass productivity across Northern Italy. Their models achieved prediction accuracies exceeding $R^2 = 0.89$ and estimated biomass resources capable of generating approximately 100 billion kWh of electricity annually. However, the study also projected future productivity declines due to rising temperatures and water deficits. Similarly, Onah *et al*. (2026) used satellite rainfall products and climate reanalysis datasets to improve drought monitoring and agricultural planning in Nigeria. Their results revealed that rainfall variability rather than long-term rainfall decline posed the greatest agricultural risk. Yeggina *et al.* (2026) integrated remote sensing, Random Forest classification, carbon modeling, and socio-economic assessments to monitor regenerative agriculture systems in India. Their framework successfully linked ecosystem health indicators with climate-resilient agricultural planning. At the policy level, Huang *et al.* (2026) demonstrated that digitalization, climate-smart technologies, and financial support systems are major drivers of agricultural resilience across China.

**Soil Health, Carbon Sequestration and Bio-Based Innovations**

Healthy soils form the foundation of climate-smart agriculture. Emerging technologies are enabling more effective management of soil resources while enhancing carbon sequestration.

Robles *et al.* (2026) reported that integrating no-tillage systems, cereal rye cover crops, and biochar increased soil organic carbon by 30-42% and improved microbial activity and enzyme functioning in soybean production systems. A global synthesis conducted by Zhang et al. (2026) further showed that conservation agriculture increased soil organic carbon by 21%, improved soil fertility by 11%, reduced erosion by 12%, and lowered greenhouse gas emissions by 5% while maintaining crop productivity. Digital soil monitoring technologies are also advancing rapidly. Novais *et al.* (2026) introduced BraSpecS, a cloud-based hyperspectral

**Table 2: Emerging Climate-Smart Technologies and their Contributions**

| Innovation Category | Representative Authors | Climate Challenge Addressed | Major Contribution |
|---|---|---|---|
| Artificial Intelligence & ML | Zhang *et al.* (2026); Ray *et al*. (2026); Dar *et al.* (2026) | Resource inefficiency, climate uncertainty | Yield optimization, forecasting, carbon prediction |
| Precision Irrigation | Hasbi *et al*. (2026); Zhang *et al.* (2026) | Water scarcity | Improved water-use efficiency and drought resilience |
| Remote Sensing & GIS | Shi *et al.* (2026); Onah *et al*. (2026); Yeggina *et al.* (2026) | Drought monitoring, climate risk | Climate-informed planning |
| Digital Soil Intelligence | Novais *et al*. (2026); Ray *et al.* (2026) | Soil degradation, carbon loss | Real-time soil diagnostics |
| Biofertilizers | Gutierrez *et al*. (2026); Metwally *et al.* (2026) | Drought stress, soil degradation | Enhanced productivity and resilience |
| Conservation Agriculture | Zhang *et al*. (2026); Robles *et al*. (2026) | GHG emissions, erosion | Carbon sequestration and soil improvement |
| Participatory CSA Frameworks | Wijeratne *et al*. (2026); Huang *et al.* (2026) | Low adaptive capacity | Strengthened resilience and adaptation planning |

soil platform capable of rapidly predicting soil properties using machine-learning algorithms. The system offers scalable and cost-effective soil diagnostics that can support precision agriculture and environmental monitoring.

## Biofertilizers and Nature-Based Climate Solutions

Nature-based technologies are becoming increasingly important components of climate-smart agriculture. Gutierrez *et al*. (2026) demonstrated that co-inoculation of quinoa with *Azospirillum brasilense* and *Glomus iranicum* nearly tripled grain yields compared with untreated controls. The microbial consortium substantially improved root development and nutrient acquisition. Similarly, Metwally *et al*. (2026) found that *Trichoderma harzianum* significantly enhanced maize drought tolerance by improving antioxidant activity, chlorophyll retention, and plant water status under stress conditions. These studies indicate that microbial technologies can complement digital innovations by improving resilience while reducing dependence on chemical inputs.

## Farmers at the Center of Climate Adaptation

Technological innovation alone is insufficient to achieve climate resilience. Farmer awareness, institutional support, and social inclusion remain critical. Wijeratne *et al*. (2026) found that 96.7% of Sri Lankan farmers had observed climate change impacts, while over 80% reported noticeable seasonal shifts. However, inadequate insurance coverage and limited institutional support constrained adaptation efforts. Kihoro *et al*. (2024) demonstrated that women's empowerment significantly enhances access to climate-smart agricultural practices and adaptation resources, highlighting the importance of gender-responsive approaches. Similarly, Shumiye *et al.* (2026) reported that access to irrigation, extension services, improved varieties and community organizations significantly improved food security among rural households in Ethiopia.

These findings emphasize that successful climate adaptation requires both technological and social innovation.

## Future Outlook

The next generation of climate-smart agricu-

lture will likely be characterized by the integration of AI, IoT, remote sensing, cloud computing, and biological innovations. Future farming systems may rely on real-time decision-support platforms that combine satellite observations, weather forecasts, soil intelligence, and machine-learning algorithms to guide management decisions. In addition, explainable AI, digital twins, carbon accounting tools, regenerative agriculture monitoring systems, and climate-smart biofertilizers are expected to play increasingly important roles. However, achieving widespread adoption will require investments in digital infrastructure, extension services, farmer training, and inclusive policies that ensure smallholder farmers benefit from technological advances.

## Conclusion

Climate-smart agriculture is rapidly evolving through the convergence of digital technologies, precision resource management, conservation practices and nature-based solutions. Artificial intelligence, machine learning, remote sensing, precision irrigation, digital soil intelligence, and biofertilizers are enabling farmers to produce more with fewer resources while strengthening resilience to climate change. As climate risks continue to intensify, integrating technological innovation with farmer participation, supportive policies, and sustainable management practices will be essential for achieving long-term food security and environmental sustainability. The future of agriculture will depend not only on producing more food but on producing it more intelligently, efficiently, and sustainably.

## References

Dar, A. A., Chen, Z., Rodríguez-Rodríguez, S., Haghighat, F., An, C., Reyes, R. A. G. and González-Rosales, B. (2026). Ecological and technological insights to enhance rice production: A machine learning approach for sustainable agriculture in Granma, Cuba. *Sustainable Development*. Advance online publication. https://doi.org/10.1002/sd.7059

Hasbi, M., Darma, R., Akzar, R., Nishantha, B., Ali, H. N. B., Nawi, N. M., Maulidyah, N. and Syakur, K. A. (2026). Development of a semi-automated drip irrigation system to enhance water productivity and tuber yield of Gajah cassava under rainfed conditions. *Journal of Global Innovations in Agricultural Sciences,* 14(1): 207-218.

Novais, J. J. M., Demattê, J. A. M., Santos, U. J., Terra, F. D. S., Falcioni, R., Nanni, M. R., Araújo, M. S. B., Boechat, C. L., Pedron, F. A., Dalmolin, R. S. D., Souza, D. T. M., Moura-Bueno, J. M., Barreto-Garcia, P. A. B., Siqueira, G. M., Amorim, M. T. A., … and Tziolas, N. (2026). A cloud-based hyperspectral framework for scalable and sustainable soil analysis. *ACS Agricultural Science & Technology,* 6(3): 443-453.

Ray, A., Li, X., Chen, Y., Yang, X., Zhang, W. and Hui, D. (2026). Predicting biochar-induced changes in soil organic carbon with ensemble machine learning. *GCB Bioenergy,* 18(5): e70112.

Shi, Z., Marinello, F. and Pezzuolo, A. (2026). AI-driven spatiotemporal modelling of agricultural biomass residues in Northern Italy: A data-fusion and explainable-AI framework. *Computers and Electronics in Agriculture, 240*, 111246.

Zhang, H., Liang, C., Zhang, W., Shukla, M., Fang, Y., Chen, S. and Du, T. (2026). Spatial distributed management strategies for maize high-yield and high-efficiency under different production-demand scenarios in Northwest China. *Agricultural Water Management*, 325: 110166.

Zhang, W., Fang, L., Zhang, W., Wang, C., Qiu, T., Li, X., …. and Kuzyakov, Y. (2026). Global potential and trade-offs of conservation tillage for crop productivity and ecosystem services. *Global Change Biology*, 32(4): e70825.

Gutierrez, M., Quispe-Medina, E., García-Blásquez Morote, C., Quispe-Tenorio, J. A., Cántaro-Segura, H., Díaz-Morales, L. and Matsusaka, D. (2026). Microbial synergy between *Azospirillum brasilense* and *Glomus iranicum* promotes root biomass and grain yield in Andean quinoa cultivars. *Applied Microbiology*, 6(1): 12.

Huang, Y., Ren, F. and Wang, Y. (2026). Evaluation and pathways for achieving agricultural resilience under the framework of climate-smart agriculture. *Humanities and Social Sciences Communications*, 13(1): 105.

Metwally, R. A., Taha, A. S. and Soliman, S. A. (2026). Unlocking the potential of *Trichoderma harzianum* isolate Zag-1 to boost drought tolerance in maize plants. *BMC Plant Biology*, 26(1): 638.

Onah, E. U., Dombo, T. C., Nwafor, U. K., Apeh, O. I., Chukwu, K. C., Ebinne, E. S. and Ehiemere, C. I. (2026). Multi-metric evaluation of satellite and reanalysis rainfall products over Southeastern Nigeria: Implications for hydroclimatic variability and agricultural decision making. *Korean Journal of Remote Sensing*, 42(1): 103-124.

Robles, A., Agyei, B., Singh, M. P., Tiemann, L. K. and Miesel, J. R. (2026). Interactive effects of no-till, cereal rye, and softwood pine-derived biochar on soil health of a no-till northern soybean system. *Soil Science Society of America Journal*, 90(1): e70204.

Wijeratne, V. P. I. S., Mehmood, M. S., Jayatunga, J. N. D. and Manawadu, L. (2026). An integrated participatory framework for climate-smart agricultural practices from the lens of climate change, farmers' perceptions and adaptations. *Sustainability*, 18(7): 3401.

# India's Move towards Pulse Sufficient Nation through Mission on Aatmanirbharta in Pulses

**Malagouda D. Patil, Amruta P. Barigal, Kumari Basamma and Siddalingareddy**

## Introduction

Pulses are an essential component of the Indian diet, serving as a major source of protein, especially for the vegetarian population. Despite being one of the largest producers and consumers of pulses in the world, India continues to face challenges in meeting its domestic demand due to fluctuating productivity, climate variability and biotic stresses. To address these challenges, the Mission for Aatmanirbharta in Pulses, a centrally sponsored scheme was launched by government of India. This mission will span from financial year 2025-26 to 2030-31, ensuring a phased and structured approach towards achieving self-sufficiency in pulse production.

## Objectives of the Mission for Aatmanirbharta in Pulses

The Mission for Aatmanirbharta in Pulses has been designed with a comprehensive approach to strengthen pulse production, improve farmer livelihoods, and enhance nutritional security in India. The key objectives of the mission include:

**Boosting Pulse Production:** Enhancing the production and productivity of major pulse crops, with special emphasis on Tur (Pigeonpea), Urad (Blackgram) and Masoor (Lentil) to meet the growing domestic demand.

**Promoting Climate-Resilient Seeds:** Ensuring the availability of high-quality, climate-resilient seed varieties that can withstand biotic and abiotic stresses, thereby improving crop stability and farmers' resilience to climate change.

**Expanding Cultivation Area:** Increasing the area under pulse cultivation by encouraging farmers to adopt pulses in suitable cropping systems and fallow lands.

**Strengthening Post-Harvest Management:** Promoting modern post-harvest storage, processing, and management technologies to minimize losses and improve grain quality.

**Assured Procurement of Key Pulses:** Guaranteeing 100 per cent procurement of Tur, Urad, and Masoor through the procurement agencies, namely the National Cooperative Consumers' Federation of India Ltd.

**Malagouda D. Patil**
Scientist (Plant Breeding), AICRP on *Kharif* Pulses, Main Agricultural Research Station, UAS, Dharwad, Karnataka

**Amruta P. Barigal**
Research Scholar, Department of Plant Pathology, College of Agriculture Dharwad, UAS, Dharwad, Karnataka

**Kumari Basamma**
Senior Technical Officer, Seed Unit, UAS Dharwad, Karnataka

**Siddalingareddy**
Assistant Professor (Economics), Godutai Doddappa Appa Arts, Commerce and Science Degree College for Women, Kalaburagi, Karnataka

(NCCF) and National Agricultural Cooperative Marketing Federation of India Ltd. (NAFED), thereby ensuring remunerative prices for farmers.

**Price Support for Other Pulses:** Providing assured procurement of other pulse crops under the norms of the Price Support Scheme (PSS) to safeguard farmers against market price fluctuations.

**Enhancing Nutritional Security:** Increasing the availability and consumption of protein-rich pulses, thereby contributing to improved nutritional and food security for the nation.

## Cluster-Based Implementation Strategy

The Mission for Aatmanirbharta in Pulses will be implemented through a cluster-based development model aimed at strengthening the entire pulse value chain, from seed production and crop cultivation to storage, processing, and marketing. The cluster approach will facilitate efficient technology transfer, better resource utilization, and collective benefits for farmers. Each cluster will cover a minimum area of 10 hectares, while a minimum of 2 hectares will be considered for hilly and North-Eastern regions.

## Selection of Priority Districts and Clusters

Districts and clusters will be identified from potential pulse-growing regions across States and Union Territories. The selection process will focus on maximizing production potential and regional inclusiveness.

- ✓ Priority will be given to districts categorized by NITI Aayog under the High Area-High Yield (HA-HY), High Area-Low Yield (HA-LY), Low Area-High Yield (LA-HY), and Low Area-Low Yield (LA-LY) framework.
- ✓ Special attention will also be given to rice fallow lands, rainfed ecosystems, watershed areas, districts covered under the Prime Minister Dhan-Dhaanya Krishi Yojana, aspirational districts, border districts, and areas affected by Left Wing Extremism (LWE).
- ✓ North-Eastern states, Himalayan regions, island territories, backward areas, and villages under Adarsh Gram Yojana will receive focused support to expand pulse cultivation and improve regional agricultural development.

## Inclusive Beneficiary Coverage

The mission emphasizes equitable distribution of benefits among different sections of the farming community. Provisions have been made to ensure adequate participation of Scheduled Castes (SCs) and Scheduled Tribes (STs) through earmarked allocations, while States and Union Territories may allocate funds according to their demographic composition. The mission also promotes social inclusion by encouraging participation from vulnerable and underserved farming communities. Priority is given to small and marginal farmers and women farmers.

## Assistance and Eligibility Norms

Individual farmers and seed growers will be eligible to receive assistance under various mission components for up to 5 hectares in a season. In addition, Forest Rights Act (FRA) patta holders will be eligible to avail mission benefits, provided they

satisfy the prescribed eligibility criteria. This ensures that support reaches a broader section of pulse growers, including those farming on recognized forest lands.

**Strategic Pillars of the Mission**

**Quality Seed Production:** Promotion of breeder, foundation and certified seed production of improved pulse varieties.

**Seed Distribution:** Supply of high-yielding, climate-resilient, and bio-fortified pulse seeds to farmers at subsidized rates.

**Demonstrations:** Conducting FLDs, CFLDs, and block demonstrations to showcase improved production technologies.

**Seed Hub Strengthening:** Enhancing seed hubs at ICAR institutes, SAUs, KVKs, and other agencies for quality seed availability.

**Farmer Capacity Building:** Training farmers and seed growers on improved cultivation, seed production and post-harvest practices.

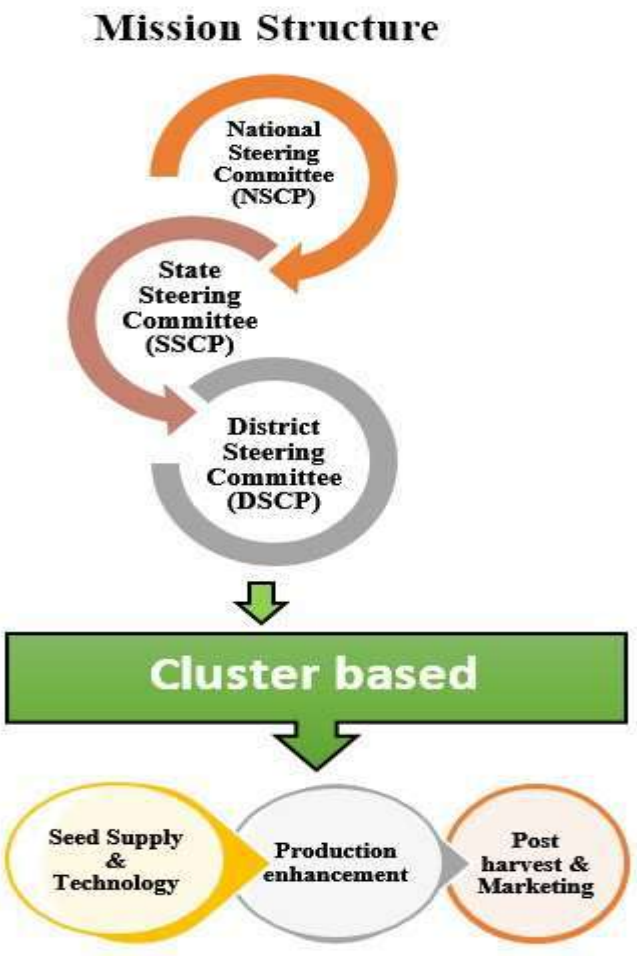
**Technology Promotion:** Encouraging adoption of climate-smart technologies, bio-fertilizers, nano-fertilizers, and modern crop management practices.

**Digital Monitoring:** Use of digital platforms such as SATHI and Krishi Mapper for transparency, monitoring and traceability.

**Post-Harvest and Market Support:** Improving storage, processing, procurement and market linkages to enhance farmer profitability.

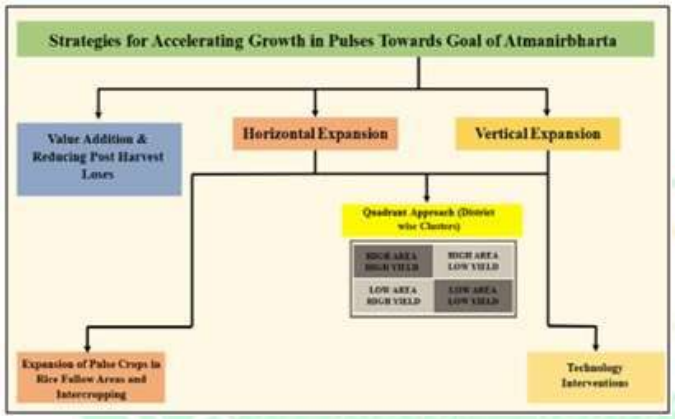
**Mission Structure**

The Mission for Aatmanirbharta in Pulses will be implemented through a three-tier institutional framework comprising National, State, and District-level committees. The National Steering Committee on Pulses (NSCP) will provide policy guidance, resource allocation, and overall monitoring of the mission. At the state level, the State Steering Committee on Pulses (SSCP) will prepare action plans, coordinate implementation, and oversee progress. The District Steering Committee on Pulses (DSCP) will be responsible for cluster formation, seed distribution, farmer training, and field-level execution. Through this coordinated structure, the mission aims to ensure effective implementation, increased pulse production, and achievement of self reliance in pulses.



## Strategies for accelerating growth in Pulses towards Goal of Aatmanirbharta

To achieve the goal of *Atmanirbharta* in pulses, a multi-pronged strategy focusing on both horizontal and vertical expansion is essential. Horizontal expansion can be achieved by increasing the area under pulse cultivation through the inclusion of pulses in rice fallows and intercropping systems, thereby utilizing available land resources more efficiently.




Vertical expansion emphasizes enhancing productivity through improved technologies, quality seed, precision nutrient management, and effective pest and disease control measures. A district-wise cluster or quadrant approach can help identify areas with high or low productivity and cultivation area, enabling targeted interventions. Additionally, value addition, processing and reduction of post-harvest losses can significantly improve farmers' income and market opportunities. Together, these strategies can boost pulse production, ensure nutritional security, and strengthen self-reliance in agriculture.

## Conclusion

The Mission for Aatmanirbharta in Pulses marks a significant step towards achieving self-sufficiency in pulse production while improving farmers' income and nutritional security. Its successful implementation will not only reduce dependence on imports but also strengthen food security and contribute to the vision of an Aatmanirbhar Bharat.

# Sustainable Agriculture Development: Insights from Cow-Based Natural Farming Approach

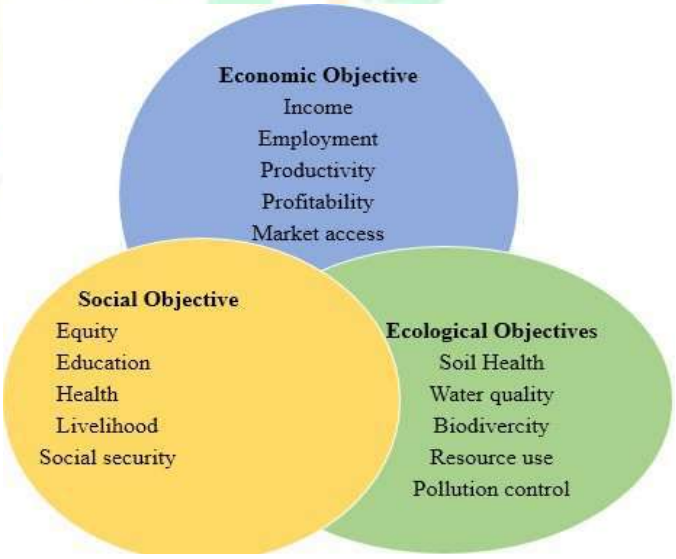
**Ganga Devi, Pramod and J. P. Mishra**

## Introduction

Agriculture remains a vital sector of the Indian economy, contributing about 16-18 per cent to the Gross Domestic Product (GDP) and providing livelihood to a large share of the population. Nearly 46-60 per cent of the workforce, particularly in rural areas, depends on agriculture as their primary source of livelihood. India has also made remarkable progress in food production, with total foodgrain output reaching around 357 million tonnes in 2024-25, ensuring national food security. However, declining yields and excessive use of inputs in many regions have resulted in soil degradation and growing health concerns. In this context, sustainable agriculture has become essential for holistic rural development, as it ensures food security, generates employment, and promotes environmentally sound practices such as soil conservation, efficient resource management, and biodiversity protection.

## Concept of Sustainable Development

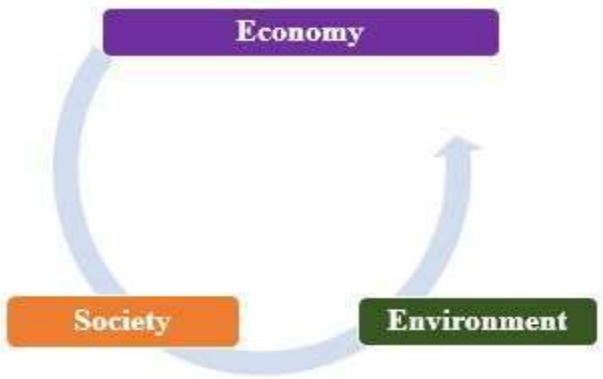
Sustainable development refers to meeting present needs without compromising the ability of future generations to meet their own needs. It emphasizes intergenerational equity and maintaining harmony between human activities and nature. The concept integrates ecological, economic, and social dimensions, ensuring balanced and inclusive development. Therefore, the interrelated dimensions of sustainability, ecology, economics, and equity are essential for achieving sustainable development. Ecological security ensures the conservation and regeneration of natural resources, economic efficiency promotes optimal use of resources under existing conditions, and social equity ensures fair distribution of benefits and secure livelihoods, particularly for vulnerable sections of society. Together, these dimensions form the foundation of a balanced and sustainable development framework.




Sustainable development is a long-term process involving appropriate use of resources, technological advancement, and institutional support to improve human well-being. Over time, it has become central to global policy discussions. The three key pillars environmental protection, economic

**Ganga Devi, Pramod and J. P. Mishra**
ICAR-Agricultural Technology Application Research Institute, Zone-II, Jodhpur, Rajasthan

efficiency, and social equity form the foundation of sustainable development.




## Agricultural Sustainability and Cow-Based Natural Farming

Agriculture plays a crucial role in this framework, as it both influences and depends on natural resources. Sustainable agriculture integrates environmental health, economic viability, and social equity, promoting practices that conserve resources and ensure long-term productivity. Despite agricultural growth, farmers continue to face agrarian distress due to rising input costs, low price realization, and frequent climatic uncertainties. Although production has increased, the cost of cultivation has risen faster, reducing farm profitability. Additionally, excessive use of chemical fertilizers and pesticides has degraded soil health and affected long-term productivity. To address these challenges, natural farming has emerged as a sustainable alternative. It relies on ecological processes with minimal external inputs, where farmers act as facilitators. Cow-Based Natural Farming (CBNF) is based on agro-ecological principles that enhance soil health through organic matter management, biological activity and recycling of farm resources. The core inputs, cow dung and urine from indigenous breeds improve soil fertility, structure, and water retention while promoting microbial activity.

In addition to agronomic benefits, indigenous cows support rural livelihoods by providing low-cost inputs such as organic manure, bio-fertilizers, and bio-pesticides. These inputs also support eco-friendly pest management and energy production such as biogas. CBNF operates on the following key principles;

**Jeevamrita (Jivamrita):** A fermented microbial culture that enhances soil biological activity, improves nutrient availability, and helps control plant diseases.

**Bijamrita (Beejamrita):** A seed treatment that protects young plants from soil- and seed-borne diseases.

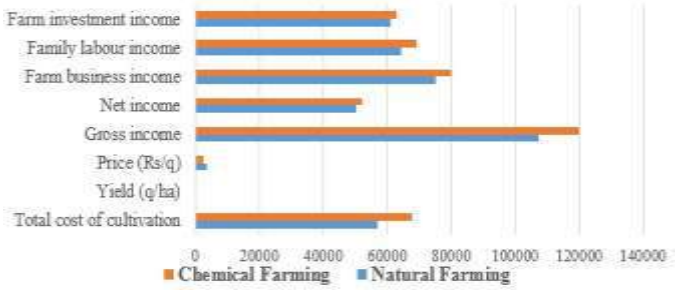
**Acchadana (Mulching):** Use of organic residues to conserve moisture, suppress weeds, and improve soil fertility.

**Wapsa:** Maintenance of an optimal balance of air and moisture in the soil for better root growth and efficient water use.

**Mixed Cropping:** Cultivation of multiple crops together to improve biodiversity, soil health, and income stability while reducing production risks.

## A Case of Wheat Cultivation: Economic Efficiency of Chemical and Natural Farming

Insights from a field-level study in Gujarat shows that there are clear differences between chemical and natural farming systems in wheat cultivation with respect to costs, returns, and income. Chemical farming involves a higher cost of cultivation due to greater use of inputs such as fertilizers and pesticides, whereas natural farming maintains lower production costs because of its reduced dependence on external inputs. Although chemical farming achieves higher yields, leading to greater gross income, this advantage is largely offset when net income is considered. The higher costs associated with chemical farming reduce its overall profitability, resulting in only a marginal difference in net returns between the two systems. Natural farming, with its lower input costs, achieves a relatively balanced net income. The analysis also indicates that farm business income, family labour income, and farm investment income are generally higher under chemical farming, mainly due to higher production levels. However, these gains are not proportionately large when viewed against the higher investment involved.




## Conclusion

Sustainable agriculture and Cow-Based Natural Farming together offer a holistic approach by integrating ecological sustainability, economic viability and social well-being. Government initiatives such as Prakrutik Krishi Abhiyan have played an important role in promoting natural farming practices by providing training, equipment, and eco-friendly inputs. The implementation of these programmes through institutions like ATMA has strengthened grassroots outreach and encouraged wider adoption among farmers. Overall, these efforts highlight the growing importance of natural farming as a viable pathway for sustainable agricultural development.

# Effect of Various Methods Adopted for Sustainable and Profitable Vegetable Production in Coastal Ecosystems

**K. Sha**


## Abstract

Vegetable cultivation plays a vital role in ensuring food and nutritional security, generating employment, and enhancing farm income in coastal regions of India. However, weed infestation remains one of the major constraints affecting vegetable productivity and profitability. Coastal agro-ecosystems are characterized by sandy soils, high humidity, salinity intrusion, and erratic rainfall, all of which create favourable conditions for weed growth. Weeds compete with crops for nutrients, water, light, and space, causing significant yield losses. In vegetable crops, uncontrolled weed infestation may reduce yields by 45-95% (Gharde *et al*., 2018). Integrated Weed Management (IWM), involving cultural, mechanical, biological, and chemical methods, offers a sustainable approach to weed suppression while minimizing environmental hazards. This review discusses weed flora, crop–weed competition, critical periods of weed interference, integrated weed management practices, and future strategies for sustainable vegetable production in coastal ecosystems.


## Introduction

Vegetable crops are important components of Indian agriculture because of their nutritional value, high productivity, and economic returns. They provide essential vitamins, minerals, dietary fibre, and antioxidants necessary for human health (Balasubramanian and Palaniappan, 2001). Coastal districts of Tamil Nadu, including Cuddalore, are important vegetable-producing regions where crops such as tomato, brinjal, bhendi, chilli, onion, and cucurbits are cultivated throughout the year. The tropical maritime climate of coastal regions supports continuous crop production but simultaneously favours rapid weed growth. High temperature, humidity and intermittent rainfall create ideal conditions for weed germination and proliferation (Haripriya *et al*., 2019). Weeds compete aggressively with crops for essential resources and interfere with cultivation, irrigation, harvesting and crop protection operations. Vegetable crops are particularly vulnerable because many exhibit slow initial growth and poor canopy development during early stages (Knezevic *et al*., 2002). The adoption of Integrated Weed Management (IWM) has become increasingly important as a sustainable alternative to sole dependence on herbicides. IWM integrates preventive, cultural, mechanical, biological and chemical methods to maintain weed populations below economically damaging levels while protecting environmental quality (Swanton and Weise, 1991).

## Weed Flora in Coastal Vegetable Ecosystems

Coastal vegetable ecosystems support diver-

**K. Sha**
Department of Horticulture, Reginal Research Station, TNAU, Virudhachalam, Tamil Nadu

se weed species belonging to grasses, sedges, and broad-leaved groups. The composition and abundance of weed flora depend on soil characteristics, irrigation practices, cropping systems, and seasonal conditions. Among grassy weeds, *Cynodon dactylon*, *Echinochloa colonum*, *Digitaria sanguinalis*, and *Dactyloctenium aegyptium* are commonly observed. These weeds possess extensive root systems and rapid growth rates, enabling them to compete effectively with vegetable crops for nutrients and moisture (Rao, 2000). Sedges are particularly problematic in irrigated vegetable fields. *Cyperus rotundus* is considered one of the most troublesome perennial weeds because of its underground tubers and rhizomes, which enable rapid regeneration after control measures. Other important sedges include *Cyperus iria* and *Cyperus esculentus*.

Broad-leaved weeds such as *Amaranthus viridis*, *Parthenium hysterophorus*, *Portulaca oleracea*, and *Trianthema portulacastrum* frequently dominate coastal vegetable fields. These weeds produce large quantities of seeds and possess strong adaptability to salinity and moisture stress. Certain species such as *Parthenium hysterophorus* also exhibit allelopathic effects that suppress crop growth (Altieri and Liebman, 1988).

## Effects of Weeds on Vegetable Crops

Weeds adversely affect vegetable crops through competition for nutrients, water, light, and space. Their aggressive growth habit often enables them to utilize available resources more efficiently than crop plants.

**Competition for Nutrients:** Weeds absorb nutrients rapidly through their extensive root systems. Essential nutrients such as nitrogen, phosphorus, and potassium are often depleted by weeds before crops can utilize them effectively (Reddy and Reddi, 2012). In coastal sandy soils, where nutrient retention is already low, nutrient competition becomes particularly severe.

**Competition for Moisture:** Coastal agriculture frequently experiences moisture stress because sandy soils have poor water-holding capacity. Weeds exacerbate this problem by extracting large amounts of soil moisture, thereby reducing water availability to crops. This results in poor plant growth, delayed flowering, and reduced yield (Arnon, 1992).

**Competition for Light:** Fast-growing weeds often overshadow young crop plants and reduce light interception. Reduced photosynthesis leads to poor vegetative growth, weak stems, delayed flowering, and lower fruit production (Singh *et al*., 2015).

**Allelopathic Effects and Pest Incidence:** Certain weeds release toxic compounds that inhibit seed germination and crop development. *Parthenium hysterophorus* is well known for its allelopathic properties. In addition, many weeds serve as alternate hosts for insect pests, nematodes, fungi, bacteria, and viruses, thereby increasing pest and disease incidence in vegetable crops (Sharma, 2001). Uncontrolled weed infestation may reduce vegetable yields by 45-95%, depending on crop species, weed density, and environmental conditions (Gharde *et al*., 2018).

**Critical Period of Weed Competition:** The critical

period of weed competition refers to the stage during crop growth when weeds must be controlled to prevent significant yield losses. Vegetable crops are generally poor competitors during their early growth stages because of slow initial development and limited canopy cover (Knezevic *et al*., 2002). In most direct-seeded vegetables, the critical period occurs between 15 and 45 days after sowing, whereas in transplanted crops it extends from 20 to 50 days after transplanting. Weed interference during this period can cause irreversible damage to crop growth and yield potential. Therefore, timely weed control during the critical period is essential for achieving maximum productivity and profitability.

## Integrated Weed Management Approaches

Integrated Weed Management combines several complementary weed control methods to achieve sustainable and effective weed suppression.

**Preventive and Cultural Methods:** Preventive measures include the use of certified weed-free seeds, clean irrigation water, properly decomposed organic manures, and sanitation of farm machinery (Norris, 1999). Cultural methods such as crop rotation, optimum spacing, cover cropping, and mulching improve crop competitiveness and suppress weed emergence. Mulching is particularly effective in vegetable crops. Organic mulches such as paddy straw and coconut husk reduce weed germination while improving soil moisture conservation. Plastic mulches, especially black polyethylene mulch, provide excellent weed control by preventing light penetration to the soil surface (Chauhan and Johnson, 2010).

**Mechanical Methods:** Hand weeding remains one of the most reliable methods of weed control, particularly during the critical period of crop growth. Hoeing, intercultivation, and the use of power weeders help remove weeds and improve soil aeration (Singh and Punia, 2018).

**Chemical Methods:** Herbicides play an important role in modern vegetable production systems. Pre-emergence herbicides such as pendimethalin, fluchloralin, and oxyfluorfen effectively suppress weed germination and early growth (Kaur *et al*., 2016). Post-emergence herbicides such as quizalofop-ethyl selectively control grassy weeds in broad-leaved vegetable crops. Although herbicides provide rapid and economical weed control, excessive dependence on chemicals may lead to herbicide resistance and environmental contamination (Norsworthy *et al*., 2012). Therefore, herbicides should be used judiciously within an integrated management framework.

**Biological Methods:** Biological weed management involves the use of insects, pathogens, and bioherbicides to suppress weed populations. While biological methods alone may not provide complete weed control, they contribute significantly to sustainable weed management programs (Charudattan, 2001).

## Weed Management in Major Vegetable Crops

Weed management practices vary among vegetable crops depending on crop characteristics and weed flora. In brinjal, pendimethalin application

followed by one hand weeding at 30 days after transplanting provides effective weed control (Tomar *et al*., 2003). Tomato cultivation benefits from black polyethylene mulching combined with drip irrigation and supplementary hand weeding (Chaudhari and Patel, 2018). In bhendi, fluchloralin incorporation before sowing followed by inter cultivation effectively suppresses weeds. Chilli cultivation responds well to integrated use of organic mulches, hand weeding, and oxyfluorfen application (Patel *et al*., 2004). Onion, owing to its shallow root system and poor competitive ability, requires pre-emergence herbicides followed by hand weeding during bulb development (Raskar and Bhoi, 2003).

## Economics and Future Prospects

Effective weed management improves crop productivity, nutrient-use efficiency, water-use efficiency, and produce quality. Integrated weed management practices generally provide higher benefit-cost ratios and net returns than single-method approaches (Ahamed *et al*., 2018). In coastal regions facing labour shortages and rising wage rates, the adoption of herbicides, mulches, and mechanical weeders significantly reduces production costs. Future weed management strategies should focus on precision agriculture, sensor-based weed detection, robotics, artificial intelligence, and biodegradable mulches. Bioherbicides and climate-resilient weed management technologies also offer promising opportunities for sustainable vegetable production under changing environmental conditions.

## Conclusion

Weed infestation remains a major challenge to profitable vegetable production in coastal agro-ecosystems. Coastal environmental conditions favour rapid weed growth and intensify crop-weed competition. Integrated Weed Management offers a sustainable and economically viable solution by combining preventive, cultural, mechanical, biological and chemical methods. Adoption of location-specific IWM practices, mulching technologies, precision agriculture tools, and bioherbicides can substantially improve vegetable productivity, profitability, and environmental sustainability in coastal regions.

## References

Ahamed, S., Kumar, R. and Singh, P. (2018). Integrated weed management in vegetable crops: A review. *Indian Journal of Weed Science*, 50(4): 321-329.

Altieri, M. A. and Liebman, M. (1988). *Weed Management in Agroecosystems: Ecological Approaches*. CRC Press.

Arnon, I. (1992). *Agricultural Research in Drylands*. Elsevier.

Balasubramanian, P. and Palaniappan, S.P. (2001). *Principles and Practices of Agronomy*. Agrobios Publications.

Chaudhari, H. C. and Patel, S. Y. (2018). Effect of different weed management practices on growth and yield of tomato. *Environment and Ecology*, 37(1): 139-142.

Reddy, T. Y. and Reddi, G. H. S. (2012). *Principles of Agronomy*. Kalyani Publishers.

Chauhan, B. S. and Johnson, D. E. (2010). The role of mulching in weed management. *Crop Protection*, 29: 100-105.

Gharde, Y., Singh, P. K., Dubey, R. P. and Gupta, P. K. (2018). Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection*, 107: 12-18.

Haripriya, K., Sathyamoorthi, K. and Manickam, T. S. (2019). Integrated weed management in vegetable crops under coastal ecosystem. *International Journal of Chemical Studies*, 7(3): 1802-1808.

Kaur, R., Walia, U. S. and Bhullar, M. S. (2016). Bio-efficacy of herbicides against weeds in vegetable crops. *Indian Journal of Weed Science*, 48(2): 203-208.

Knezevic, S. Z., Evans, S. P., Blankenship, E. E., Van Acker, R. C. and Lindquist, J. L. (2002). Critical period for weed control. *Weed Science*, 50(6): 773-786.

Narayanasamy, P. (2002). *Integrated Weed Management in Crops and Cropping Systems*. Kalyani Publishers.

Patel, B. D., Patel, V. J. and Meisuriya, M. I. (2004). Integrated weed management in chilli. *Indian Journal of Weed Science*, 36(1-2): 140-141.

Rao, V. S. (2000). *Principles of Weed Science*. Oxford and IBH Publishing.

Raskar, B. S. and Bhoi, P. G. (2003). Weed management in onion under irrigated conditions. *Journal of Maharashtra Agricultural Universities*, 28(1): 107-108.

Sharma, O. L. (2001). *Textbook of Weed Science*. Kalyani Publishers.

Singh, R., Verma, S. K. and Singh, A. P. (2015). Weed management practices in tomato cultivation. *Vegetable Science*, 42(1): 62-65.

Singh, S. and Punia, S. S. (2018). Herbicide resistance in weeds: Challenges and management strategies. *Indian Journal of Weed Science*, 50(2): 105-112.

Swanton, C. J. and Weise, S. F. (1991). Integrated weed management: The rationale and approach. *Weed Technology*, 5(3): 657-663.

Tomar, S. S., Bhan, V. M. and Tripathi, S. S. (2003). Weed management in brinjal under irrigated conditions. *Indian Journal of Weed Science*, 35(3-4): 302-304.

# Potato Tuber Moth (*Phthorimaea operculella* Z.) Biology and IPM Approaches for Sustainable Potato Cultivation

**Prince Gond, Chandan Singh, Nandini Singh and Rutuja Gajanan**


## Abstract

Potato tuber moth (*Phthorimaea operculella* Z.) is a major pest of potato that damage crops both in the field and during storage. The larvae feed on leaves, stems and tubers, causing significant yield and quality losses. Under favorable conditions, storage damage may become severe, resulting in substantial economic losses. This article highlights the biology, damage symptoms and integrated pest management (IPM) strategies for sustainable control of the pest. Adoption of cultural, mechanical, biological, botanical and need-based chemical measures can effectively reduce infestation and ensure sustainable potato production.


## Introduction

The potato tuber moth, *Phthorimaea operculella* (Zeller), is one of the most destructive pests of potato worldwide. The pest is native to South America and is believed to have co-evolved with its primary host, the potato. The introduction of the potato to Europe in the sixteenth century saw the moth spread rapidly around the world with the movement and cultivation of potatoes (Graf, 1917). The first written record of the pest was in 1855 when Capt. H. Berthon described the "potato grub" that was devastating potato crops in Tasmania in 1854. During the same period (Chadel *et al.*, 2020), Australia, the United States and Algeria also reported infestations. *P. operculella* is now widespread in tropical, subtropical and Mediterranean regions and is considered a major constraint to potato production.

The pest attacks foliage and tubers in the field and still causes serious damage during storage. It is one of the most economically important pests of potato because under favourable conditions, storage losses may be as high as 100%. Its potential to damage crops from field to storage, especially in warm and dry climates, emphasizes the importance of effective and sustainable management strategies (Kushala *et al.*, 2020).

**Distribution and status:** The potato tuber moth, *Phthorimaea operculella* (Z.), was first introduced into India in 1906 with potato seed imported from Italy. Since then, the pest has spread far and wide and is now reported from more than 21 states across the country. It is found in many major potato-growing states like Punjab, Gujarat, West Bengal, Odisha, Chhattisgarh, Jharkhand, Tripura, Uttarakhand and

**Prince Gond and Rutuja Gajanan**
Department of Entomology and Agricultural Zoology, Banaras Hindu University, Varanasi, Uttar Pradesh
**Chandan Singh and Nandini Singh**
Department of Entomology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh

Jammu & Kashmir but is often less severe because cold storage practices inhibit its development and survival (Chadel *et al.*, 2020).

**Host:** Solanaceous crops such as tomato, eggplant (brinjal), tobacco, pepper and several wild hosts belonging to the family Solanaceae.

**Biology**

**Egg:** The eggs of potato tuber moth (*Phthorimaea operculella* Z.) are tiny, oval and creamy white to yellowish in colour. They are laid singly or in small groups on the underside of leaves, stem, exposed, tubers, soil cracks or storage bags. A female moth may lay 100-200 eggs. The average length is 0.39 mm and width 0.30 mm. Depending on temperature, the eggs hatch within 3-7 days.

**Larvae:** Newly hatched larvae of *Phthorimaea operculella* are creamy white, while mature larvae develop a pale green to pinkish coloration with a distinct brown head capsule. Fully grown larvae measure approximately 10-12 mm in length. They feed mining leaves, stems and tubers, leaving behind tunnels packed with frass. The larval stage typically last 10-15 days, depending on environmental conditions.

**Pupa:** The pupa is brown, smooth, conical in shape, and approximately 6.4-6.9 mm long. There is uniform tapering of the body to the last abdominal segment Spin a silken cocoon on plant epidermis or plant debris. Sporadically, pupation can occur amid dead potato leaves in the soil, or on potato tubers that have been kept. The pupal stage generally lasts 5-10 days.

**Adult:** The adult potato tuber moth (*Phthorimaea operculella*) is a small, delicate moth measuring about 6-8 mm in body length, with a wingspan of 12-15 mm. It possesses a narrow silvery-grey body and greyish-brown wings marked with small dark specks. .ptm has black mark-ings on its forewings (two to three dots on males, “X”on females). Both the forewings and hind wings are fringed with long hairs along their margins. Adults are primarily nocturnal, becoming active at night for mating and oviposition, and generally survive for 1-2 weeks. The potato tuber moth is capable of completing several generations each year, depending on the prevailing agro-climatic conditions. Moderate temperatures are highly favou-rable for egg laying and the development of immature stages, whereas excessively high temperatures may adversely affect its growth, development and survival.

**Nature of Damage:** Potato tuber moth damages potato crops both in the field and during storage. Newly hatched larvae mine the leaves, creating irregular blotches and tunnels within the leaf tissues. As the infestation progresses, larvae may also borne into stem and exposed tubers. In tubers, the larvae tunnel beneath the skin and feed internally, producing galleries filled with frass. Infested tubers become unmarketable and are highly susceptible to secondary infection by fungi and bacteria. Severe infestations can result in substantial yield losses in the field and may cause up to 100% damage to stored potatoes under favorable conditions.

**Management**

## Cultural control

- ✓ Use healthy, pest-free seed tubers for planting.
- ✓ Crop rotation with non-solanaceous crops.
- ✓ Harvest the crop immediately after maturity and avoid leaving tubers I the field.
- ✓ To control this pest, healthy seed tubers should be planted at 10 cm depth.
- ✓ Tuber infestation is generally lower in fields with sprinkler irrigation compared to those using in furrow irrigation.
- ✓ Earthing up at 60 days after planting to avoid female moths laying eggs on the exposed tubers.
- ✓ The pupal stage of *P. operculella* survives in soil. the timely collection and destruction of pupa can help reduce the pet population

## Botanicals & Biological control

- ✓ The application of vegetable oil has been shown to help prevent infestation. In particular, the fertility of *Phthorimaes operculella* was reduced when treated with orange peel oil.
- ✓ Neem seed extract was found to be effective in suppressing *Phthorimaes operculella* infestation in stored potatoes. In an Egyptian study, treatment with neem extract at 100 ppm reduced pest damage, resulting in only 25% storage loss after six months of storage (Lamsal *et al.*, 2023).
- ✓ Dried chopped leaves and flowers of *Minthostachys* species has been reported to reduce potato tuber moth damage in stored tubers by approximately 80%.
- ✓ Release larval parasitoids such as *Copidosoma koehleri* and *Apanteles subandinus* where available.
- ✓ Apply microbial biopesticides such as *Bacillus thuringiensis* and *Beauveria bassiana* larval against larval stages.

## Storage Management

- ✓ In India, dry leaves of indigenous plants and similar natural materials are commonly used to cover potato tubers, helping to reduce infestation by the potato tuber moth.
- ✓ Potato tuber moth infestation has been successfully controlled by covering tubers with sand, ash or a mixture of ash and lime.
- ✓ Maintain inspect stored potatoes and remove infested tubers.
- ✓ Clean and disinfect storage structure before storage.

## Mechanical control

- ✓ Pheromone traps are used both for monitoring pest populations and for managing infestations in the field (10-12 traps $ha^{-1}$) as well as during storage.
- ✓ Use light trap to monitor adult moth activity.
- ✓ A formulation prepared with plant oils and ultraviolet (UV) absorbers, applied in 100-µL droplet sizes, proved highly effective-causing 100% mortality of male *Phthorimaea operculella* within 3-4 days (Adhikari *et al.*, 2022).

## Chemical control

- ✓ Apply insecticides only when pest populations reach economic threshold levels.
- ✓ The seed tubers can be dusted with malathion dust (5%) or quinalphos dust (1.5%) at 125 g/100

kg seed tubers before storing.

- ✓ Potatoes kept in gunny bags impregnated with solutions of malathion 50 EC and azadirachtin 1,400 ppm were also free of damage.

## Conclusion

Potato tuber moth is a major pest that threatens potato production from field to storage. Effective management requires an integrated approach combining cultural practices, proper storage management, biological control agents, botanicals and judicious use of insecticides. Adoption of these IPM strategies can reduce pest infestation, minimize economic losses and promote sustainable potato cultivation.

## References

Adhikari, A., Oli, D., Pokhrel, A., Dhungana, B., Paudel, B., Pandit, S. and Dhakal, A. (2022). A review on the biology and management of potato tuber moth *Agriculture* (*Polnohospodarsto*), 68(3): 97-109.

Chandel, R. S., Vashisth, S., Soni, S., Kumar, R. and Kumar, V. (2020). The potato tuber moth, *Phthorimaea operculella* (Zeller), in India: biology, ecology, and control. *Potato Research*, 63(1): 15-39.

Kushala, G., Ramesh, B. H. and Rajeshwari, N. (2020). Biology of potato tuber moth *Phthorimaea Operculella* (Z.) under storage at different seasons in Hassan district, Karnataka, India. *Plant Archives*, 20(2): 4015-4021.

Lamsal, B., Magar, S. K., Bhusal, K. K. and Bharati, S. (2023). A study on the efficacy of different botanicals against potato tuber moth (*Phthorimaea operculella*) in stored potatoes. *International Journal of Quantitative Research and Modeling*, 4(4): 185-190.

# Blue Ports Initiative

**Archana R. and Mahiwal Singh**


## Abstract

Ports are the gateways of global trade and play a vital role in connecting people, goods, and communities. However, they face environmental, social, and economic challenges such as pollution, climate change, poor working conditions, and lack of innovation. The Blue Port Initiative, launched by FAO, provides a pathway to transform traditional fishing ports into hubs of sustainability. A Blue Port balances economic growth, social well-being, and environmental care and contributes directly to the Sustainable Development Goals. This article explores the idea of blue ports, their key components, the challenges in transitioning, and examples from around the world. By adopting innovation, collaboration, and inclusive development, blue ports can safeguard marine ecosystems, empower fishing communities, and ensure long-term sustainability.


## Introduction

Do you know around 80% of world trade is handled in ports? Ports are the dynamic hubs that connect land and marine areas. Activities like aquatic value chains occur in and around ports. A port is a site on the coast or shore that has one or more harbors where ships may dock and transport persons or cargo to or from land (Dwarakish and Salim, 2015). Ports play an important role in supply chain management and the national and supranational economies by providing transportation and services while maintaining safety and security. However, the port faces various environmental, economic, and social challenges.

- ✓ The environmental challenges include pollution, carbon footprints, climate change, ineffective waste management, and mismanagement of marine resources.
- ✓ The social challenge includes an aging population of fishers, food security, ensuring fair employment, promoting decent working conditions and gender inequality.
- ✓ The economic challenges include insufficient revenue and output gains from the aquatic value chain, IUU fishing, supporting innovation, strengthening infrastructure, promoting sustainable trade, and ensuring market competitiveness.

To address these challenges, The Blue Port Initiative began in 2019 with the Food and Agriculture Organization (FAO) initiating an international consultation process to better understand how ports can promote sustainable development.


**Archana R.**
M.Sc. Scholar, Department of Fisheries Extension, Economics and Statistics, Faculty of Fisheries Science, Kerala University of Fisheries and Ocean Studies, Kochi, Kerala

**Mahiwal Singh**
Research Scholar, Department of Agril. Extension, CoA, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala

## What are Blue Ports?

Blue Port is a hub for sustainable development, fostering value creation across social, economic, and environmental dimensions. Blue ports directly or indirectly contribute to 9 Sustainable Development Goals, including No poverty, zero hunger, gender equality, affordable and clean energy, decent work and economic growth and responsible consumption and production, climate action, life below water, and partnership for goals. A blue fishing port aligns with the "green port" concept, which prioritizes safeguarding the environment, sustainable utilization of resources, and energy efficiency (Pradana *et al.,* 2023). The concept of a Blue Port is built on the principles of the Blue Economy and Blue Transformation, making it essential to understand these ideas first.

## Blue economy and blue transformation

The blue economy approach is defined by the World Bank as the "sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem" (Vierros and Fontaubert, 2017). It serves as a catalyst for the port to transition towards a holistic blue port approach. The core idea is that it balances three pillars of sustainability (economic, social, environmental) to ensure benefits are shared across communities and future generations. Blue ports contribute to the broader goal of the blue economy. Blue transformation is defined by FAO as a vision for the transformation of aquatic food systems for better production, better nutrition, a better environment, and a better life for all (FAO, 2023). The Blue Transformation is aligned with the Food and Agriculture Organization (FAO) Strategic Framework 2022-2031 and the FAO Committee on Fisheries' 2021 Declaration on Sustainable Fisheries and Aquaculture, both of which seek to enhance the role of aquatic food systems in achieving the Sustainable Development Goals. It emphasizes the adoption of innovative technologies, management practices, and policies to enhance the economic viability of the sector. It promotes sustainable infrastructure, optimizes value chains and ensures inclusive governance.

## Components of Blue port

Blue ports specifically focus on marine fishing ports. It involves activities that have direct/indirect impact on fishing activity. Various components of blue port include

**Cargo Terminals:** Handle the movement of goods and exports.

**Landing sites:** Facilities for both small-scale fishers and large commercial vessels.

**Fish markets:** Spaces where fresh catches are traded and sold.

**Shipyards and Repair docks:** Includes dry-dock facilities, vehicle storage, and terminals for vessel maintenance

**Cold storage and Processing units:** Preserve and process fish and seafood for wider markets.

**Waterfront services:** Support various commercial activities and businesses.

**Transport hub:** Connects Sea transport with road

and other networks.

**Tourism and Recreation:** Areas for cruise ships, diving, snorkeling, and coastal tourism.

## Challenges in Transitioning Fishing ports into blue ports

The blue ports serve as sustainable development hubs, addressing global concerns with varying dimensions such as environmental, social, and economic sustainability.

### Environmental sustainability

- ✓ Decarbonization remains a challenge, as clean fuel options for vessels are still costly and under development, making ports and fleets dependent on fossil fuels. While renewable energy can be introduced in port facilities, this shift requires significant investment and international support.
- ✓ Fishing ports lack efficient waste management systems and strategies for reusing fish waste. Without circular economy approaches, valuable resources are lost, and pressures on already stressed fish stocks continue to grow.
- ✓ Port operations often disturb marine ecosystems due to insufficient pollution control, inadequate waste facilities, and plastic leakage. Sustainable dredging and reducing underwater noise remain under-addressed.

**Social sustainability:** Lack of financial resources and poor communication among stakeholders are major barriers in providing safe and decent working conditions.

**Economic sustainability:** Access to technology, knowledge transfer, stakeholder sensitization, and the capability of fishing ports and value chains are key barriers for technological innovation (Morales *et al.*, 2023).

## Examples that show the path to environmental, social, and economic change

Vancouver Port in Canada has initiated the Maplewood Marine Restoration Project to mitigate the impact of infrastructure developments and restore natural ecosystems. Port of Açu, Brazil, has created the Employability Network, a single-window portal controlled by the port administration. It links local workers with job openings and the professional qualifications needed for them. The Bahia Blanca Port Authority in Argentina runs the Smart Port Lab, an acceleration program that promotes open innovation and encourages new business ideas to meet the difficulties facing the country's ports and communities (Morales *et al.*, 2023).

## Conclusion

Becoming a blue fishing port offers a pathway to sustainable development by integrating environmental, social, and economic goals. Success depends on stakeholder collaboration, innovation, and context-specific strategies, supported by clear planning, measurable indicators, and knowledge sharing. By developing partnerships and holistic approaches, blue port can enhance livelihoods, protect marine ecosystems, and contribute to long-term food security and prosperity for coastal communities.

"*If ports are the gateway of our economy, Blue ports can be the guardians of our oceans.*"

## References

Dwarakish, G. S. and Salim, A. M. (2015). Review on the Role of Ports in the Development of a Nation. *Aquatic Procedia*, 4: 295-301.

FAO. (2023). *Blue Transformation in brief* (p. 20). FAO ; https://openknowledge.fao.org/handle/20.500.14283/cc6646en

Morales, Y., Carballo, J. E. and Aragon, L. L. de. (2023). *Roadmap to a blue port*. https://books.google.com/books?hl=en&lr=&id=OCDgEAAAQBAJ&oi=fnd&pg=PR3&dq=Molares,+Y.,+Estors+Carballo,+J.,+L%C3%B3pez+de+Arag%C3%B3n,+L.+2023.+Roadmap+to+a+Blue+Port.+Rome,+FAO.+&ots=NNEyLxdDzR&sig=xMvvvSnvt2dhdixEXoTtvdORosA

Pradana, A. S., Pinagara, F. A. and Luxianto, R. (2023). Green port concept and its impact on port cost efficiency and green performance indicator in Tanjung Perak Port. *AIP Conference Proceedings*, 2765(1). https://doi.org/10.1063/5.0154860

Vierros, M. and Fontaubert, C. De. (2017). The potential of the blue economy: increasing long-term benefits of the sustainable use of marine resources for small island developing states and coastal least. https://policycommons.net/artifacts/1509557/the-potential-of-the-blue-economy/2177714/

# Flaxseed: A Sustainable Feed Alternative for Livestock

**Srashti Dixit**

Flaxseed (*Linum usitatissimum*), commonly referred to as linseed, belongs to the Linaceae family and stands as one of the oldest domesticated crops with archeological evidence of its cultivation spanning several millennia. Historically valued for its dual utility in producing high-quality fiber and oil, the seed also holds a long-standing place in animal husbandry for its therapeutic values. Specifically, it is utilized as a natural laxative and as a dietary supplement to enhance skin and coat health in animals. The byproduct known as flaxseed or linseed meal serves as a valuable source of plant based protein in commercial livestock formulations. In recent years, researchers and producers have shown a renewed interest in incorporating both whole flaxseed and its oil into animal diets. This interest is driven by the seed's ability to favorably modify the fatty acid profiles of products like eggs, milk and meat, thereby delivering functional health benefits to both the animals and consumers. As a premier global oilseed, flaxseed maintains a substantial agricultural footprint. Global flaxseed production stabilizes at around 3.5 million metric tons, driven by its high nutritional value. Recently, a persistent supply and demand imbalance for traditional protein ingredients has driven up feed costs, threatening the long-term economic sustainability of livestock and poultry operations. To counter this resource scarcity, the agricultural sector must prioritize the development and adoption of non-conventional feed resources. Utilizing alternative protein sources like flaxseed provides a practical strategy to alleviate shortages in conventional feeds, minimize volatile input costs and secure farm profitability.

**Nutritional composition of Flaxseed:** Flaxseed is comprised of 42% to 46% fat, 28% dietary fiber, 21% crude protein, 6% carbohydrates and 4% ash. The lipid fraction of the seed shows a highly favorable fatty acid profile characterized by low levels of saturated fats (approximately 9%), moderate levels of monounsaturated fats (18%) and an exceptionally high concentration of polyunsaturated fatty acids (PUFAs), which account for 73% of the total oil content. Within this PUFA fraction, omega-6 fatty acids predominantly linoleic acid (LA) make up roughly 16%, while alpha-linolenic acid (ALA), a crucial omega-3 fatty acid, constitutes the remaining 57% (Newkirk, 2015). From an amino acid perspective, flaxseed protein is particularly rich in arginine, aspartic acid and glutamic acid, though lysine remains the primary limiting amino acid (Singh *et al*., 2011). Notably, this protein fraction also exhibits natural antifungal properties (Xu *et al*., 2022). In terms of dietary metrics, a standard 10 g allocation of ground flaxseed supplies approximately

**Srashti Dixit**
College of Veterinary Science and Animal husbandry, DUVASU, Mathura, Uttar Pradesh

55 calories, 2.8 g of fiber, 1.9 g of protein, and 2.3 g of ALA omega-3 fatty acids. Owing to its superior nutritional profile and diverse health benefits, flaxseed is highly effective as a functional food (Oomah, 2020).

**Antinutritional factors in flaxseed:** Raw flaxseed naturally contains 264 to 354 mg per 100 g of cyanogenic glycosides predominantly linamarin which can be enzymatically converted into harmful hydrogen cyanide within the digestive tract. To optimize the nutritional efficiency and safety of flaxseed, various processing techniques such as rolling, grinding and thermal treatments are routinely employed. Applying heat effectively neutralizes this risk by permanently inactivating the specific enzymes responsible for this toxic conversion. Additionally, hydro-thermal processing like boiling activates the seed's internal mucilaginous compounds. These soluble fibers form a protective layer over the gastric mucosa, soothing the gastrointestinal tract and enhancing overall digestive efficiency. For practical farm management, simply soaking flaxseed in hot water prior to ration incorporation is sufficient to eliminate safety risks and unlock these digestive benefits.

## Different forms of flaxseed fed to livestock

Prior feeding to livestock, flaxseed is commonly processed into several different products having specific properties and uses in livestock nutrition.

**Whole flaxseed:** It is the most common form of flaxseed feeding. The seeds must be boiled before feeding to ensure the removal of cyanogenic compounds and the formation of a gel-like mucilage which has a beneficial effect on digestive tract health of ruminants and monogastric animals. Heat treatment of flaxseed can help to avoid biohydrogenation, resulting in milk with as high as 20% ALA content (Gonthier *et al.*, 2005).

**Extruded flaxseed:** It is produced by thermo-mechanical processing of whole flaxseed making it more digestible and readily available resulting in deactivation of cyanogenic compounds, making the product completely safe without the need for boiling before feeding.

**Flaxseed oil:** Cold-pressed oil is usually recommended for livestock feeding than heat pressed because this process preserves more natural nutrients and unsaturated fatty acids. Flaxseed oil is highly rich in omega-3 fatty acids, flaxseed oil serves as a major energy source in animal diets. Its inclusion supports skin and coat health while providing valuable anti-inflammatory benefits.

**Flaxseed press cake (meal):** It is the solid by-product that remains after oil extraction via mechanical pressing. It is highly valued in animal feeding for its balanced fiber and protein content, alongside residual fat levels.

**Extracted flaxseed meal:** It is produced by further chemical processing of the mechanical press cake, treated with organic solvents to maximize oil removal. Because the residual oil is extracted, it has a lower energy value compared to whole seeds, oil or press cakes. However, it yields a highly concentrated

protein source, making it excellent for muscle development in animals like horses.

**Flaxseed hulls:** It is obtained by mechanically separating the outer seed coat from the inner kernel, hulls possess a high concentration of dietary fiber, making them ideal for promoting healthy digestion and supporting overall gastrointestinal function.

**Flaxseed for ruminant production**

Flaxseed serves as a valuable oilseed capable of supplying both energy and protein in ruminant rations. It can be incorporated into diets in various forms, including raw seeds, crushed seeds, press cakes or extracted oil. Inclusion of flaxseed in dairy rations alters milk fat synthesis, decreasing the concentration of short and medium-chain fatty acids while elevating the concentration of health promoting long-chain fatty. It is ideal for increasing energy density in dairy cattle diets because, unlike alternative lipid sources, it does not exert a negative impact on rumen fermentation. Furthermore, dairy cows can be fed either whole or ground flaxseed effectively, as the natural seed coat provides built-in protection for the internal fat content. This dietary strategy allows for the production of superior dairy products that offer enhanced nutritional benefits for consumers. For instance, conventional milk from dairy cows fed standard corn, soybean, and canola products typically exhibits a less-than-ideal omega-6 to omega-3 ratio of approximately 5.77. In contrast, grass-fed and organic milks achieve superior omega-6 to omega-3 ratios of around 0.95 and 2.28, respectively. Consequently, dietary supplementation with flaxseed represents a far more cost-effective alternative for altering these profiles than transitioning an operation to certified organic or entirely grass-fed systems. Additionally, the fatty acid components in flaxseed optimize the endocrine system, supporting reproductive health and overall fertility performance in dairy herds (Moallem *et al.*, 2020), while concurrently demonstrating the capacity to significantly suppress enteric methane production. In beef production, flaxseed meal functions as an efficient protein supplement suitable for cattle across all production stages. Its dense levels of protein and energy have been shown to improve dry matter intake, accelerate daily weight gain and boost overall disease resistance (Newkirk, 2008). Supplementation strategies also directly upgrade final carcass quality (Choi, 2015). Integration of 8% flaxseed into the rations of bull calves led to a significant increase in alpha-linolenic acid (ALA) levels, rising from a 3,200 mg to 9,300 mg per 100 g of intramuscular fat.

**Flaxseed for swine production:** Integrating flaxseed into swine rations effectively elevates the omega-3 fatty acid content of the resulting pork. Dietary supplementation also yields broader production benefits, including enhanced sow productivity, improved piglet health and vitality and the development of juicier, highly palatable meat. For grower and finisher pigs, flaxseed can be successfully added to the total ration at levels up to 10%, while maintaining a consistent 5% inclusion rate provides long-term reproductive advantages within the breeding herd (Newkirk, 2008).

Studies confirm that flaxseed supplementation drives statistically significant increases in essential ALA concentrations within pork tissue while simultaneously reducing saturated and monounsaturated fatty acid profiles, achieving these improvements with no detrimental effects on growth efficiency or meat flavor (Turner, 2014). Demonstrating this conversion efficiency, grower pigs fed diets containing up to 15% flaxseed meal exhibited an increase in linolenic acid deposition, rising from 11 mg $g^{-1}$ to 48 mg $g^{-1}$ of back fat (Xu *et al*., 2022).

**Flaxseed for poultry production:** Milled flaxseed and processed flaxseed meals are widely used in commercial laying hen operations to systematically increase the omega-3 fatty acid content of commercial eggs. Similarly, introducing flaxseed to broiler diets 14 days prior to slaughter functions as a highly effective in improving carcass quality attributes. Incorporating between 50 to 100 g $kg^{-1}$ of flaxseed meal into the rations of laying hens optimizes the health profile of the eggs while simultaneously boosting the birds' internal immune responses (Tarek *et al.*, 2015). Dietary levels ranging from 10% to 15% of either whole or ground flaxseed consistently yield egg yolks composed of 4% to 7% omega-3 fatty acids (Scheideler and Froning, 1996). Specifically, adding a 10% flaxseed level to a standard laying ration increased the ALA content from 38.5 mg to 306.3 mg per 50 g egg, while the corresponding DHA content rise from 53.3 mg to 83.7 mg per 50 g egg. Furthermore, overall production metrics including the Feed Conversion Rate (FCR), protein efficiency ratio (PER) and energy efficiency ratio (EFR) improve significantly in poultry flocks supplemented with 5 g and 10 g of flaxseed meal per kg of feed.

## Author's Perspective: The Veterinarian's View on the Flaxseed Paradigm

As livestock production shifts toward precision nutrition and sustainable management, we must look beyond the immediate feed cost per kilogram and evaluate the holistic return on investment. From a clinical and management perspective, flaxseed is not just a feed commodity; it is a preventative health asset. The transition from conventional feeding systems to high-input alternative rations often brings concerns regarding metabolic stability and ration costs. However, the true value of flaxseed lies in its multi-systemic benefits. Reducing systemic inflammation, lowering heat stress vulnerability in delicate ruminants and shortening the calving-to-conception interval directly addresses the invisible profit leaks on commercial farms such as high veterinary costs and wasted breeding cycles. Integrating alternative functional crops like flaxseed into standard rations is a practical, necessary step toward building resilient, climate-smart livestock enterprises that safeguard animal welfare while driving premium farm profitability.

## Conclusion

In recent years, market interest has intensified regarding the bio-fortified production of eggs, meat, and dairy to enhance their nutritional profile and satisfy consumer demand. While these enriched

products offer an accessible framework for consumers to elevate their daily omega-3 intake without shifting standard eating habits, the direct biological advantages to the animals themselves are equally significant. Supplementing livestock with flaxseed delivers profound systemic benefits, including improved immune response, reduced inflammation, lower heat stress markers, and improved reproductive efficiency. To maximize these dual benefits for both animal welfare and human nutrition, ongoing research remains essential. Future advancements will benefit from combining optimized feed science with selective breeding programs, targeting livestock lines with an enhanced natural capacity for alpha-linolenic acid (ALA) conversion to ensure a more efficient, profitable and sustainable production cycle.

## References


Choi, C. B., Kwon, H., Kim, S. I., Yang, U. M., Lee, J. H. and Park, E. K. (2015). Effects of rice bran, flax seed, and sunflower seed on growth performance, carcass characteristics, fatty acid composition, free amino acid and peptide contents, and sensory evaluations of native Korean cattle (Hanwoo). *Asian-Australasian Journal of Animal Sciences*, 29 (2): 195.

Gonthier, C., Mustafa, A. F., Ouellet, D. R., Chouinard, P. Y., Berthiaume, R. and Petit, H. V. (2005). Feeding micronized and extruded flaxseed to dairy cows: Effects on blood parameters and milk fatty acid composition. *Journal of Dairy Science*, 88(2): 748-756.

Moallem, U., Lehrer, H., Livshits, L., Zachut, M. J. L. S. (2020). The effects of omega-3 α-linolenic acid from flaxseed oil supplemented to high-yielding dairy cows on production, health, and fertility. *Livestock Science*, 242: 104302.

Oomah, B. D. (2020). Flaxseed by-products. Food wastes and by-products: nutraceutical and health potential, 267-289.

Scheideler, S. E. and Froning, G. W. (1996). The combined influence of dietary flaxseed variety, level, form, and storage conditions on egg production and composition among vitamin E-supplemented hens. *Poultry Science*, 75(10): 1221-1226.

Moallem, U., Lehrer, H., Livshits, L. and Zachut, M. J. L. S. (2020). The effects of omega-3 α-linolenic acid from flaxseed oil supplemented to high-yielding dairy cows on production, health, and fertility. *Livestock Science*, 242: 104302.

Singh, K. K., Mridula, D., Rehal, J. and Barnwal, P. (2011). Flaxseed: a potential source of food, feed and fiber. *Critical Reviews in Food Science and Nutrition*, 51(3): 210-222.

Turner, T. D., Mapiye, C., Aalhus, J. L., Beaulieu, A. D., Patience, J. F., Zijlstra, R. T. and Dugan, M. E. R. (2014). Flaxseed fed pork: n- 3 fatty acid enrichment and contribution to dietary recommendations. *Meat Science*, 96(1): 541.

Rex Newkirk (2008). PhD, "Flax Feed Industry Guide," Flax Council of Canada.

Xu, L., Wei, Z., Guo, B., Bai, R., Liu, J., Li, Y. and Pi, Y. (2022). Flaxseed meal and its application in animal husbandry: A review. *Agriculture*, 12(12): 2027

# Cluster Bean (Guar) Cultivation in Rajasthan

**Gharsiram and Priya Sharma**

## Introduction

Cluster bean or guar (*Cyamopsis tetragono-loba* L.) is an important drought-tolerant legume crop grown extensively in the arid and semi-arid regions of India. Rajasthan is the leading producer of cluster bean, accounting for the largest share of area and production in the country. The crop is valued for vegetable pods, fodder, green manure, and industrial production of guar gum. Due to its adaptability to low rainfall conditions and ability to improve soil fertility through biological nitrogen fixation, cluster bean has become an integral component of dryland farming systems in Rajasthan. Scientific cultivation practices can substantially improve productivity and profitability.

**Climate and Soil Requirements:** Cluster bean is a warm-season crop that performs best under arid and semi-arid climatic conditions. The optimum temper-ature for germination and growth ranges between 25°C and 35°C. The crop is highly drought tolerant but sensitive to waterlogging. A well-distributed rainfall of 250-500 mm during the growing season is considered adequate. Sandy loam to loam soils with good drainage and a pH range of 7.0-8.5 are ideal for cultivation. The crop can also tolerate moderate salinity.

**Recommended Varieties:** Selection of suitable varieties is crucial for obtaining higher yields. Some popular varieties recommended for Rajasthan include: RGC-1002, RGC-1038, RGC-1066, HG-2-20, Durgajay, Durgapura Safed. These varieties possess better yield potential, adaptability to dry conditions, and improved gum content.

**Land Preparation:** The field should be prepared with one deep ploughing followed by two to three harrowings to obtain a fine tilth. All weeds and crop residues should be removed. Application of 5-10 tonnes of well-decomposed farmyard manure (FYM) per hectare during land preparation improves soil structure and moisture retention. Proper leveling of field facilitates uniform germination and efficient water management.

**Time of Sowing:** In Rajasthan, sowing is generally undertaken during the *kharif* season with the onset of monsoon rains. Irrigated conditions: Mid-June to early July and Rainfed conditions: Immediately after receiving effective monsoon rainfall.

**Gharsiram**
Assistant Professor, LSRC College of Agriculture, Mandawa, SKRAU, Bikaner, Rajasthan
**Priya Sharma**
Research Scholar, Junagadh Agriculture University, Junagadh, Gujarat

**Seed Rate and Sowing Method:** A seed rate of 15-20 kg per hectare is generally recommended for grain production. Seeds should be sown in rows spaced 45 cm apart with a plant-to-plant spacing of 10-15 cm. Sowing can be done using a seed drill or behind the plough at a depth of 3-5 cm. Proper spacing ensures adequate aeration, light interception, and efficient nutrient utilization.

**Seed Treatment:** Before sowing, seeds should be treated with fungicides to protect against seed-borne diseases. Rhizobium inoculation is recommended to enhance biological nitrogen fixation and improve crop growth. Seed treatment helps in achieving better germination and plant vigor.

**Nutrient Management:** Although cluster bean is a leguminous crop capable of fixing atmospheric nitrogen, a starter dose of nutrients is beneficial. Nitrogen (N): 20-25 kg $ha^{-1}$; Phosphorus ($P_2O_5$): 40-50 kg $ha^{-1}$; Potassium ($K_2O$): 20-25 kg $ha^{-1}$ (where deficient). Application of FYM along with phosphorus enhances root development and nodulation. Balanced fertilization is essential for achieving higher seed yield and gum quality.

**Water Management:** Cluster bean is generally cultivated under rainfed conditions in Rajasthan. However, supplemental irrigation during prolonged dry spells can significantly improve productivity. The critical growth stages for moisture availability are: Flower initiation; Pod development and Seed filling stage. Waterlogging should be avoided because the crop is highly sensitive to excess moisture.

**Weed Management:** Weeds compete with the crop for nutrients, moisture, and sunlight during the early growth period. The crop should be kept weed-free during the first 40-45 days after sowing. First hand weeding at 20-25 DAS, Second weeding at 40-45 DAS and Pre-emergence application of Pendimethalin.

**Pest and Disease Management:** Major Insect Pests are Aphids, Jassids, Whiteflies and Pod borers and diseases are Bacterial blight, Leaf spot, Powdery mildew and Root rot. Regular field monitoring and need-based insecticide application help minimize losses. Use of disease-free seed, crop rotation, seed treatment, and recommended fungicides effectively reduce disease incidence. Integrated Pest Management (IPM) practices should be encouraged for sustainable production.

**Harvesting and Yield:** The crop attains maturity within 90-120 days depending upon variety and environmental conditions. Harvesting should be done when leaves dry and pods turn brown. Delayed harvesting may result in pod shattering and seed losses. Average grain yield: 10-15 q $ha^{-1}$, Improved management yield: 15-20 q $ha^{-1}$ and Green fodder yield: 20-30 q $ha^{-1}$.

## Conclusion

Cluster bean is one of the most suitable crops for the drought-prone regions of Rajasthan due to its low water requirement, soil fertility improvement capacity, and strong industrial demand for guar gum. Adoption of improved varieties, timely sowing, balanced nutrition, proper weed management, and integrated pest management can significantly enhan-

ce productivity and profitability. With increasing demand for guar gum in domestic and international markets, scientific cultivation of cluster bean offers excellent opportunities for sustainable agricultural development in Rajasthan.

# Reproduction in Prokaryotes

Vinodhini A., Jesima Barveen U. and Sumitha S.

## Introduction

Bacteria are small, unicellular, prokaryotic organisms. The cell wall is composed of pepdidoglycan, and the nucleus is not surrounded by a nuclear membrane. There are three ways the bacteria can proliferate. These include vegetative reproduction, asexual reproduction, and genetic recombination.

## Vegetative reproduction

**Binary Fission:** The most popular approach. To create two identical daughter cells, the cell lengthens, duplicates its single circular chromosome, separates the DNA to opposing ends, and pinches in the middle (cytokinesis). Under ideal circumstances, this process can happen quickly for species like *E. coli*, it frequently takes less than 20 minutes. Eg: *E. coli.*

**Budding:** The bacterial growth and swelling or bud form from the parent cell. The bud is attached to the parent cell and eventually detach when it is genetically identical. Eg: Yeast

**Fragmentation:** The bacterial cell is break down or fragment into two or more pieces. That fragment pieces grow into the new bacterial cell. Eg. *Streptomyces, cyanobacteria*

## Asexual reproduction

**Conidial formation:** Certain filamentous bacteria exhibit this reproduction. When a transverse septum develops as a filament's tip, a chain of conidia is created that, under the right circumstances, separate and germinate into new mycelia. Eg: *Streptomyces griseus, Streptomyces coelicolor*

**Endospore formation:** A seven-stage survival mechanism where a hardy, dormant spore grows inside a bacterial cell to protect its DNA in response to food deficiency. This is in a bad situation. Eg: *Bacillus anthracis*

## Genetic recombination

**Conjugation:** It involves direct physical contact between two bacteria via a pilus. Conjugation is the horizontal exchange of genetic material between two bacteria. Donor cells are considered male and represented as F+. The donor cell contains a conjugation plasmid. F plasmid, where F stands for fertility factor, is an example of a Prokaryotic conjugation plasmid. Recipient cells are considered female and represented by F–.

## Steps

**Pilus formation and attachment:** The donar cell (F+) product a sex pilus, which attach to a recipient (F-).

**Cell to cell contact:** The pilus retract, pulling the two bacteria close together to form a connection or bridge.

**Single strand DNA transfer:** One strand of plasmid

**Vinodhini A., Jesima Barveen U. and Sumitha S.**
M.Sc. Scholar, Department of Plant Pathology, SRM College of Agricultural Sciences, SRMIST, Baburayanpettai, Chengalpattu, Tamil Nadu

DNA is nacked and transferred from the donar to the recipient through the bridge.

**DNA replication and completion:** Both the donar and recipient cell synthezis a new complementary strand their existing single strand DNA. This result in a double stranded plasmid in both cell, and the previously F- recipient cell become F+.

**Transduction**

Transduction is the special type of horizontal genetic transfer which involves bacteriophages to transfer DNA from one bacterium to another.

**Step 1: Injection and Infection:** After adhering to a donor bacterial cell wall, a virulent bacteriophage injects its viral genome into the cytoplasm of the host.

**Step 2: Host Genome Destruction:** The circular chromosome of the donor bacterium is purposefully cut into random linear pieces by the viral enzymes, which take over the host's machinery.

**Step 3: Inadvertent Mispackaging:** The viral packaging system inadvertently inserts a piece of the bacterial chromosome rather than the viral genome into a viral capsid during the assembly of new viral heads. A transducing particle is produced as a result.

**Step 4: Release and Cell Lysis:** Hundreds of regular phages and the unintentional, faulty transducing particle are released into the environment when the host bacterium lyses.

**Step 5: Recipient Delivery:** The transducing particle inserts the bacterial DNA from the prior donor into a fresh, healthy recipient bacterial cell.

**Step 6: Consistent Integration:** The recipient cell survives because no viral DNA was introduced. Through homologous recombination, the donor DNA integrates with the recipient's chromosome.

**Transformation**

Transformation is defined as a kind of genetic recombination in which the DNA of the donor cell is transferred to the host bacteria in vitro.

**Step 1: DNA liberation:** When a donor bacterial cell dies and lyses (bursts open), its plasmids and chromosomal fragments are released into the extracellular environment.

**Step 2: Attaching to Receptor Locations:** The free-floating double-stranded DNA (dsDNA) fragments are bound by certain surface proteins (such as ComEA) on the cell membrane of a living, capable recipient cell.

**Step 3: Transport and Uptake:** The attached DNA fragment is drawn across the bacterial cell wall and outer membrane by a multi-protein translocase complex.

**Step 4: Degradation of the Strand:** One of the two strands of DNA is broken down by a specialized nuclease enzyme as it enters the cytoplasm. There is only one complete strand of DNA (ssDNA) that enters the cell.

**Step 5: RecA Pathway Homologous Integration:** The entering single-stranded DNA is coated by a bacterial protein known as RecA. In order to create a permanent genetic recombinant, it looks for a homologous location on the host chromosome and substitutes the new DNA strand for the host's original sequence.

## References

Prescott's Microbiology, Willey, J. M., Sherwood, L. M. and Woolverton, C. J. (2020). *Prescott's Microbiology* (11th Edition).

Microbiology, Pelczar, M. J., Chan, E. C. S. and Krieg, N. R. (2010). *Microbiology* (5th Edition).

Brock Biology of Microorganisms, Madigan, M. T., Bender, K. S., Buckley, D. H., Sattley, W. M. and Stahl, D. A. (2021). *Brock Biology of Microorganisms* (16th Edition).

# IoT-Based Smart Seed Storage System

Yeshwanth B., Kaameshvaran A. and S. Ambika

## Importance of Seed Storage

Seed is basic unit for agriculture. Nevertheless, retaining seed quality in post-harvest stages poses one of the main challenges facing farmers and other stakeholders in agricultural production. Seed storage in conditions of excessive moisture, temperature fluctuations and insect invasion can severely undermine their quality, viability and germination capacity. Conventional methods are unable to guarantee proper monitoring and maintenance of favorable conditions, thus, causing considerable post-harvest losses every year. The need for more efficient agricultural management has become apparent. With the advent of the Internet of Things (IoT) technology, there has emerged an opportunity to enhance seed management. IoT-based solutions allow creating smart seed storage by using a combination of modern sensors, communication channels, and mechanisms of automated operation of the system.

## IoT-Based Smart Seed Storage System

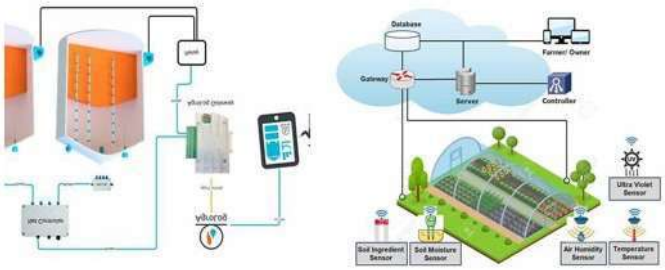
In essence, this technique makes use of the Internet of Things (IoT), sensor technology, and analytics in managing the quality of stored seeds. For starters, the idea behind this technology is the use of smart sensors within storage areas that constantly track important environmental variables such as temperature, humidity, moisture, and sometimes gases. These variables play an important role in determining whether seeds will be spoilt or not since any form of variation would mean that the quality of stored seeds will not remain intact. The data collected through sensors is then communicated to a remote location via the internet where farmers and storage personnel can monitor storage environments from wherever they might be. Additionally, these devices generate alerts in cases where conditions go beyond the expected levels. Based on the information gathered, the system can regulate various devices like fans, heaters, ventilation systems, and even dehumidifiers to manage storage conditions without the need for human effort.

## Types

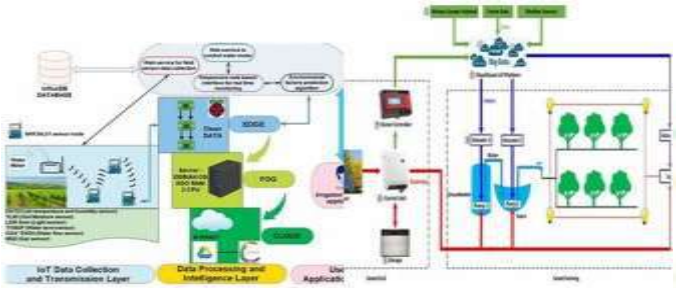
**Temperature and Humidity Controlled Storage Systems:** This type of storage system serves as the core technology behind smart seed storage. The seeds are very vulnerable to their environment, namely the temperature and humidity that directly influence their germination rate. In the case of this technology, IoT sensors continuously track the levels of temperature and relative humidity in the storage facility. If either of these parameters exceeds the

**Yeshwanth B. and Kaameshvaran A.**
Department of Vegetable Science, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu
**S. Ambika**
Department of Genetics and Plant Breeding, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu

optimal range, control systems will start to operate cooling/heating devices or fans/dehumidifiers until normal conditions are reached. Thus, there would be no chances for mold to form in this way. This is the most common type of storage facilities.

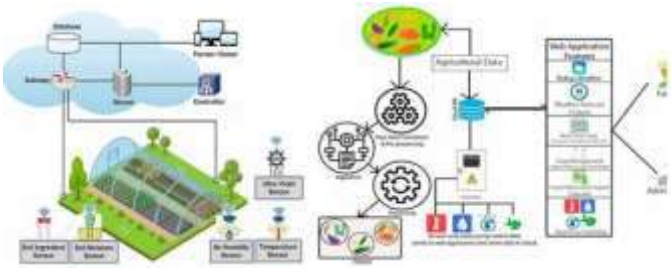


**Cloud-Connected Smart Seed Storage System**

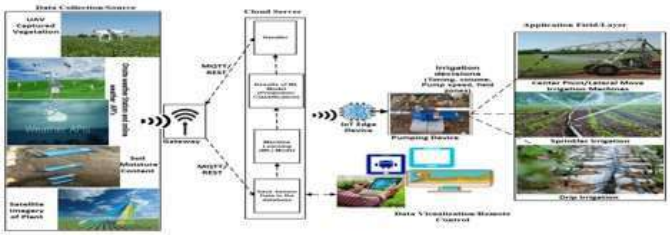


This type is more advanced than the previous one, but it involves some additional elements. As opposed to simple IoT storage systems, cloud-connected systems can be remotely monitored via internet-enabled sensors that send all the collected information to cloud-based platforms where this data could be analyzed. Farmers, scientists, or managers who work in seed companies would have an opportunity to check out all the environmental parameters of any storage facility through the use of applications and/or websites.

**AI-Based Predictive Storage Systems:** Through the integration of Artificial Intelligence (AI), IoT seed storage gains additional capacity to make predictions and decisions concerning seed protection. Thus, AI algorithms not only respond to the current conditions but also analyze historical data to predict any future problems associated with storing seeds, such as accumulation of moisture, pest infestation, or decreased viability of seeds.



**Solar-Powered IoT Seed Storage Systems:** Due to the lack of a stable source of electricity in certain rural or remote farming areas, farmers are likely to face challenges when installing regular IoT seed storage systems. In this case, solar-powered IoT seed storage systems would be able to overcome this problem through generating energy from sunlight for further operating sensors, controllers and environmental control devices.



**Pest and Gas Monitoring Storage Systems:** When storing seeds in bulk form, one may have issues associated with the emergence of pests or the processes of fermentation, which might be quite challenging to detect without specialized equipment. Therefore, the discussed IoT seed storage system utilizes gas monitors to measure the concentration of different gases, such as carbon dioxide and ammonia, emitted by pests and seeds.

**IoT-Based Container/Bin Storage System:** In this

approach, individual containers or bins are used for seed storage. Each of them has its own sensor capabilities, making it possible to monitor the conditions inside the bin easily. They have better labeling features as they can use labels such as QR codes for management purposes.

## Advantages

**Continuous Real-Time Monitoring:** One of the most prominent features of the IoT system is that they help keep track of the storage condition on a real-time basis. With the use of sensors within the storage unit, parameters like temperature, moisture content, and even gases are measured constantly. Unlike other methods that involved periodic checks of the storage, with IoT, there are no gaps in monitoring storage conditions.

**Reduction in Seeds' Loss:** Seeds tend to be very fragile to any change in the environment. In cases of moisture, it can lead to fungus formation whereas, in case of excessive temperatures, it may decrease its capability to germinate. Hence, IoT system maintains a controlled environment for storage.

**Automated Control Systems:** The IoT-based system can control the environment of storage automatically based on conditions detected. This means, in case of increased humidity content, automatic systems like dehumidifiers are activated instantly.

**Data collection and Analysis:** Analysis can then be carried out to discover trends and predict potential dangers, thus making it possible to devise improved storage practices. For instance, if it is noted that humidity tends to increase in specific months, measures can be put in place prior to the onset of such periods. Therefore, the system will not be reactionary but will rather anticipate problems.

## Disadvantages

**High Initial Investment:** The introduction of IoT seed storage can be quite costly, especially when compared to the older systems that have been relied upon by small-scale farmers for years. The cost comes from not having just one piece of equipment, but the entire range of tools including the sensors, controller units, internet connectivity components, as well as software for monitoring the condition of the stored seed.

**Need for Constant Internet Connection:** This type of solution requires internet connection for the transmission of notifications and alerts. In areas with poor connectivity, this becomes a challenge since the system will require reliable access to the internet. Consider the situation in which you are waiting for a notification regarding a particular change in temperature inside the seed storage area.

**Importance of Technical Skills:** The introduction of such a technology to the farm environment implies a transition towards more sophisticated processes and operations. Traditional seed storage methods usually require minimal technical knowledge.

## Conclusion

The implementation of smart seed storage systems via IoT is an innovative breakthrough in seed storage technology. Smart storage technologies ensure optimal environmental conditions in terms of

humidity, temperature, and other parameters. In this way, not only the level of seed losses will be minimized, but also the quality of seeds will be improved. However, there are several disadvantages to this system. Firstly, it is associated with the relatively high cost of introducing the system, especially for small farmers. Secondly, the use of IoT technology requires stable access to electricity and the Internet. Finally, some farmers may face certain difficulties in understanding the principles of operation of such a complex system. All these aspects should be considered carefully when implementing IoT-based technologies for storing seeds. Future projections of IoT-based smart seed storage appear bright.

## References

Priyadarsani, S., Pradhan, A. K. and Jena, P. C. (2023). Smart food grain storage system using Internet of Things (IoT): A review. *ORYZA - An International Journal of Rice*, 60(3): 371-387.

Doltade, A., Kadam, A., Honmore, S. and Wagh, S. (2019). Intelligent grain storage management system based on IoT. *International Journal of Science and Research*, 8(3): 1749-1752.

Riskiawan, H. Y., Anwar, S., Setyohadi, D. P. S., Arifin, S., Widiawan, B., Jannah, A. N. H. and Setiawan, A. B. (2025). Field evaluation of an IoT-VFD smart ventilation system for energy-efficient rice seed storage. *Sinkron: Jurnal dan Penelitian Teknik Informatika*.

Wanyonyi, E. N. (2025). A smart IoT-based real-time system for monitoring storage conditions of maize grains. *East African Journal of Information Technology*.

# Climate Change Effects on Vegetable Seed Production and Viability

**Kaameshvaran A., Yeshwanth B. and S. Ambika**

## Introduction

Seeds form the basis for worldwide vegetable cultivation. One kg of good tomato or cabbage seeds has the capacity to cultivate numerous hectares, which feed many people. However, seed crops are particularly sensitive to climatic changes as they need two entire growing seasons, one devoted to vegetative growth and the other to flowering and seed formation. Temperature, water, and carbon dioxide levels in the atmosphere play vital roles in controlling all these phases. With increasing climate change, interference in any of these stages results in reduced crop yield as well as poor seed quality, which determines its capability to germinate again in the coming season.

## Main Factors Impairing Seed Production

**Heat Stress during the Process of Flowering and Fertilization:** Most of the vegetables are sensitive to heat during reproductive development. The viability of pollen decreases significantly beyond 32°C causing abortion of flowers and low-quality seeds. Moreover, night temperatures are just as important as daytime heat stress as higher temperatures cause increased respiration and reduce the availability of assimilates needed for the development of seeds, which causes low seed weight and vitality.

**Variations in Water Availability:** Drought stress during the process of seed filling reduces the period of starch and proteins accumulation leading to low quality seeds. In contrast, unexpected rainfall close to harvest causes germination of seeds before harvest as well as infections from fungi like Alternaria and Fusarium, especially affecting onions and carrots in South Asia.

**Vernalization Disruption:** Biennial crops such as cabbage, carrot, and onion need a period of low temperature for proper flowering to occur. With waring winters, there will be inadequate and irregular vernalization resulting in asynchronous bolting with minimal seed production. Increased $CO_2$ and Pollinator Activity. Whereas increased levels of carbon dioxide improve overall plant productivity, research has indicated that increased carbon dioxide reduces levels of proteins, iron, and zinc in seeds. Besides, increased carbon dioxide changes the quantity of nectar produced as well as its sugars, making the flowers less attractive to bees.

## Examples of Climate Effects Specific to Crops

**Onion:** There is an increasing problem of excessive February-March rainfall affecting the drying of seeds in fields in Maharashtra and Tamil Nadu. This necessitates artificial drying of wet seeds and makes

**Kaameshvaran A. and Yeshwanth B.**
Department of Vegetable Science, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu
**S. Ambika**
Department of Genetics and Plant Breeding, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu

the seeds vulnerable to Aspergillus infection.

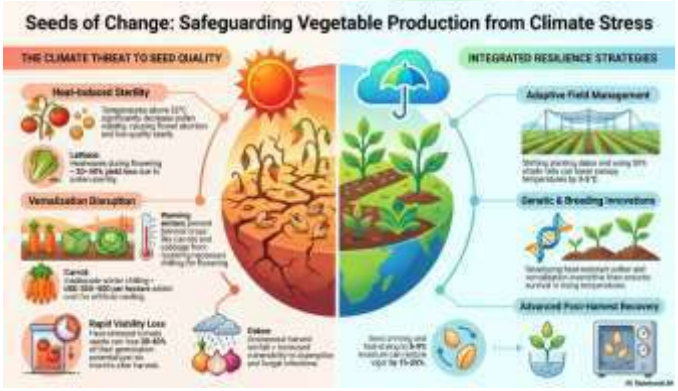
**Lettuce:** It is a cool season crop used for seed propagation. Heatwaves that occur during flowering in California's Central Valley have resulted in losses of 20-50 percent owing to pollen sterility.

**Carrot:** Inadequate chilling of seeds in winter in northern Europe has led to the necessity for vernalization using controlled environment at an added cost of USD 300-500 $ha^{-1}$.

**Effects of Stress on Seed Viability and Vigor:** Seed viability refers to the potential to germinate into healthy seedlings. The effects of climate stress on seed viability occur through three avenues.

| Climate Factor | Physiological Effect | Field Consequence |
|---|---|---|
| Heat during maturation | Membrane damage, protein denaturation | Low germination, abnormal seedlings |
| Drought during fill | Reduced reserves of starch, lipids | Poor seedling vigor, slow emergence |
| Wet conditions at harvest | Fungal colonization, premature aging | Shortened storage life, seedling blights |

In studies done on tomatoes and peppers, seeds exposed to heat stress in laboratory tests have been observed to show 90% germination, but only 6 months later their viability reduces by 30-40%.




**Adaption and Mitigation Strategies Agronomic interventions**

Moving the planting schedule away from the time of peak heat stress during flower development according to seasonal forecasts. Moving crop cultivation to higher latitudes/altitudes with cooler nighttime temperatures and drier conditions during harvest using microclimatic techniques like shade netting when plants are flowering, which decreases canopy temperatures by 3-5°C. Genetic methods Plant breeding to produce varieties with heat-resistant pollen grains, early maturity, and resistant seed coat is currently being pursued by both government and commercial organizations. Post-harvest management fast drying of harvested seeds within six hours of harvesting, storing at 15°C and 30% relative humidity, or seed coating to restore viability following stress.

**Implications for Food Systems:** Vegetable seeds are a high-value commodity traded worldwide. Problems associated with any particular production area lead to shortages one to two years after due to the nature of the seed cycle. Decreased vigor necessitates increased seeding rates, thereby escalating expenses and environmental impacts. Making climate-resilient seeds more viable is thus an issue of food security, not simply an industry issue. Management Strategies: From Fields to Storage Management of climate change impacts on seed crops requires intervention in 4 stages.

**Field-Level Management**

**Manage crop-sowing time with forecasts:** Follow the extended-range forecasts by IMD. Shifting the planting date of onion seeds in Tamil Nadu from October 15 to November 1 can prevent harvesting during rains in March. In North India, planting carrot

stecklings 10 days early can prevent flowering in hot April.

**Shift location of cultivation:** Seed companies are increasingly changing locations of cultivation. For example, onion seeds are being produced not in Nashik, but in cooler locations of Karnataka and AP. Similarly, cabbage seeds are being moved out of Nilgiris and cultivated in HP and Uttarakhand for improved vernalization.

**Modification of microclimate:** Shade nets of 50% cover during the flowering period lower the temperature inside the canopy by 3-5°C. Essential for the production of hybrids of tomatoes and chillies. Sprinkling during extreme heat waves will cool down the flowers to improve pollen quality. Windbreaks and inter-cropping prevent hot winds on the open seeds fields.

**Water management:** Combination of drip and mulching will keep the soil moisture level low during seed formation. For rainy weather at harvesting time, polyethylene sheets or temporary rain shelters must be available.

## Genetic/Breeding management

Select breeds resilient to climate change: The important traits are:

- ✓ Heat-resistant pollen that can withstand temperature of 38 $^{o}$C in tomato and capsicum.
- ✓ Early maturity to survive terminal heat/ precipitation.
- ✓ Vernalization-insensitive lines in cabbage and onion for survival in hot winters.
- ✓ Thick seed coat in beans and peas to resist weathering.

**Protected seed multiplication:** Hybrid seeds of tomato, capsicum and cucumber will be raised under insect-proof net houses/polyhouses. Temperature, rainfall, and pollinators become controllable. It is costly, but economically viable due to high value of seeds.

## Pollination Management

**Hand Pollination:** For cucurbits, hand pollination or hiring bee hives between 6-10 AM can increase fruit setting if natural activity of bees reduces because of high temperatures. Do not spray pesticides from 6 AM - 11 AM as bees may be busy working.

## Harvesting and Post-harvest Management

**Timely harvesting:** Harvest crops at physiological maturity and not after complete drying. For onions, harvest when about 10-20% capsules have burst. Delaying harvest causes weather risks. Fast drying: Thrash seeds immediately and transport seeds into mechanical dryers if raining is predicted. Aim at 8-9% moisture content in onion seeds and 6-7% in tomato within 24 hours.

## Seed improvement

**Priming:** Soaking and re-drying heat-damaged seeds help restore membrane integrity and improve vigor by 15-25%.

**Coating:** Using fungicides and polymers helps protect seeds from storage pathogens. Biologicals such as *Trichoderma* and *Pseudomonas* can be used too.

## Policy and Institutions

**Seed buffer stocks:** The government and private

sector should develop buffer stocks of important vegetable seeds for 1 year's adverse climatic situation. Weather indexed insurance should cover both seed crops and cereal crops.

**Farmers' training:** Season-specific schools of 'Climate-smart Seed Production' to be organized by KVKs in advance.

**Research investments:** The public sector needs to breed open pollinated varieties that can withstand adverse climatic conditions.

## Conclusion

The effects of climate change on reducing vegetable seed yield are not limited. Climate change also affects the quality of the vegetable seeds, but the impacts of such changes are only visible when the farmer plants the seeds. There is an urgent need to develop an integrated strategy for managing climate risks through seed forecasting, relocation, breeding, and storage management. Seeds are too precious to be left to the mercy of the weather conditions.

## References

Hatfield, J. L. and Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes*, 10: 4-10.

Drew, J., Andrews, M. and Morton, J. (2019). Vernalization requirements of *Daucus carota* under climate warming. *Euphytica*, 215(4): Article 78.

Food and Agriculture Organization of the United Nations. (2022). Climate-smart seed systems: Technical guidelines. FAO.

Pathak, H., Kumar, M. and Gowda, P. H. (2023). Breeding vegetables for climate resilience. *Current Science*, 124(6): 678-685.

Singh, D. P., Sharma, R. K. and Kumar, S. (2021). Impact of unseasonal rainfall on onion seed quality in India. *Seed Research*, 49(2): 112-119.

# High-Performance Liquid Chromatography: Principles, Instrumentation and Applications

**Akanksha**


## Abstract

High-Performance Liquid Chromatography (HPLC) is a powerful and widely utilized analytical technique for the separation, identification, and quantification of compounds present in complex mixtures. The technique operates on the principle of differential interactions between analytes, a stationary phase, and a liquid mobile phase under high pressure, enabling highly efficient and reproducible separations. Since its development, HPLC has become an indispensable tool in pharmaceutical, food, environmental, clinical, agricultural, and biotechnological research. This review provides a comprehensive overview of the fundamental principles, instrumentation, and operational mechanisms of HPLC. The major components of an HPLC system, including solvent reservoirs, pumps, injectors, chromatographic columns, detectors and data processing systems, are discussed in detail. Various chromatographic modes such as reverse-phase, normal-phase, ion-exchange, size-exclusion, and affinity chromatography are also described. Factors affecting chromatographic performance, including mobile phase composition, pH, flow rate, temperature, particle size, and sample characteristics, are highlighted. Furthermore, the broad range of HPLC applications in quality control, drug development, food safety, environmental monitoring, biomolecule analysis and agricultural research is examined. The review also discusses the advantages, limitations and recent technological advancements, including Ultra-High-Performance Liquid Chromatography (UHPLC), hyphenated techniques such as LC-MS/MS, automated sample preparation systems, and green chromatography approaches. Overall, HPLC remains one of the most versatile, sensitive, and reliable analytical techniques in modern scientific research and industrial applications.


## Introduction

High-Performance Liquid Chromatography (HPLC) is one of the most important analytical techniques used for the separation, identification, and quantification of components present in complex mixtures. It is an advanced form of liquid chromatography that utilizes high pressure to force a liquid mobile phase through a column packed with a stationary phase (Ali, 2022). The technique provides rapid, accurate and reproducible analysis of compounds that may be difficult to separate using conventional methods. The development of HPLC revolutionized analytical chemistry by enabling the analysis of a wide variety of organic and inorganic compounds with high precision (Ahmed, 2024). Since its introduction in the 1960s and 1970s, HPLC

**Akanksha**
Centre of Food Technology, Institute of Professional Studies, University of Allahabad, Prayagraj, Uttar Pradesh

has become a standard tool in pharmaceutical industries, food and dairy laboratories, environmental monitoring agencies, clinical diagnostics, forensic investigations, and biotechnology research. The ability of HPLC to analyze compounds at very low concentrations and in highly complex matrices has made it indispensable in modern science and industry. The growing demand for quality assurance, food safety, drug development, and environmental protection has further increased the importance of HPLC. Today, it is considered one of the most reliable and versatile analytical methods available for routine and advanced laboratory applications.

## Principle of HPLC

The fundamental principle of HPLC is based on the differential distribution of analytes between a stationary phase and a mobile phase as shown in Fig. 1. A sample mixture is injected into a stream of liquid mobile phase that flows through a chromatographic column. The column contains a stationary phase that interacts differently with each component of the sample. As the sample moves through the column, individual compounds experience varying degrees of attraction toward the stationary phase. Components with stronger interactions remain in the column for a longer period, whereas those with weaker interactions move more rapidly. Consequently, the compounds become separated and elute from the column at different times, known as retention times. The separated compounds pass through a detector that records their presence as peaks on a chromatogram. The retention time helps identify compounds, while the peak area or height is used for quantitative analysis (Ahmed, 2024).

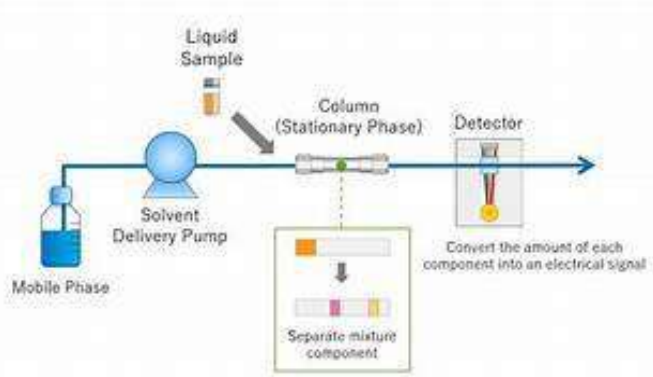



Fig 1: Schematic Diagram of HPLC

## Instrumentation of HPLC

An HPLC system consists of several interconnected components that work together to ensure efficient separation and analysis.

- ✓ Solvent Reservoir
- ✓ Degasser
- ✓ High-Pressure Pump
- ✓ Sample Injector
- ✓ Chromatographic Column
- ✓ Detector
- ✓ Data Processing System

## Factors Affecting HPLC Performance

Several variables influence chromatographic separation and analytical accuracy (Ali, 2022).

- ✓ Mobile Phase Composition
- ✓ pH of Mobile Phase
- ✓ Flow Rate
- ✓ Column Temperature
- ✓ Particle Size
- ✓ Sample Characteristics
- ✓ Applications of HPLC

## Pharmaceutical Analysis

HPLC is extensively used in pharmaceutical industries for:

- ✓ Drug development
- ✓ Quality control
- ✓ Stability studies
- ✓ Dissolution testing
- ✓ Impurity profiling
- ✓ Bioavailability studies

## Food and Dairy Industry

In food science and dairy technology, HPLC is employed for the determination of:

- ✓ Vitamins
- ✓ Sugars
- ✓ Organic acids
- ✓ Amino acids
- ✓ Preservatives
- ✓ Artificial sweeteners
- ✓ Food additives
- ✓ Antioxidants
- ✓ Phenolic compounds

## Limitations of HPLC

Despite its numerous benefits, HPLC has some limitations:

- ✓ High equipment cost
- ✓ Expensive maintenance
- ✓ Requirement for high-purity solvents
- ✓ Skilled personnel needed for operation
- ✓ Potential column deterioration
- ✓ Complex method development for some samples

## Conclusion

High-Performance Liquid Chromatography is a powerful analytical technique that has transformed the field of chemical analysis. Its ability to separate, identify, and quantify compounds with exceptional accuracy and precision makes it indispensable in pharmaceutical, food, environmental, agricultural, clinical and biotechnology applications. The continuous development of advanced chromatographic systems such as UHPLC and LC-MS has further expanded its analytical capabilities. As scientific research and industrial quality requirements continue to evolve, HPLC will remain one of the most valuable and widely utilized analytical tools in modern laboratories worldwide.

## References

Ahmed, R. (2024). High-performance liquid chromatography (HPLC): principles, applications, versatality, efficiency, innovation and comparative analysis in modern analytical chemistry and in pharmaceutical sciences.

Ali, A. H. (2022). High-performance liquid chromatography (HPLC): A review. *Annals of Advanced Chemistry*, 6(1): 010-020.

# Jeeraphool Rice: Reviving a Tribal Heritage through GI Recognition, Value Addition and Biodiversity Conservation

**Manoj Kumar Dara, Praveen Kumar Verma and M. J. S. L. Naga Durga**


## Abstract

India possesses a rich diversity of indigenous rice varieties that have evolved through centuries of farmer-led selection and adaptation. Among these traditional landraces, Jeeraphool rice of the Surguja region in Chhattisgarh is renowned for its distinctive aroma, grain quality, and cultural significance. Although the cultivation of Jeeraphool declined due to changing agricultural practices and increasing preference for high-yielding varieties, collective efforts involving tribal communities, self-help groups, Krishi Vigyan Kendras (KVKs), research institutions, and government agencies have successfully revived this traditional crop. Through value addition, branding, and Geographical Indication (GI) recognition, Jeeraphool has emerged as a premium specialty rice capable of generating livelihood opportunities while conserving agricultural biodiversity. The Jeeraphool experience demonstrates how traditional crops can contribute simultaneously to biodiversity conservation, rural entrepreneurship, and sustainable rural development.


## Introduction

Chhattisgarh is widely recognized as the "Rice Bowl of Central India" because of its rich repository of indigenous rice varieties. The state possesses numerous aromatic and specialty rice cultivars that have been conserved by farming communities for generations. These traditional varieties represent valuable genetic resources and form an integral part of local food culture, farming systems, and rural livelihoods. Among these indigenous varieties, Jeeraphool occupies a unique place in the northern hill region of Chhattisgarh, particularly in Surguja district and adjoining areas. The variety derives its name from its small grains resembling cumin seeds (jeera) and its characteristic aroma. For generations, tribal communities have cultivated Jeeraphool under low-input farming systems, preserving its unique qualities through traditional knowledge and seed-saving practices. Like many indigenous crops, Jeeraphool faced the threat of gradual decline due to changing cropping patterns, reduced profitability, and inadequate market support. The spread of modern high-yielding varieties resulted in a decline in the area under cultivation, raising concerns about genetic erosion and loss of traditional knowledge. The revival of Jeeraphool through community participation, scient-ific intervention, value addition, and GI recognition

**Manoj Kumar Dara and M. J. S. L. Naga Durga**
Research Scholar, Department of Agricultural Economics, IGKV, Raipur, Chhattisgarh
**Praveen Kumar Verma**
Assistant Professor, Department of Agricultural Economics, IGKV, Raipur, Chhattisgarh

now stands as a remarkable example of linking biodiversity conservation with livelihood enhancement. Economic studies have demonstrated the profitability of Jeeraphool cultivation, with farmers realizing gross returns of more than ₹90,000 per hectare and an input-output ratio of nearly 1:2.5 under prevailing production conditions.

| Particular | Details |
|---|---|
| Scientific Category | Traditional aromatic rice landrace |
| Region | Surguja Division, Chhattisgarh |
| GI Status | 14 March 2019 |
| Grain Character | Short-grained, cumin-shaped |
| Maturity | About 145 days |
| Average Yield | Approximately 3 t $ha^{-1}$ |
| Major Uses | Kheer, pulao and premium table rice |
| Unique Feature | Distinct aroma and tenderness after cooking |
| Livelihood Impact | Value addition by women SHGs enhanced farmer income |

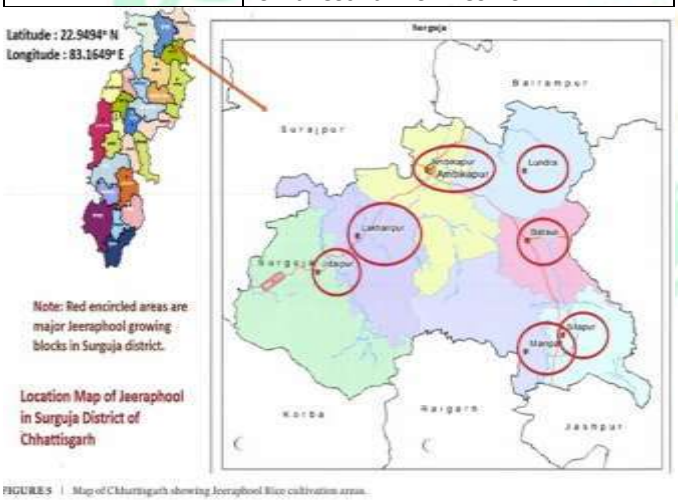



FIGURE 5 | Map of Chhattisgarh showing Jeeraphool Rice cultivation areas.

FIGURE 7 | Fields of Jeeraphool rice in the Surguja District.

Jeeraphool cultivation is concentrated in Ambikapur, Lundra, Lakhanpur, Udaipur, Batauli, Mainpat and Sitapur blocks of Surguja district. The unique agro-climatic conditions of these areas contribute significantly to the characteristic aroma and grain quality of the variety.

## Unique Features and Importance

Jeeraphool is a short-grained aromatic rice known for its excellent cooking quality, tenderness, and pleasant fragrance. The variety enjoys high consumer preference because of its distinctive flavour and texture. Traditionally, it has been used during festivals, family functions, and special occasions, reflecting its cultural significance among tribal communities. Unlike many modern rice cultivars, Jeeraphool is largely cultivated under low-input production systems. Farmers rely extensively on farmyard manure, organic inputs, and traditional cultivation practices. Such farming systems contribute to the unique quality attributes of the rice while promoting environmentally sustainable agriculture. Apart from its culinary appeal, Jeeraphool represents an important component of agricultural biodiversity. Indigenous landraces possess valuable genetic traits that can play a critical role in future crop improvement programmes. Conserving these traditional varieties therefore contributes not only to cultural preservation but also to long-term food and nutritional security

## Community-Led Conservation and Revival

The survival of Jeeraphool rice is largely attributable to the commitment of tribal farming communities who continued cultivating the variety despite economic constraints. However, declining productivity, poor market access and reduced profit-

ability threatened the long-term sustainability of cultivation. Recognizing the importance of preserving this unique genetic resource, several institutions-initiated efforts to revive the crop. Scientists from Indira Gandhi Krishi Vishwavidyalaya (IGKV), Krishi Vigyan Kendra (KVK), Ambikapur, local self-help groups, and district administration collaborated to improve seed quality, strengthen cultivation practices, and enhance farmer awareness. Training programmes, demonstrations, field visits, and awareness campaigns helped farmers adopt improved production technologies while retaining the traditional characteristics of the variety. Seed purification programmes were undertaken to maintain genetic purity and improve grain quality. These interventions strengthened farmer confidence and contributed to the expansion of Jeeraphool cultivation in several villages. The revival process demonstrates that biodiversity conservation becomes sustainable when local communities are actively involved and receive tangible economic benefits from conserving traditional crops. Studies conducted in Batauli block revealed that farmers currently realize only about 69.52% of the potential yield, indicating significant opportunities for productivity enhancement through improved management practices and quality inputs.

**Value Addition and Entrepreneurship: The Bansajhal Experience:** One of the most inspiring examples of Jeeraphool-based rural entrepreneurship emerged from Bansajhal village in Surguja district. Traditionally, farmers sold Jeeraphool paddy to local traders at relatively low prices, thereby receiving only a small portion of the final consumer value. The intervention of KVK scientists transformed this situation by encouraging farmers to focus on value addition, branding, and collective marketing. Farmer groups and women self-help groups were trained in seed purification, processing, packaging, quality control, and marketing. Infrastructure support in the form of mini rice mills, weighing machines, and packaging equipment enabled local processing and value addition. Instead of selling paddy, farmers began marketing branded Jeeraphool rice in attractive consumer packs. Packaging enhanced product visibility and consumer confidence, while branding helped establish a premium market identity. As a result, farmers were able to obtain better prices and improve their share in the value chain. The Bansajhal experience clearly demonstrates that value addition can transform traditional crops into profitable agribusiness opportunities. It also highlights the role of collective action in strengthening rural entrepreneurship and livelihood security.

**Recognition and Market Opportunities:** A major milestone in the development journey of Jeeraphool rice was its registration as a Geographical Indication (GI) product in 2019. GI recognition protects products whose quality, reputation and characteristics are linked to a specific geographical region. The GI tag has strengthened the identity of Jeeraphool rice and enhanced consumer confidence regarding its authenticity. It has also provided legal protection against misuse of the name and helped

preserve traditional knowledge associated with cultivation and processing. The increasing demand for specialty foods, traditional products, and traceable agricultural commodities has created significant opportunities for GI-tagged products. Jeeraphool rice possesses considerable potential in premium domestic markets owing to its aroma, quality, and cultural significance. Opportunities also exist for expanding value-added products, promoting agro-tourism, and exploring niche export markets. The GI recognition of Jeeraphool demonstrates how intellectual property protection can contribute to rural development by creating economic incentives for biodiversity conservation.

**Economic Benefits and Livelihood Enhancement:**

Recent studies indicate that Jeeraphool cultivation is economically rewarding despite its relatively moderate yield levels. An economic analysis conducted in Balrampur district reported an average cost of cultivation of ₹36,430.77 per hectare and a gross return of ₹90,864.17 per hectare, resulting in an input-output ratio of 1:2.49. The study also revealed that the marketable surplus of Jeeraphool rice was as high as 86.02 per cent, indicating its strong commercial potential. Nearly half (49.97%) of the marketed produce was sold through Cluster Level Federations (CLFs) and KVK-supported channels, highlighting the importance of institutional support in strengthening market access. Value-addition initiatives have further enhanced farmers' incomes. Experiences from Bansajhal village demonstrated that processing, packaging and branding of Jeeraphool rice enabled farmers to capture a greater share of consumer expenditure and substantially improve price realization. Women's self-help groups emerged as important stakeholders in these activities, contributing to employment generation, entrepreneurship development, and household income enhancement.

Although Jeeraphool yields are generally around 3 tonnes $ha^{-1}$ under farmers' conditions, studies have reported an average yield gap of 9.14 q $ha^{-1}$ in Surguja district, suggesting considerable scope for increasing productivity through improved adoption of recommended cultivation practices, quality seed, irrigation support, and plant protection measures. Beyond economic returns, Jeeraphool contributes to livelihood resilience, food security, and cultural identity among tribal communities. The GI recognition of the variety has further strengthened its market position and created opportunities for premium pricing, sustainable farming, and rural development. Recent research has highlighted the role of the Jeeraphool GI in promoting food security, environmentally friendly farming practices, and livelihood enhancement, thereby contributing to the broader objectives of Sustainable Development Goal 2 (Zero Hunger).

**Challenges and Future Prospects**

Despite its success, several challenges continue to affect Jeeraphool cultivation. Farmers often face constraints related to quality seed availability, irrigation infrastructure, processing facilities, and market awareness. Productivity levels remain relatively low compared with modern rice

varieties, although premium pricing helps compensate for this limitation. Future efforts should focus on strengthening farmer producer organizations, expanding value-addition facilities, promoting direct marketing channels, and enhancing consumer awareness regarding GI products. Research support aimed at improving productivity while maintaining traditional quality characteristics will be essential for sustaining long-term growth. Digital marketing, e-commerce platforms, and institutional procurement mechanisms may further enhance market opportunities for Jeeraphool rice in the coming years. The estimated overall yield gap of 9.14 q $ha^{-1}$ and yield gap index of 30.48% suggest that substantial gains in productivity can still be achieved through better adoption of recommended production technologies and improved access to quality inputs.

Jeeraphool rice represents much more than a traditional aromatic rice variety; it is a symbol of biodiversity conservation, cultural heritage, and sustainable rural development. As an indigenous landrace of the Surguja region, it contributes to the preservation of valuable rice genetic resources that are increasingly threatened by the widespread adoption of modern high-yielding varieties. The cultivation of Jeeraphool helps conserve traditional farming knowledge and cultural practices that have been nurtured by tribal communities over generations. Grown largely under low-input farming systems, the variety promotes environmentally sustainable agriculture while reducing dependence on external inputs. The revival of Jeeraphool has also created opportunities for value addition through processing, packaging, branding, and marketing, thereby enhancing its market appeal and economic potential. Importantly, women's self-help groups have played a significant role in these activities, strengthening rural entrepreneurship and household incomes. Through premium pricing and GI-based market recognition, Jeeraphool has improved livelihood opportunities for farmers while demonstrating how geographical indication protection can simultaneously support biodiversity conservation, cultural preservation, and inclusive rural development.

## Conclusion

The journey of Jeeraphool rice from a traditional tribal landrace to a nationally recognized GI-tagged product offers valuable lessons for agricultural development. It demonstrates that conseration and commercialization need not be conflicting objectives. When supported by community participation, scientific guidance, value addition, and effective market linkages, indigenous crops can simultaneously generate income, preserve biodiversity and strengthen rural livelihoods. The Jeeraphool experience provides a replicable model for promoting sustainable agriculture, conserving traditional crop diversity, and advancing inclusive rural development across India. The Jeeraphool experience demonstrates that traditional crops can be economically competitive, with studies reporting gross returns exceeding ₹90,000 per hectare while simultaneously contributing to biodiversity conservation, cultural preservation, and sustainable rural

development.

## References


Bhagat, P. and Pathak, H. (2025). Economic viability and business potential of GI-tagged organic Jeeraphool rice in Chhattisgarh. *International Journal of Agriculture Extension and Social Development,* 8(9): 673-677.

Bhagat, U., Bharti, A. and Kujur, P. (2020). An economic analysis of production and marketing of Jeeraphool rice in Balrampur district of Chhattisgarh. *Journal of Pharmacognosy and Phytochemistry*, 9(5): 28-32.

Bhagat, U. and Chandrakar, M. R. (2020). An economic analysis of Jeeraphool rice in Balrampur district of Chhattisgarh. *Journal of Pharmacognosy and Phytochemistry,* 9(5): 86-90.

Kumar, V., Singh, R. and Singh, G. P. (2025). Geographical indications: Agricultural perspectives with special reference to rice genetic resources in India. *Journal of Cereal Research*, 17(2): 135-145.

Devi, S. A., Mansingh, J. P. and Nisha, A. (2021). *Geographical indication tag for agricultural produce in India*. VIT School of Agricultural Innovations and Advanced Learning.

Sharma, D. (2018). Application for geographical indication registration of Jeeraphool traditional rice variety (Technical document). Department of Genetics and Plant Breeding, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh.

Pradhan, S. K., Khan, M. A. and Narbaria, S. (2019). The tribal farmers' perceptions about weeds affecting the productivity of scented rice cultivars in Jashpur district of Chhattisgarh, India. *International Journal of Current Microbiology and Applied Sciences,* 8(12): 989-995.

Tigga, R., Kumar, A., Markam, S. and Kerketta, D. P. (2018). Doubling income through value addition of organic scented Jeeraphool rice by tribal farmers. *International Journal of Current Microbiology and Applied Sciences, Special Issue-7*: 2637-2642.

Tigga, R. and Singh, S. (2018). Yield gap analysis of Jeeraphool rice in Batauli block of Surguja. *International Journal of Current Microbiology and Applied Sciences,* 7(12): 907-914.

Tripathi, S. and Bhattacharya, N. S. (2026). Agricultural geographical indication in achieving Sustainable Development Goal 2: A case study of Jeeraphool rice from India. *Sustainable Development*. https://doi.org/10.1002/sd.70864

# Sea Buck Thorn: A Nutritional and Medicinal Powerhouse

**Anjali H. Patel, Sandip D. Ninama and Sunil K. Patel**

## Introduction

Sea buckthorn **(***Hippophae rhamnoides***)** is a highly resilient, thorny, spiny deciduous shrub native to the cold regions of Europe and Asia (Eurasia). The genus name *Hippophae* comes from Ancient Greek word *hippos*, meaning "Horse" and *phae*, meaning "Light" and is due to the ancient Greeks Sea-buckthorn leaves are used as horse fodder to make their coats shine more. It is species of flowering plant in the family Elaeagnaceae. It is also known as Sand thorn, Sallowthorn or Sea berry. Sometime also referred as a "Wonder plant" or "Sanjivani Booti" in India. It is famous for producing vibrant orange berries that serve as a nutritional and medicinal powerhouse. In India it is native to the Himalayas, growing at elevations between 2,000 and 4,300 meters. The plant grows wide across five Himalayan states (Ladhak, Uttarakhand, Himachal Pradesh, Arunachal Pradesh and Sikkim), covering roughly 15,000 hectares (Plant Atlas., 2026). The plant can tolerate extreme temperatures, drought and poor soil conditions. In India, it is often referred to as *Leh Berry*, *Chharma* (in Himachal Pradesh), Ames (in Uttarakhand), or *Dhurchuk*, *Ladhak gold* (in Ladakh). The bright orange berries are known as a "Superfood" due to their high concentration of Vitamin C, antioxidants, and rare Omega-7 fatty acids. The fruit contains sugars, sugar alcohols, fruit acids, vitamins, polyphenols, carotenoids, fibre, amino acids, minerals and plant sterols. Oil content in the pulp is 1.5-3.0%, while in seeds, oil is 11% of the fresh weight. Major sugars in Sea-buckthorn fruit are fructose and glucose (e-Floras.org Home., 2026). The fruit is rich in phyto-sterols (340-520 mg $kg^{-1}$), β-sitosterol being the major sterol compound as it constitutes 57-83% of total sterols (Plants of the World Online., 2022). Due to its medicinal and nutritional properties, it is used in the preparation of juices, jam, cosmetics, pharmaceuticals and health supplements.

## Key Features

- ✓ Thorny nitrogen fixing shrub.
- ✓ Produces bright orange berries.
- ✓ Rich source of vitamin C and antioxidants.
- ✓ Drought and cold resistant.
- ✓ Helps in soil reclamation and soil erosion.
- ✓ Valuable for food, medicinal and cosmetic industries.

## Characteristics

**Growth Habit:** A dense, highly branched and thorny shrub that typically grows between 2 to 5 meters tall. It features an extensive, aggressive root system equipped with nitrogen-fixing nodules that improve soil health.

**Anjali H. Patel, Sandip D. Ninama and Sunil K. Patel**
Assistant Research Scientist, Cotton Research Station, Talod, Sabarkantha, Gujarat

**Appearance:** Spiny shrubs with silvery-green, lance-shaped leaves.

**Dioecious Nature:** Plants are either male or female, meaning you must plant at least one male shrub nearby for the wind-pollinated female plants to produce berries.

**Hardiness:** These plants survive temperatures ranging from -40℃ to +40℃ and can even thrive in drought-prone or salty soils.

**Flowers:** Small, greenish-yellow apetalous (petal-less) flowers that bloom in early spring.

**Foliage:** Narrow, lance-shaped leaves that are dark grey-green on top with a distinct silvery-grey underside covered in tiny scales. This adaptation reflects sunlight and prevents excessive moisture loss.

**Wind Pollination:** The plant relies entirely on the wind for pollination.

**Maturation:** It takes about 3 to 4 years for a plant to reach flowering age.

**Sub-species of Sea Buckthorn:** Seven subspecies are accepted, with three in Europe and four more in Asia. The sub-species vary in size, shape, number of main lateral veins in the leaves and quantity and colour of stellate hairs (Baker, 1996).

| Name of sub species | Growing area |
|---|---|
| *Hippophae rhamnoides* subspp. *carpatica* Rousi | Carpathian Mountains in Central and Eastern Europe |
| *Hippophae rhamnoides* subspp. *caucasica* Rousi | Southeastern Europe (Bulgaria), Southwestern Asia in Iran, Turkey and the Caucasus Mountains |
| *Hippophae rhamnoides* subspp. *mongolica* Rousi | East-Central Asia |
| *Hippophae rhamnoides* subspp. *rhamnoides* | Northern & Western Europe |
| *Hippophae rhamnoides* subspp. *turkestanica* Rousi | West-Central Asia |
| *Hippophae rhamnoides* subspp. *wolongensis* | Central China |
| *Hippophae rhamnoides* subspp. *yunnanensis* Rousi | Southwestern China, Tibet |

## Uses of Sea Buckthorn

### Land reclamation

- ✓ Sea-buckthorn can be used for land reclamation, alongside trees like pine, larch, black locust, alder, sycamore maple and manna ash, silverberry and wild privet.
- ✓ Its strong root system effectively stabilises slopes, reduces surface runoff and controls sediment transport, particularly in areas prone to erosion from rainstorms.
- ✓ Additionally, as Sea-buckthorn plantations age, soil fertility improves, evidenced by elevated carbon and nitrogen accumulation (Bal *et al.*, 2011).
- ✓ This progressive soil enhancement makes Sea-buckthorn valuable for land restoration, particularly in degraded temperate regions.

### Nutritional values

- ✓ The fruit has a high vitamin C content, approximately 400 mg per 100 grams.
- ✓ Additionally, the fruit has high concentrations of vitamin E and vitamin K.
- ✓ The berries also contain vitamin $B_{12}$. The main carotenoid is the pro-vitamin A, beta-carotene, while other carotenoids include Zeaxanthin and Lycopene (Yang *et al.*, 2001)
- ✓ The most prevalent dietary minerals in Sea-buckthorn fruit are potassium (300-380 mg/100 g), manganese (0.28-0.32 mg/100 g), and copper (0.1 mg/100 g).

## As a culinary purpose

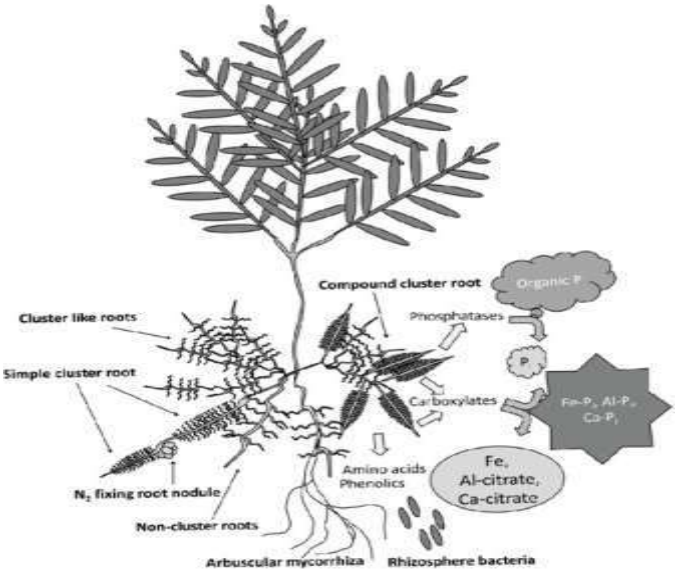
- ✓ The berries are usually washed and then pressed, resulting in pomace and juice.
- ✓ The fruit pomace can be used to obtain oil, natural food colour (yellow/orange) or jam, while the juice is further processed and packaged (Bernath *et al.*, 1992).
- ✓ The leaves of the shrub can be air dried, eventually ground and used for tea.

## As a livestock feed

- ✓ Leaves and fruit residues (left after oil extraction) can be used for feeding livestock, such as for poultry.
- ✓ The weight of livestock and poultry has been shown to increase considerably after being fed sea buckthorn (Biswas *et al.*, 1980).

## As a nitrogen fixer

- ✓ It is a highly effective, non-leguminous nitrogen fixer. It builds soil fertility through a symbiotic relationship with *Frankia* bacteria housed in its root nodules.
- ✓ It can fix up to 180 kg of nitrogen per hectare annually while also increasing soil organic matter and phosphorus levels.




## Different oil extraction methods in Sea Buckthorn

Sea buckthorn oil is extracted from either the seeds or the fruit pulp using cold-pressing, supercritical fluid extraction (SCFE) or solvent extraction. These methods vary in yield, purity, and thermal preservation, and yield oils with entirely different nutrient profiles (Bernath *et al.*, 1992).

## Supercritical Fluid Extraction (SCFE - $CO_2$)

- ✓ Liquid carbon dioxide under extremely high pressure is used as a solvent to draw out the oil in this method.
- ✓ This method operates at low temperatures, which perfectly preserves heat-sensitive nutrients like α-tocopherol (Vitamin E) and carotenoids. It leaves zero chemical residues.
- ✓ Whole-fruit oil and seed oil, preserving the maximum biological value.

## Cold-Pressing (Mechanical)

- ✓ This method commonly used for food-grade like oils and small-scale operations.
- ✓ In this method seeds or dried pulps are fed through an expeller press where heavy mechanic-

al pressure physically squeezes the oil out.

- ✓ This helps in completely solvent-free and retains the rich, natural flavour of the berry.
- ✓ The friction of the press can generate temperatures exceeding 60°C, which can slightly degrade delicate antioxidants and vitamins.

### Solvent Extraction

- ✓ Highly efficient method, typically used in large-scale commercial manufacturing.
- ✓ Dried, milled seeds or pulp are submerged in organic solvents like ethanol, hexane, or 2-methyl tetra hydrofuran to dissolve the lipids. The solvent is then evaporated and recycled, leaving the raw oil behind.
- ✓ This method yields the highest percentage of total oil.
- ✓ Requires thermal evaporation and thorough purification to ensure no toxic chemical residues remain in the product.

### Centrifugal Separation (Fruit Pulp Oil)

- ✓ This method is specific to the fleshy, oil-rich fruit pulp.
- ✓ The fresh berries are pulped and the juice is pressed out. The remaining juice/oil emulsion goes through centrifugal separation to spin out the pure fruit oil.
- ✓ Fruit oil is deeply orange-red, rich in palmitoleic acid (Omega-7), and highly sought after for skin healing.

### Subcritical Fluid Extraction

- ✓ An emerging, eco-friendly alternative to standard solvent extraction method.
- ✓ Utilizes liquefied gases (like propane or butane) under relatively mild pressure (lower than $CO_2$ extraction) to dissolve the oils.
- ✓ Highly efficient, retains active ingredients well, and features lower energy costs than super critical methods.

### References


Plant Atlas. Retrieved 29 January 2026.

Baker, R. M. (1996). The future of the invasion shrub, sea buckthorn (*Hippophae rhamnoides*), on the west coast of Britain. *Aspects of Applied Biology*, 44: 461-468.

Bal, L. M., Meda, V., Naik, S. N. and Satya, S. (2011). Sea buckthorn berries: A potential source of valuable nutrients for nutraceuticals and cosmoceuticals. *Food Research International*, 44 (7): 1718-1727.

Yang, B., Karlsson, R. M., Oksman, P. H. and Kallio, H. P. (2001). Phytosterols in sea buckthorn (*Hippophaë rhamnoides* L.) berries: identification and effects of different origins and harvesting times. *Journal of Agricultural and Food Chemistry*, 49 (11): 5620-5629.

Bernáth, J. and Földesi, D. (1992). Sea Buckthorn (*Hippophae rhamnoides* L.): A Promising New Medicinal and Food Crop. *Journal of Herbs, Spices & Medicinal Plants*< 1 (1-2): 27-35.

Baker, R. M. (1996). The future of the invasion shrub, sea buckthorn (*Hippophae rhamnoides*) on the west coast of Britain. *Aspects of Applied Biology*, 44: 461-468.

eFloras.org Home. Retrieved 29 January 2026.

Plants of the World Online. Royal Botanic Gardens, Kew. Retrieved 8 March 2022.

Biswas, M. R. and Biswas, A. K. (1980). In desertification, control the deserts and create pastures. *Environmental Science Applied*, 12: 145-162.

# Microplastics and their Impact on Insect Biodiversity: A Hidden Threat to Ecosystem Sustainability

**Priyanka K.**

## Introduction

Plastic pollution has emerged as one of the most significant environmental challenges of the twenty-first century. The global production of plastics has increased dramatically over the past few decades due to their versatility, durability, and low cost. However, improper disposal and poor waste management have resulted in the accumulation of plastic debris in terrestrial and aquatic ecosystems. Of particular concern are microplastics, which are plastic particles smaller than 5 mm in diameter. These particles originate either from the degradation of larger plastic materials or from products intentionnally manufactured in microscopic sizes. While the effects of microplastics on marine organi-sms have received considerable attention, their impacts on terrestrial ecosystems remain less explored. Insects, which constitute nearly 80% of all known animal species, play fundamental roles in ecosystem functioning through pollination, biological control, decomposition, nutrient cycling, and food-web maintnance. Recent evidence suggests that microplastic contamination may negatively affect insect physiology, behavior, reproduction, and biodiversity, thereby posing a serious threat to ecosystem sustainability (Wang *et al.*, 2022).

## Understanding Microplastics

Microplastics are generally categorized into primary and secondary microplastics. Primary microplastics are intentionally manufactured small plastic particles used in cosmetics, industrial products and cleaning agents. Secondary microplastics are formed through the fragmentation of larger plastic items such as bags, bottles, fishing nets, and agricultural plastic films under the influence of sunlight, temperature fluctuations, and mechanical weathering (Ziani *et al.*, 2023). Agricultural ecosystems have become important reservoirs of microplastic contamination. Plastic mulching, greenhouse cultivation, irrigation with contaminated water, sewage sludge application and compost amendments contribute significantly to the accumulation of microplastics in agricultural soils. Unlike many conventional pollutants, microplastics are highly persistent and can remain in the environment for decades, continuously interacting with living organisms.

## How Insects are exposed to Microplastics

Insects can encounter microplastics through multiple exposure pathways. Soil-dwelling insects may ingest contaminated soil particles during feeding activities, while aquatic insects are exposed through polluted freshwater systems. Herbivorous insects may consume microplastic-contaminated

**Priyanka K.**
Research Scholar, Department of Entomology, College of Agriculture, Iroisemba, CAU, Imphal, Manipur

plant tissues, whereas predatory insects can acquire microplastics indirectly through trophic transfer from contaminated prey (Liang *et al.,* 2022). Recent studies have reported the presence of microplastics in several insect groups, including beetles, flies, mosquitoes, silkworms, termites, ants, and aquatic insect larvae. Because insects occupy diverse ecological niches and trophic levels, they are particularly vulnerable to widespread environmental contamination. The accumulation of microplastics within insect populations raises concerns about their movement through terrestrial and aquatic food webs.

**Physiological Effects on Insects:** Microplastic exposure has been shown to induce various physiological disturbances in insects. One of the most commonly reported effects is oxidative stress, which occurs when the production of reactive oxygen species exceeds the organism's antioxidant defense capacity. Elevated oxidative stress can damage cellular components, including proteins, lipids, and DNA, leading to impaired physiological functioning (Polenogova *et al.,* 2024). Studies involving model insects such as *Drosophila melanogaster* and *Bombyx mori* have demonstrated that chronic exposure to microplastics can alter growth rates, developmental duration, metabolic processes, and energy allocation patterns. Reduced body weight, delayed development, and increased mortality have been observed under laboratory conditions (Xu and Kong, 2024). Microplastics can also disrupt the gut microbiota of insects. The insect gut contains beneficial microorganisms that contribute to digestion, nutrient absorption, detoxification, and immune regulation. Alterations in microbial communities caused by microplastic ingestion may compromise insect health and reduce overall fitness (Liaqat *et al.,* 2024). Furthermore, microplastics often act as carriers of pesticides, heavy metals, and persistent organic pollutants. These contaminants can adsorb onto plastic surfaces and enter insect bodies upon ingestion, amplifying the toxic effects of environmental pollution (Wang *et al.,* 2022).

**Behavioral and Reproductive Consequences:** Behavioral alterations are increasingly recognized as important consequences of microplastic exposure. Insects rely on complex behavioral responses for locating food, avoiding predators, selecting mates, and identifying suitable oviposition sites. Exposure to microplastics may interfere with these behaviors by affecting sensory perception and physiological performance. Several studies have reported reduced feeding activity, altered movement patterns, impaired foraging efficiency, and changes in habitat preference among insects exposed to microplastics. Such behavioral disruptions can reduce survival and reproductive success, particularly under natural environmental conditions where insects must compete for resources (Xu and Kong, 2024). Reproductive impairment is another growing concern. Experimental evidence suggests that micro-plastic exposure can reduce egg production, decrease fertility, lower hatchability, and negatively affect offspring development. Long-term exposure may therefore contribute to population declines and

reduced genetic diversity within insect communities.

**Consequences for Biodiversity and Ecosystem Services:** The ecological significance of insects extends far beyond their individual species. Insects provide essential ecosystem services that support environmental stability and agricultural productivity. Predatory insects suppress pest populations, decomposers facilitate nutrient recycling, and numerous species contribute to food-web functioning. Microplastic contamination has the potential to disrupt these services by affecting insect abundance and diversity. Reduced populations of predatory insects may lead to increased pest outbreaks, while declines in decomposer communities can slow nutrient cycling processes. Such changes may ultimately affect soil fertility, crop productivity, and ecosystem resilience (Ziani *et al.*, 2023). Insects also serve as a critical food source for birds, reptiles, amphibians, fish, and mammals. The transfer of microplastics from insects to higher trophic levels may facilitate the movement of plastic particles throughout entire ecosystems. This process, known as trophic transfer, has become an important area of ecological research due to its implications for biodiversity conservation and ecosystem health (Liang *et al.*, 2022).

**Microplastics in Indian Agricultural Ecosystems:** India is among the world's largest agricultural producers and consumers of plastic-based agricultural technologies. Plastic mulching, greenhouse cultivation, drip irrigation systems, and packaging materials have become increasingly common in modern farming systems. Although these technologies provide agronomic benefits, they also contribute to the accumulation of plastic residues in agricultural landscapes. Recent investigations have documented the presence of microplastics in Indian soils, rivers, lakes and urban ecosystems. Agricul-tural regions are particularly vulnerable due to intensive cultivation practices and increasing plastic use. Beneficial insects such as predators, parasitoids, decomposers and pollinators may therefore experience chronic exposure to microplastic contamination. The issue is especially relevant in vegetable production systems where plastic mulch films are extensively utilized. Continuous degradation of these materials may lead to long-term soil contamination, potentially affecting insect biodiversity and ecosystem functioning. Sustainable waste mana-gement, improved recycling infrastructure, and adoption of biodegradable alternatives are essential for reducing ecological risks associated with plastic pollution.

**Can Insects Help Combat Plastic Pollution?**

Interestingly, insects themselves may contribute to solving the plastic pollution problem. Recent studies have demonstrated that certain insect species possess the ability to degrade plastic materials through the action of their gut microorganisms. Larvae of the mealworm (*Tenebrio molitor*) and wax moth (*Galleria mellonella*) have shown the capacity to consume and partially degrade polyethylene, polystyrene, and related polymers (Ahmad, 2025). The degradation process is believed to involve specialized microbial communities capable of breaking down complex plastic molecules into simpler

compounds. Although large-scale application remains challenging, these discoveries have opened new opportunities for developing environmentally friendly plastic waste management strategies (Vital-Vilchis *et al.*, 2025).

## Conclusion

Microplastic pollution has emerged as a hidden but potentially significant threat to insect biodiversity. Increasing evidence indicates that microplastics can alter insect physiology, disrupt gut microbiota, impair reproduction, modify behavior, and reduce overall fitness. Given the essential ecological roles played by insects in nutrient cycling, biological control, decomposition, and ecosystem functioning, continued accumulation of microplastics may have far-reaching consequences for environmental sustainability. The growing presence of microplastics in agricultural ecosystems highlights the need for greater attention to terrestrial biodiversity conservation. Protecting insect communities from emerging environmental pollutants is critical not only for maintaining ecological balance but also for ensuring long-term agricultural productivity and food security. Addressing plastic pollution through sustainable management practices and responsible resource use will be essential for safeguarding insect biodiversity in the future.

## References

Ahmad, F. (2025). Mechanisms and perspectives of microplastic biodegradation by insects and associated microorganisms. *Microplastics*, 5 (1): 1-18.

Liaqat, I., Ahmed, M., Khan, S. and Ali, Z. (2024). Microplastic interactions with insect gut microbiota and ecological consequences. *Journal of Hazardous Materials*, 472: 134 602.

Liang, Y., Zhang, Y., Wang, J. and Chen, X. (2022). Effects of microplastic exposure on insect physiology and development. *Environmental Pollution*, 308: 119667.

Polenogova, O., Ivanov, A., Smirnova, E. and Petrova, N. (2024). Microplastic-induced immune and oxidative stress responses in mosquito larvae. *Ecotoxicology and Environmental Safety*, 279: 116420.

Vital-Vilchis, I., García-Rodríguez, A. and Martínez, P. (2025). Using insect larvae and their microbiota for plastic degradation. *Microorganisms*, 13(2): 312.

Wang, Y., Zhao, L., Chen, H. and Li, X. (2022). Microplastic ingestion and physiological responses in terrestrial insects. *Science of the Total Environment*, 827: 154239.

Xu, Y. and Kong, F. (2024). Chronic microplastic exposure alters metabolism and reproduction in insects. *Environmental Research*, 245: 117890.

Ziani, K., El Hachimi, M. and Benlemlih, M. (2023). Microplastics: A global threat for environment and food security. *International Journal of Environmental Research and Public Health*, 20(4): 3056.

# Black Gold Beneath Our Feet: The Role of Soil Organic Carbon in Productive Soils

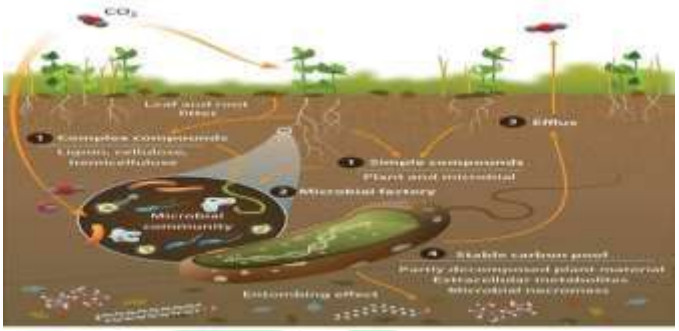
**CH. Mounika, K. Sannihitha and M. Divya Tejaswini**

## What is Soil organic carbon?

Soil organic carbon (SOC) is the carbon-rich component of soil organic matter derived from decomposed plant, animal and microbial residues. It is essential for maintaining soil health by improving soil structure, nutrient availability and biological activity. SOC enhances water infiltration and retention, helping crops withstand drought stress. It also supports beneficial microorganisms that drive nutrient cycling and soil fertility. By storing carbon in the soil, SOC contributes to climate change mitigation and reduces greenhouse gas emissions. Ultimately, higher SOC levels increase the productivity and resilience of agricultural systems.

## Why Organic Carbon is called the Foundation of Productive Soils

Organic carbon is often called the "storehouse of nutrients" of soil because it supports healthy and productive crop growth. It improves soil structure, making the soil loose, well-aerated and better able to hold water. It acts as a storehouse of essential nutrients and releases them gradually for plant use. Organic carbon also feeds beneficial soil microorganisms that help recycle nutrients and suppress harmful pests and diseases. By improving soil health, water availability and nutrient efficiency, organic carbon plays a key role in sustaining crop productivity and building resilient farming systems.

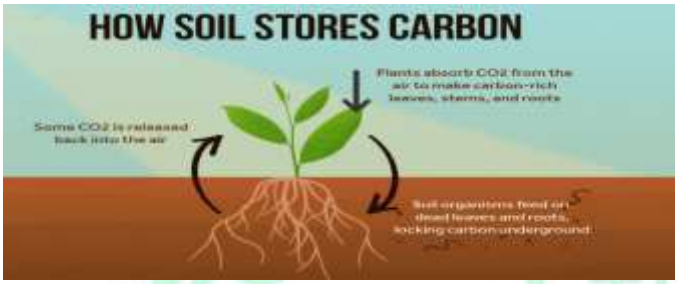



## Role of Soil Organic Carbon in Enhancing Vegetable Crop Productivity and Quality

Soil organic carbon is a key determinant of soil health and plays a vital role in the growth, productivity and quality of vegetable crops. It improves soil structure, enhances water-holding capacity and promotes better root development, creating favourable conditions for crop establishment and growth. Soil organic carbon also supports beneficial microbial activity, which facilitates nutrient cycling and improves nutrient availability to plants. By enhancing nutrient and water-use efficiency, soil organic carbon contributes to higher yields and improved produce quality.

**CH. Mounika**
Research Scholar, Department of Vegetable Science, Dr. YSRHU, Venkataramannagudem, Andhra Pradesh
**K. Sannihitha**
M.Sc. Scholar, Department of Fruit Science, Dr. YSRHU, Anantharajupeta, Andhra Pradesh
**M. Divya Tejaswini**
M.Sc. Scholar, Department of Post Harvest Management, Dr. YSRHU, Anantharajupeta, Andhra Pradesh

In vegetable crops such as tomato, chilli, brinjal, okra, cabbage and cauliflower, adequate levels of soil organic carbon support vigorous plant growth, better fruit and head development and improved post-harvest quality. Furthermore, it helps reduce nutrient losses and improves the efficiency of applied fertilizers, contributing to more sustainable and resilient vegetable production systems.



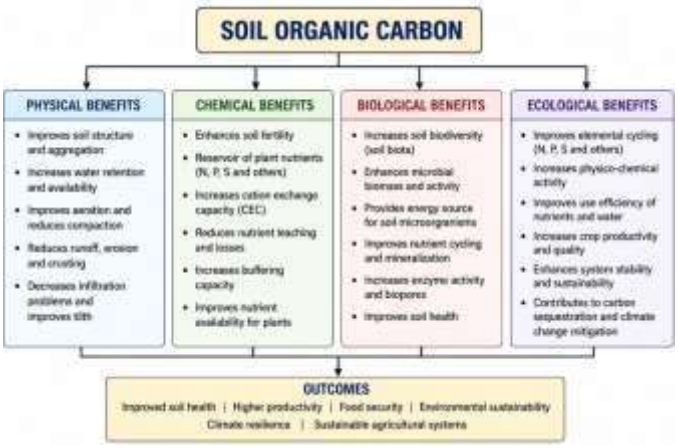

## Benefits of Soil Organic Carbon in Sustainable Agriculture

- ✓ Improves soil health and fertility
- ✓ Enhances water infiltration and water-holding capacity
- ✓ Reduces soil erosion and land degradation
- ✓ Increases nutrient availability and nutrient-use efficiency
- ✓ Promotes beneficial soil microorganisms
- ✓ Reduces dependence on chemical fertilizers
- ✓ Improves crop productivity and quality
- ✓ Enhances resilience to drought and climate variability
- ✓ Sequesters carbon and mitigates climate change
- ✓ Supports long-term agricultural sustainability and food security

## Soil Organic Carbon: Nature's Climate Solution

Soil organic carbon sequestration is the process of capturing and storing carbon in the soil through sustainable management practices. Techniques such as residue incorporation, compost application, crop diversification and reduced tillage increase soil carbon stocks while improving soil health. This helps mitigate climate change, enhances agricultural productivity and strengthens the resilience of farming systems. Soils rich in organic carbon function as effective carbon sinks, capturing and storing carbon for long periods while simultaneously improving soil fertility and productivity. Increased soil carbon also enhances water retention, nutrient availability and soil biodiversity, enabling crops to better withstand droughts and other climate-related stresses.

By reducing carbon losses and promoting sustainable land management, soil organic carbon contributes to lower greenhouse gas emissions and supports more resilient agricultural systems. Its role extends beyond the farm, contributing to global efforts toward climate action, food security, ecosystem conservation and sustainable development.




## Causes of Declining Soil Organic Carbon

- ✓ Excessive tillage

- ✓ Residue burning
- ✓ Monocropping
- ✓ Imbalanced fertilizer use
- ✓ Soil erosion
- ✓ Low organic matter addition

## Practical Ways to Increase Soil Organic Carbon

- ✓ Apply farmyard manure (FYM), compost and vermicompost regularly to enrich the soil with organic matter.
- ✓ Incorporate green manure crops to add fresh biomass and improve soil fertility.
- ✓ Grow cover crops to protect the soil and increase carbon inputs.
- ✓ Retain and incorporate crop residues instead of burning them.
- ✓ Adopt conservation tillage or minimum tillage to reduce soil carbon losses.
- ✓ Practice crop rotation and Integrated Nutrient Management (INM) to sustain soil fertility and organic carbon levels.

## Conclusion

Healthy soils begin with healthy levels of organic carbon. As a key driver of soil fertility, crop productivity, and environmental sustainability, soil organic carbon is central to the future of agriculture. Enhancing and conserving soil carbon will be critical for meeting the growing demand for food while protecting natural resources and adapting to a changing climate.

"Soil organic carbon is the hidden wealth beneath our feet the foundation of productive soils and sustainable agriculture."

# Ebola Virus Disease: A Global Public Health Threat

**Bhoomika, Anjay, Seuli Saha Roy, P. Kaushik and Vivek Kumar Naik**


## Abstract

Ebola Virus Disease (EVD) is a severe acute hemorrhagic fever caused by different species of *Orthoebolavirus*. First identified in the Democratic Republic of the Congo in 1976, the disease is endemic in several African countries and has caused recurrent outbreaks. Fruit bats are the natural reservoir hosts, transmitting the virus to animals and occasionally to humans through contact with infected body fluids. Human-to-human transmission occurs through direct contact with the blood or other bodily fluids of infected individuals. The incubation period ranges from 2 to 21 days. Initial symptoms include fever, fatigue, headache, and muscle pain, which may progress to hemorrhage, severe fluid loss, and hypovolemic shock. Although treatment options are limited, preventive measures such as avoiding contact with infected animals and persons, refraining from consuming bush meat, using Personal Protective Equipment (PPE), and maintaining proper infection-control practices are essential for controlling the disease.


## Introduction

Ebola Virus Disease (EVD) is a severe, highly contagious, and often fatal zoonotic disease caused by viruses belonging to the genus *Orthoebolavirus* of the family *Filoviridae*. The disease was first identified in 1976 during simultaneous outbreaks in Sudan and the Democratic Republic of the Congo, near the Ebola River, from which it derives its name. Since then, multiple outbreaks have occurred across Africa, making EVD a major global public health concern. During the ongoing 2026 outbreak involving the Bundibugyo virus strain in the Democratic Republic of the Congo and Uganda, the World Health Organization (WHO) declared the event a Public Health Emergency of International Concern (PHEIC) under the International Health Regulations (IHR), highlighting the need for immediate international notification, surveillance, and response measures. Fruit bats are considered the natural reservoir hosts of the virus, while non-human primates such as monkeys, chimpanzees, and gorillas act as intermediate hosts. Humans acquire infection through direct contact with infected animals or their body fluids, and human-to-human transmission occurs through contact with the blood, secretions, or other bodily fluids of infected individuals, particularly among family members, caregivers, and healthcare workers. The incubation period ranges from 2 to 21 days. Initial symptoms include fever, headache, fatigue, muscle pain and sore throat, which

**Bhoomika, Anjay, Seuli Saha Roy and P. Kaushik**
Department of Veterinary Public Health and Epidemiology, Bihar Veterinary College, BASU, Patna, Bihar
**Vivek Kumar Naik**
Veterinary Officers, Chhattisgarh Government

may progress to vomiting, diarrhea, hemorrhage, multi-organ failure, and hypovolemic shock. Case fatality rates have varied from 25% to 90% in different outbreaks. Although no universally effective specific antiviral treatment is available, early diagnosis, aggressive supportive care, and maintenance of fluid and electrolyte balance can significantly improve survival outcomes.

**Aetiology and Host range:** The genus Ebola is one of the genera under Filoviridae family. Ebolavirus is having 5 species Zaire, Bundibugyo, Sudan, Reston and Tai Forest in Ebolavirus. Fruit bats of the family *Pteropodidae* are the recognized reservoir of the virus. Non- Human primates such as Monkey, Gorrila and Chimpanzees are primary host.

**How it spreads**

**From Animals to Human:** Handling Infected Bats/ non-Human Primates by hunting, butchering, or handling infected animals often exposes humans to the virus, as it can be present in blood, organs, and secretions.

**Consumption of Bushmeat:** In many regions, meat of fruit bats and non-primates i.e. Gorrila, Monkeys, chimpanzee are preferred as a food source. Ingesting inadequately cooked or raw infected meat spreads the virus directly to humans.

**Contact with Contaminated fomites:** Humans may become infected through contact with surfaces, fruits, or vegetation contaminated with the saliva, urine, or feces of infected bats. For instance, consumption of fruit partially eaten or contaminated by infected bats may facilitate transmission of the virus.

**From Person to Person**

**Direct Fluid Contact:** Contact with blood or bodily fluids (including saliva, sweat, tears, mucus, vomit, feces, breast milk, urine, and semen) of a person who is sick with or has died from Ebola.

**Contaminated fomites:** Touching items (like needles, medical equipment, clothing, or bedding) that have been contaminated with these infected fluids.

**Sexual Contact:** The virus can remain in certain parts of the body (like semen) and can be transmitted via sexual activity even after a patient has recovered.

**Signs and symptoms**

Ebola Virus Disease (EVD) is an acute haem-orrhagic fever with an incubation period ranging from 2 to 21 days. The disease typically begins with non-specific flu-like symptoms, including fever, chills, malaise, headache, diarrhea, and myalgia. As the infection progresses, patients may develop a maculopapular rash involving the face, neck, trunk, and arms, usually appearing between 5 and 7 days after symptom onset. Severe gastrointestinal manifestations, particularly profuse diarrheoa and vomiting, can lead to significant fluid and electrolyte loss, resulting in dehydration, metabolic disturb-ances, hypovolemic shock, multi-organ dysfunction, and in severe cases, death. Haemorrhagic manifest-ations may occur in some patients during the advanced stages of the disease.

**Treatment:** Currently, there is no universally effective specific antiviral therapy for EVD.

Treatment primarily consists of early diagnosis, aggressive supportive care, maintenance of fluid and electrolyte balance, oxygen therapy and management of secondary infections and complications. These measures significantly improve patient survival.

For prevention, the ERVEBO® (rVSV-ZEBOV) vaccine has been approved by the U.S. Food and Drug Administration (FDA) for protection against Ebola virus disease caused by *Zaire ebolavirus* (*Orthoebolavirus zairense*). The vaccine is recommended for adults at risk of occupational exposure, including healthcare workers, laboratory personnel, and outbreak response teams. In addition, two monoclonal antibody therapies, Inmazeb® (atoltivimab, maftivimab, and odesivimab-ebgn) and Ebanga® (ansuvimab-zykl), have been approved for the treatment of EVD caused by *Zaire ebolavirus*. These therapies target the Ebola virus glycoprotein and have demonstrated improved survival outcomes when administered early in the course of infection.

## Prevention and Control

### Avoid contact with body fluids

- ✓ Blood, urine, feces, saliva, sweat, vomit, breast milk, amniotic fluid, semen, and vaginal fluid from people who are sick
- ✓ Semen from someone who has recovered from Ebola disease until testing shows that the virus is no longer in the semen

### Avoid contact with infected fomites

- ✓ Clothes, bedding, needles, medical equipment, or other items that may have soiled with an infected person's blood or body fluids
- ✓ Contact with dead body of the person infected with EVD.
- ✓ Bats, forest antelopes, primates, and blood, fluids, or raw meat from these or unknown animals

**Wear personal protective equipment:** Wear personal protective equipment if you come in contact with infected people or during the healthcare services.

**Monitor your health:** If you return from an area with an ongoing Ebola outbreak, monitor your health for 21 days. Seek medical care immediately if you develop symptoms of Ebola disease.

# Economic Impact of Insect Pests on Tomato Cultivation and their Management

**Raman Sankar, Premika Ramasamy, Lakshmanan Sankar, Selvaprabu Palanivel and Ajay Raja Anandhan**


## Abstract

Tomato is one of the most widely cultivated vegetable crops worldwide and serves as an important source of vitamins, minerals, antioxidants, and income for farmers. However, tomato production is severely constrained by various insect pests that cause significant economic losses through direct feeding damage, transmission of plant pathogens, and reduction in fruit quality and marketability. Major insect pests such as fruit borer, whitefly, aphids, thrips, leaf miners and spider mites can result in yield losses ranging from 20% to 100% under severe infestations. These losses increase production costs due to expenditure on pesticides, labor and crop protection measures. Furthermore, indiscriminate pesticide use can lead to pest resistance, environmental contamination and health hazards. Integrated Pest Management (IPM) has emerged as a sustainable approach combining cultural, mechanical, biological and chemical methods to minimize pest damage while reducing economic losses. This review discusses the major insect pests affecting tomato cultivation, their economic impacts and effective management strategies aimed at improving productivity and profitability.


## Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops cultivated globally for fresh consumption and processing purposes. Tomato production in India is projected at 22.70 million tonnes during 2025-26, compared with 20.60 million tonnes during 2024-25. The average productivity is estimated at approximately 25.8 tonnes $ha^{-1}$ with major contributions from Andhra Pradesh, Madhya Pradesh, Karnataka and Gujarat.

It is valued for its high nutritional content, including vitamins A and C, potassium, lycopene and other antioxidants. The crop contributes significantly to food security, nutritional health, employment generation and agricultural income. Despite its economic importance, tomato cultivation faces several challenges, among which insect pest infestation is one of the most serious constraints. Insect pests attack tomato plants throughout their growth stages, from seedling establishment to fruit harvesting.

**Raman Sankar and Premika Ramasamy**
Department of Agricultural Entomology, TNAU, Coimbatore, Tamil Nadu
**Lakshmanan Sankar**
Department of Agronomy, TNAU, Coimbatore, Tamil Nadu
**Selvaprabu Palanivel and Ajay Raja Anandhan**
Department of Vegetable Science, Horticultural College and Research Institute, TNAU, Coimbatore, Tamil Nadu

**Table 1: Integrated Pest Management Strategies for Major Tomato Pests**

| Management Method | Strategy | Target Pest(s) | Description | Reference |
|---|---|---|---|---|
| **Cultural Control** | Crop rotation | Soil-borne and foliar pests | Rotation with non-solanaceous crops reduces pest carryover and disrupts pest life cycles. | Pedigo and Rice (2014) |
| | Field sanitation | Fruit borer (*Helicoverpa armigera*), whitefly (*Bemisia tabaci*), aphids thrips (*Thrips tabaci, Frankliniella schultzei*) | Removal and destruction of infested plant debris, weeds, and alternate hosts reduce pest reservoirs. | Srinivasan (2010) |
| | Healthy seedling production | Whitefly (*Bemisia tabaci*) and virus vectors | Use of pest-free seedlings minimizes early infestation and disease transmission. | Srinivasan (2010) |
| | Balanced fertilization | Aphids, whiteflies (*Bemisia tabaci*) | Avoidance of excessive nitrogen reduces susceptibility to sap-sucking pests. | Dhaliwal *et al.* (2015) |
| | Adjustment of planting dates | Fruit borer (*Helicoverpa armigera*), whitefly (*Bemisia tabaci*) | Synchronizing planting periods helps avoid peak pest incidence. | Sharma (2005) |
| **Mechanical Control** | Hand picking of larvae and damaged fruits | Fruit borer (*Helicoverpa armigera*) | Regular removal of larvae and damaged fruits reduces pest population. | Sharma (2005) |
| | Yellow sticky traps | Whiteflies (*Bemisia tabaci*), aphids | Sticky traps attract and monitor sap-sucking pests. | Srinivasan (2010) |
| | Blue sticky traps | Thrips (*Thrips tabaci, Frankliniella schultzei*) | Effective for monitoring and reducing thrips populations. | Srinivasan (2010) |
| | Pheromone traps | Fruit borer (*Helicoverpa armigera*) | Used for monitoring and mass trapping adult moths. | Sharma (2005) |
| | Insect-proof netting | Whiteflies (*Bemisia tabaci*), aphids, thrips (*Thrips tabaci, Frankliniella schultzei*) | Physical barriers prevent pest entry into nurseries and protected cultivation structures. | Srinivasan (2010) |
| **Biological Control** | Release of *Trichogramma* spp. | Fruit borer (*Helicoverpa armigera*) | Egg parasitoids suppress *Helicoverpa armigera* populations. | Sharma (2005) |
| | Conservation of ladybird beetles (*Coccinellidae*) | Aphids, whiteflies (*Bemisia tabaci*) | Predators consume large numbers of soft-bodied insects. | Pedigo and Rice (2014) |
| | Release of lacewings (*Chrysoperla* spp.) | Aphids, thrips (*Thrips tabaci, Frankliniella schultzei*), whiteflies (*Bemisia tabaci*) | Predatory larvae effectively suppress pest populations. | Pedigo and Rice (2014) |
| | Application of *Beauveria bassiana* | Whiteflies (*Bemisia tabaci*), aphids, thrips (*Thrips tabaci, Frankliniella schultzei*) | Entomopathogenic fungus infects and kills insect pests. | Horowitz *et al.* (2020) |
| | Application of *Bacillus thuringiensis* (Bt) | Fruit borer larvae (*Helicoverpa armigera*) | Biological insecticide effective against lepidopteran larvae. | Sharma (2005) |
| | Neem seed kernel extract (5%) | Fruit borer (*Helicoverpa armigera*), Whiteflies (*Bemisia tabaci*), aphids | Acts as repellent, antifeedant, and growth regulator. | Srinivasan (2010) |
| | Neem oil (2-3%) | Sap-sucking pests | Reduces feeding and reproduction of insects. | Srinivasan (2010) |
| **Chemical Control** | Selective insecticides based on ETL | Fruit borer (*Helicoverpa armigera*), whiteflies (*Bemisia tabaci*), aphids | Applied only when pest populations exceed economic threshold levels. | Pedigo and Rice (2014) |
| | Insecticide rotation | Multiple pests | Rotating insecticides with different modes of action delays resistance development. | Horowitz *et al.* (2020) |
| | Targeted spraying | Major tomato pests | Need-based application reduces unnecessary pesticide use and environmental contamination. | Dhaliwal *et al.* (2015) |
| | Compliance with recommended dosage and waiting period | All pests | Ensures effective control while minimizing residue problems. | Horowitz *et al.* (2020) |

Feeding damage not only reduces plant vigor and yield but also affects fruit quality, resulting in reduced market value. In many tomato-growing regions, farmers rely heavily on chemical pesticides to manage pests. However, excessive pesticide use increases production costs and can result in pesticide resistance, resurgence of secondary pests, environmental pollution and food safety concerns. Therefore, understanding the economic impact of insect pests and implementing effective management strategies are essential for sustainable tomato production.

## Conclusion

Insect pests remain one of the major constraints limiting tomato productivity and profitability worldwide. Pests such as fruit borers, whiteflies, aphids, thrips, leaf miners, and spider mites cause substantial economic losses through direct feeding damage, disease transmission, and deterioration of fruit quality. These losses not only reduce farmer income but also increase production costs associated with pest control measures. Sustainable management requires an integrated approach combining cultural, mechanical, biological, botanical, and chemical control methods. Adoption of Integrated Pest Management practices can significantly reduce pest-related losses, enhance crop productivity, improve profitability and promote environmentally sustainable tomato cultivation. Continued research, farmer education, and technological innovations will play a vital role in strengthening tomato pest management strategies in the future.

## References

Dhaliwal, G. S., Jindal, V. and B. Mohindru. (2015). Crop losses due to insect pests: global and Indian scenario. *Indian Journal of Entomology*, 77(2): 165-168.

Richardson, E. B., Troczka, B. J., Gutbrod, O., Davies, T. E. and R. Nauen. (2020). Diamide resistance: 10 years of lessons from lepidopteran pests. *Journal of Pest Science*, 93(3): 911-928.

Akhter, W., Shah, F. M., Yang, M., Freed, S., Razaq, M., Mkindi, A. G. and Hanif, M. (2023). Botanical biopesticides have an influence on tomato quality through pest control and are cost-effective for farmers in developing countries. *Plos One*, 18(11): e0294775.

# Green Synthesis of Nanoparticles in Plant Stress Management and Growth Promotion

**P. V. S. Ramunaidu, Dharminder and Sunil Kumar**

## Introduction

- ✓ Green synthesis of nanoparticles has gained prominence in material and life sciences due to their exceptional properties such as extremely small size, high surface area-to-volume ratio, and antimicrobial effects (Abdullah *et al.*, 2020).
- ✓ These characteristics make them highly valuable for various applications in agriculture and environmental management. Green synthesis of nanoparticles has gained prominence in material and life sciences due to properties such as extremely small size, high surface area-to-volume ratio, and antimicrobial effects.
- ✓ This eco-friendly method employs phyto-constituents from plant extracts as reducing and stabilizing agents, eliminating the need for high energy inputs or toxic chemicals.

## Eco-Friendly Method

- ✓ This eco-friendly method employs phytoconstituents from plant extracts as reducing and stabilizing agents, eliminating the need for high energy inputs or toxic chemicals (Kurdekar *et al.*, 2024; Ovais *et al.*, 2016).
- ✓ This approach is sustainable and environmentally benign, making it an ideal choice for agricultural applications.

**Use of Leaves:** Leaves are commonly used in green synthesis due to their rich composition of polyol and heterocyclic compounds that aid in the reduction and stabilization of metal nanoparticles. This makes plant leaves an ideal biological resource for nanoparticle synthesis (Singh *et al.*, 2018).

**Methodology of Green Synthesis of Nano Zinc:** Nayak *et al.*, 2025.

## Leaf Sample Preparation

- ✓ Collected fresh leaves from various plants
- ✓ Washed with distilled water 2-3 times
- ✓ Dried with water absorbent paper
- ✓ Cut into small pieces
- ✓ Dispersed in distilled water (500 ml)
- ✓ Filtered using Whatman filter paper
- ✓ Centrifuged at 6000 rpm for 15 minutes

## Zinc Nanoparticle Synthesis

- ✓ Mixed leaf extract with Zn $(NO_3)_2$ solution
- ✓ Maintained 1:1 proportion
- ✓ Synthesized zinc nanoparticles (pale yellow color)
- ✓ Characterized using UV-Vis spectrophotometer

**P. V. S. Ramunaidu**
Department of Agronomy, PGCA, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar
**Dharminder**
Associate Professor-cum-Senior Scientist, Department of Agronomy, PGCA, Dr. RPCAU, Pusa, Bihar
**Sunil Kumar**
Assistant Professor-cum-Scientist, Department of Agronomy, PGCA, Dr. RPCAU, Pusa, Bihar

- ✓ Analyzed by double beam spectrophotometer
- ✓ Confirmed synthesis of nano zinc particles

Fig. 1: Synthesis and Applications of green nano particles

## Nanotechnology

- ✓ The word nano is taken from Greek language meaning "dwarf".
- ✓ Nanotechnology is the study of manipulating matter on an atomic scale.
- ✓ Nanotechnology refers to the constructing and engineering of the functional systems at very micro level or we can say it atomic level.
- ✓ Father of nano technology Richard Feynman.

## Superior Properties of Nanoparticles

Nanoparticles possess superior properties compared to bulk substances due to their unique characteristics:

**Surface to Volume Ratio:** Dramatically increased, leading to enhanced reactivity

**Surface Reactivity:** Enhanced due to increased active sites

**Mechanical Strength:** Improved durability and structural integrity

**Thermal Stability:** Better resistance to temperature variations

**Catalytic Activity:** Enhanced ability to accelerate chemical reactions

**Electrical Conductivity:** Improved electron transport properties

**Magnetic Properties:** Enhanced magnetic responses

**Optical Properties:** Unique light absorption and emission characteristics

## Plant Stress Management

Plant stress management is a critical area of research that addresses the various biotic and abiotic stresses affecting crop productivity. The application of green nanoparticles has shown tremendous potential in mitigating these stresses and enhancing plant resilience.

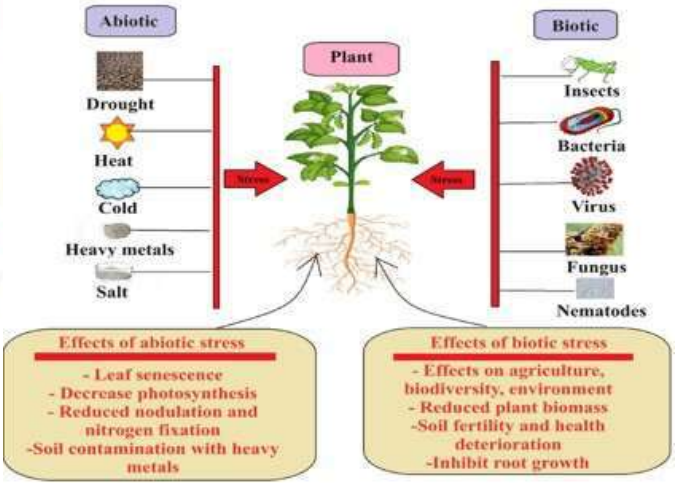



Fig. 2: Effects of Abiotic and Biotic stresses (Ying Ying *et al.*, 2025)

## Effects of Nanoparticles on Plants Exposed to Stress

The Table 1 presents comprehensive research findings on how various nanoparticles affect different plant species under stress conditions. This table demonstrates the significant impact of various nanoparticle types in mitigating both abiotic stresses (drought, salinity, heat) and biotic stresses (pests, pathogens) in different crop species.

**Table 1: Effects of Nanoparticles on Plants Exposed to Stress**

| S.No. | Source Plant / NP Type | Target Plant | Stress Type | Key Effect |
|---|---|---|---|---|
| 1. | *Moringa oleifera* / Ag | Wheat | Heat stress | Enhanced antioxidant enzymes; reduced MDA and $H_2O_2$ |
| 2. | *Euphorbia hirta* / Ag | Cotton | Cotton bollworm | Toxic effect on pest intestinal tract; increased lethality |
| 3. | *Agathosma betulina* / ZnO | Sorghum | Salinity stress | Protected transport pathways; maintained $Na^+/K^+$ ratio |
| 4. | Cocoa / Ag | *Corchorus olitorius* | Soil pathogens | Decreased phytopathogenic fungi and nematodes |
| 5. | Rice / Si | Rice | Bakanae disease | Reduced disease symptoms; improved crop productivity |
| 6. | *Vernonia cinerea* / ZnO | Tomato | Pb toxicity | Increased seedling emergence and antioxidant defense |
| 7. | *Beta vulgaris* / $Fe_3O_4$, $MnO_2$ | Potato | Micro tuberization | Increased tuber size and total biomass; gene upregulation |
| 8. | *Coleus forskohlii* / ZnO | Tomato | Drought stress | Enhanced root/shoot biomass; reduced stress indicators |

**Table 2: Green Synthesized Nanoparticles *Vs* Market-Available Nano Fertilizers**

| Parameters | Green Synthesized NPs | Market-Available Nano Fertilizers |
|---|---|---|
| **Synthesis Method** | Plant extracts, leaf extracts, microorganisms at room temperature | Chemical & physical methods (heating, high pressure, chemicals) |
| **Source Materials** | Biological (weeds, plants, fungi, bacteria) | Chemical precursors and metal salts |
| **Environmental Impact** | Minimal; uses renewable biological resources | Higher; toxic by-products & chemical discharge |
| **Cost of Production** | Low; simple extraction process | High; requires sophisticated equipment & chemicals |
| **Chemical Stability** | Organic corona provides stability & capping | More prone to aggregation & oxidation |
| **Sustainability** | Highly sustainable; circular economy approach | Resource-intensive; reliant on chemical inputs |

## How Nanoparticles Promote Plant Growth

### Key Mechanisms of Growth Promotion

**Nutrient Uptake:** Nanoparticles enhance the absorption of essential minerals including nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) through improved root penetration and nutrient translocation.

**Hormone Regulation:** Nanoparticles modulate plant hormones such as auxins and gibberellins, which promote growth processes including cell elongation, root development, and overall plant architecture.

**Antioxidant Defense:** Nanoparticles increase enzyme activities such as catalase (CAT) and ascorbate peroxidase (APX), which reduce oxidative stress by scavenging harmful reactive oxygen species (ROS).

**Photosynthesis Enhancement:** Nanoparticles enhance chlorophyll content and photosynthetic efficiency, resulting in improved plant productivity and biomass accumulation.

### Nanoparticle Types and their Effects

**Silver Nanoparticles (AgNPs):** AgNPs promote seed germination and possess strong antimicrobial properties, making them effective for controlling pathogenic microorganisms.

**Zinc Oxide Nanoparticles (ZnONPs):** ZnONPs function as nutrient fertilizers, enhance stress tolerance, and significantly increase crop yield potential.

**Iron Oxide Nanoparticles ($Fe_3O_4$):** $Fe_3O_4$ nanoparticles promote biomass accumulation and enhance disease resistance in plants.

**Titanium Dioxide Nanoparticles ($TiO_2$):** $TiO_2$ nanoparticles provide UV protection and improve photosynthetic efficiency through enhanced light

absorption and utilization.

## Green Synthesized Nanoparticles *Vs* Market-Available Nano Fertilizers

A comprehensive comparison between bio-synthesized green nanoparticles and market-available nano fertilizers demonstrates distinct advantages and limitations of each approach:

## Green Synthesized Nanoparticles: Advantages and Disadvantages

### Advantages of Green synthesized Nanoparticles

- ✓ Eco-friendly synthesis process requiring minimal energy and no toxic by-products
- ✓ Uses plant extracts and microorganisms as natural reducing and capping agents
- ✓ No toxic chemicals required in the synthesis process
- ✓ Cost-effective production using readily available biological resources
- ✓ Rapid absorption and translocation within plant tissues
- ✓ Enhanced nutrient availability and bio-availability
- ✓ Improves crop growth, development, and yield
- ✓ Effectively mitigates abiotic stresses (drought, salinity, heat)
- ✓ Reduces environmental footprint and promotes sustainability
- ✓ Low phytotoxicity at optimal doses

### Disadvantages of Green Nanoparticles

- ✓ Batch-to-batch variability in nanoparticle size and properties
- ✓ Long-term effects on soil microbiota and eco-system unknown
- ✓ Potential toxicity at high doses
- ✓ Aggregation tendency during storage leading to particle agglomeration
- ✓ Stability challenges in field conditions (UV exposure, temperature fluctuations)
- ✓ Particle size inconsistency across different synthesis batches
- ✓ Higher concentrations may exhibit phytotoxic effects

## Conclusions

- ✓ Green synthesized nanoparticles, particularly silver nanoparticles (AgNPs), zinc oxide nano-particles (ZnONPs), and iron oxide nanoparticles ($Fe_3O_4$), demonstrate remarkable potential in mitigating plant stress and promoting growth across multiple crop species.
- ✓ Enhanced nutrient bioavailability combined with improved antioxidant enzyme activities (cata-lase, ascorbate peroxidase, superoxide dismutase) enable plants to better withstand both abiotic stresses (drought, salinity, heavy metal toxicity) and biotic stresses (pest damage, pathogenic infections).
- ✓ Green synthesis of nanoparticles using plant extracts provides an eco-friendly, cost-effective, and sustainable alternative to conventional chemical synthesis methods.
- ✓ Integration of nanotechnology with sustainable agricultural practices is crucial to meet the projected 60% increase in global food demand by 2050 while maintaining ecological integrity and

environmental sustainability.

## References


Kurdekar, A. K., Marulappa, J. H., Sannagoudar, M. S., Suresh, K. B., Ayyappa, S., Kumargoud, V., ... and Elansary, H. O. (2024). Eco-friendly green synthesised nano iron particles from weed leaf extract: A potential nutritional source for enhancing germination and yield of aerobic rice. *Cogent Food & Agriculture*, 10(1): 2419438.

Nayak, P., Jayadeva, H. M., Sannagoudar, M. S., Somashekharappa, P. R., Kurdekar, A. K., Kadalli, G. G., George, A., Shantharaja, C. S., Sripathy, K. V., Rajanna, G. A., Paramesh, V., Halli, H. M., Arif, M., Chand, S., Gupta, G., Tyagi, V., Mahesha, H. S. and Vanishree, G. (2025) Biogenic zinc nano-particles from weeds as an innovative zinc source for boosting growth, yield, and profitability in maize. *Frontiers in Sustainable Food Systems*, 9: 1613410

Ovais, M., Khalil, A. T., Raza, A., Khan, M. A., Ahmad, I., Shahid, M. and Raza, G. (2016). Green synthesis of silver nanoparticles via plant extracts: Beginning a new era in cancer theranostics. *Nanomedicine*, 12(23): 3157-3177.

YingYing, J., Balasubramanian, B., Park, S., Anand, A., Meyyazhagan, A., Pappusamy, M., ... and Chelliapan, S. (2025). Green nanoparticles in agriculture: Enhancing crop growth and stress tolerance. *Plant Stress*, 18: 101017.

Abdullah, J. A. A., Laouini, S. E., Boudjema, A., Alonso-González, M., Guerrero, A. and Romero, A. (2020). Green synthesis and characterization of iron oxide nanoparticles by *Phoenix dactylifera* leaf extract and evaluation of their antioxidant activity. *Sustainable Chemistry and Pharmacy*, 17: 100280.

# Precision Pollination Technique for Vegetable

Indulekshmi S., S. Ambika, S. Parvathy and D. S. Parkavan

## Introduction

Precision pollination techniques are targeted, controlled, manual systems that place the right pollen on receptive flowers at the right time to improve fertilization, fruit set, and breeding efficiency in crops, especially vegetables and protected-culture crops. In precision pollination technology, drones, robots, AI, and sensors are being used. Global climate change and human activities have led to a decline in insect pollinators worldwide. Agricultural globalization and intensification have also removed crops from their natural insect pollinators and have sparked research to identify alternative natural insect pollinators and artificial technologies. To increase fruit and vegetable production, manual hand pollination is commonly used in small farms. In this method, people transfer pollen using tools like hand brushes, sprayers, blowers, and vibrators. However, these methods require a lot of labour, are expensive, and are difficult to use on large commercial farms.

Precision pollination in crop (tomato) can improve seed formation, fruit size, yield, and quality under good environmental conditions, making it economically beneficial. Tomato flowers are naturally self-pollinating, but they need vibration or movement of the flower parts to release pollen from the anthers. In recent years, researchers have studied the design and development of insect- or bee-like small flying vehicles for crop pollination. Although these technologies are promising, managing large numbers of robots, controlling their movement and flight, and providing sufficient power remain major challenges. In addition, improving their accuracy, flexibility, and performance in outdoor conditions to enable effective pollen transfer and crop pollination requires further research and development.

## Major precision pollination techniques

**Hand pollination:** In this method, pollen is manually transferred from male flowers to female flowers using fingers, brushes, or cotton swabs. While tedious and labour-intensive, hand emasculation allows plant breeders to control pollination and produce $F_1$ hybrids that combine desirable traits from two parents, such as disease resistance from one and high yield from the other. This method is commonly used in tomato, brinjal, cucumber, and chilli plants. This ensures controlled crossing and prevents unwanted pollination.

**Emasculation and bagging:** Removal of anthers or stamens from the bisexual flower before the pollen release to avoid self-pollination. It is usually done in the bud stage. Bagging means covering the emasculated flower with a bag, usually butter paper or a perforated polythene bag, to prevent unwanted pollen from reaching the stigma.

**Marker-assisted pollination:** Marker-assisted poll-

Indulekshmi S., S. Ambika, S. Parvathy and D. S. Parkavan
SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu, Tamil Nadu

ination uses DNA-based molecular markers to identify compatible parent plants and confirm successful hybrids with traits like disease resistance and high yield, making crop breeding faster and more efficient.

**Mechanical Pollination:** Mechanical pollination uses tools or vibrating devices to transfer pollen between flowers. It is commonly used in greenhouse crops like tomato, where natural pollination is limited. This method improves fruit set and reduces dependence on manual labour.

**Drone-Assisted Pollination:** Drone-assisted pollination uses small drones to spray or distribute pollen over crop fields. It is useful in areas with low pollinator populations or large-scale cultivation. This technique improves pollination efficiency and supports precision agriculture.

**Robotic Pollination:** Robotic pollination involves the use of AI-based robots to identify flowers and transfer pollen accurately. These robots can operate continuously with high precision under protected-cultivation conditions. It helps reduce labour costs and increases pollination efficiency.

**Electrostatic Pollination:** Electrostatic pollination uses electrically charged pollen particles for better attachment to flower stigmas. The electrostatic force improves pollen transfer efficiency and reduces pollen wastage. This method is useful for controlled and precise pollination.

**Bee-Mediated Precision Pollination:** Bee-mediated precision pollination uses managed honey bees or bumble bees for efficient pollen transfer in crops. Bees are introduced into greenhouses or fields to improve fruit set and uniform crop development. This technique is commonly used in cucumber, capsicum, and tomato cultivation.

**Pollen storage and controlled application:** Pollen storage and controlled application involve collecting, drying, and storing pollen under specific temperature and humidity so it can be used later for artificial pollination, enabling off-season breeding and long-distance hybridization.

**Sensor and AI-Based Pollination Monitoring:** Sensors and AI systems monitor flower opening, stigma receptivity, temperature, and humidity for effective pollination timing. These technologies help determine the best conditions for pollen transfer and fertilization. They improve pollination success and increase crop productivity under a precision farming system.

Precision pollination techniques significantly improve fertilization accuracy and efficiency in vegetable crops by replacing traditional pollination with targeted, technology-based methods. Modern tools such as drones, autonomous robots, AI-powered sensors, and controlled pollination systems help deliver viable pollen to flowers at the most suitable time, reducing pollen wastage and improving fruit set. These technologies are especially important in protected cultivation systems such as greenhouses and net houses, where natural pollinators are limited or absent. In advanced vegetable breeding programs, precision pollination helps breeders perform specific crosses and maintain gene-

tic purity. It also supports the development of improved crop varieties with higher yield, disease resistance, better quality, and longer shelf life.

## References

Vairam, N. and Murugan, N. (2026). Innovations in Pollination Methods: Transition towards Modern Pollination in Precision Agriculture. *Journal of Advances in Biology & Biotechnology*, 29(6): 1-13.

Zafar, M. U., Iqbal, T., Saleem, S. R., Haq, Z. U., Raza, S. M., Nawab, N. N., ... and Hassan, M. A. (2026). Energy-efficient artificial pollination device for tomato production under protected agriculture. *Pakistan Journal of Science*, 78(01): 29-39.

Singh, R., Seneviratne, L. and Hussain, I. (2025). Robust pollination for tomato farming using deep learning and visual servoing. *Robotica*, 43(1): 86-109.

# A Comparative Analysis of Agricultural Practices: India vs. the Czech Republic

**Debdipta Dolai**


## Abstract

This research article explores the profound structural and technological differences between the agricultural landscapes of India and the Czech Republic. While India's agrarian economy is rooted in smallholder farming and high labor intensity, the Czech Republic represents the modern European model of large-scale, highly mechanized, and data-driven cultivation. By analyzing farm structure, mechanization, irrigation, and sustainability, this article identifies key technological interventions from the Czech model that could pivot Indian agriculture toward greater efficiency and climate resilience.


## Introduction

Agriculture is a foundational pillar of human civilization, yet its execution varies wildly based on geography, policy, and economic history. India and the Czech Republic stand as two distinct archetypes of agricultural development. In India, agriculture is a socio-economic lifeline, employing nearly half the workforce. In the Czech Republic, it is a high-tech industry that ensures national food security while adhering to the stringent environmental standards of the European Union. As an Agriculture student who participated in an exchange program at Mendel University in Brno, the oldest specialized agricultural university in the Czech Republic, I had a front-row seat to these differences. This article synthesizes academic research with personal observations from the Moravian fields to compare these two systems and extract lessons for the future.

## Farm Structure and Land Tenure Systems

### The Indian Context: Fragmentation

The defining characteristic of Indian agriculture is fragmentation. Over 85% of Indian farmers are classified as small and marginal, holding less than two hectares of land. This is largely due to inheritance laws and population pressure. Small plot sizes create a "diseconomy of scale," where the cost of modern inputs often outweighs the returns, and large machinery like combine harvesters cannot physically navigate the tiny, irregular fields.

### The Czech Context: Consolidation

In contrast, the Czech Republic has some of the largest average farm sizes in the European Union (averaging around 130 hectares, with many reaching thousands). This structure is a legacy of the post-Communist transition, where collective farms were transformed into large cooperatives or joint-stock companies. These massive tracts of land allow for "industrial-scale" efficiency, where a single

**Debdipta Dolai**
B.Sc. (Hons.) Agriculture, Lovely Professional University, Phagwara, Punjab
Semester Exchange Student, Mendel University, Brno, Czech Republic

operator can manage hundreds of hectares using high-capacity machinery.

## Technological Paradigm: Mechanization and Precision

**Manual Intensity in India:** While India is the world's largest tractor market, the depth of mechanization is uneven. Primary tillage is often mechanized, but sowing, weeding, and harvesting frequently remain labor-intensive. The "Custom Power Hiring" model is growing, where small farmers rent equipment, but adoption remains hindered by lack of capital and technical awareness.

**The Digital Revolution in Czechia:** The Czech Republic is a leader in Precision Agriculture (PA). During my time at Mendel University, I witnessed the integration of GPS-guided tractors that reduce overlap to within 2 centimeters, minimizing waste of fuel and seeds. Data from satellite imagery (Sentinel) and drones are used to create variable-rate application maps for fertilizers, ensuring that nutrients are only applied where needed. This "sensors-to-soil" approach significantly reduces the environmental footprint.

## Cropping Systems and Soil Management

| Feature | India | Czech Republic |
|---|---|---|
| Primary Crops | Rice, Wheat, Pulses, Spices, Tropical Fruits | Wheat, Barley, Rapeseed (Canola), Maize, Sugar Beet |
| Climate Influence | Monsoon-driven; Tropical to Temperate | Continental/Temperate; Four distinct seasons |
| Diversification | High: Mixed cropping and intercropping are standard | Specialized: Large-scale monocultures with strict rotation |

Crop rotation in the Czech Republic is not just a choice but often a regulatory necessity under EU "Greening" rules. For instance, rapeseed is crucial for the biofuel industry but requires a 4-year break between plantings on the same plot to prevent clubroot and other pathogens. Indian systems utilize pulses for nitrogen fixation, a practice that is highly sustainable but often lacks the systematic tracking seen in European soil management.

**Water Management and Irrigation:** Water is the most significant constraint for Indian agriculture. With the erratic nature of the Monsoons, India has built the world's largest irrigation network, yet it faces a groundwater crisis. The shift toward drip and sprinkler irrigation is a policy priority to improve water-use efficiency. The Czech Republic relies heavily on "rain-fed" agriculture. However, climate change is bringing more frequent droughts to Central Europe. The Czech focus is on Landscape Water Retention. This involves creating polders, restoring wetlands, and maintaining soil organic matter to act as a sponge a crucial lesson for Indian regions facing desertification.

## Reflections from Mendel University

Walking through the university's experimental fields in Žabčice, I was struck by the seamless link between the laboratory and the land. Every hectare was mapped digitally, and students were trained not just in biology, but in data science and mechanical engineering. It redefined my view of a "farmer" as a "resource manager."

**Sustainability and Policy Frameworks:** Europe's "Farm to Fork" strategy heavily influences Czech practices, aiming for a 50% reduction in pesticide use

and 20% in fertilizers by 2030. Indian sustainability efforts, such as *Paramparagat Krishi Vikas Yojana*, focus on returning to traditional organic roots. While the goals are similar, the methods differ: India looks to tradition, while Czechia looks to "Green Technology."

## Key Lessons for Indian Agriculture

**Farming-as-a-Service (FaaS):** To overcome land fragmentation, India should adopt the Czech organizational model through cooperatives or digital platforms that provide high-tech machinery to smallholders.

**Data-Driven Decisions:** Adopting simple digital soil-health monitors and weather-forecasting apps can mimic the "Precision" approach on a smaller scale.

**Soil Organic Carbon:** Following the Czech emphasis on cover crops and minimum tillage to improve soil resilience against heatwaves.

## Conclusion

The comparison between Indian and Czech agriculture is not a story of one being "better" than the other, but of two different answers to the same question: How do we feed a nation sustainably? India offers lessons in biodiversity and resource-fulness under constraints, while the Czech Republic provides a blueprint for technological efficiency and environmental regulation. For a future-ready agricultural sector, India should strive to integrate these high-tech Czech methodologies within its unique socio- cultural framework.

# From Farm to Plate: Can India Make Healthy Eating Affordable?

**Malavika Kashyap**

Food is one of the basic necessities for survival, providing nourishment, helping in growth and disease prevention. However, many families face the dilemma of whether nutritious eating can be affordable. A nutritious and balanced diet should consist of grains, legumes, fruits, vegetables, dairy, proteins, and good fats. However, due to rising food prices and constrained incomes, families are forced to make difficult choices. Addressing hunger issues typically becomes more important than maintaining a diverse, nutritious and healthy diet. This challenge is not merely a nutrition issue. It is closely linked to agriculture, markets, prices and consumer purchasing power. In simple terms, it is an issue of economics.

## When Healthy Food Becomes Expensive?

India has made remarkable advancements in food production, becoming one of the top producers globally of grains, dairy, fruits, veggies, and legumes. Despite this progress, the availability of nutritious food is uneven. The Food and Agriculture Organization (FAO) states that about 2.6 billion people globally, roughly 31.9% of the world's population, were unable to purchase a nutritious diet in 2024. This highlights that food affordability is not just a local concern but a global challenge. Although staple foods such as rice and wheat are still affordable for a lot of families, purchasing products like fruits, vegetables, beans, nuts, dairy, and high-quality protein can put a significant financial burden on them. As a result, many households might fulfil their calorie requirements but face challenges in obtaining vital nutrients for good health.

## The Long Journey from Farm to Plate

When customers buy a kilogram of tomatoes or a collection of fruits, they typically only notice the eventual cost at the market. What often remains unnoticed is the extensive process that food undergoes before it arrives at the dinner table. Farmers invest into seeds, fertilizers, watering systems, workforce, equipment, and methods to protect crops. After harvesting, the produce passes through multiple stages involving traders, transporters, wholesalers, retailers and sometimes food processors. At every stage, costs add up. Expenses like shipping fees, petrol expenses, warehouse costs, packaging outlays, and market fees all contribute to establishing the final amount customers have to pay.

An even bigger challenge is post-harvest loss. Research suggests that between the harvest and consumption, 30-40 per cent of fruits and vegetables in India are wasted due to inadequate storage facilities, inefficient transportation networks, and ineffective handling methods. These losses decrease the amount of food accessible in the market and contribute to increased prices.

**Malavika Kashyap**
Research Scholar (Commerce), Lovely Professional University, Phagwara, Punjab

The economic consequences are significant. It is estimated that post-harvest wastage in India leads to about ₹92,651 crore in losses every year, resulting in a considerable waste of food, farmer earnings, and valuable nutritional resources. Interestingly, even though consumers often complain about rising food prices, farmers may not necessarily benefit from these increases. Inefficiencies in the supply chain tend to use up a significant part of what consumers spend. As a result, there is a gap between what consumers pay and what farmers earn.

## Why Nutritious Foods Cost More?

Not all food items have the same production and distribution costs. Staple grains like wheat and rice can be stored for longer periods with the help of government procurement and distribution systems. On the other hand, perishable items like fruits, vegetables, dairy, and protein-rich foods need special care, refrigeration and prompt transportation, making them more vulnerable to price fluctuations. Weather conditions also play a crucial role, as extreme weather conditions can lower production and disrupt supply chains, leading to price hikes when supplies run low. The issue is further complicated by food inflation, with global food prices rising significantly from 2.3 per cent in 2020 to 13.6 per cent in 2023 according to international assessments. This rise in prices has reduced the purchasing power of consumers worldwide, affecting low- and middle-income families the most. Consequently, these families frequently need to reduce buying healthy foods and opt for more affordable options.

## Changing Food Habits in India

India's eating habits are swiftly changing due to urbanization, evolving lifestyles, the rise of packaged foods and busy work routines, which is impacting the food preferences. Convenience often takes priority over nutritional quality. Studies comparing Indian food patterns with healthy eating guidelines reveal that many diets heavily rely on cereals, with consumption of fruits, vegetables, nuts and high-quality protein sources below the recommended levels. This dietary imbalance contributes to a growing public health challenge. On one hand, undernourishment and micronutrient deficiencies continue to affect vulnerable populations. On the other hand, obesity, diabetes, hypertension, and other lifestyle-related ailments are increasing at an alarming rate. It is evident food security alone is no longer sufficient. Nutrition security has become equally important.

## Agriculture Must Move Beyond Calories

Traditionally, the effectiveness of agriculture was measured by the amount of production and crop yields. In the present day, a new viewpoint is arising that highlights the importance of nutrition in addition to production. Agriculture must not just create enough food now but also cultivate suitable varieties of food. Diversification towards pulses, fruits, vegetables, oilseeds and crops rich in nutrients can boost dietary diversity while opening up new income prospects for farmers. The increasing popularity of millets serves as an encouraging example. Millets are packed with nutrients, need fewer inputs, and are

suitable for changing climate conditions. Encouraging the use of millets demonstrates how agriculture can support nutrition, sustainability and farmer earnings simultaneously. Similarly, investments in food processing, cold storage and value addition can reduce losses and improve market access for both producers and consumers.

## Making Healthy Diets Affordable

Ensuring that nutrition remains inexpensive necessitates collaborative efforts. Here are some actions different stakeholders can take:

### Farmers are able to

- ✓ Diversify production systems.
- ✓ Cultivate valuable and nutritious crops.
- ✓ Engage in Farmer Producer Organizations (FPOs).

### Governments can

- ✓ Strengthen cold-chain infrastructure.
- ✓ Improve rural storage facilities.
- ✓ Reduce post-harvest losses.
- ✓ Support efficient agricultural marketing systems.

### Food businesses can

- ✓ Enhance the efficiency of the supply chain.
- ✓ Develop cost-effective nutritious food products.
- ✓ Promote responsible food processing and distribution.

### Consumers can

- ✓ Choose seasonal and locally available foods.
- ✓ Incorporate traditional foods like legumes and millets into daily meals.
- ✓ Plan purchases carefully to reduce household food waste.

Making slight adjustments at each level can enhance the accessibility and affordability of nutritious diets.

## Looking Beyond Price

Consumers often judge food only by its price. However, food should also be evaluated in terms of its nutritional value. A packet of processed snacks may appear inexpensive, but it may provide little nutritional benefit. In contrast, a serving of fruits, pulses, or vegetables contributes directly to long-term health. Healthy eating should therefore be viewed as an investment rather than an expense. The consequences of inadequate nutrition go beyond just the cost of food. These include higher medical expenses, reduced productivity, decreased academic success and a diminished standard of living.

## The Path Forward

India's forthcoming challenge is not about increasing the amount of food produced but about making sure that nutritious food is available to every household at an affordable price. Statistics show that approximately 30% of food produced worldwide is lost or discarded before reaching consumers. Simply by reducing these losses, it is possible to enhance food availability, boost farmers' incomes and decrease consumer prices. Bridging the gap between farm, market and consumer requires efficient supply chains, better infrastructure, nutrition-sensitive agriculture and informed consumer choices. A nation's health starts with a balanced diet and making this diet is affordable for all households is not just an agricultural target but also an economic and societal

need. The success of Indian agriculture will not only be judged by the volume of food generated but also by its capability to provide reasonably priced, nourishing food to all citizens. Only then can the process from farm to table genuinely contribute to a healthier and more prosperous India.

## References

Food and Agriculture Organization (FAO). 2025. The State of Food Security and Nutrition in the World 2025. Rome: FAO. P 234. https://doi.org/10.4060/cd6008en

Ranjan, Juhi and Sahni, R K. (2023). Post Harvest Losses of Fruits and Vegetables in India. *Ropan*, September 2023: 41-43.

Sharma, M., Kishore, A., Roy, D. and Joshi, K. (2020). A comparison of the Indian diet with the EAT-Lancet reference diet. *BMC Public Health*, 20(1): 812.

Agarwal, M., Agarwal, S., Ahmad, S., Singh, R. and Jayahari, K. M. (2021). Food Loss and Waste in India: The Knowns and the Unknowns. Working Paper. Mumbai: World Resources Institute India. Available online at http:// www.wri.org/publication/food-loss-and-waste-in-india.

# Nanotechnology in Soil Science: Transforming Nutrient and Soil Management

**Sharwan Lal Yadav**


## Abstract

The increasing demand for agricultural production, coupled with concerns regarding soil degradation and inefficient nutrient utilization, has necessitated the development of innovative technologies for sustainable farming. Nanotechnology has emerged as a promising tool in agriculture, offering new opportunities for improving nutrient management, soil monitoring, and environmental sustainability. Nanomaterials possess unique physical and chemical properties due to their extremely small size and large surface area, enabling enhanced interactions with soil and plant systems. Applications such as nano-fertilizers, nano-sensors, and nanomaterials for soil remediation have demonstrated significant potential in improving nutrient-use efficiency and reducing environmental pollution. This article discusses the concept, principles, applications, challenges, and future prospects of nanotechnology in soil science and its role in transforming nutrient and soil management for sustainable agriculture.


## Introduction

Soil health is fundamental to sustainable agricultural production and global food security. However, declining soil fertility, nutrient losses, environmental pollution, and inefficient fertilizer utilization continue to challenge modern agriculture. Conventional nutrient management practices often result in low nutrient-use efficiency, leading to economic losses and adverse environmental impacts. Recent advances in science and technology have introduced innovative approaches to address these challenges. Among them, nanotechnology has gained considerable attention due to its ability to manipulate materials at the nanometer scale. Nanotechnology offers opportunities to improve nutrient delivery, enhance soil monitoring and support sustainable resource management. By increasing the efficiency of agricultural inputs and minimizing nutrient losses, nanotechnology has the potential to revolutionize soil science and contribute to environmentally sustainable farming systems.

## Concept of Nanotechnology in Soil Science

Nanotechnology involves the design, production and application of materials with dimensions ranging from 1 to 100 nanometers. At this scale, materials exhibit unique properties such as increased surface area, enhanced reactivity, and improved physical characteristics compared with their conventional counterparts. In soil science, nanotechnology focuses on the development of nanomaterials and nano-enabled products that improve soil fertility, nutrient management, environmental monitoring,

**Sharwan Lal Yadav**
Department of Soil Science, GBPUAT, Pantnagar, Uttarakhand

and remediation of degraded soils. These technologies enable more precise delivery of nutrients and better understanding of soil processes. The primary objective is to enhance agricultural productivity while reducing environmental impacts associated with conventional farming practices.

## Major Components of Nanotechnology in Soil Science

**Nano-Fertilizers:** Nano-fertilizers are nutrient carriers designed to release nutrients gradually and in a controlled manner according to crop requirements. Due to their small particle size and large surface area, nano-fertilizers can improve nutrient availability and uptake by plants.

Major advantages include:

- ✓ Increased nutrient-use efficiency.
- ✓ Controlled nutrient release.
- ✓ Reduced fertilizer losses.
- ✓ Improved crop growth and productivity.
- ✓ Lower fertilizer application rates.

Nano-fertilizers have shown considerable potential for improving the efficiency of nitrogen, phosphorus, potassium and micronutrient management.

**Nano-Sensors:** Nano-sensors are highly sensitive devices capable of detecting changes in soil properties and environmental conditions. These sensors provide real-time information that supports precision nutrient management and sustainable farming practices. Key benefits include:

- ✓ Rapid soil analysis.
- ✓ Monitoring of nutrient availability.
- ✓ Detection of soil moisture status.
- ✓ Early identification of nutrient deficiencies.
- ✓ Improved decision-making for nutrient management.

The use of nano-sensors can help farmers optimize fertilizer applications and reduce unnecessary input use.

**Nanomaterials for Soil Remediation:** Nanomaterials can be used to remove or neutralize contaminants present in soils. Their high adsorption capacity enables them to interact effectively with pollutants and improve soil quality.

Major benefits include:

- ✓ Removal of heavy metals.
- ✓ Reduction of soil contamination.
- ✓ Improvement in soil quality.
- ✓ Enhanced environmental protection.
- ✓ Restoration of degraded soils.

These applications are particularly valuable in areas affected by industrial pollution and excessive chemical usage.

## Impact of Nanotechnology on Soil Health

Nanotechnology has the potential to improve various aspects of soil health by enhancing nutrient availability, reducing nutrient losses, and supporting efficient resource utilization.

**Improvement in Soil Nutrient Management:** One of the most important applications of nanotechnology is the enhancement of nutrient-use efficiency. Conventional fertilizers often suffer from significant nutrient losses through leaching, runoff, volatilization, and fixation.

Nano-fertilizers provide a controlled nutrient release mechanism that improves nutrient availability to plants.

Major improvements include:

- ✓ Enhanced nutrient uptake.
- ✓ Reduced nutrient losses.
- ✓ Improved fertilizer efficiency.
- ✓ Increased crop productivity.
- ✓ Better nutrient management.

These benefits contribute to sustainable crop production and reduced environmental pollution.

**Improvement in Soil Monitoring:** Accurate assessment of soil conditions is essential for effective nutrient management. Nano-sensors enable continuous monitoring of soil properties and provide timely information regarding nutrient status and soil health.

Important benefits include:

- ✓ Real-time monitoring of soil conditions.
- ✓ Improved nutrient management decisions.
- ✓ Early detection of soil constraints.
- ✓ Increased efficiency of agricultural inputs.
- ✓ Enhanced precision agriculture practices.

**Environmental Sustainability:** Nanotechnology contributes to environmental sustainability by reducing the quantity of fertilizers required and minimizing nutrient losses to the environment.

Major environmental benefits include:

- ✓ Reduced groundwater contamination.
- ✓ Lower greenhouse gas emissions.
- ✓ Improved resource-use efficiency.
- ✓ Reduced environmental pollution.
- ✓ Enhanced sustainability of farming systems.

## Applications of Nanotechnology in Agriculture

Nanotechnology is increasingly being integrated into modern agricultural systems.

**Precision Nutrient Management:** Nano-enabled fertilizers and sensors facilitate site-specific nutrient management by supplying nutrients according to crop requirements and soil conditions.

**Smart Fertilizer Delivery Systems:** Controlled-release nano-fertilizers improve nutrient availability throughout crop growth stages and enhance nutrient recovery by plants.

**Soil Health Monitoring:** Nano-sensors assist in monitoring nutrient availability, pH, moisture content, and other important soil properties, enabling timely management interventions.

**Soil Remediation:** Nanomaterials are used to rehabilitate contaminated soils through adsorption and detoxification of pollutants, thereby improving soil quality and environmental safety.

**Sustainable Crop Production:** Improved nutrient efficiency and reduced environmental impacts make nanotechnology an important component of sustainable agricultural production systems.

## Challenges and Limitations

Despite its considerable potential, the application of nanotechnology in agriculture faces several challenges. The high cost of research, development and production of nano-enabled products may limit widespread adoption. Concerns regarding the environmental fate and long-term effects of nanomaterials on soil organisms and ecosystems require further investigation.

Limited awareness among farmers and insufficient regulatory frameworks may also slow adoption. Additionally, the behavior of nanomaterials in different soil types and climatic conditions remains an area requiring extensive research. Therefore, careful evaluation of safety, effectiveness and environmental implications is essential before large-scale implementation.

## Future Prospects

The future of nanotechnology in soil science is highly promising due to ongoing advancements in materials science, biotechnology and digital agriculture. Researchers are developing more efficient nano-fertilizers, smart nano-sensors and environmentally friendly nanomaterials for agricultural applications. Future opportunities include:

- ✓ Development of next-generation nano-fertilizers.
- ✓ Integration with precision agriculture technologies.
- ✓ Expansion of smart soil monitoring systems.
- ✓ Improved soil remediation technologies.
- ✓ Enhanced sustainability of nutrient management.
- ✓ Greater resource-use efficiency in farming systems.

Continued research and innovation are expected to accelerate the adoption of nanotechnology for sustainable soil and crop management.

## Conclusion

Nanotechnology has emerged as a transformative tool in soil science, offering innovative solutions for nutrient management, soil monitoring, and environmental sustainability. Through the development of nano-fertilizers, nano-sensors, and remediation technologies, it enhances nutrient-use efficiency, reduces environmental pollution, and supports sustainable agricultural production. Although challenges related to cost, safety assessment and regulatory frameworks remain, ongoing research continues to expand its potential applications. As agriculture moves toward precision and sustainability, nanotechnology is expected to play a significant role in improving soil health, optimizing resource utilization, and ensuring future food security.

## References

Nair, R., Varghese, S. H., Nair, B. G., Maekawa, T., Yoshida, Y. and Kumar, D. S. (2010). Nanoparticulate material delivery to plants. *Plant Science*, 179(3): 154-163.

Kah, M., Kookana, R. S., Gogos, A. and Bucheli, T. D. (2018). A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues. *Nature Nanotechnology*, 13(8): 677-684.

Dimkpa, C. O. and Bindraban, P. S. (2017). Nanofertilizers: new products for the industry? *Journal of Agricultural and Food Chemistry*, 66(26): 6462-6473.

Singh, M. D. (2017). Nano-fertilizers is a new way to increase nutrients use efficiency in crop production. *International Journal of Agriculture Sciences, ISSN*, 9(7): 0975-3710.

# Carbon Farming: Sustainable Agriculture for Climate Change Mitigation

**Shubham Singh**


## Abstract

Climate change has emerged as one of the greatest challenges facing global agriculture and environmental sustainability. Rising concentrations of greenhouse gases, particularly carbon dioxide ($CO_2$), have intensified global warming and increased the frequency of extreme weather events. Agriculture is both a contributor to and a victim of climate change, making it essential to adopt farming practices that reduce emissions while maintaining productivity. Carbon farming has gained significant attention as a sustainable agricultural approach that enhances the capture and storage of atmospheric carbon in soils, vegetation, and agricultural landscapes. Through practices such as conservation tillage, cover cropping, agroforestry, crop residue management, and improved grazing systems, carbon farming contributes to climate change mitigation while improving soil health and farm productivity. This article discusses the concept, principles, applications, challenges, and future prospects of carbon farming as a pathway toward sustainable and climate-resilient agriculture.


## Introduction

Agriculture plays a vital role in ensuring food security and supporting rural livelihoods. However, agricultural activities are also associated with significant greenhouse gas emissions resulting from land-use changes, soil degradation, excessive tillage, and the intensive use of fertilizers and fossil fuels. These emissions contribute to global climate change, which in turn affects agricultural productivity through rising temperatures, erratic rainfall patterns, droughts, floods, and emerging pest and disease problems. The growing urgency to address climate change has encouraged the development of sustainable agricultural practices that can simultaneously enhance productivity and reduce environmental impacts. Among these approaches, carbon farming has emerged as a promising strategy that utilizes agricultural land as a carbon sink. By capturing atmospheric carbon dioxide and storing it in soils and vegetation, carbon farming helps reduce greenhouse gas concentrations while improving soil fertility and ecosystem health. As governments, researchers, and farmers increasingly focus on climate-smart agricultural solutions, carbon farming is gaining recognition as an important component of sustainable land management and climate change mitigation efforts.

## Concept of Carbon Farming

Carbon farming refers to a set of agricultural practices designed to increase the capture and storage of carbon in soils, plants, and agricultural ecosystems. The primary objective is to remove carbon dioxide from the atmosphere and convert it into stable forms of carbon that can be stored for long periods. The concept is based on natural biological

**Shubham Singh**
Department of Agronomy, GBPUAT, Pantnagar, Uttarakhand

processes, particularly photosynthesis, through which plants absorb carbon dioxide and convert it into organic matter. A portion of this carbon is subsequently transferred to the soil through plant residues, root biomass, and microbial activity. By adopting management practices that increase soil organic carbon and biomass production, farmers can enhance the carbon sequestration potential of agricultural lands. Carbon farming not only contributes to climate change mitigation but also improves soil health, water retention, nutrient cycling, and overall agricultural sustainability.

## Principles and Practices of Carbon Farming

**Soil Carbon Sequestration:** Soil carbon sequestration forms the foundation of carbon farming. Agricultural soils have the capacity to store substantial amounts of carbon when managed appropriately. Practices such as reduced tillage, organic amendments, cover cropping, and residue retention increase soil organic matter and enhance carbon storage. Improved soil carbon levels contribute to better soil structure, enhanced fertility, and increased resilience to environmental stresses. The accumulation of soil organic carbon also supports long-term agricultural productivity and ecosystem stability.

**Conservation Agriculture:** Conservation agriculture promotes minimal soil disturbance, permanent soil cover, and diversified crop rotations. These practices reduce carbon losses from soils while encouraging the accumulation of organic matter. By minimizing tillage and maintaining crop residues on the soil surface, conservation agriculture enhances carbon sequestration and improves soil biological activity. The approach also reduces erosion and improves water-use efficiency.

**Agroforestry and Vegetation Management:** The integration of trees and perennial vegetation into agricultural landscapes significantly increases carbon storage above and below ground. Agroforestry systems capture atmospheric carbon through biomass accumulation while providing additional environmental and economic benefits. Trees contribute to soil improvement, biodiversity conservation, microclimate regulation, and enhanced ecosystem services. The long lifespan of trees allows carbon to remain stored for extended periods, making agroforestry an effective carbon farming strategy.

## Applications of Carbon Farming

**Climate Change Mitigation:** One of the most important applications of carbon farming is its contribution to climate change mitigation. By increasing carbon storage in soils and vegetation, carbon farming helps offset greenhouse gas emissions and reduce atmospheric carbon dioxide concentrations. The widespread adoption of carbon farming practices can play a significant role in achieving national and global climate goals while supporting sustainable agricultural development.

**Improving Soil Health:** Carbon-rich soils are generally healthier, more fertile and more productive. Increased soil organic matter improves soil structure, nutrient availability, microbial activity and water-holding capacity. These improvements enhance crop growth and reduce the need for external

inputs, contributing to sustainable agricultural production.

**Enhancing Climate Resilience:** Climate change has increased the frequency of droughts, floods, and other environmental stresses. Carbon farming practices improve soil moisture retention and increase the resilience of agricultural systems to climatic variability. Healthy soils with higher organic matter content are better able to withstand extreme weather events and maintain productivity under challenging conditions.

**Promoting Sustainable Agricultural Production:** Carbon farming supports sustainable agriculture by improving resource-use efficiency and reducing environmental degradation. Practices that enhance carbon sequestration often contribute simultaneously to soil conservation, biodiversity enhancement, and nutrient management. This integrated approach helps ensure long-term productivity while protecting natural resources.

**Creating Economic Opportunities;** Growing interest in carbon markets and climate policies has created new economic opportunities for farmers. Carbon credit programs may provide financial incentives for adopting carbon-sequestering agricultural practices. Participation in such programs can generate additional income while encouraging the widespread implementation of sustainable farming systems.

## Challenges and Limitations

Despite its considerable potential, carbon farming faces several challenges that may limit widespread adoption. The amount of carbon that can be sequestered varies depending on soil type, climate, vegetation, and management practices. Measuring and verifying soil carbon stocks accurately remains technically complex and often requires specialized tools and expertise. In some cases, the benefits of carbon sequestration may take several years to become apparent, which can discourage farmers seeking immediate economic returns. Limited awareness, inadequate policy support, and uncertainties regarding carbon credit markets may further constrain adoption. Ensuring the long-term permanence of stored carbon is another important challenge, as carbon can be released back into the atmosphere through land-use changes or unsustainable management practices.

## Future Prospects

The future of carbon farming is closely linked to global efforts to address climate change and promote sustainable agriculture. Advances in soil monitoring technologies, remote sensing, digital agriculture, and carbon accounting systems are expected to improve the measurement and verification of carbon sequestration. Increasing recognition of the role of agriculture in climate mitigation is likely to strengthen policy support and investment in carbon farming initiatives. The expansion of carbon markets and ecosystem service payment schemes may provide additional incentives for farmers to adopt carbon-sequestering practices. As climate-smart agricultural strategies continue to evolve, carbon farming is expected to become an integral compone-

nt of sustainable land management and environmental conservation programs.

## Conclusion

Carbon farming represents a promising approach for addressing the dual challenges of climate change mitigation and sustainable agricultural development. By enhancing carbon sequestration in soils and vegetation, the approach contributes to reducing greenhouse gas concentrations while improving soil health, productivity, and ecosystem resilience. Practices such as conservation agriculture, agroforestry, cover cropping, and soil carbon management offer multiple environmental and economic benefits. Although challenges related to measurement, adoption, and long-term carbon storage remain, continued research, technological advancements, and supportive policies can enhance the effectiveness of carbon farming systems. As agriculture seeks sustainable solutions for the future, carbon farming has the potential to play a crucial role in building resilient agricultural landscapes and achieving climate goals.

## References

Saikanth, D. R. K., Kishore, A. J., Sadineni, T., Singh, V., Upadhyay, L., Kumar, S. and Panigrahi, C. K. (2023). A review on exploring carbon farming as a strategy to mitigate greenhouse gas emissions. *International Journal of Plant & Soil Science*, 35(23): 380-388.

Tariq, S. *et al.* (2023). Mitigation of Climate Change Through Carbon Farming. In Jatoi, W. N., Mubeen, M., Hashmi, M. Z., Ali, S., Fahad, S. and Mahmood, K. (eds.), *Climate Change Impacts on Agriculture*. Springer, Cham.

Raihan, A. (2023). A review of climate change mitigation and agriculture sustainability through soil carbon sequestration. *Journal of Agriculture Sustainability and Environment*, 2997: 23-56.

# Climate-Smart Agriculture: Building Resilient Cropping Systems for the Future

**Shubham Singh**


## Abstract

Agriculture is increasingly vulnerable to the impacts of climate change, including rising temperatures, erratic rainfall, prolonged droughts, floods, and the emergence of new pests and diseases. These challenges threaten food security, farm profitability, and the sustainability of agricultural production systems worldwide. Climate-Smart Agriculture (CSA) has emerged as an innovative approach that seeks to enhance agricultural productivity, strengthen resilience to climate change, and reduce greenhouse gas emissions wherever possible. By integrating sustainable crop management practices, efficient resource utilization, and climate adaptation strategies, climate-smart agriculture supports the development of resilient cropping systems capable of withstanding environmental uncertainties. This article discusses the concept, principles, applications, challenges, and future prospects of climate-smart agriculture as a pathway toward sustainable and climate-resilient agricultural development.


## Introduction

Agriculture is highly dependent on climatic conditions, making it one of the sectors most vulnerable to climate change. Rising global temperatures, shifting rainfall patterns, increasing frequency of extreme weather events, and growing environmental degradation are placing immense pressure on agricultural systems. These changes not only affect crop productivity but also threaten the livelihoods of millions of farmers who depend on agriculture for their income and food security.

Traditional agricultural practices are often insufficient to cope with the increasing uncertainties associated with climate change. Farmers are facing greater challenges in managing water resources, maintaining soil fertility, controlling pests and diseases, and sustaining crop yields under changing environmental conditions. Consequently, there is an urgent need for agricultural approaches that can improve resilience while ensuring long-term productivity and sustainability. Climate-Smart Agriculture has gained global recognition as a comprehensive framework for addressing these challenges. By integrating climate adaptation, mitigation, and sustainable productivity goals, CSA provides a practical pathway for building resilient agricultural systems capable of meeting future food demands.

## Concept of Climate-Smart Agriculture

Climate-Smart Agriculture is an agricultural approach designed to improve productivity, enhance resilience to climate change and contribute to climate

**Shubham Singh**
Department of Agronomy, GBPUAT, Pantnagar, Uttarakhand

change mitigation. The concept recognizes that agriculture must simultaneously address food security, environmental sustainability, and climate adaptation challenges. Unlike conventional production systems that primarily focus on maximizing yields, climate-smart agriculture promotes farming practices that improve resource-use efficiency and strengthen the capacity of agricultural systems to withstand climatic stresses. The approach encourages the adoption of technologies and management strategies that support sustainable production while reducing vulnerability to climate-related risks. Climate-smart agriculture is not a single technology or practice. Rather, it represents a flexible framework that integrates multiple interventions according to local environmental, social and economic conditions.

## Key Components of Climate-Smart Agriculture

**Sustainable Crop Management:** Sustainable crop management forms the foundation of climate-smart agriculture. Practices such as crop diversification, improved varieties, conservation tillage, residue management, and integrated nutrient management contribute to enhanced productivity and resilience. These practices improve soil health, reduce resource degradation, and strengthen the ability of cropping systems to cope with climatic variability. The adoption of climate-resilient crop varieties capable of tolerating drought, heat, salinity, and flooding further enhances the stability of agricultural production under adverse environmental conditions.

**Efficient Resource Management:** Efficient utilization of natural resources is a central principle of climate-smart agriculture. Water, nutrients, energy, and land resources must be managed carefully to maximize productivity while minimizing environmental impacts. Practices such as precision irrigation, integrated nutrient management, rainwater harvesting, and efficient fertilizer use improve resource-use efficiency and reduce production costs. Improved resource management not only enhances productivity but also increases the resilience of farming systems to climate-related stresses.

**Climate Adaptation and Risk Reduction:** Climate-smart agriculture places strong emphasis on adaptation strategies that help farmers manage climate risks. These strategies include diversification of cropping systems, adoption of stress-tolerant varieties, improved weather forecasting, crop insurance, and integrated pest management. By reducing vulnerability to climatic shocks, these interventions improve the capacity of agricultural systems to maintain productivity under changing environmental conditions.

## Applications of Climate-Smart Agriculture

**Enhancing Agricultural Productivity:** One of the primary objectives of climate-smart agriculture is to increase agricultural productivity in a sustainable manner. Improved crop management practices, efficient resource utilization, and adoption of climate-resilient technologies contribute to higher and more stable yields. Enhanced productivity is essential for meeting the growing global demand for food while reducing pressure on natural resources.

**Building Climate Resilience:** Climate-smart agri-

culture strengthens the resilience of cropping systems by improving their ability to withstand environmental stresses. Diversified production systems, improved soil health, and efficient water management reduce vulnerability to droughts, floods, heat waves, and other climate-related challenges. This resilience is particularly important for smallholder farmers who are often most affected by climatic uncertainties.

**Promoting Sustainable Resource Management:** The approach encourages the sustainable management of soil, water, and biodiversity resources. Conservation agriculture, agroforestry, integrated farming systems and improved nutrient management practices contribute to long-term resource conservation and environmental sustainability. These practices help maintain ecosystem services that support agricultural production.

**Supporting Climate Change Mitigation:** Agriculture contributes significantly to greenhouse gas emissions through various production activities. Climate-smart agriculture promotes practices that reduce emissions and enhance carbon sequestration. Improved nutrient management, reduced tillage, agroforestry, and soil carbon enhancement strategies contribute to climate change mitigation while maintaining agricultural productivity.

**Improving Livelihood Security:** Climate-smart agriculture supports the economic well-being of farming communities by improving productivity, reducing risks, and increasing income opportunities. More resilient farming systems help stabilize production and provide greater livelihood security, particularly in regions highly vulnerable to climate change.

## Challenges and Limitations

Despite its considerable potential, the adoption of climate-smart agriculture faces several challenges. Limited awareness and technical knowledge among farmers often restrict the implementation of climate-smart practices. Financial constraints, inadequate infrastructure, and limited access to climate-resilient technologies may further hinder adoption, particularly among smallholder farmers. The effectiveness of climate-smart interventions can also vary depending on local environmental and socio-economic conditions. In addition, accurate climate information, extension services, and institutional support are essential for successful implementation. Addressing these challenges requires coordinated efforts involving researchers, policymakers, extension agencies, and farming communities.

## Future Prospects

The future of climate-smart agriculture is closely linked to the global effort to achieve sustainable development and climate resilience. Advances in digital agriculture, artificial intelligence, precision farming, remote sensing, and climate forecasting technologies are expected to enhance the effectiveness of climate-smart interventions. Increasing investments in climate adaptation and sustainable agriculture programs will further support the adoption of resilient farming practices.

Policy initiatives promoting resource conservation, carbon sequestration and sustainable land management are likely to strengthen the role of climate-smart agriculture in future agricultural development. As climate change continues to influence global food systems, climate-smart agriculture will become increasingly important in ensuring food security and environmental sustainability.

## Conclusion

Climate-Smart Agriculture provides a comprehensive framework for addressing the complex challenges posed by climate change while ensuring sustainable agricultural productivity. By integrating adaptation, mitigation, and productivity goals, the approach supports the development of resilient cropping systems capable of withstanding environmental uncertainties. Sustainable crop management, efficient resource utilization, and climate-resilient technologies form the foundation of climate-smart agricultural systems. Although challenges related to adoption, infrastructure, and technical capacity remain, continued innovation and policy support can accelerate implementation. As agriculture adapts to a changing climate, climate-smart agriculture will play a critical role in building resilient farming systems, improving livelihoods, and securing the future of global food production.

## References

Khan, A. T. and Banik, D. (2025). Climate-Smart Agriculture: Pathways to Resilient Farming Systems. *Vigyan Varta*, 6: 261-267.

Farooq, U., Raza, M. Y., Malik, A., Ahmed, M. and Ahmad, M. (2026). Transformative adaptation: From climate-smart to climate-resilient cropping systems. In *Sustainable Cropping Systems under a Changing Climate* (pp. 307-314). Academic Press.

Ahmed, M., Raza, M. Y. and Malik, N. A. (2025). Farming the Future: A Transformative Shift from Climate-Smart to Climate-Resilient Agriculture. In *Climate Resilient and Sustainable Agriculture: Volume 1: Adaptation and Mitigation Strategies* (pp. 459-481). Springer Nature Switzerland.

# Cover Cropping: A Sustainable Strategy for Soil and Crop Management

**Shubham Singh**


## Abstract

Sustainable agricultural production requires farming practices that enhance soil health, conserve natural resources, and maintain crop productivity. Intensive cultivation, excessive soil disturbance, and declining organic matter levels have contributed to widespread soil degradation, threatening long-term agricultural sustainability. Cover cropping has emerged as an effective and environmentally friendly strategy for improving soil quality and supporting resilient cropping systems. Cover crops are plants grown primarily to protect and improve the soil rather than for direct harvest. They provide multiple benefits, including erosion control, nutrient conservation, weed suppression, enhanced soil organic matter, and improved biological activity. In addition, cover cropping contributes to climate resilience, water conservation, and sustainable crop production. This article discusses the concept, principles, applications, challenges, and future prospects of cover cropping as a key component of sustainable agriculture.


## Introduction

Agricultural soils are among the most valuable natural resources supporting global food production. However, decades of intensive farming, frequent tillage, monocropping, and improper land management have led to declining soil fertility, soil erosion, loss of biodiversity, and reduced organic matter content. These challenges threaten agricultural productivity and environmental sustainability, particularly under the increasing pressures of climate change. Modern agriculture is therefore seeking practices that not only maintain crop yields but also improve soil health and ecosystem functioning. Among the various conservation practices available, cover cropping has gained considerable attention as a practical and sustainable solution. Cover crops are cultivated during periods when the main cash crop is not actively growing, ensuring that the soil remains covered throughout the year. The use of cover crops has expanded globally due to their ability to enhance soil quality, improve resource-use efficiency, and contribute to environmentally sustainable farming systems. By protecting and enriching the soil, cover crops play an important role in promoting long-term agricultural productivity and resilience.

## Concept of Cover Cropping

Cover cropping refers to the practice of growing specific plant species primarily for soil improvement, resource conservation and ecosystem enhancement rather than for direct economic harvest. These crops are typically grown between successive cash crops, during fallow periods, or alongside main crops in certain production systems. The primary objective of cover cropping is to maintain continuous

**Shubham Singh**
Department of Agronomy, GBPUAT, Pantnagar, Uttarakhand

soil cover and improve soil health through biological and ecological processes. Cover crops help protect the soil surface from erosion, enhance nutrient cycling, suppress weeds, improve water infiltration, and support beneficial soil organisms. Depending on production goals, different types of cover crops such as legumes, grasses, brassicas, and mixed-species combinations may be used. Each group offers unique benefits and contributes to the overall sustainability of cropping systems.

## Key Components of Cover Cropping Systems

**Soil Protection and Erosion Control:** One of the most important functions of cover crops is protecting the soil surface from erosion caused by wind and water. The vegetative cover reduces the impact of raindrops, slows surface runoff, and stabilizes soil particles through root systems. Continuous soil cover minimizes soil loss, preserves fertile topsoil, and contributes to long-term land productivity. This function is particularly valuable in regions vulnerable to heavy rainfall, drought, and land degradation.

**Soil Organic Matter Enhancement:** Cover crops contribute significantly to the accumulation of soil organic matter through the addition of plant biomass above and below the soil surface. As cover crop residues decompose, they provide organic carbon that supports soil fertility and biological activity. Higher soil organic matter improves soil structure, nutrient retention, water-holding capacity, and overall soil quality. These improvements create a more favorable environment for crop growth and sustainable production.

**Nutrient Cycling and Soil Fertility Improvement:** Cover crops play a vital role in nutrient management by capturing residual nutrients that might otherwise be lost through leaching or runoff. Leguminous cover crops can fix atmospheric nitrogen through symbiotic associations with nitrogen-fixing bacteria, thereby enriching soil fertility. The decomposition of cover crop residues gradually releases nutrients back into the soil, making them available for subsequent crops. This process improves nutrient-use efficiency and reduces dependence on synthetic fertilizers.

## Applications of Cover Cropping in Sustainable Agriculture

**Improving Soil Health:** One of the primary applications of cover cropping is the improvement of soil health. Cover crops enhance soil structure, increase organic matter content, promote microbial activity, and improve nutrient cycling processes. Healthy soils are better able to support crop growth, resist degradation, and maintain long-term productivity. The biological activity stimulated by cover crops contributes to a more dynamic and resilient soil ecosystem capable of sustaining agricultural production under diverse environmental conditions.

**Weed Suppression and Pest Management:** Cover crops can effectively suppress weeds by competing for sunlight, water, nutrients, and space. Dense cover crop canopies reduce weed germination and growth, thereby decreasing reliance on herbicides. In addition, some cover crop species release natural

compounds that inhibit weed development.

**Water Conservation and Moisture Management:** Water availability is a major factor influencing crop productivity. Cover crops improve soil water dynamics by enhancing infiltration, reducing evaporation and increasing water-holding capacity.The protective soil cover helps conserve moisture during dry periods and improves water-use efficiency.

**Climate Change Mitigation and Carbon Sequestration:** Cover cropping contributes to climate change mitigation through increased carbon sequestration and reduced greenhouse gas emissions. The addition of plant biomass enhances soil organic carbon storage and supports long-term carbon accumulation.

**Sustainable Crop Productivity:** The combined benefits of improved soil fertility, enhanced nutrient cycling, better moisture management, and reduced weed pressure contribute to improved crop productivity. Cover cropping supports stable and sustainable yields while reducing the need for external inputs.

## Challenges and Limitations

Despite their numerous benefits, cover crops are not without challenges. The successful adoption of cover cropping requires careful selection of species, appropriate planting and termination methods, and effective integration into existing cropping systems. Farmers may face additional costs associated with seed purchase, planting operations, and management activities. In some situations, cover crops may compete with cash crops for water and nutrients if not managed properly. Limited awareness, technical knowledge, and access to suitable equipment may further restrict adoption. Furthermore, the benefits of cover cropping often accumulate gradually over time, which may discourage farmers seeking immediate economic returns.

## Future Prospects

The future of cover cropping appears highly promising as agriculture increasingly emphasizes sustainability, climate resilience, and soil health restoration. Advances in precision agriculture, remote sensing, and digital decision-support tools are expected to improve cover crop management and optimization. Research on multi-species cover crop mixtures and region-specific cover cropping systems is expanding our understanding of their ecological and agronomic benefits. Growing awareness of carbon sequestration, regenerative agriculture, and conservation farming is likely to further promote the adoption of cover crops. Supportive government policies, extension programs, and incentive-based conservation initiatives may also encourage wider implementation of cover cropping practices worldwide.

## Conclusion

Cover cropping represents a practical and sustainable strategy for improving soil health, conserving resources, and enhancing agricultural productivity. By maintaining continuous soil cover, increasing organic matter, improving nutrient cycling, and supporting biodiversity, cover crops

contribute significantly to resilient and environmentally responsible farming systems. Their role in erosion control, water conservation, climate change mitigation, and sustainable crop management makes them an essential component of modern conservation agriculture. Although challenges related to management, costs, and adoption remain, continued research and technological advancements are expanding the potential of cover cropping systems. As agriculture moves toward greater sustainability and climate resilience, cover cropping will continue to play a crucial role in supporting productive and healthy agricultural landscapes.

## References

He, Q., Lu, C., Cowie, A., Zhao, S., Liu, D.L., Yi, B. and Li, L. (2025). Optimizing cover cropping application for sustainable crop production. *NPJ Sustainable Agriculture*, 3(1): 10.

Quintarelli, V., Radicetti, E., Allevato, E., Stazi, S. R., Haider, G., Abideen, Z., Bibi, S., Jamal, A. and Mancinelli, R. (2022). Cover crops for sustainable cropping systems: A review. *Agriculture*, 12(12): 2076.

Sharma, P., Singh, A., Kahlon, C. S., Brar, A. S., Grover, K. K., Dia, M. and Steiner, R. L. (2018). The role of cover crops towards sustainable soil health and agriculture-A review paper. *American Journal of Plant Sciences*, 9(9): 1935-1951.

Fageria, N. K., Baligar, V. C. and Bailey, B. A. (2005). Role of cover crops in improving soil and row crop productivity. *Communications in Soil Science and Plant Analysis*, 36(19-20): 2733-2757.

# Integrated Farming Systems: Diversifying Agriculture for Sustainability and Profitability

**Shubham Singh**


## Abstract

Agriculture today faces multiple challenges, including declining farm profitability, shrinking landholdings, resource degradation, climate variability, and increasing production costs. Conventional farming systems that rely on a single enterprise often expose farmers to economic and environmental risks. Integrated Farming Systems (IFS) have emerged as a sustainable agricultural approach that combines various farm enterprises such as crops, livestock, poultry, fisheries, horticulture, agroforestry, and other allied activities within a single farm unit. The integration of these enterprises promotes efficient resource utilization, enhances productivity, minimizes waste, and increases farm income. By creating synergistic interactions among different components, integrated farming systems improve sustainability, strengthen climate resilience, and support rural livelihoods. This article discusses the concept, components, applications, challenges, and future prospects of integrated farming systems as a pathway toward sustainable and profitable agriculture.


## Introduction

Agriculture serves as the backbone of rural economies and remains the primary source of livelihood for millions of farming households worldwide. However, modern agriculture is increasingly confronted with challenges such as declining natural resources, fluctuating market prices, climate change, and rising production costs. Small and marginal farmers, in particular, face difficulties in maintaining profitability when relying solely on crop production. Dependence on a single enterprise often increases vulnerability to weather extremes, pest outbreaks, and market uncertainties.

To address these challenges, agricultural scientists and policymakers have promoted diversified farming approaches that improve resource-use efficiency and farm resilience. Integrated Farming Systems (IFS) have gained considerable attention as a holistic approach that combines different agricultural enterprises in a mutually supportive manner. The concept seeks to maximize productivity while reducing environmental impacts and improving farm profitability. By integrating crops with livestock and other enterprises, farmers can optimize available resources, generate multiple income streams, and achieve long-term sustainability.

## Concept of Integrated Farming Systems

Integrated Farming Systems refer to a farming approach in which various agricultural enterprises are combined and managed as inter-connected components of a single production system.

**Shubham Singh**
Department of Agronomy, GBPUAT, Pantnagar, Uttarakhand

These enterprises may include crop cultivation, dairy farming, poultry, fisheries, agroforestry, horticulture, mushroom cultivation, beekeeping, and other complementary activities. The fundamental principle of integrated farming is the efficient recycling of resources. The waste or by-products generated from one enterprise become useful inputs for another. For example, crop residues can be used as livestock feed, while animal manure can be utilized as an organic fertilizer for crops. Such interactions reduce dependence on external inputs and improve overall farm efficiency. The primary objective of integrated farming systems is to enhance productivity, profitability, resource conservation and environmental sustainability while reducing production risks and improving livelihood security.

## Components of Integrated Farming Systems

**Crop Production:** Crop production forms the foundation of most integrated farming systems. Food crops, fodder crops, vegetables, fruits, and other agricultural products provide the primary source of food and income for farming households. Crop residues generated after harvest serve as valuable resources that can be utilized as livestock feed, composting material, or mulch. Crop diversification within integrated systems further enhances productivity by improving soil fertility, reducing pest incidence, and minimizing economic risks.

**Livestock Integration:** Livestock enterprises play a vital role in integrated farming systems by converting crop residues and agricultural by-products into economically valuable products such as milk, meat, and manure. The integration of livestock strengthens nutrient recycling within the farming system and contributes significantly to farm income. Animal manure improves soil fertility and reduces the need for synthetic fertilizers, while livestock provide a stable source of income throughout the year.

**Fisheries, Poultry, and Allied Enterprises:** Many integrated farming systems include additional enterprises such as fisheries, poultry, duck farming, beekeeping, mushroom cultivation, and agroforestry. These enterprises create opportunities for better utilization of available resources and diversify income sources. Fish ponds can be integrated with crop and livestock production, while poultry manure can be used to enrich pond ecosystems and agricultural fields. Such integration improves overall system efficiency and economic returns.

## Applications of Integrated Farming Systems

**Enhancing Farm Productivity:** One of the most significant benefits of integrated farming systems is the enhancement of overall farm productivity. The efficient utilization of land, labor, water, and biological resources allows farmers to obtain higher production from the same unit area. The complementary interactions among enterprises contribute to greater output and resource-use efficiency compared with conventional monocropping systems.

**Improving Farm Income and Profitability:** Integrated farming systems provide multiple sources of income, thereby reducing economic dependence on a single agricultural activity.

Diversification enables farmers to generate revenue throughout the year from different enterprises, improving financial stability and reducing vulnerability to market fluctuations. The recycling of farm resources also reduces production costs, leading to higher profitability.

**Strengthening Climate Resilience:** Climate variability poses significant threats to agricultural production. Integrated farming systems enhance resilience by diversifying production activities and reducing risks associated with adverse climatic conditions. If one enterprise experiences reduced productivity due to drought, floods or pest outbreaks, other enterprises can continue to generate income and sustain farm operations. This diversification improves the adaptability of farming systems to changing environmental conditions.

**Resource Conservation and Environmental Sustainability:** The efficient recycling of nutrients and organic materials within integrated farming systems contributes to environmental sustainability. Crop residues, livestock manure, and other farm by-products are effectively utilized rather than discarded. This reduces waste generation, improves soil fertility, enhances biodiversity, and minimizes environmental pollution. Integrated farming systems also promote sustainable use of land and water resources.

**Employment Generation and Rural Development :** Integrated farming systems create year-round employment opportunities because different enterprises require continuous management and labor inputs. This helps reduce seasonal unemployment and strengthens rural livelihoods. Increased farm productivity and profitability contribute to economic development and improve the quality of life for farming communities.

## Challenges and Limitations

Despite its numerous advantages, the adoption of integrated farming systems is often constrained by several factors. Successful implementation requires adequate knowledge, technical expertise, and effective management of multiple enterprises. Farmers may face challenges related to initial investment, infrastructure development, and access to quality inputs. Marketing diversified farm products can also be difficult, particularly in areas with limited market access. Additionally, the complexity of managing multiple enterprises may increase labor requirements and management demands. Inadequate extension support and limited awareness regarding integrated farming practices further restrict large-scale adoption in some regions.

## Future Prospects

The future of integrated farming systems is highly promising, particularly in the context of sustainable agriculture and climate resilience. Growing concerns about environmental degradation, resource scarcity, and farm profitability are increasing interest in diversified farming approaches. Advances in digital agriculture, precision farming, climate-smart technologies, and sustainable resource management are expected to enhance the efficiency of integrated farming systems.

Government programs promoting income diversification, organic farming, and sustainable agricultural development may further accelerate adoption. As farmers increasingly seek resilient and profitable production systems, integrated farming is likely to become a key component of future agricultural strategies.

## Conclusion

Integrated Farming Systems offer a comprehensive approach to sustainable agricultural development by combining multiple enterprises within a single farming framework. Through efficient resource recycling, diversification of income sources and enhanced productivity, the system contributes significantly to profitability, environmental sustainability, and climate resilience. The integration of crops, livestock, fisheries, and allied enterprises improves resource-use efficiency while reducing production risks and strengthening rural livelihoods. Although challenges related to management complexity, infrastructure, and market access remain, continued technological advancements and supportive policies can facilitate wider adoption. Integrated farming systems provide a practical and sustainable pathway for ensuring long-term agricultural productivity, profitability, and environmental conservation.

## References

Gill, M. S., Singh, J. P. and Gangwa, K. S. (2009). Integrated farming system and agriculture sustainability. *Indian Journal of Agronomy*, 54(2): 128-139.

Sánchez, A. C., Kamau, H. N., Grazioli, F. and Jones, S. K. (2022). Financial profitability of diversified farming systems: A global meta-analysis. *Ecological Economics*, 201: 107595.

Singh, V. K., Rathore, S. S., Singh, R. K., Upadhyay, P. K. and Shekhawat, K. (2020). Integrated farming system approach for enhanced farm productivity, climate resilience and doubling farmers' income. *Indian Journal of Agricultural Sciences*, 90(8): 1378-1388.

# Smart Irrigation Technologies: Enhancing Water Use Efficiency in Agriculture

**Shubham Singh**


## Abstract

Water is one of the most critical resources for agricultural production, yet increasing water scarcity, climate change, and growing food demands are placing immense pressure on available freshwater resources. Agriculture accounts for the largest share of global freshwater consumption, making efficient water management essential for sustainable crop production. Traditional irrigation methods often result in significant water losses through evaporation, runoff, and inefficient application. Smart irrigation technologies have emerged as innovative solutions that utilize sensors, automation, Internet of Things (IoT), artificial intelligence, and data-driven decision-making to optimize water use in agriculture. These technologies enable precise irrigation scheduling, real-time monitoring, and efficient resource management, thereby improving water-use efficiency and crop productivity. This article discusses the concept, components, applications, challenges, and future prospects of smart irrigation technologies in modern agriculture.


## Introduction

Agriculture is highly dependent on water availability for maintaining crop growth and productivity. However, increasing population growth, urbanization, industrial development, and climate change have intensified competition for freshwater resources. In many regions, water scarcity has become a major constraint to agricultural production, threatening food security and rural livelihoods. Traditional irrigation systems, although widely used, often suffer from inefficiencies that lead to substantial water losses. Over-irrigation, poor scheduling, uneven water distribution, and inadequate monitoring contribute to the wastage of valuable water resources.

These inefficiencies not only reduce water-use efficiency but may also lead to soil degradation, nutrient leaching, and increased production costs. The advancement of digital technologies has created new opportunities for improving irrigation management. Smart irrigation technologies combine modern sensors, communication networks, automation systems, and data analytics to deliver water precisely when and where it is needed. By optimizing irrigation practices, these technologies support sustainable agricultural production while conserving water resources.

## Concept of Smart Irrigation Technologies

Smart irrigation refers to the use of advanced technologies and automated systems to manage

**Shubham Singh**
Department of Agronomy, GBPUAT, Pantnagar, Uttarakhand

irrigation based on real-time crop and environmental conditions. Unlike conventional irrigation methods that often rely on fixed schedules, smart irrigation systems continuously monitor factors such as soil moisture, weather conditions, crop water requirements and evapotranspiration rates. The information collected from sensors and monitoring devices is analyzed using digital platforms and decision-support tools to determine the optimal amount and timing of irrigation. Automated controllers can then regulate water delivery accordingly, ensuring efficient use of available water resources. The primary objective of smart irrigation is to maximize crop productivity while minimizing water consumption, energy use, and environmental impacts.

## Components of Smart Irrigation Technologies

**Soil Moisture Sensors:** Soil moisture sensors are among the most widely used components of smart irrigation systems. These sensors continuously measure the moisture content of the soil and provide real-time information regarding water availability in the root zone. The data generated by these sensors enable farmers to apply irrigation only when necessary, preventing both over-irrigation and water stress. Improved soil moisture monitoring contributes significantly to enhanced water-use efficiency and crop performance.

**Internet of Things (IoT) and Automation Systems :** The Internet of Things (IoT) has transformed irrigation management by connecting sensors, controllers and communication devices into integrated monitoring systems. IoT-enabled irrigation systems collect data from multiple sources and transmit it to centralized platforms for analysis and decision-making. Automation systems can regulate irrigation schedules without requiring continuous manual intervention. This improves precision, reduces labor requirements and enhances operational efficiency.

**Weather-Based Monitoring Systems:** Weather conditions play a critical role in determining crop water requirements. Smart irrigation systems often incorporate weather stations and climate-monitoring devices that collect information on temperature, humidity, rainfall, solar radiation, and wind speed. This information is used to estimate evapotranspiration and adjust irrigation schedules according to prevailing environmental conditions. Weather-based irrigation management helps optimize water application and improves resource conservation.

## Applications of Smart Irrigation Technologies

**Enhancing Water Use Efficiency:** One of the most important applications of smart irrigation technologies is the improvement of water-use efficiency. By delivering water according to actual crop requirements, these systems significantly reduce water wastage associated with conventional irrigation methods. Precise irrigation management ensures that crops receive adequate moisture while minimizing losses due to runoff, evaporation, and deep percolation. This contributes to sustainable water resource management and increased agricultural productivity.

**Improving Crop Productivity:** Adequate and

timely irrigation is essential for optimal crop growth and yield development. Smart irrigation technologies help maintain optimal soil moisture conditions throughout the crop growth cycle, reducing water stress and improving plant performance. Enhanced water management often results in improved crop yields, better quality produce, and increased farm profitability. The ability to respond quickly to changing environmental conditions further supports consistent agricultural production.

**Reducing Energy Consumption:** Efficient irrigation management not only conserves water but also reduces energy requirements associated with pumping and water distribution. Smart irrigation systems optimize irrigation schedules and minimize unnecessary water applications, thereby lowering energy consumption.

**Supporting Precision Agriculture:** Smart irrigation technologies are an integral component of precision agriculture systems. By integrating sensor data, weather information, geographic information systems, and decision-support tools, farmers can implement site-specific irrigation management strategies.

**Climate Resilience and Sustainable Agriculture:** Climate change has increased the frequency of droughts, heat waves, and erratic rainfall patterns, creating new challenges for water management in agriculture. Smart irrigation technologies improve the resilience of farming systems by enabling adaptive irrigation practices based on real-time environmental conditions.

## Challenges and Limitations

Despite their numerous benefits, smart irrigation technologies face several challenges that may limit widespread adoption. The initial investment required for sensors, automation systems, communication networks, and monitoring equipment can be substantial, particularly for smallholder farmers. Technical expertise is often needed for installation, operation, and maintenance of these systems. Limited internet connectivity and unreliable power supplies may also affect system performance in rural areas. Additionally, farmers may require training to effectively interpret data and utilize decision-support tools. Concerns regarding data security, system reliability and long-term maintenance costs must also be addressed to ensure successful implementation.

## Future Prospects

The future of smart irrigation technologies is highly promising as advances in artificial intelligence, machine learning, remote sensing, and Internet of Things technologies continue to evolve. Increasing availability of affordable sensors and cloud-based platforms is expected to make smart irrigation systems more accessible to farmers worldwide. Integration of satellite data, drone imagery, and predictive analytics will further enhance irrigation decision-making and resource-use efficiency. Growing concerns about water scarcity and climate change are likely to accelerate investments in smart irrigation infrastructure and research.

As agriculture becomes increasingly digitalized, smart irrigation technologies will play a crucial role in achieving sustainable water management and climate-resilient food production systems.

## Conclusion

Smart irrigation technologies represent a significant advancement in agricultural water management by enabling precise, data-driven, and efficient irrigation practices. Through the integration of sensors, automation, IoT, and weather-based monitoring systems, these technologies enhance water-use efficiency, improve crop productivity, reduce energy consumption, and support sustainable agriculture. Their ability to optimize resource utilization makes them particularly valuable in regions facing water scarcity and climate-related challenges. Although barriers related to cost, technical expertise, and infrastructure remain, ongoing technological innovations are steadily improving accessibility and effectiveness. As the demand for sustainable agricultural production continues to grow, smart irrigation technologies will become increasingly important in ensuring efficient water management and long-term agricultural sustainability.

## References

Priyambada, I. B., Budihardjo, M. A., Wati, H. R. and A'yun, H. K. Q. (2024). Enhancing water usage efficiency in agriculture through smart systems: A review. In *IOP Conference Series: Earth and Environmental Science*, 1414 (1): 012023.

Ali, A., Hussain, T. and Zahid, A. (2025). Smart irrigation technologies and prospects for enhancing water use efficiency for sustainable agriculture. *AgriEngineering*, 7(4): 106.

Bwambale, E., Abagale, F. K. and Anornu, G. K. (2022). Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. *Agricultural Water Management*, 260: 107324.

Daraz, U., Bojnec, Š. and Khan, Y. (2025). Energy-efficient smart irrigation technologies: A pathway to water and energy sustainability in agriculture. *Agriculture*, 15(5): 554.

# Biochar for Soil Improvement and Sustainable Crop Production

**Sharwan Lal Yadav**


## Abstract

Sustainable agriculture requires innovative approaches to improve soil health, enhance crop productivity, and mitigate environmental degradation. Biochar, a carbon-rich material produced through the pyrolysis of biomass under limited oxygen conditions, has gained considerable attention as a promising soil amendment. Its unique physical and chemical properties enable it to improve soil structure, increase nutrient retention, enhance water-holding capacity, and promote beneficial microbial activity. In addition to improving soil fertility, biochar contributes to climate change mitigation through long-term carbon sequestration. The use of biochar in agricultural systems has shown positive effects on crop growth, nutrient-use efficiency, and environmental sustainability. This article discusses the concept, production, properties, effects on soil health, applications, challenges, and future prospects of biochar for sustainable crop production.


## Introduction

Soil degradation is one of the major challenges affecting agricultural productivity worldwide. Continuous cultivation, excessive fertilizer use, erosion, nutrient depletion, and declining organic matter have adversely affected soil quality in many regions. Maintaining healthy soils is essential for ensuring sustainable crop production and long-term food security. In recent years, biochar has emerged as an effective soil amendment capable of improving soil health while addressing environmental concerns. Derived from agricultural residues, forestry waste, animal manure, and other biomass sources, biochar has attracted attention because of its ability to enhance soil fertility and store carbon for extended periods. The incorporation of biochar into agricultural soils not only improves crop productivity but also contributes to sustainable resource management and climate resilience.

## Concept of Biochar

Biochar is a stable, carbon-rich material produced by heating organic biomass under limited or no oxygen conditions through a process known as pyrolysis. Unlike ordinary organic matter that decomposes rapidly, biochar is highly resistant to decomposition and can remain in soil for decades or even centuries. The porous structure and large surface area of biochar enable it to interact effectively with soil particles, nutrients, water, and microorganisms. These characteristics make biochar a valuable tool for improving soil quality and enhancing agricultural sustainability. The properties of biochar vary depending on the feedstock used and the conditions under which pyrolysis is carried out.

**Sharwan Lal Yadav**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

Common feedstocks include crop residues, wood chips, rice husk, sugarcane bagasse, animal manure, and forestry waste.

## Production and Properties of Biochar

**Production of Biochar:** Biochar is produced through the thermal decomposition of biomass in an oxygen-limited environment. During pyrolysis, organic materials are converted into biochar, bio-oil, and syngas. The efficiency and quality of biochar depend on factors such as:

- ✓ Type of feedstock used.
- ✓ Pyrolysis temperature.
- ✓ Heating duration
- ✓ Moisture content of biomass.
- ✓ Production technology employed.

Generally, higher pyrolysis temperatures produce biochar with greater stability and carbon content.

**Properties of Biochar;** Biochar possesses several unique characteristics that make it beneficial for agricultural soils. Important properties include:

- ✓ High carbon content.
- ✓ Large surface area.
- ✓ Porous structure.
- ✓ High water-holding capacity
- ✓ Good nutrient retention ability.
- ✓ Resistance to decomposition.

These properties allow biochar to function as a long-term soil conditioner and carbon storage material.

## Impact of Biochar on Soil Health

Biochar influences soil health through improvements in physical, chemical, and biological properties.

**Improvement in Soil Physical Properties:** The porous nature of biochar improves soil structure and enhances water movement within the soil profile. Incorporation of biochar often reduces soil bulk density and increases porosity.

Major benefits include:

- ✓ Improved soil aggregation.
- ✓ Increased water-holding capacity.
- ✓ Enhanced infiltration rate.
- ✓ Reduced soil compaction.
- ✓ Better root growth and development.

These improvements are particularly beneficial in degraded and sandy soils where water retention is often limited.

**Improvement in Soil Chemical Properties:** Biochar contributes to soil fertility by increasing nutrient retention and reducing nutrient losses. Its large surface area provides sites for nutrient adsorption, making nutrients more available to plants. Key chemical benefits include:

- ✓ Increased cation exchange capacity.
- ✓ Improved nutrient retention.
- ✓ Enhanced nutrient-use efficiency.
- ✓ Reduced nutrient leaching.
- ✓ Improved soil pH in acidic soils.
- ✓ Increased soil organic carbon.

These effects help create a more favorable environment for crop growth and nutrient uptake.

**Improvement in Soil Biological Properties:** Biochar provides a suitable habitat for beneficial soil

microorganisms due to its porous structure and stable carbon content. Enhanced microbial activity improves nutrient cycling and organic matter decomposition. Major biological benefits include:

- ✓ Increased microbial biomass.
- ✓ Enhanced microbial diversity.
- ✓ Improved nutrient mineralization.
- ✓ Better soil ecosystem functioning.
- ✓ Increased biological activity in the rhizosphere.

The interaction between biochar and soil microorganisms plays an important role in maintaining soil fertility and productivity.

## Applications of Biochar

Biochar has numerous applications in sustainable agriculture and environmental management.

**Soil Fertility Improvement:** Biochar is widely used as a soil amendment to improve nutrient availability, nutrient retention, and overall soil fertility. Its application can enhance the effectiveness of both organic and inorganic fertilizers.

**Sustainable Crop Production:** Improved soil conditions resulting from biochar application often lead to better crop growth and higher yields. Enhanced water and nutrient availability contribute to increased productivity under diverse cropping systems.

**Carbon Sequestration:** One of the most important environmental benefits of biochar is its ability to sequester carbon in soils for long periods. This helps reduce atmospheric carbon dioxide concentrations and contributes to climate change mitigation.

**Waste Management:** Agricultural and forestry residues can be converted into biochar rather than being burned or discarded. This promotes efficient biomass utilization and reduces environmental pollution.

**Integrated Nutrient Management:** Biochar can be combined with compost, farmyard manure, biofertilizers, and chemical fertilizers to improve nutrient-use efficiency and support sustainable nutrient management strategies.

## Challenges and Limitations

Despite its numerous benefits, biochar application faces several challenges. The quality and effectiveness of biochar vary depending on feedstock type and production conditions. Lack of standardization may result in inconsistent performance across different soils and cropping systems. Production technologies can be expensive, particularly for small-scale faers. In addition, transportation and application costs may limit large-scale adoption.The response of crops to biochar application may also vary depending on soil characteristics, climate, and management practices. Therefore, site-specific recommendations are necessary to maximize benefits. Further research is needed to determine optimal application rates and long-term effects under different agroecological conditions.

## Future Prospects

Growing interest in sustainable agriculture and climate-smart farming is expected to increase the adoption of biochar technologies.

Advances in biochar production systems, feedstock utilization, and application methods are likely to improve efficiency and affordability.

Future opportunities include:

- ✓ Integration with precision agriculture.
- ✓ Development of biochar-based fertilizers.
- ✓ Expansion of carbon credit programs.
- ✓ Utilization of agricultural waste for biochar production.
- ✓ Improvement of degraded soils and reclaimed lands.
- ✓ Promotion of climate-resilient farming systems.

As research continues to advance, biochar is expected to become an increasingly important component of sustainable soil management.

## Conclusion

Biochar has emerged as a promising soil amendment capable of improving soil health, enhancing crop productivity, and supporting environmental sustainability. Its unique physical, chemical, and biological properties contribute to improved nutrient retention, water-holding capacity, microbial activity, and soil fertility. In addition to agricultural benefits, biochar offers significant environmental advantages through carbon sequestration and sustainable waste management. Although challenges related to production costs, standardization, and site-specific responses remain, ongoing research and technological innovations are expected to enhance its adoption. Biochar represents an important tool for achieving sustainable crop production and improving soil quality in the face of increasing environmental and agricultural challenges.

## References

Lehmann, J. and Joseph, S. (Eds.). (2024). Biochar for environmental management: science, technology and implementation. *Taylor & Francis.*

Jeffery, S., Verheijen, F. G., van der Velde, M. and Bastos, A. C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems & Environment,* 144(1): 175-187.

Glaser, B., Lehmann, J. and Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-a review. *Biology and Fertility of Soils*, 35(4): 219-230.

Agegnehu, G., Bass, A. M., Nelson, P. N. and Bird, M. I. (2016). Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment*, 543: 295-306.

Karan, S. K., Woolf, D., Azzi, E. S., Sundberg, C. and Wood, S. A. (2023). Potential for biochar carbon sequestration from crop residues: A global spatially explicit assessment. *GCB Bioenergy*, 15(12): 1424-1436.

# Conservation Agriculture and Soil Health

**Sharwan Lal Yadav**


## Abstract

The sustainability of agricultural production largely depends on maintaining healthy soils. However, intensive tillage, residue burning, monocropping, and excessive exploitation of natural resources have accelerated soil degradation in many parts of the world. Conservation Agriculture (CA) has emerged as an effective approach to address these challenges while ensuring sustainable crop production. Based on the principles of minimum soil disturbance, permanent soil cover, and crop diversification, conservation agriculture improves soil structure, enhances nutrient cycling, conserves moisture, and promotes biological activity. These practices not only improve soil health but also increase resource-use efficiency and resilience to climate change. This article discusses the concept, principles, impact on soil health, applications, challenges, and future prospects of conservation agriculture in sustainable farming systems.


## Introduction

Soil is the foundation of agricultural productivity and plays a critical role in food security, environmental sustainability, and ecosystem functioning. Healthy soils provide nutrients, water, and a favorable environment for plant growth. However, decades of intensive cultivation, frequent tillage, residue removal, and unbalanced nutrient management have resulted in declining soil fertility, erosion, compaction, and loss of organic matter. As agricultural systems face increasing pressure from climate change, population growth, and resource degradation, there is a growing need for sustainable farming practices. Conservation Agriculture has gained global recognition as a resource-conserving production system that improves soil health while maintaining crop productivity.

By reducing soil disturbance and enhancing natural ecological processes, conservation agriculture offers a practical pathway toward sustainable agriculture.

## Concept and Principles of Conservation Agriculture

Conservation Agriculture is a farming system designed to achieve sustainable and profitable crop production while protecting soil and environmental resources. The system is based on three interconnected principles.

**Minimum Soil Disturbance:** Conventional tillage often breaks down soil aggregates, accelerates organic matter decomposition, and increases erosion risks. Conservation agriculture promotes reduced tillage or zero tillage, where soil disturbance is minimized during crop establishment. This helps preserve soil structure, reduce erosion, and improve

**Sharwan Lal Yadav**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

water infiltration.

**Permanent Soil Organic Cover:** Maintaining crop residues, mulch, or cover crops on the soil surface protects the soil from the direct impact of rainfall, wind, and extreme temperatures. Soil cover reduces moisture loss, suppresses weed growth, and gradually contributes organic matter through residue decomposition.

**Crop Diversification:** Crop rotation and diversification improve soil fertility and biological activity. Different crops utilize nutrients from varying soil depths and help break pest and disease cycles. Inclusion of legumes in cropping systems further contributes to biological nitrogen fixation and improved soil fertility.

## Impact of Conservation Agriculture on Soil Health

Soil health refers to the capacity of soil to function as a living ecosystem that supports plant growth, maintains environmental quality and sustains biological productivity. Conservation agriculture positively influences soil physical, chemical, and biological properties.

**Improvement in Soil Physical Properties:** One of the major benefits of conservation agriculture is the improvement of soil structure. Reduced tillage preserves soil aggregates and enhances porosity. Improved soil structure facilitates water infiltration and root growth while reducing runoff and erosion. Residue retention also increases water-holding capacity and reduces evaporation losses. As a result, crops are better able to withstand moisture stress during dry periods. Long-term conservation agriculture systems often exhibit improved soil stability and reduced compaction compared with conventionally tilled soils.

**Improvement in Soil Chemical Properties:** Conservation agriculture contributes significantly to the buildup of soil organic matter. Crop residues left on the soil surface gradually decompose and release nutrients, improving nutrient availability and nutrient-use efficiency. Increased organic matter enhances cation exchange capacity, nutrient retention, and soil buffering capacity. Furthermore, reduced erosion helps conserve nutrient-rich topsoil. Studies have reported higher levels of soil organic carbon and improved fertility status in fields managed under conservation agriculture for extended periods.

**Improvement in Soil Biological Properties:** Healthy soils contain diverse populations of microorganisms, earthworms, insects, and other beneficial organisms that drive nutrient cycling and organic matter decomposition. Conservation agriculture creates favorable conditions for these organisms by minimizing soil disturbance and maintaining a continuous supply of organic residues. Enhanced microbial activity improves nutrient mineralization and soil aggregation. Earthworms contribute to soil aeration and organic matter incorporation, while increased biodiversity improves overall ecosystem stability and resilience.

## Applications of Conservation Agriculture

Conservation agriculture has numerous

applications in modern farming systems and plays an important role in sustainable land management.

**Soil and Water Conservation:** By reducing soil erosion and improving infiltration, conservation agriculture helps conserve both soil and water resources. Surface residues act as a protective barrier that reduces runoff and prevents the loss of fertile topsoil.

**Sustainable Crop Production:** Improved soil fertility, better moisture retention, and enhanced biological activity contribute to stable and sustainable crop yields. Conservation agriculture helps maintain productivity while reducing dependence on external inputs.

**Residue Management:** Crop residue retention is an environmentally friendly alternative to residue burning. It improves soil organic matter content, supports nutrient recycling, and reduces air pollution.

**Climate-Smart Agriculture:** Conservation agriculture is increasingly recognized as an important component of climate-smart agriculture. By improving resilience to drought and reducing greenhouse gas emissions, it helps farmers adapt to changing climatic conditions.

**Carbon Sequestration:** The accumulation of organic matter under conservation agriculture increases soil carbon storage. This contributes to carbon sequestration and supports efforts to mitigate climate change.

## Challenges and Limitations

Despite its advantages, conservation agriculture faces several challenges that may limit its adoption. Some farmers may be reluctant to shift from traditional tillage-based systems due to lack of awareness or technical knowledge. Specialized machinery required for zero tillage can involve additional investment. In many regions, crop residues are used as livestock feed, limiting their availability for soil cover. Weed management during the transition period can also be challenging, particularly in reduced-tillage systems. Moreover, the benefits of conservation agriculture may vary depending on soil type, climate, and cropping systems. Therefore, location-specific recommendations and farmer training are essential for successful implementation.

## Future Prospects

The future of conservation agriculture is closely linked with sustainable intensification and climate-resilient agriculture. Increasing emphasis on soil health, resource conservation, and carbon sequestration is expected to promote wider adoption of conservation agriculture practices. Integration of conservation agriculture with precision farming technologies, improved residue management techniques, and diversified cropping systems can further enhance its effectiveness. Government support, extension programs, and farmer capacity-building initiatives will play a crucial role in accelerating adoption.

## Conclusion

Conservation Agriculture represents a sustainable approach to improving soil health and

ensuring long-term agricultural productivity. Through minimum soil disturbance, permanent soil cover, and crop diversification, it enhances soil physical, chemical, and biological properties while conserving water and reducing environmental degradation. The system also contributes to climate change mitigation through improved carbon sequestration and resource-use efficiency. Although challenges remain, continued research, technological innovations, and policy support can facilitate wider adoption. Conservation agriculture will remain a key strategy for building resilient agricultural systems and sustaining soil health for future generations.

## References


Food and Agriculture Organization of the United Nations. (n.d.). *Conservation agriculture*. FAO. https://www.fao.org/conservation-agriculture/en/

Kassam, A., Friedrich, T., Shaxson, F. and Pretty, J. (2009). The spread of Conservation Agriculture: justification, sustainability and uptake. *International Journal of Agricultural Sustainability*, *7*(4): 292-320.

Jat, M. L., Chakraborty, D., Ladha, J. K., Rana, D. S., Gathala, M. K., McDonald, A. and Gerard, B. (2020). Conservation agriculture for sustainable intensification in South Asia. *Nature Sustainability*, 3(4): 336-343.

Thierfelder, C. and Wall, P. C. (2016). Effects of conservation agriculture techniques on soil quality and water conservation. *Soil and Tillage Research*, 105: 217-227.

Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability*, 7(5): 5875-5895.

Wall, P. and Thierfelder, C. (2016). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. https://doi.org/10.1016/J.STILL.2009.07.007

# Natural Farming: Revitalizing Soil Health for Sustainable Agriculture

**Sharwan Lal Yadav**


## Abstract

Modern agriculture has significantly increased food production, but intensive use of chemical fertilizers, pesticides, and excessive tillage has raised concerns regarding soil degradation, environmental pollution, and declining soil fertility. Natural farming has emerged as a sustainable alternative that emphasizes the use of locally available biological inputs and ecological processes to maintain soil health and crop productivity. By reducing dependence on external chemical inputs, natural farming promotes soil biodiversity, nutrient cycling, and ecosystem resilience. The approach focuses on enhancing the natural capacity of soil to support plant growth through biological activity and organic matter management. This article discusses the concept, principles, impact on soil health, applications, challenges, and future prospects of natural farming as a pathway toward sustainable agriculture.


## Introduction

Agriculture plays a crucial role in ensuring food security and supporting rural livelihoods. However, decades of intensive farming practices have led to several challenges, including declining soil fertility, loss of soil biodiversity, groundwater contamination, and environmental degradation. Excessive dependence on synthetic fertilizers and pesticides has often disrupted natural ecological processes and reduced the biological health of soils. Growing awareness of these concerns has increased interest in sustainable farming systems that promote environmental conservation while maintaining agricultural productivity. Natural farming has gained considerable attention as an eco-friendly production system that seeks to restore the natural balance between soil, plants, microorganisms and the environment. By minimizing external inputs and utilizing biological resources available on farms, natural farming aims to enhance soil health, improve resource-use efficiency, and promote long-term sustainability.

## Concept of Natural Farming

Natural farming is a farming system that relies on natural biological processes rather than synthetic chemical inputs for crop production. The approach encourages the use of locally available resources to maintain soil fertility, improve nutrient cycling, and enhance biological activity. The fundamental objective of natural farming is to create a self-sustaining agricultural ecosystem where soil organisms, plants, animals, and environmental factors work together to support crop growth. Instead of focusing solely on nutrient supplementation

**Sharwan Lal Yadav**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

through external inputs, natural farming emphasizes restoring the natural functioning of soil ecosystems. This approach seeks to reduce production costs, improve environmental quality, and strengthen the resilience of farming systems under changing climatic conditions.

## Principles of Natural Farming

Natural farming is based on several principles that support soil regeneration and ecological sustainability.

**Biological Soil Enrichment:** Healthy soils contain diverse populations of microorganisms that play an essential role in nutrient cycling and organic matter decomposition. Natural farming promotes biological activity through the application of microbial formulations and organic inputs.

Major benefits include:

- ✓ Enhanced microbial activity.
- ✓ Improved nutrient availability.
- ✓ Better organic matter decomposition.
- ✓ Increased soil fertility.

**Soil Cover and Mulching:** Maintaining continuous soil cover through crop residues, mulch, or living vegetation protects the soil from erosion and moisture loss. Important advantages include:

- ✓ Conservation of soil moisture.
- ✓ Suppression of weed growth.
- ✓ Regulation of soil temperature.
- ✓ Reduction in soil erosion.
- ✓ Improvement in organic matter content.

**Promotion of Natural Ecological Processes:** Natural farming encourages the utilization of ecological interactions for nutrient management and crop protection. The system aims to strengthen natural biological processes rather than relying on external chemical interventions.

Major benefits include:

- ✓ Improved ecosystem stability.
- ✓ Enhanced nutrient cycling.
- ✓ Increased biodiversity.
- ✓ Reduced dependence on synthetic inputs.
- ✓ Greater environmental sustainability.

## Impact of Natural Farming on Soil Health

Natural farming positively influences the physical, chemical, and biological properties of soil, thereby improving its overall health and productivity.

**Improvement in Soil Physical Properties:** Continuous addition of organic residues and biological inputs contributes to better soil structure and aggregation. Improved soil structure enhances root growth and water movement within the soil profile.

Major improvements include:

- ✓ Better soil aggregation.
- ✓ Increased porosity.
- ✓ Enhanced water infiltration.
- ✓ Improved water-holding capacity.
- ✓ Reduced soil compaction.

These improvements help crops withstand moisture stress and improve overall soil resilience.

**Improvement in Soil Chemical Properties:** Natural farming enhances soil fertility through improved nutrient cycling and organic matter accumulation. Organic inputs gradually release nutrients, ensuring

their availability throughout the crop growth period. Major benefits include:

- ✓ Increased soil organic carbon.
- ✓ Improved nutrient availability.
- ✓ Enhanced nutrient retention.
- ✓ Better soil buffering capacity.
- ✓ Reduced nutrient losses.

The gradual improvement in soil fertility contributes to sustainable crop production over time.

**Improvement in Soil Biological Properties:** One of the most significant advantages of natural farming is the enhancement of soil biological activity. The absence of excessive chemical inputs creates favorable conditions for beneficial soil organisms. Major biological benefits include:

- ✓ Increased microbial biomass.
- ✓ Enhanced earthworm activity.
- ✓ Greater microbial diversity.
- ✓ Improved nutrient mineralization.
- ✓ Strengthened soil ecosystem functioning.

Healthy biological communities support efficient nutrient cycling and long-term soil productivity.

## Applications of Natural Farming

Natural farming has wide applicability in sustainable agricultural systems.

**Sustainable Crop Production:** Natural farming promotes sustainable crop production by improving soil fertility and reducing dependence on external inputs. Improved soil health contributes to stable crop performance under diverse conditions.

**Soil Restoration:** Degraded soils can benefit significantly from natural farming practices. Enhanced organic matter accumulation and biological activity help restore soil productivity and ecological balance.

**Resource Conservation:** Natural farming encourages efficient utilization of locally available resources, reducing the need for synthetic fertilizers and pesticides. This contributes to resource conservation and lower production costs.

**Climate-Resilient Agriculture:** Improved soil organic matter and water-holding capacity increase the resilience of farming systems to drought and climatic variability. Natural farming therefore supports climate adaptation strategies.

**Environmental Protection:** Reduced chemical use lowers the risk of soil and water pollution while promoting biodiversity conservation. Natural farming also contributes to improved ecosystem health and environmental sustainability.

## Challenges and Limitations

Despite its potential benefits, natural farming faces several challenges that may limit large-scale adoption.One of the major concerns is the transition period required for soil ecosystems to stabilize after reducing chemical inputs. During this phase, farmers may experience fluctuations in crop performance. Limited scientific awareness and inadequate technical knowledge can also hinder adoption. Availability of quality biological inputs and effective extension support remains a challenge in some regions.Furthermore, the response of natural farming practices may vary depending on soil type, climate,

crop species and management conditions. Therefore, location-specific recommendations and continued research are necessary to optimize outcomes.

## Future Prospects

Growing concerns regarding soil degradation, environmental sustainability, and climate change are expected to increase interest in natural farming. Government initiatives promoting sustainable agriculture and reduced chemical dependence may further encourage adoption.

Future opportunities include:

- ✓ Integration with climate-smart agriculture.
- ✓ Improved biological input technologies.
- ✓ Expansion of farmer training programs.
- ✓ Strengthening soil health management initiatives.
- ✓ Greater emphasis on ecosystem-based farming approaches.
- ✓ Development of region-specific natural farming models.

As scientific understanding of soil biological processes advances, natural farming is expected to become an increasingly important component of sustainable agricultural development.

## Conclusion

Natural farming offers a promising pathway for revitalizing soil health and promoting sustainable agricultural production. By emphasizing biological processes, organic matter management and ecological balance, it improves soil physical, chemical, and biological properties while reducing dependence on synthetic inputs. The approach supports soil restoration, resource conservation, environmental protection and climate resilience. Although challenges related to adoption, awareness, and location-specific performance remain, continued research and policy support can enhance its effectiveness. Natural farming has the potential to play a significant role in building resilient agricultural systems and ensuring long-term sustainability of soil resources.

## References

Palekar, S. (2006). The Philosophy of Spiritual Farming. Zero Budget Natural Farming Research. *Development and Extension Movement, Amravati (Maharashtra).*

Ramesh, P., Panwar, N. R., Singh, A. B., Ramana, S., Yadav, S. K., Shrivastava, R. and Rao, A. S. (2010). Status of organic farming in India. *Current Science*, 1190-1194.

Obaisi, A. I., Adegbeye, M. J., Elghandour, M. M., Barbabosa-Pliego, A. and Salem, A. Z. M. (2022). Natural resource management and sustainable agriculture. In *Handbook of Climate Change Mitigation and Adaptation* (pp. 2577-2613). Cham: Springer International Publishing.

Bharucha, Z. P., Mitjans, S. B. and Pretty, J. (2020). Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India. *International Journal of Agricultural Sustainability*, 18(1): 1-20.

# Precision Nutrient Management: Enhancing Fertilizer Use Efficiency for Sustainable Agriculture

**Sharwan Lal Yadav**


## Abstract

Nutrient management is a critical component of modern agriculture, directly influencing crop productivity, soil health and environmental sustainability. Conventional blanket fertilizer recommendations often fail to account for spatial and temporal variations in soil fertility, resulting in inefficient nutrient use, increased production costs, and environmental degradation. Precision Nutrient Management (PNM) has emerged as an innovative approach that applies nutrients at the right rate, source, time, and place according to crop requirements and field conditions. By integrating soil testing, remote sensing, Geographic Information Systems (GIS), Global Positioning Systems (GPS), and decision-support tools, precision nutrient management enhances fertilizer use efficiency while minimizing nutrient losses. This article discusses the concept, principles, technologies, applications, challenges, and future prospects of precision nutrient management in achieving sustainable agricultural production.


## Introduction

Agriculture today faces the challenge of producing more food for a growing population while conserving natural resources and minimizing environmental impacts. Fertilizers play a crucial role in improving crop yields; however, inefficient fertilizer use has become a major concern in many agricultural systems. Excessive or imbalanced nutrient application not only increases production costs but also contributes to soil degradation, nutrient depletion, groundwater contamination, and green-house gas emissions. Traditional fertilizer recommendations are often generalized and may not adequately address variations in soil fertility, crop nutrient demand, and environmental conditions. Consequently, nutrient use efficiency remains low in many cropping systems. Precision Nutrient Management (PNM) has emerged as a sustainable strategy that aims to optimize nutrient application based on site-specific requirements. By ensuring that crops receive nutrients according to their actual needs, precision nutrient management improves productivity, profitability, and environmental sustainability.

## Concept of Precision Nutrient Management

Precision Nutrient Management is a scientific approach that involves the site-specific application of nutrients to match crop demand while considering soil variability and environmental conditions. The objective is to maximize nutrient use efficiency and

**Sharwan Lal Yadav**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

crop productivity while minimizing nutrient losses and environmental impacts. The approach recognizes that soil fertility can vary considerably within and between fields. Therefore, nutrient application should be based on detailed information regarding soil nutrient status, crop requirements, and yield potential rather than generalized recommendations. Precision nutrient management integrates advanced technologies and data-driven decision-making to achieve efficient nutrient utilization and sustainable agricultural production.

## Principles of Precision Nutrient Management

The foundation of precision nutrient management lies in the concept of applying nutrients according to crop requirements and field-specific conditions.

**Right Source:** The selection of an appropriate fertilizer source is essential for efficient nutrient utilization. Different crops and soils may require specific nutrient formulations to maximize nutrient availability and uptake. Benefits of selecting the right nutrient source include:

- ✓ Improved nutrient availability.
- ✓ Enhanced nutrient uptake efficiency.
- ✓ Reduced nutrient losses.
- ✓ Better crop performance.

**Right Rate:** Nutrients should be applied in quantities that meet crop requirements without causing deficiency or excess. Major advantages include:

- ✓ Improved fertilizer use efficiency.
- ✓ Reduced input costs.
- ✓ Prevention of nutrient toxicity.
- ✓ Increased economic returns.

**Right Time:** Applying nutrients when crops require them most enhances nutrient uptake and minimizes losses through leaching, volatilization, or runoff.

Key benefits include:

- ✓ Improved nutrient recovery.
- ✓ Increased crop growth and yield.
- ✓ Reduced environmental pollution.
- ✓ Enhanced nutrient-use efficiency.

**Right Place:** Proper placement ensures that nutrients are available within the crop root zone where they can be effectively utilized. Major benefits include:

- ✓ Increased nutrient availability.
- ✓ Improved root absorption.
- ✓ Reduced nutrient wastage.
- ✓ Better crop productivity.

Together, these principles form the basis of the widely accepted 4R Nutrient Stewardship framework.

## Tools and Technologies Used in Precision Nutrient Management

The success of precision nutrient management depends on accurate information and advanced technologies that facilitate site-specific nutrient application.

**Soil Testing:** Soil testing remains the foundation of nutrient management planning. It provides information on nutrient availability, soil pH, organic matter content, and fertility status.

Benefits of soil testing include:

- ✓ Identification of nutrient deficiencies.
- ✓ Development of balanced fertilizer recommend-

ations.

- ✓ Efficient nutrient management planning.
- ✓ Improved soil fertility management.

**Geographic Information System (GIS) and Global Positioning System (GPS):** GIS and GPS technologies enable the collection, analysis, and mapping of spatial variability in soil properties and crop performance. These tools help generate nutrient management zones and site-specific fertilizer recommendations.

**Remote Sensing:** Satellite imagery, drones, and sensor-based technologies provide valuable information regarding crop health, nutrient status, and field variability. Vegetation indices such as NDVI are commonly used to assess crop nutrient requirements.

**Decision Support Systems:** Computer-based decision support tools assist farmers and agronomists in making informed nutrient management decisions based on field data, crop requirements, and environmental conditions.

## Applications of Precision Nutrient Management

Precision nutrient management has become an important component of modern sustainable agriculture.

**Site-Specific Nutrient Management:** Nutrient recommendations are developed according to the fertility status of individual fields or management zones. This improves nutrient-use efficiency and reduces unnecessary fertilizer application.

**Sustainable Crop Production:** By matching nutrient supply with crop demand, precision nutrient management improves crop growth, productivity, and profitability while maintaining soil fertility.

**Resource Conservation:** Efficient nutrient utilization reduces fertilizer wastage and conserves valuable natural resources. Improved nutrient management also contributes to sustainable land use.

**Environmental Protection:** Precision nutrient management minimizes nutrient losses through leaching, runoff, and volatilization. This reduces water pollution, soil degradation, and greenhouse gas emissions.

**Integrated Nutrient Management:** Precision approaches can be integrated with organic manures, crop residues, biofertilizers, and chemical fertilizers to achieve balanced nutrient management and improved soil health.

## Contribution to Sustainable Agriculture

Precision nutrient management contributes significantly to sustainable agricultural development by improving productivity while reducing environmental impacts. Major contributions include:

- ✓ Increased fertilizer use efficiency.
- ✓ Improved crop yields and profitability.
- ✓ Enhanced soil fertility management.
- ✓ Reduced nutrient losses.
- ✓ Lower environmental pollution.
- ✓ Improved resource-use efficiency.
- ✓ Greater sustainability of farming systems.

The approach helps farmers achieve higher productivity with lower inputs, making agriculture both economically and environmentally sustainable.

## Challenges and Limitations

Despite its benefits, the adoption of precision nutrient management faces several challenges.One of the major constraints is the high initial investment required for advanced technologies such as sensors, drones, GPS equipment, and precision application machinery. Smallholder farmers may find these technologies difficult to access due to financial limitations. Inadequate technical knowledge and limited awareness regarding precision farming practices can also hinder adoption. Furthermore, reliable field data, infrastructure, and skilled personnel are essential for successful implementation. Variability in climatic conditions and the complexity of interpreting large datasets may further limit the effectiveness of precision nutrient management in some situations.

## Future Prospects

The future of precision nutrient management is closely associated with advancements in digital agriculture and smart farming technologies. Emerging innovations such as artificial intelligence, machine learning, Internet of Things (IoT) devices, and real-time nutrient sensors are expected to enhance nutrient management decisions. The increasing availability of remote sensing data, mobile-based advisory services, and automated fertilizer application systems will further improve accessibility and adoption. Government initiatives promoting soil health management and precision agriculture are also expected to accelerate the implementation of precision nutrient management practices. As agriculture moves toward sustainability and climate resilience, precision nutrient management will play a crucial role in improving nutrient-use efficiency and ensuring long-term soil productivity.

## Conclusion

Precision Nutrient Management represents a modern and sustainable approach to fertilizer management that enhances nutrient-use efficiency while minimizing environmental impacts. By applying nutrients according to crop requirements and site-specific conditions, it improves productivity, profitability and resource conservation. The integration of soil testing, GIS, GPS, remote sensing, and decision-support systems has significantly improved the ability to manage nutrients efficiently. Although challenges related to cost, infrastructure, and technical expertise remain, continued technological advancements and policy support are expected to expand adoption. Precision nutrient management will be a key component of sustainable agriculture and future food security.

## References

Dobermann, A. and Cassman, K. (2002). Plant nutrient management for enhanced productivity in intensive grain production systems of the United. *Plant and Soil*, 247(1): 153-175.

Dutta, S. K., Majumdar, K., Satyanarayana, T. and Singh, A. K. (2015). 4R nutrient stewardship-a way forward towards sustainable agriculture.

Mulla, D. J. (2013). Twenty five years of remote sensing in precision agriculture: Key advan-

ces and remaining knowledge gaps. *Biosystems Engineering*, 114(4): 358-371.

Varma, D. J., Shankar, T., Praharaj, S., Sahoo, U. and Maitra, S. (2021). Precision Nutrient Management for Enhancement of Nutrient use Efficiency. 12(69): 37280-37286.

Zhang, N., Wang, M. and Wang, N. (2002). Precision agriculture-a worldwide overview. *Computers and Electronics in Agriculture*, 36(2-3): 113-132.

# Artificial Intelligence in Soil Science: Revolutionizing Soil Management and Decision-Making

**Vishal Kumar**


## Abstract

The increasing demand for sustainable agricultural production and efficient natural resource management has accelerated the adoption of advanced digital technologies in soil science. Among these innovations, Artificial Intelligence (AI) has emerged as a transformative tool capable of analyzing complex soil data, predicting soil behavior, and supporting informed decision-making. AI integrates machine learning, deep learning, data analytics, and predictive modeling to process large volumes of soil-related information with unprecedented speed and accuracy. Applications of AI in soil science range from soil classification and digital soil mapping to nutrient management, soil health assessment, and precision agriculture. By enabling data-driven decisions, AI contributes to improved resource-use efficiency, enhanced crop productivity, and sustainable soil management. This article discusses the concept, components, applications, challenges, and future prospects of artificial intelligence in soil science and its role in shaping the future of smart agriculture.


## Introduction

Soil is one of the most valuable natural resources, serving as the foundation for agricultural production, ecosystem services, and environmental sustainability. Effective soil management requires accurate information regarding soil properties, nutrient status, moisture availability, organic matter content, and degradation risks. Traditionally, soil assessment has relied on field surveys, laboratory analyses, and expert interpretation, which are often labor-intensive, time-consuming, and costly. The rapid advancement of digital technologies has created new opportunities for improving soil assessment and management. The increasing availability of soil databases, remote sensing imagery, sensor networks, and geospatial information has generated vast amounts of data that require advanced analytical tools for effective utilization. Artificial Intelligence has emerged as a powerful solution for managing and interpreting complex soil datasets. By learning patterns from large volumes of information, AI enables researchers, agronomists, and policymakers to make more accurate predictions and informed decisions regarding soil management and agricultural sustainability.

## Concept of Artificial Intelligence in Soil Science

Artificial Intelligence refers to the ability of computer systems to perform tasks that normally require human intelligence, including learning, reasoning, problem-solving, pattern recognition, and decision-making. In soil science, AI utilizes computational algorithms to analyze soil-related data

**Vishal Kumar**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

and generate meaningful insights. The technology integrates information from various sources, including soil samples, climate records, satellite imagery, sensors, and geographic information systems. Through advanced analytical techniques, AI can identify patterns, predict outcomes, and support soil management decisions. The primary objective of AI in soil science is to improve the accuracy, efficiency, and speed of soil assessment while enabling sustainable land management practices.

## Components and Technologies of Artificial Intelligence in Soil Science

**Machine Learning Algorithms:** Machine learning is one of the most widely used AI technologies in soil science. These algorithms learn from historical data and identify relationships between soil properties and environmental factors.

Major applications include:

- ✓ Soil property prediction.
- ✓ Soil classification.
- ✓ Nutrient status assessment.
- ✓ Yield forecasting.
- ✓ Soil degradation monitoring.

Machine learning improves prediction accuracy and supports evidence-based decision-making.

**Remote Sensing and Geospatial Data Integration:** Artificial Intelligence is increasingly integrated with remote sensing technologies to analyze large-scale environmental datasets. Satellite imagery, drone observations, and geospatial information provide valuable inputs for AI-based models.

Important benefits include:

- ✓ Rapid soil assessment.
- ✓ Large-scale monitoring capabilities.
- ✓ Detection of spatial variability.
- ✓ Improved land-use planning.
- ✓ Continuous environmental monitoring.

The integration of AI and remote sensing has significantly enhanced soil mapping and resource management.

**Deep Learning and Big Data Analytics:** Deep learning techniques enable the analysis of highly complex datasets that contain multiple variables and nonlinear relationships. These methods are particularly useful for processing images, sensor data, and large environmental databases.

Major advantages include:

- ✓ Improved predictive performance.
- ✓ Automated feature extraction.
- ✓ Enhanced image interpretation.
- ✓ Real-time data processing.
- ✓ Greater analytical efficiency.

These capabilities allow researchers to generate more detailed and accurate soil information.

## Applications of Artificial Intelligence in Soil Science

**Soil Mapping and Classification:** One of the most important applications of AI is digital soil mapping and classification. Machine learning models can predict soil properties across large landscapes using environmental and geospatial data. AI-based soil maps provide detailed information regarding soil texture, organic matter content, nutrient status, and land suitability, supporting sustainable land manage-

ment.

**Precision Nutrient Management:** Artificial Intelligence enables site-specific nutrient management by analyzing soil fertility data and recommending optimal fertilizer applications. This approach improves nutrient-use efficiency and minimizes environmental impacts. Benefits include:

- ✓ Reduced fertilizer wastage.
- ✓ Improved nutrient management.
- ✓ Enhanced crop productivity.
- ✓ Lower environmental pollution.

Precision nutrient management contributes significantly to sustainable agriculture.

**Soil Health Assessment:** AI tools can evaluate multiple soil health indicators simultaneously and generate comprehensive assessments of soil quality. By integrating biological, chemical, and physical soil properties, AI facilitates rapid soil health monitoring. This helps identify degraded areas and supports timely management interventions.

**Prediction of Soil Organic Matter and Carbon Dynamics:** Soil organic matter is a critical indicator of soil fertility and carbon sequestration potential. Artificial Intelligence models can predict soil organic carbon levels and assess changes over time using field observations and remote sensing data. Such predictions support climate-smart agriculture and sustainable soil management strategies.

**Decision Support for Sustainable Land Management:** AI-powered decision-support systems assist farmers, researchers, and policymakers in selecting appropriate management practices based on soil conditions and environmental factors. These systems facilitate evidence-based planning, risk assessment, and resource allocation, ultimately improving agricultural sustainability.

## Challenges and Limitations

Despite its immense potential, the adoption of artificial intelligence in soil science faces several challenges. The effectiveness of AI models depends heavily on the quality, quantity and representativeness of input data. In many regions, limited soil databases and inconsistent data collection methods restrict model performance. AI systems also require substantial computational resources, specialized software, and technical expertise for development and implementation. Furthermore, complex machine learning models may function as “black boxes,” making their predictions difficult to interpret. Concerns regarding data privacy, model transparency, and the transferability of AI models across different environmental conditions also need careful consideration. Addressing these challenges is essential for ensuring the reliable and widespread use of AI technologies in soil management.

## Future Prospects

The future of artificial intelligence in soil science is highly promising due to rapid advancements in machine learning, cloud computing, sensor technologies, and big-data analytics. Increasing availability of real-time soil and environmental data will enhance the predictive capabilities of AI systems. Integration of AI with remote sensing, Internet of Things (IoT) devices, robotics, and

precision agriculture technologies is expected to revolutionize soil monitoring and management practices. AI-driven decision-support systems will become increasingly important for addressing challenges related to climate change, soil degradation and food security. As computational tools become more accessible and affordable, artificial intelligence is likely to become a standard component of modern soil science and sustainable agricultural management.

## Conclusion

Artificial Intelligence is transforming soil science by enabling rapid, accurate, and data-driven assessment of soil properties and management needs. Through machine learning, remote sensing integration and advanced analytics, AI supports soil mapping, nutrient management, soil health evaluation and sustainable land-use planning. The technology offers significant opportunities for improving resource-use efficiency, enhancing agricultural productivity and addressing environmental challenges. Although limitations related to data availability, technical expertise, and model interpretation remain, continuous technological advancements are expanding the scope and effectiveness of AI applications. As agriculture enters the era of digital transformation, artificial intelligence will play a pivotal role in revolutionizing soil management and decision-making for a more sustainable future.

## References

Wadoux, A. M. C. (2025). Artificial intelligence in soil science. *European Journal of Soil Science*, 76(2): e70080.

Zhang, X., Yang, P. and Lu, B. (2024). Artificial intelligence in soil management: The new frontier of smart agriculture. *Advances in Resources Research*, 4(2): 231-251.

Minasny, B. and McBratney, A. B. (2025). Machine learning and artificial intelligence applications in soil science. *European Journal of Soil Science*, 76(2): e70093.

Lal, R. (2024). Artificial intelligence for assessing organic matter content and related soil properties. *Journal of Soil and Water Conservation*, 79(4): 66A-73A.

# Digital Soil Mapping: Transforming Soil Assessment and Land Management

**Vishal Kumar**


## Abstract

Accurate information about soil properties is essential for sustainable agriculture, land-use planning, environmental management, and natural resource conservation. Traditional soil survey methods have contributed significantly to soil characterization but are often labor-intensive, time-consuming, and costly when applied over large areas. Advances in geospatial technologies, remote sensing, Geographic Information Systems (GIS), and computational modeling have led to the emergence of Digital Soil Mapping (DSM), a modern approach for predicting and mapping soil properties with greater accuracy and efficiency. By integrating field observations, environmental data, and predictive models, digital soil mapping enables the generation of high-resolution soil information for diverse applications. This technology is transforming soil assessment and land management by supporting precision agriculture, sustainable soil management, and informed decision-making. This article discusses the concept, components, applications, challenges, and future prospects of digital soil mapping in modern agriculture.


## Introduction

Soils are fundamental natural resources that support agricultural production, ecosystem functioning, water regulation, and biodiversity conservation. Effective management of these resources requires accurate and up-to-date information regarding soil properties, distribution and variability. Traditionally, soil surveys have been conducted through extensive field sampling and laboratory analysis. While these methods provide valuable information, they are often expensive, time-consuming and difficult to implement over large geographic areas. Increasing demands for sustainable land management and precision agriculture have created the need for faster and more efficient approaches to soil assessment.

Advances in geospatial technologies and data science have provided new opportunities to improve soil mapping and characterization. Digital Soil Mapping (DSM) has emerged as a powerful tool that combines soil observations with environmental information and predictive models to generate detailed soil maps. The approach enables researchers, planners, and farmers to better understand soil variability and make informed management deciions that enhance productivity and sustainability.

## Concept of Digital Soil Mapping

Digital Soil Mapping is the process of creating spatial soil information using mathematical models, environmental data, and geospatial technologies. It involves predicting soil properties

**Vishal Kumar**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

and soil classes across landscapes by establishing relationships between observed soil characteristics and environmental factors. Unlike conventional soil surveys that rely heavily on manual interpretation, DSM uses digital data sources such as satellite imagery, terrain attributes, climate information, and field observations to generate soil maps. The primary objective of digital soil mapping is to provide accurate, high-resolution, and continuously updated soil information that supports agricultural management, environmental monitoring, and land-use planning.

## Components and Technologies of Digital Soil Mapping

**Geographic Information Systems (GIS):** GIS serves as one of the fundamental tools in digital soil mapping. It enables the storage, analysis, visualization and management of spatial data related to soil properties and environmental variables.

Major benefits include:

- ✓ Integration of multiple datasets.
- ✓ Spatial analysis of soil variability.
- ✓ Generation of thematic soil maps.
- ✓ Improved decision-making for land management.

GIS provides the framework for organizing and analyzing large volumes of soil-related information.

**Remote Sensing Technologies:** Remote sensing plays a crucial role in acquiring environmental information across large geographic areas. Satellite imagery, aerial photographs and drone-based observations provide valuable data for soil mapping.

Important applications include:

- ✓ Assessment of land cover.
- ✓ Monitoring vegetation patterns.
- ✓ Detection of soil moisture variability.
- ✓ Identification of soil degradation.
- ✓ Collection of large-scale environmental data.

Remote sensing significantly improves the efficiency and coverage of soil assessment activities.

**Predictive Modeling and Machine Learning:** Digital soil mapping relies on predictive models that establish relationships between soil observations and environmental variables. Recent advances in machine learning have further improved the accuracy of soil predictions. Major advantages include:

- ✓ Enhanced prediction accuracy.
- ✓ Efficient processing of large datasets.
- ✓ Identification of complex relationships.
- ✓ Generation of high-resolution soil maps.
- ✓ Continuous updating of soil information.

These tools enable the development of detailed and reliable soil databases for various applications.

## Applications of Digital Soil Mapping

**Precision Agriculture:** One of the most important applications of digital soil mapping is precision agriculture. High-resolution soil maps help identify spatial variability in soil properties, allowing farmers to implement site-specific management practices. Improved soil information supports efficient fertilizer application, irrigation management, and crop selection, thereby enhancing productivity and

resource-use efficiency.

**Sustainable Soil Management:** Digital soil mapping provides valuable information for monitoring soil health and identifying areas vulnerable to degradation. Soil maps assist in developing conservation strategies and sustainable management practices.

**Land-Use Planning:** Accurate soil information is essential for determining the suitability of land for agriculture, forestry, urban development, and conservation purposes. Digital soil maps support informed land-use decisions and reduce the risk of inappropriate land utilization.

**Soil Degradation and Environmental Monitoring:** Digital soil mapping is widely used to assess soil degradation processes such as erosion, salinity, nutrient depletion and desertification. The technology enables continuous monitoring of soil conditions and environmental changes. Early identification of problem areas facilitates timely interventions and restoration efforts.

**Climate-Smart Agriculture:** Climate change is increasing the need for adaptive and resilient agricultural systems. Digital soil mapping helps identify soil characteristics that influence carbon sequestration, water retention, and climate resilience. This information supports the implementation of climate-smart agricultural practices and sustainable land management strategies.

## Challenges and Limitations

Despite its numerous advantages, digital soil mapping faces several challenges. The accuracy of soil predictions depends heavily on the quality and availability of soil observations and environmental datasets. In many regions, limited field data can restrict the reliability of digital soil maps. Differences in spatial resolution, data formats, and environmental conditions may also affect prediction accuracy. Furthermore, advanced computational tools, specialized software, and technical expertise are often required for successful implementation. The interpretation of large datasets and integration of multiple information sources can be complex and resource-intensive. Addressing these challenges will require improved data collection systems, standardized methodologies, and enhanced capacity-building efforts.

## Future Prospects

The future of digital soil mapping is highly promising due to rapid advancements in remote sensing, artificial intelligence, machine learning, and geospatial technologies. The increasing availability of high-resolution satellite imagery and drone-based data is expected to improve soil mapping accuracy and accessibility. Emerging technologies such as cloud computing and big-data analytics will facilitate the processing of massive datasets and support real-time soil monitoring. Integration of digital soil mapping with precision agriculture, climate-smart agriculture, and decision-support systems will further enhance sustainable land management. As the demand for accurate soil information continues to grow, digital soil mapping is expected to become an essential component of modern agricultural and

environmental management systems.

## Conclusion

Digital Soil Mapping has revolutionized the way soil information is collected, analyzed, and utilized for agricultural and environmental applications. By integrating field observations with geospatial technologies, remote sensing, and predictive modeling, it provides accurate and high-resolution soil information for decision-making. The technology supports precision agriculture, sustainable soil management, land-use planning, and environmental monitoring while improving resource-use efficiency and agricultural productivity. Although challenges related to data quality, technical expertise, and model accuracy remain, continuous technological advancements are enhancing the effectiveness of digital soil mapping. As agriculture moves toward data-driven and sustainable management systems, digital soil mapping will play a crucial role in transforming soil assessment and land management practices.

## References

Ma, Y., Minasny, B., Malone, B. P. and McBratney, A. B. (2019). Pedology and digital soil mapping (DSM). *European Journal of Soil Science*, 70(2): 216-235.

Grunwald, S., Thompson, J. A., Minasny, B. and Boettinger, J. L. (2012). Digital soil mapping in a changing world. In *Digital Soil Assessments and Beyond* (pp. 301-306).

Santra, P., Kumar, M., Panwar, N. R. and Yadav, R. S. (2021). Digital Soil Mapping: The Future Need of Sustainable Soil Management. In Mitran, T., Meena, R. S. and Chakraborty, A. (eds.), *Geospatial Technologies for Crops and Soils*. Springer, Singapore.

Dash, P. K. (2024). Remote sensing as a potential tool for advancing digital soil mapping. In *Remote Sensing of Soils* (pp. 357-370). Elsevier.

# Microplastics in Agricultural Soils: Emerging Challenges for Soil Health

**Vishal Kumar**


## Abstract

Plastic materials have become indispensable in modern society due to their versatility, durability, and low cost. However, the widespread use and improper disposal of plastics have resulted in the accumulation of plastic debris in terrestrial and aquatic ecosystems. Microplastics, defined as plastic particles smaller than 5 mm in size, have emerged as a significant environmental concern. While considerable attention has been given to marine pollution, agricultural soils are increasingly recognized as major sinks for microplastic contamination. These particles enter soils through various pathways, including plastic mulching, sewage sludge application, irrigation with contaminated water, and atmospheric deposition. Microplastics can alter soil physical, chemical, and biological properties, thereby affecting soil health, crop productivity, and environmental sustainability. This article discusses the sources, impacts, applications of research, challenges, and future prospects related to microplastic pollution in agricultural soils.


## Introduction

Agricultural soils are the foundation of food production and environmental sustainability. Healthy soils support plant growth, regulate nutrient cycling, store water, and sustain diverse biological communities. However, increasing anthropogenic activities have introduced new contaminants into soil ecosystems, posing significant threats to soil health and agricultural productivity. Among emerging pollutants, microplastics have gained considerable attention in recent years. These tiny plastic particles originate from the breakdown of larger plastic materials or are intentionally manufactured for industrial and commercial applications. Due to their small size and persistence, microplastics can accumulate in soils over extended periods and interact with soil components, microorganisms, plants, and environmental processes. The growing use of plastic products in agriculture, including mulching films, greenhouse coverings, irrigation systems, and packaging materials, has increased the risk of soil contamination. As concerns regarding food safety, ecosystem health, and environmental sustainability continue to rise, understanding the implications of microplastics in agricultural soils has become an important area of research.

## Concept of Microplastics in Agricultural Soils

Microplastics are plastic particles smaller than 5 mm that persist in the environment due to their resistance to degradation. They may originate directly as small particles, known as primary microplastics, or result from the fragmentation of larger plastic materials, known as secondary microplastics. Agricultural soils have emerged as important reserv-

**Vishal Kumar**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

oirs for microplastic accumulation. Once introduced into the soil, these particles may persist for long periods, interact with soil organisms, and influence various biological and physicochemical processes. Unlike many conventional pollutants, microplastics do not readily decompose and may accumulate continuously over time, making them a growing environmental concern for sustainable agriculture.

## Sources of Microplastics in Agricultural Soils

**Agricultural Plastic Mulches:** Plastic mulching is widely used to conserve soil moisture, suppress weeds, and improve crop productivity. Over time, weathering and mechanical damage cause plastic films to fragment into smaller particles that accumulate in the soil.

Major contributions include:

- ✓ Degradation of polyethylene mulch films.
- ✓ Residual plastic fragments after harvesting.
- ✓ Long-term accumulation in cultivated fields.
- ✓ Increased soil contamination levels.

Agricultural mulch films are considered one of the major sources of microplastic pollution in croplands.

**Organic Amendments and Sewage Sludge:** Organic amendments such as compost and sewage sludge may contain microplastic particles originating from domestic and industrial waste streams.

Important sources include:

- ✓ Municipal biosolids.
- ✓ Wastewater treatment residues.
- ✓ Organic waste recycling systems.
- ✓ Contaminated compost materials.

The repeated application of these materials can gradually increase microplastic concentrations in agricultural soils.

**Irrigation Water and Atmospheric Deposition:** Microplastics can also enter agricultural systems through irrigation water and atmospheric deposition. Contaminated surface water, groundwater, and airborne particles contribute to their widespread distribution. Major pathways include:

- ✓ Wastewater irrigation.
- ✓ River and canal water contamination.
- ✓ Atmospheric transport.
- ✓ Dust deposition on agricultural land.

These sources facilitate the continuous introduction of microplastics into soil ecosystems.

## Impacts on Soil Health and Crop Production

**Effects on Soil Physical Properties:** Microplastics can alter the physical characteristics of soil by affecting aggregation, porosity and water movement. Their presence may disrupt natural soil structure and influence soil-water relationships.

Major impacts include:

- ✓ Changes in soil aggregation.
- ✓ Altered bulk density.
- ✓ Modified water-holding capacity.
- ✓ Changes in soil porosity.
- ✓ Reduced structural stability.

These modifications can influence root growth and overall crop performance.

**Effects on Soil Chemical Properties:** Microplastics can interact with nutrients, pollutants, and soil organic matter, affecting chemical processes within

the soil environment. Important effects include:

- ✓ Altered nutrient availability.
- ✓ Changes in soil pH.
- ✓ Modification of nutrient cycling processes.
- ✓ Adsorption of toxic contaminants.
- ✓ Increased mobility of pollutants.

Such interactions may influence nutrient-use efficiency and environmental quality.

**Effects on Soil Biological Properties:** The soil microbiome plays a critical role in maintaining soil fertility and ecosystem functioning. Microplastic contamination can affect microbial communities and biological processes.

Major biological impacts include:

- ✓ Changes in microbial diversity.
- ✓ Disruption of microbial activity.
- ✓ Altered enzyme functions.
- ✓ Effects on earthworms and soil fauna.
- ✓ Disturbance of nutrient cycling.

These biological changes may have long-term consequences for soil health and productivity.

**Effects on Crop Growth and Food Safety:** Microplastics can influence plant growth directly or indirectly through changes in soil properties. Recent studies suggest that plants may absorb nano-sized plastic particles through their root systems.

Potential consequences include:

- ✓ Reduced seed germination.
- ✓ Impaired root development.
- ✓ Altered nutrient uptake.
- ✓ Reduced crop productivity.
- ✓ Potential transfer into the food chain.

These concerns highlight the need for continued research on the relationship between microplastics and food safety.

## Applications of Research on Microplastics

Research on microplastics in agricultural soils has important implications for environmental monitoring, risk assessment, and sustainable soil management. Understanding the sources and movement of microplastics can help develop effective pollution control strategies. Scientific studies are also supporting the development of biodegradable alternatives to conventional plastics used in agriculture. Furthermore, improved monitoring techniques are enabling researchers to assess contamination levels and evaluate their impact on soil ecosystems. Such knowledge is essential for formulating policies and management practices aimed at reducing plastic pollution in agricultural landscapes.

## Challenges and Limitations

Despite growing awareness, several challenges remain in addressing microplastic contamination in agricultural soils. The detection and quantification of microplastics are often difficult due to their small size and diverse composition. Standardized methodologies for sampling, identification, and analysis are still evolving, making comparisons among studies challenging. Furthermore, the long-term ecological impacts of microplastics on soil ecosystems remain poorly understood. Limited information regarding interactions between microplastics, soil microorganisms, plants and environme-

ntal factors creates uncertainty in risk assessment. Addressing these knowledge gaps requires inter-disciplinary research and improved monitoring systems.

## Future Prospects

Future efforts to manage microplastic pollution in agricultural soils will focus on prevention, monitoring, and sustainable alternatives. The development of biodegradable mulch films and environmentally friendly agricultural materials may reduce the accumulation of plastic residues in soils. Advances in analytical technologies will improve the detection and characterization of microplastics, facilitating better environmental monitoring. Increased awareness among farmers, policymakers, and industry stakeholders will support the adoption of responsible plastic management practices. As research continues to uncover the ecological and agricultural impacts of microplastics, more effective strategies for protecting soil health and environmental sustainability are expected to emerge.

## Conclusion

Microplastics have emerged as a significant environmental pollutant with far-reaching implications for agricultural soils and sustainable food production. Their accumulation in soil ecosystems can alter physical, chemical, and biological properties, potentially affecting crop growth, soil biodiversity, and environmental quality. The persistence of microplastics and their potential entry into food chains raise important concerns regarding ecosystem and human health.

Although substantial progress has been made in understanding their impacts, many uncertainties remain regarding their long-term effects. Continued research, improved waste management practices, sustainable agricultural technologies, and policy interventions will be essential for minimizing microplastic pollution and safeguarding soil health for future generations.

## References

Hasan, M. M. and Tarannum, M. N. (2025). Adverse impacts of microplastics on soil physico-chemical properties and crop health in agricultural systems. *Journal of Hazardous Materials Advances*, 17: 100528.

Yu, H., Zhang, Y., Tan, W. and Zhang, Z. (2022). Microplastics as an emerging environmental pollutant in agricultural soils: Effects on ecosystems and human health. *Frontiers in Environmental Science*, 10: 855292.

Panda, S. and Behera, R. (2024). Microplastic accumulation in agricultural soils: Impacts on crop microbiomes and soil health. *Journal of Agriculture and Livestock Farming*, 1: 1-4.

Nath, S., Enerijiofi, K. E., Astapati, A. D. and Guha, A. (2024). Microplastics and nanoplastics in soil: Sources, impacts, and solutions for soil health and environmental sustainability. *Journal of Environmental Quality*, 53(6): 1048-1072.

# Regenerative Agriculture: Restoring Soil Health and Ecosystem Resilience

Vishal Kumar


## Abstract

Modern agriculture has significantly increased food production, but intensive farming practices have often resulted in soil degradation, biodiversity loss, declining soil organic matter, and environmental challenges. Regenerative agriculture has emerged as a holistic and sustainable farming approach that seeks to restore soil health, enhance ecosystem functions, and improve agricultural resilience. Unlike conventional systems that focus primarily on productivity, regenerative agriculture emphasizes rebuilding soil organic matter, promoting biodiversity, improving water retention, and strengthening ecological processes. Through practices such as reduced tillage, cover cropping, crop diversification, integrated livestock management, and organic matter enhancement, regenerative agriculture contributes to climate resilience and long-term sustainability. This article discusses the concept, principles, applications, challenges, and future prospects of regenerative agriculture and its role in restoring soil health and ecosystem resilience.


## Introduction

Agriculture depends fundamentally on healthy soils and functioning ecosystems. However, decades of intensive cultivation, excessive tillage, monocropping, overuse of chemical inputs, and unsustainable land management practices have contributed to widespread soil degradation across the globe. Declining soil fertility, erosion, reduced biodiversity, and increased vulnerability to climate change have become major concerns for agricultural sustainability. As the global population continues to grow and climate-related challenges intensify, there is an urgent need for farming systems that can maintain productivity while restoring natural resources. Regenerative agriculture has gained increasing attention as an innovative and sustainable approach that focuses on rebuilding ecological functions rather than merely sustaining existing conditions. The concept extends beyond conservation by actively improving soil quality, biodiversity, water cycles, and ecosystem services. By enhancing the natural regenerative capacity of agricultural landscapes, regenerative agriculture offers a promising pathway toward resilient food production systems and environmental sustainability.

## Concept of Regenerative Agriculture

Regenerative agriculture is a holistic land management approach that seeks to restore and enhance the biological, physical, and chemical functions of soils while improving ecosystem health. The primary objective is to regenerate natural resources and ecological processes that support agricultural productivity.

**Vishal Kumar**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

Unlike conventional farming systems that often depend heavily on external inputs, regenerative agriculture emphasizes working with natural processes to improve soil fertility and ecosystem resilience. The approach recognizes soil as a living system and promotes practices that increase soil organic matter, enhance biodiversity, and improve nutrient cycling. The ultimate goal is to create productive agricultural systems that simultaneously support environmental sustainability, climate resilience, and long-term food security.

## Principles of Regenerative Agriculture

**Minimizing Soil Disturbance:** Excessive tillage disrupts soil structure, accelerates organic matter decomposition, and negatively affects soil biological communities. Regenerative agriculture promotes reduced tillage or conservation tillage practices to protect soil integrity. Major benefits include:

- ✓ Improved soil structure.
- ✓ Reduced soil erosion.
- ✓ Enhanced water infiltration.
- ✓ Increased soil organic carbon.
- ✓ Greater biological activity.

Minimizing soil disturbance helps maintain a stable and productive soil environment.

**Maintaining Continuous Soil Cover:** Keeping the soil covered through cover crops, crop residues, or mulches protects the soil surface from erosion and environmental stress. Important advantages include:

- ✓ Reduced moisture loss.
- ✓ Improved weed suppression.
- ✓ Enhanced organic matter accumulation.
- ✓ Protection against erosion.
- ✓ Moderation of soil temperature.

Continuous soil cover supports healthy soil ecosystems and improves resource conservation.

**Promoting Biodiversity and Crop Diversity:** Diverse cropping systems enhance ecological stability and improve nutrient cycling. Regenerative agriculture encourages crop rotation, intercropping, agroforestry, and integration of livestock.

Major benefits include:

- ✓ Improved soil fertility.
- ✓ Enhanced pest and disease management.
- ✓ Greater ecosystem stability.
- ✓ Increased biological diversity.
- ✓ Better utilization of natural resources.

Biodiversity strengthens ecosystem resilience and supports sustainable agricultural production.

## Applications of Regenerative Agriculture

**Soil Health Restoration:** One of the primary applications of regenerative agriculture is the restoration of degraded soils. Practices such as cover cropping, residue retention, compost application, and reduced tillage contribute to the rebuilding of soil organic matter and biological activity.

**Climate Change Mitigation:** Regenerative agriculture contributes to climate change mitigation through increased carbon sequestration in soils and vegetation. Enhanced soil organic matter serves as a significant carbon sink, reducing atmospheric carbon dioxide concentrations. In addition, regenerative practices often reduce greenhouse gas emissions associated with intensive agricultural operations.

**Water Conservation and Drought Resilience:** Healthy soils rich in organic matter have greater water-holding capacity and infiltration rates. This improves water availability for crops and increases resilience to drought conditions. Enhanced water management contributes to stable agricultural production under changing climatic conditions.

**Biodiversity Conservation:** Regenerative agriculture supports diverse communities of soil microorganisms, insects, pollinators, birds, and other beneficial organisms. Increased biodiversity strengthens ecosystem functions and contributes to natural pest regulation and nutrient cycling.

**Sustainable Food Production:** By improving soil fertility, ecosystem functioning, and resource-use efficiency, regenerative agriculture supports sustainable food production systems capable of maintaining productivity over the long term.

## Challenges and Limitations

Despite its numerous benefits, the transition to regenerative agriculture presents several challenges. Farmers often require time to adapt to new management practices and may experience temporary fluctuations in crop yields during the transition period. Limited awareness, inadequate technical knowledge, and insufficient access to training programs can hinder adoption. In some regions, economic constraints and lack of policy support may discourage farmers from implementing regenerative practices. Furthermore, the outcomes of regenerative agriculture can vary depending on soil type, climate, cropping systems, and management conditions. Scientific methods for measuring ecosystem benefits and soil regeneration are also still evolving. Overcoming these challenges will require coordinated efforts involving researchers, extension agencies, policymakers, and farming communities.

## Future Prospects

The future of regenerative agriculture appears highly promising as global attention increasingly focuses on soil health, climate resilience and sustainable food systems. Advances in soil science, digital agriculture and ecosystem monitoring technologies are improving the understanding and implementation of regenerative practices. Growing interest in carbon markets and ecosystem service payments may provide economic incentives for farmers adopting regenerative systems. Increased consumer demand for sustainably produced food is also expected to drive adoption. Governments and international organizations are recognizing the role of regenerative agriculture in achieving climate and sustainability goals, which may lead to stronger policy support and investment. As research continues to validate its benefits, regenerative agriculture is likely to become an important component of future agricultural development strategies.

## Conclusion

Regenerative agriculture represents a transformative approach to farming that seeks not only to sustain but also to restore soil health and ecosystem functionality. By emphasizing soil regeneration, biodiversity enhancement, water cons-

ervation, and carbon sequestration, it addresses many of the environmental challenges facing modern agriculture. The approach offers significant opportunities for improving soil fertility, strengthening climate resilience, conserving natural resources, and ensuring long-term agricultural sustainability. Although challenges related to adoption, knowledge dissemination, and economic transition remain, continued research, technological innovation, and supportive policies can accelerate its implementation. Regenerative agriculture has the potential to play a vital role in building resilient agricultural systems capable of meeting future food and environmental demands.

## References

Rizvi, A. H. (2026). Regenerative Agriculture: Restoring Soil Health and Ecosystem Balance. *PhytoTalks*, 3(1): 682-683.

Mi, H. (2025). Reviving the Soil: The Promise of Regenerative Farming.

Durgude, S. A., Yeggina, P. K., Mishra, A. K. and Sharma, S. (2025). Key Drivers for Transitioning to Regenerative Agriculture. In *Transition to Regenerative Agriculture: Principles and Indicators of Soil Health Management* (pp. 77-88). Singapore: Springer Nature Singapore.

Bhardwaj, N., Wadatkar, H., Mohanty, S., Salve, R. and Patil, S. (2025). Regenerative agriculture: Opportunities and challenges: A review. *International Journal of Research in Agronomy*, 8(5): 651-656.

# Soil Carbon Sequestration: A Natural Solution for Climate Change Mitigation

**Vishal Kumar**


## Abstract

Climate change has emerged as one of the most pressing global challenges of the twenty-first century, driven largely by the increasing concentration of greenhouse gases in the atmosphere. Among various mitigation strategies, soil carbon sequestration has gained significant attention as a natural, cost-effective, and sustainable approach to reducing atmospheric carbon dioxide levels. Soils represent one of the largest terrestrial carbon reservoirs and possess immense potential to capture and store carbon through appropriate land management practices. By increasing soil organic carbon, soil carbon sequestration not only contributes to climate change mitigation but also improves soil health, agricultural productivity, and ecosystem sustainability. This article discusses the concept, mechanisms, applications, challenges, and future prospects of soil carbon sequestration as a vital tool for building climate-resilient and sustainable agricultural systems.


## Introduction

The increasing concentration of greenhouse gases, particularly carbon dioxide ($CO_2$), has accelerated global warming and climate change. Rising temperatures, erratic rainfall patterns, extreme weather events, and declining agricultural productivity have highlighted the urgent need for effective climate change mitigation strategies. While reducing emissions remains essential, there is also a growing need to remove carbon dioxide already present in the atmosphere. Natural ecosystems play a critical role in regulating the global carbon cycle. Among these systems, soils serve as one of the largest carbon sinks on Earth, storing more carbon than the atmosphere and vegetation combined. However, unsustainable agricultural practices, deforestation, excessive tillage, and land degradation have led to substantial losses of soil organic carbon over time. Soil carbon sequestration has emerged as a promising solution to address these challenges. By capturing atmospheric carbon and storing it in soils, this process helps mitigate climate change while simultaneously improving soil fertility, water retention, and agricultural sustainability.

## Concept of Soil Carbon Sequestration

Soil carbon sequestration refers to the process of capturing atmospheric carbon dioxide and storing it in the soil as organic or inorganic carbon for extended periods. Plants absorb carbon dioxide through photosynthesis and convert it into organic compounds. A portion of this carbon enters the soil through plant residues, roots, root exudates and deco-

**Vishal Kumar**
Department of Soil Scienec, GBPUAT, Pantnagar, Uttarakhand

mposing organic matter. When properly managed, soils can accumulate and retain carbon over long periods, reducing the amount of carbon dioxide in the atmosphere. The stored carbon contributes to the formation of soil organic matter, which plays a fundamental role in maintaining soil health and productivity. The primary objective of soil carbon sequestration is to increase carbon storage while enhancing the ecological and agricultural functions of soils.

## Mechanisms of Soil Carbon Sequestration

Several biological and ecological processes contribute to carbon storage in soils.

**Plant Photosynthesis and Biomass Production:** Photosynthesis serves as the entry point of carbon into terrestrial ecosystems. Plants absorb carbon dioxide from the atmosphere and convert it into biomass. Major contributions include:

- ✓ Carbon capture from the atmosphere.
- ✓ Production of plant biomass.
- ✓ Addition of organic residues to soil.
- ✓ Enhancement of soil organic matter formation.

The greater the biomass production, the larger the potential for carbon input into the soil.

**Soil Organic Matter Formation:** Plant residues and organic materials undergo decomposition by soil microorganisms, leading to the formation of soil organic matter. Major benefits include:

- ✓ Long-term carbon storage.
- ✓ Improved soil fertility.
- ✓ Enhanced nutrient cycling.
- ✓ Greater soil stability.

Soil organic matter acts as a major reservoir of carbon and contributes significantly to soil quality.

**Biological and Microbial Processes:** Soil micro-organisms play a crucial role in transforming organic materials into stable carbon compounds. Their activities influence both carbon storage and nutrient cycling. Important functions include:

- ✓ Decomposition of organic residues.
- ✓ Formation of stable carbon pools.
- ✓ Improvement of soil aggregation.
- ✓ Enhancement of soil biological activity.

Healthy microbial communities are essential for efficient carbon sequestration and sustainable soil functioning.

## Applications of Soil Carbon Sequestration

**Climate Change Mitigation:** One of the most important applications of soil carbon sequestration is its ability to reduce atmospheric carbon dioxide concentrations. Increased carbon storage in soils helps offset greenhouse gas emissions and contributes to climate change mitigation efforts. By functioning as a natural carbon sink, agricultural soils can play a significant role in achieving global climate goals.

**Improvement of Soil Health:** Soil organic carbon is a key indicator of soil health. Increased carbon levels improve soil structure, nutrient availability, water-holding capacity, and biological activity.

Benefits include:

- ✓ Improved soil fertility.
- ✓ Better aggregation and structure.

- ✓ Enhanced microbial activity.
- ✓ Increased nutrient-use efficiency.

These improvements support long-term agricultural productivity.

**Sustainable Agricultural Production:** Carbon-rich soils are generally more productive and resilient. Enhanced soil organic matter improves crop growth by providing a favorable environment for root development and nutrient uptake. As a result, soil carbon sequestration contributes to sustainable crop production while reducing dependence on external inputs.

**Climate Resilience and Water Conservation:** Soils with higher organic carbon content exhibit greater water retention capacity and improved resilience to drought conditions. This becomes increasingly important as climate variability intensifies. Improved water infiltration and storage help crops withstand periods of moisture stress and maintain productivity under adverse conditions.

**Ecosystem Restoration and Environmental Protection:** Soil carbon sequestration supports ecosystem restoration by improving degraded lands and promoting biodiversity. Increased carbon storage also reduces soil erosion and enhances ecosystem stability.

## Challenges and Limitations

Despite its immense potential, soil carbon sequestration faces several challenges. The amount of carbon that can be stored varies depending on soil type, climate, vegetation, and management practices. Carbon sequestration is often a slow process that may require years or decades to produce significant results. Additionally, carbon stored in soils can be lost through inappropriate land management practices, erosion, deforestation, or intensive tillage. Accurate measurement and monitoring of soil carbon stocks also remain technically challenging and require advanced methodologies. Economic incentives and policy support are often needed to encourage widespread adoption of carbon-sequestering practices among farmers.

## Future Prospects

The future of soil carbon sequestration is closely linked to the development of climate-smart agricultural systems and sustainable land management strategies. Increasing awareness of carbon farming, regenerative agriculture, conservation agriculture, and ecosystem restoration is expected to promote greater adoption of carbon sequestration practices. Advances in remote sensing, digital soil mapping, and carbon monitoring technologies will improve the assessment and verification of soil carbon stocks. Growing interest in carbon credit markets may provide additional economic opportunities for farmers to adopt carbon-friendly management practices. As global efforts to address climate change intensify, soil carbon sequestration is expected to become a central component of sustainable agricultural and environmental policies.

## Conclusion

Soil carbon sequestration represents a natural and effective strategy for mitigating climate change while enhancing soil health and agricultural sustain-

ability. By capturing atmospheric carbon dioxide and storing it in soils, this approach contributes to greenhouse gas reduction, improved soil fertility, increased water retention, and greater ecosystem resilience. The practice offers multiple environmental and agricultural benefits, making it an attractive solution for addressing both climate and food security challenges. Although limitations related to measurement, permanence, and management exist, continued research, technological advancements, and supportive policies can enhance its effectiveness. Soil carbon sequestration will play an increasingly important role in building resilient agricultural systems and promoting a sustainable future.

## References

Kar, S., Paul, S., Hati, D., Mallick, S. and Banerjee, A. (2025). A review on soil carbon sequestration: A natural solution to climate change. *SAYAM*, 3(1): 61-69.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123(1-2): 1-22.

Prajapati, S. K., Choudhary, S., Kumar, V., Dayal, P., Srivastava, R., Gairola, A. and Borate, R. (2023). Carbon sequestration: A key strategy for climate change mitigation towards a sustainable future. *Climate Change*, 2: 1-14.

Raihan, A. (2023). A review of climate change mitigation and agriculture sustainability through soil carbon sequestration. *Journal of Agriculture Sustainability and Environment*, 2997: 23-56.

# Identification of Suitable Linseed Varieties for Mid Hill Ecosystem

**Badapmain Makdoh, Letngam Touthang, Ampee Tasung and Rajesh Khan**

## Introduction

Linseed (*Linum usitatissimum* L.) offers significant potential to boost income for marginal farmers in Northeast India. It is an important industrial and edible oil and fiber producing cropThe crop is being grown either for oil or fiber (linen) purposes depending on the varieties selected. The food products supplemented with flaxseed are becoming increasingly trendy due to their high levels of unsaturated fatty acids, protein, phytonutrients and soluble fibre. Inspite of its economic importance, most of the farmers in NEH region are not aware about the potential of this crop. The lack of improved varieties and untimely sowing, is also one of the important factor resulting in low crop yield of linseed. In NEH region, the crop is suitable for winter (*rabi*) season with optimum sowing time from October-November.

## Materials and Methods

The varietal trial of linseed was carried out at the research farm Gori, ICAR RC for NEH AP Centre. A total of 6 varieties namely JLS-95, RLC-153, LSL-93, T-395 (NC), Shekhar, Priyam (ZC) evaluated for yield and suitability to local climatic conditions in mid hill ecosystem. The crop was sown on first week of November in RBD with 3 replication with a spacing of 30 cm x 10 cm and following the recommended package of practices.

## Results and Discussions

The variation in mean values of different yield traits of linseed was shown in table-1 and the field performance of the varieties was illustrated in Figure-1. Mean plant height was highest in RLC-153 (79.01 cm) and lowest in LSL-93 (49.08 cm). Days to fifty percent flowering was shortest in LSL-93 (77.25) and longest in Priyam (103.75 days). While shortest days to maturity was recorded in T-395 (144.25 days) and longest in JLS-95 (149.5 days). Highest crop stover yield of 41.55 q $ha^{-1}$ was recorded in RLC-153, and lowest in LSL-93 (18.37q $ha^{-1}$). The highest seed yield of 13.76 q $ha^{-1}$ was recorded in Priyam followed by T-395 (13.15 q $ha^{-1}$), RLC-153 (13.05 q $ha^{-1}$), Shekher (12.73 q $ha^{-1}$), JLS-95 (12.42 q $ha^{-1}$) and lowest in LSL-93 (9.66 q $ha^{-1}$). Thus, Priyam and T-395 can be identified as most suited and promising and could be promoted in the NEH region for augmentation of oilseed yield production and productivity. In addition to that, this varieties can also be taken up as frontline demonstration for popularization of linseed in NEH region where the farmers are not much aware about the importance and potential of this crop.

**Badapmain Makdoh, Letngam Touthang and Rajesh Khan**
ICAR Research Complex for NEH Region, Umiam, Meghalaya
**Ampee Tasung**
ICAR Research Complex for NEH Region, Arunachal Pradesh Centre, Basar, Arunachal Pradesh

**Table 1: Performance of different linseed varieties in mid hill climatic condition of Arunachal Pradesh**

| Varieties | Plant height (cm) | Days to 50 % flowering | Days to maturity | Stover yield (q $ha^{-1}$) | Seed Yield (q $ha^{-1}$) |
|---|---|---|---|---|---|
| LSL-93 | 49.08 | 77.25 | 151.5 | 18.37 | 9.66 |
| RLC-153 | 79.01 | 101.5 | 152 | 41.55 | 13.05 |
| T-395 | 57.92 | 88 | 144.25 | 21.97 | 13.15 |
| Priyam | 69.83 | 103.75 | 147 | 39.9 | 13.76 |
| JLS-95 | 68.28 | 95.25 | 157.75 | 35.37 | 12.42 |
| Shekhar | 67.06 | 98 | 149.5 | 25.72 | 12.73 |
| SE(m) | 3.04 | 3.48 | 0.474 | 3.42 | 0.30 |
| C.D. | 9.25 | 10.57 | 1.443 | 10.40 | 0.92 |

Fig. 1: Field performance of different linseed varieties in mid hill condition, Arunchal Pradesh

Linseed crop is easy to grow and adaptable to any soil conditions. Hence it can be incorporated into different cropping systems for diversification in enhancing cropping intensity and income generation of small and marginal farmers. Flaxseed as a functional food has a vast array of medical benefits and nutraceutical values. It can be grown as dual purposes for seed and the extraction of fibre from the stover. With this wide array of applications, it has a huge potential to be popularized by attracting young entrepreneurs and start-ups to come up with diverse valuable products.

## Conclusion

Linseed crop with its versatility and climatic adaptability offers ample scope for its expansion for cultivation under conserved soil moisture and limited soil nutrient conditions with lesser management practices. The major constraints for cultivation of linseed in NEH region includes soil acidity, water scarcity during post monsoon period, short time lag period after harvest of paddy in case of rice-based cropping systems, lack of irrigation facilities, etc. Thus, identification of short- varieties with manipulation of sowing time is necessary to mitigate the co-incidence of pre-*kharif* monsoon showers during crop maturity. Further, sensitization and popularization programmes need to be intensified among the small and marginal farmers in the region.

# Requirement of Pulse Crops

**Namha Y. P., Kalal P. H. and Prajapati A. S.**

## Introduction

Pulse crops play a vital role in agriculture and human nutrition, especially in countries like India where they are a major source of protein. Pulses such as gram (chickpea), lentil, pigeon pea, green gram, and black gram are widely cultivated due to their ability to fix atmospheric nitrogen and improve soil fertility. Despite their importance, pulse crops are generally grown under rainfed conditions and require careful water management. Understanding their water requirements is essential for improving yield, conserving water and ensuring sustainable agriculture. Pulse crops are highly nutritious and are often called the "poor man's meat" because they are a rich and affordable source of protein. They form an essential part of the diet, especially in countries like India. Pulse crops such as chickpea, lentil, green gram, and pigeon pea are packed with essential nutrients required for human health. It helps in muscle building and repair due to high protein, and improves digestive health because of fibre, it prevents anaemia due to iron content, supports heart health by lowering cholesterol and promotes overall growth and immunity. Pulse crops are not only important for agriculture but also provide high nutritional value, making them essential for a balanced and healthy diet.

Fig. 1: Different Types of Pulse Crops

## Importance of Water in Pulse Crops

Water is a crucial factor influencing the growth, development, and productivity of pulse crops. It helps in seed germination, nutrient absorption, photosynthesis, and transportation of food within the plant. However, pulses are sensitive to both excess and deficiency of water. While insufficient water can lead to poor growth and reduced yield, excess water can cause root diseases and waterlogging, which severely affect crop performance.

## General Water Requirement of Pulse Crops

Pulse crops generally require low to moderate amounts of water compared to cereals like rice and wheat. The total water requirement depends on factors such as crop type, soil condition, climate, and growth stage. On average, pulses require about 300-500 mm of water during their growing period. Most pulse crops are drought-tolerant and can grow

**Namha Y. P.**
B.Sc. (Hons.) Agriculturee Student, Rai School of Agriculture, Rai University, Ahmedabad, Gujarat
**Kalal P. H. and Prajapati A. S.**
Assistant Professor, Department of Agronomy, Rai School of Technology, Ahmedabad, Gujarat

in areas with limited rainfall, making them suitable for dryland farming.

## Critical Growth Stages for Water Requirement

Although pulses need less water, there are certain stages where water is very important:

**Germination Stage:** Adequate moisture is necessary for proper seed sprouting.

**Flowering Stage:** Water stress at this stage can reduce flower formation and lead to poor pod development.

**Pod Formation Stage:** Sufficient water ensures better seed filling and higher yield.

Among these, the flowering and pod formation stages are the most critical for irrigation.

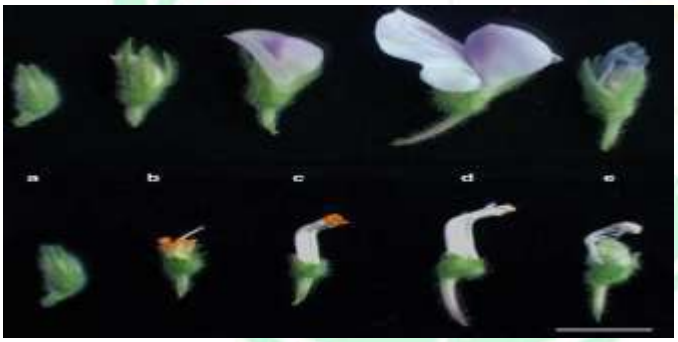


Fig. 2: 5 main stages of chickpea flower development

## Irrigation Practices for Pulse Crops

Pulse crops are usually grown under rainfed conditions, but supplemental irrigation can significantly increase yield. Proper irrigation practices include:

- ✓ Light irrigation at critical stages
- ✓ Avoiding excessive watering to prevent waterlogging
- ✓ Using efficient methods like drip irrigation or sprinkler systems
- ✓ Maintaining proper field drainage

Typically, 1-3 irrigations are sufficient depending on rainfall and soil type.

Fig. 3: Irrigation Practices

## Effect of Soil Type on Water Requirement

Soil type plays a major role in determining water needs:

**Sandy soils:** Require frequent irrigation due to low water retention

**Clay soils:** Retain more water but may cause waterlogging

**Loamy soils:** Ideal for pulse cultivation due to balanced water retention and drainage

Proper soil management helps in optimizing water use efficiency.

## Climatic Influence on Water Requirement

Climate conditions such as temperature, humidity, and rainfall affect water requirements:

- ✓ High temperature increases evaporation and water demand
- ✓ Low humidity leads to faster moisture loss
- ✓ Adequate rainfall reduces the need for irrigation

Pulse crops grow best in moderate climatic conditions with well-distributed rainfall.

## Water Stress and Its Effects

Water stress can have serious impacts on pulse crops:

- ✓ Reduced plant growth and leaf area
- ✓ Flower drop and poor pod setting

- ✓ Lower seed size and yield
- ✓ Increased susceptibility to pests and diseases

Proper irrigation management helps in minimising these effects.

Fig. 4. : Salinity and Drought stress in plants

## Waterlogging and Its Impact

Unlike some crops, pulses are highly sensitive to waterlogging:

- ✓ Roots do not get enough oxygen
- ✓ Leads to root rot and fungal diseases
- ✓ Causes yellowing of leaves and plant death

Therefore, good drainage is essential for pulse cultivation.

## Water Management Techniques

Efficient water management improves productivity and conserves resources:

- ✓ Use of mulching to reduce evaporation
- ✓ Rainwater harvesting and storage
- ✓ Use of drought-resistant varieties
- ✓ Scheduling irrigation based on crop stage
- ✓ Maintaining proper drainage systems

These practices help in maximizing water use efficiency.

## Conclusion

Pulse crops require relatively less water compared to other crops, making them suitable for sustainable agriculture and dryland farming. However, proper water management is essential, especially during critical growth stages like flowering and pod formation. Both water scarcity and excess can negatively impact yield. By adopting efficient irrigation practices and maintaining proper drainage, farmers can improve productivity while conserving water resources. Thus, understanding the water requirements of pulse crops is key to achieving higher yields and sustainable agricultural development.

## References


Indian Council of Agricultural Research. (2020). *Handbook of Agriculture* (7th ed.). Directorate of Knowledge Management in Agriculture, ICAR, New Delhi.

Food and Agriculture Organization of the United Nations. (2021). FAOSTAT database. https://www.fao.org/faostat

Food and Agriculture Organization of the United Nations. (2017). Water for Sustainable Food and Agriculture. Rome: FAO.

Indian Institute of Pulses Research. (2019). Production Technology of Major Pulse Crops. Kanpur, Uttar Pradesh.

Reddy, S. R. (2017). Principles of Agronomy (5th ed.). Kalyani Publishers, New Delhi.

# Artificial Intelligence as a Catalyst for Fruit Crop Production: Emerging Opportunities and Applications

**P. Swarnalatha and Potnuru Santosh Kumar**

## Introduction

Fruit cultivation plays a significant role in agricultural development and contributes substantially to nutritional security, rural employment, and economic growth. India is one of the world's leading producers of fruits owing to its diverse agro-climatic conditions, fertile soils, and rich biodiversity. The country cultivates a wide range of fruit crops, including mango, banana, citrus, guava, papaya, pomegranate, grapes and apple which contribute considerably to farmers' incomes and export earnings. However, fruit production is highly vulnerable to various biotic and abiotic stresses such as pest and disease outbreaks, water scarcity, nutrient deficiencies, erratic climatic conditions, and post-harvest losses. Traditional farming practices often rely on manual observations and experience-based decisions, which may not always ensure efficient management of these challenges. Therefore, there is an increasing need for advanced technologies that can support precise, timely, and data-driven decision-making in fruit production systems. Artificial Intelligence (AI) refers to the ability of machines and computer systems to mimic human intelligence by learning from data, identifying patterns, and making informed decisions. The concept of Artificial Intelligence has evolved rapidly in recent decades and is now being integrated into various sectors, including agriculture and horticulture. In fruit crops, AI technologies have emerged as powerful tools for enhancing productivity, improving resource-use efficiency, and promoting sustainable cultivation practices. Artificial Intelligence combines machine learning, computer vision, robotics, sensor technologies and data analytics to address several challenges in fruit production. AI-powered systems can monitor crop growth, identify pests and diseases at an early stage, estimate yield, optimize irrigation schedules, and automate harvesting operations. These technologies help farmers minimize production costs, improve fruit quality, reduce environmental impacts, and maximize profitability. The increasing availability of smartphones, sensors, drones, satellite imagery, and cloud computing has accelerated the adoption of AI in horticulture. By transforming conventional farming into smart farming, Artificial Intelligence has the potential to revolutionize fruit crop management and contribute significantly toward achieving sustainable agricultural development.

## Advantages of Artificial Intelligence in Fruit Crops

The major benefits of AI applications in fruit production include:

**P. Swarnalatha and Potnuru Santosh Kumar**
Teaching Associate, Advanced Post Graduate Centre (APGC), ANGAU, Lam, Guntur, Andhra Pradesh

- ✓ Facilitates precision farming and efficient resource management.
- ✓ Enhances fruit quality and productivity through data-driven decision-making.
- ✓ Enables early detection of pests, diseases, and nutrient deficiencies.
- ✓ Optimizes irrigation scheduling and water-use efficiency.
- ✓ Reduces labour requirements and operational costs.
- ✓ Supports real-time monitoring of orchard conditions.
- ✓ Improves weather forecasting and risk management strategies.
- ✓ Minimizes post-harvest losses and improves supply chain efficiency.
- ✓ Assists farmers in making timely and informed management decisions.
- ✓ Promotes sustainable and environmentally friendly fruit production systems.

## Applications of Artificial Intelligence in Fruit Crops

**Smart Disease and Pest Detection:** Artificial Intelligence-based image recognition systems can identify diseases and insect infestations in fruit crops by analyzing photographs captured using smartphones, cameras, or drones. Machine learning algorithms compare images with existing databases and provide instant recommendations regarding disease diagnosis and management. Early detection minimizes crop damage and reduces excessive pesticide usage.

**Precision Irrigation Management:** AI-integrated irrigation systems use sensors to monitor soil moisture, temperature, humidity and weather conditions. Based on real-time information, the system automatically determines the quantity and timing of irrigation required by fruit plants. Such precision irrigation techniques improve water-use efficiency and prevent over-irrigation and nutrient leaching.

**Fruit Maturity and Quality Assessment:** Computer vision technologies can accurately determine fruit maturity by analyzing colour, size, shape, and texture characteristics. AI systems help farmers identify the optimal harvesting stage, thereby improving fruit quality, extending shelf life, and reducing post-harvest losses. Automated grading systems also classify fruits into different quality categories for marketing purposes.

**Drone-Based Orchard Monitoring:** Unmanned aerial vehicles equipped with cameras and sensors provide high-resolution images of orchards. AI algorithms analyse these images to identify water stress, nutrient deficiencies, pest attacks, and canopy variations. Drone technology enables large-scale monitoring within a short time and assists farmers in implementing site-specific management practices.

**Yield Prediction and Production Forecasting:** Machine learning models analyze historical production data, weather parameters, soil characteristics, and management practices to predict fruit yield accurately. Reliable yield forecasting enables farmers and policymakers to make better decisions

regarding harvesting, storage, transportation, and marketing strategies.

**Autonomous Fruit Harvesting Systems:** Labour scarcity during harvesting seasons is a major challenge in fruit production. AI-powered harvesting robots equipped with sensors, cameras, and robotic arms can identify ripe fruits and harvest them carefully without causing damage. Such automated systems are increasingly being developed for crops like apples, strawberries, citrus, and tomatoes.

**Nutrient Management and Fertilizer Recommendations:** Artificial Intelligence systems can assess nutrient requirements by integrating information on soil fertility, plant growth stages, and environmental conditions. AI-based decision support systems recommend precise fertilizer doses, thereby reducing input costs and minimizing environmental pollution.

**Post-Harvest Management and Supply Chain Optimization:** Artificial Intelligence plays an important role in reducing post-harvest losses by monitoring storage conditions and predicting fruit deterioration. AI-assisted supply chain systems optimize transportation routes, maintain quality during storage, and improve market efficiency. These technologies ensure that high-quality fruits reach consumers while minimizing wastage.

## Future Prospects

The future of Artificial Intelligence in fruit crop production is highly promising. Continuous advancements in sensor technologies, machine learning algorithms, robotics, and Internet of Things (IoT) devices are expected to transform fruit cultivation into a highly efficient and sustainable enterprise. Integration of AI with precision agriculture technologies can significantly enhance productivity, reduce resource wastage, and improve resilience to climate variability. Although challenges such as high initial investment, limited digital literacy, and inadequate infrastructure may restrict adoption in some regions, increasing governmental support and technological innovations are expected to accelerate the implementation of AI-driven solutions in horticulture. Artificial Intelligence has the potential to become an indispensable component of modern fruit production systems and contribute substantially to food security, economic development and sustainable horticulture.

## References

Bassine, F. Z., Epule, T. E., Kechchour, A. and Chehbouni, A. (2023). Recent applications of machine learning, remote sensing, and IoT approaches in yield prediction: A critical review. *arXiv*. https://arxiv.org/abs/2306.04566.

Chandra, T., Sarika, Iquebal, M. A., Kumar, D., Dey, S. S. and Prakesh, J. (2025). Artificial intelligence-assisted technologies in horticultural crop management. *Indian Horticulture*.

Furuya, D. E. G., Bolfe, É. L., Parreiras, T. C., Barbedo, J. G. A., Santos, T. T. and Gebler, L. (2024). Combination of remote sensing and artificial intelligence in fruit growing: Progress, challenges and potential applications. *Remote Sensing*, 16(24): 4805.

Gouda, A. K., Meena, N. K., Mazumder, C., Rath, P., Inamdar, F., Singh, A., Raghuram, P. and Kant, G. (2026). Application of artificial intelligence and machine learning in fruit crop management: A review. *Plant Archives*, 26(1): 823-830.

Nawaz, U., Zaheer, M. Z., Khan, F. S., Cholakkal, H., Khan, S. and Anwer, R. M. (2025). AI in agriculture: A survey of deep learning techniques for crops, fisheries and livestock. *arXiv*. https://arxiv.org/abs/2507.22101.

Pearson, S. (2025). Artificial intelligence in horticulture. *The Journal of Horticultural Science and Biotechnology*, 100(5): 564-570.

Reddy, P. P. N. (2025). Role of artificial intelligence in fruit crop cultivation: A review. *Journal of Krishi Vigyan*, 13(4): 1-12.

Sebastian, K., Balakrishnan, D., Koshy, S. M. and Sabu, S. S. (2023). Application of artificial intelligence in horticulture: A review. *Ecology, Environment and Conservation*, 29(Suppl.): S259-S268.

Yang, B. and Xu, Y. (2021). Applications of deep-learning approaches in horticultural research: A review. *Horticulture Research*, 8: Article 123.

Aashu, Rajwar, K., Pant, M. and Deep, K. (2024). Application of machine learning in agriculture: Recent trends and future research avenues. *arXiv*. https://arxiv.org/abs/2405.17465.

# Revolutionizing Food Safety: Sensor Technology in Spoilage Detection and Microbiological Assessment

**Judy Lalthanmawii, Rathod Rohit Kailasrao and Jainam Patel Nanubhai**

## Introduction

The term "food spoilage" describes the decline in food safety and quality that results in changes to the food's flavour, texture, odour, appearance, or the growth of harmful micro-organisms, rendering it unfit for human consumption. Food spoiling is a widespread issue that affects the financial viability of the food industry as well as consumer health. Early and accurate detection of food deterioration is crucial for maintaining consumer confidence, minimizing financial losses, and ensuring food safety. Conventional techniques for identifying spoiling, such as sensory evaluation and microbiological culture-based methods, are laborious and have little sensitivity. Biosensors have developed into quick, sensitive, and extremely dependable techniques for identifying signs of food spoiling in recent years. Biosensors are one such cutting-edge technique that has been created to address some significant issues with the examination of food samples. Furthermore, using biosensors to monitor and deliver fast, real-time information will be better than using conventional microbiological techniques. Biosensors are made up of unique biological detecting and transducer components that allow for the identification and measurement of indicators linked to food spoilage.

A variety of methods, from sensitivity detection to sensory detection, can be used to identify spoiled food, even at low levels of contamination.

## Factors Affecting Food Spoilage

Effective strategies to prevent or minimize food spoilage require an understanding of the factors that influence it. A number of interrelated factors, including internal and extrinsic characteristics, influence the rotting process; proper management of these factors is required to prevent or delay food spoilage and reduce the risk of microbial contamination.

### Intrinsic factors

- ✓ **Composition:** A food's moisture content, nutritional makeup, pH level, and the presence of natural antibacterial agents such as carvacrol, vanillin, allicin, cinnamic aldehyde, etc. all affect how easily it deteriorates. Some microorganisms may flourish in environments rich in nutrients, while others may be constrained by acidic or alkaline conditions.
- ✓ **Water activity:** A food's water content, or "water activity," is a major contributor to the growth of microorganisms that cause food deterioration. Antibodies are promoted by high water activity.

### Extrinsic factors

**Judy Lalthanmawii, Rathod Rohit Kailasrao and Jainam Patel Nanubhai**
Research Scholar, Division of Livestock Products Technology, ICAR-IVRI, Izzatnagar, Bareilly, Uttar Pradesh

- ✓ **Temperature:** Temperature is one of the most significant external factors influencing food decomposition. Since microbial growth is facilitated by higher temperatures, it may accelerate degradation by speeding up enzymatic activity and microbial growth. Inadequate temperature control during storage or transportation can significantly shorten the shelf life of perishable food.

**Exposure to light and oxygen:** The availability of oxygen facilitates the easy proliferation of aerobic bacteria, which can accele-rate oxidative processes that reduce food's nutritional value and produce off-putting flavors. Similarly, food may undergo unintended changes in colour or flavour due to certain chemical reactions triggered by ultraviolet radiation. Appropriate packing techniques can reduce exposure to light and oxygen, such as vacuum packing in opaque containers.

**Humidity:** An essential component of microbial development is water content. Food deterioration can result from high humidity, which can encourage the growth of mold and yeast. It may also result in moisture migration, which could change the food's texture.

**Microorganisms:** High-protein, high-moisture foods including milk, dairy products, poultry, fish, meat, and others are nourishing, have a pH of either neutral or slightly acidic, and therefore frequently serve as an ideal environment for microbes. Temperature, water activity, pH, oxygen availability, and nutritional content all have an impact on microbiological growth. These microorganisms' proliferation leads to food spoiling, which costs the food sector a lot of money. However, if these items are consumed by humans, they can cause serious health problems. Certain enzymes that catalyze chemical reactions and alter flavor, color, texture, and nutrient composition can be released by microorganisms. Protein degradation, lipid oxidat-ion, enzymatic browning, and other spoiling-related processes can be caused by enzymatic reactions. Gram-positive spore-forming bacteria, Gram-positive rod-shaped bacteria, lactic acid bacteria, yeasts, and molds are some of the main categories into which the microorganisms that cause spoiling can be divided. Salmonella, *Escherichia coli* (*E. coli*), and norovirus are the most prevalent bacteria that cause various illnesses and outbreaks.

**Yeast and Molds:** Yeasts and molds are versatile organisms capable of thriving on various nutrients, including carbohydrates, pectin, organic acids, proteins, lipids, benzoate, propionate, and sorbate, making them widespread in nature. They can endure harsh environmental conditions such as low pH, limited moisture, extreme temperatures, and the presence of preservatives. Contamination by yeasts and molds has been documented in packaged meats, fresh seafood, deli-style salads, and fresh vegetables. Their spoilage effects include slime formation, acid production, surface pigmentation, and undesirable flavors. Mold-induced spoilage can also lead to mycotoxin release, which poses multiple toxic threats. Various fungal strains contribute to mycoto-

xin contamination, primarily from the genera *Aspergillus, Fusarium,* and *Penicillium*. These mycotoxins trigger oxidative stress, leading to DNA damage and reduced cell viability. Their presence in food results in significant spoilage and economic losses. Early detection is critical due to their extremely low concentrations (measured in parts per billion or nanograms). Exposure to mycotoxins can cause severe clinical symptoms, often requiring expensive medical treatments.

## Biosensors for Detection of Food Spoilage

A biosensor is an innovative and efficient analytical device with a biological sensing capability, widely applied in fields such as food safety, environmental monitoring, biomedicine, and drug discovery. These devices are specifically designed to detect microbial contamination by utilizing interactions between biologically active components, a transducer, and a signal conversion system. Biosensors are essential in maintaining food safety and quality, significantly benefiting the food industry by extending the shelf life of products.

These advanced tools integrate biological recognition elements with transducers to identify spoilage indicators in samples. They enable fast, sensitive, and highly specific detection, allowing timely interventions to minimize the risk of food contamination and spoilage. The biological recognition element is the core component of a biosensor, and its selection depends on the specific spoilage marker being detected. For example, microbial biosensors employ antibodies, enzymes, or DNA probes to identify bacteria responsible for food degradation, while chemical biosensors detect chemicals or metabolites associated with spoilage processes. Compared to traditional methods, biosensors offer several advantages in detecting food deterioration. They require minimal sample preparation, are cost-effective, and are portable. Additionally, they provide near real-time monitoring, enabling rapid assessment of food quality and freshness. These biosensors can be integrated into various stages of the food supply chain, including production, processing, storage, and distribution, ensuring continuous monitoring and quality control. Based on their target analyte, biosensors can be classified into different categories.

**Chemical biosensors:** Chemical biosensors are designed to identify specific metabolites or chemical compounds linked to food spoilage. To accurately capture and detect spoilage-related molecules, these biosensors incorporate various chemical recognition elements, including antibodies, aptamers, and receptors. They play a crucial role in detecting harmful substances in food, such as toxins and allergens. Additionally, these sensors help identify gases produced by bacteria responsible for food deterioration. For example, enzymatic reactions during spoilage generate different gases, including ammonia, sulfur compounds, and volatile organic compounds (VOCs).

**Enzymatic biosensors:** Enzymatic biosensors are designed to detect enzyme activity as an indicator of food spoilage. These biosensors utilize enzymes as

recognition elements to specifically interact with spoilage-associated enzymes. They can identify enzymes such as proteases, lipases, and amylases, which are either produced by spoilage bacteria or released during food decomposition.

**DNA Biosensors:** DNA biosensors operate on the principle that a specific nucleotide sequence, known as a probe, is immobilized onto a selected transducer based on its ability to bind to complementary sequences in a sample. The detection process begins with a hybridization reaction between the probe and the nucleic acid present in the sample. Electrochemical transducers, known for their robustness and sensitivity, are commonly used to detect DNA hybridization. To enhance detection efficiency, DNA biosensors are often combined with PCR technology. Additionally, a disposable electrochemical low-density genosensor array enables the simultaneous detection of multiple pathogenic bacteria.

**Optical Biosensors:** Optical biosensors detect food spoilage by monitoring changes in the optical properties of food. These sensors measure variations in color, turbidity, fluorescence, or absorbance. They can identify spoilage indicators such as oxidation, protein denaturation, and microbial metabolites that alter the optical characteristics of food samples.

**Microbial Biosensors:** Microbial biosensors are designed to detect microorganisms in food by incorporating specific microbial recognition elements, such as antibodies, enzymes, or DNA probes. These biosensors can identify spoilage-causing bacteria, yeasts and molds, even at low concentrations, allowing for early intervention to prevent food deterioration.

**Nanobiosensors:** Nanobiosensors integrate nano-scale components with biosensor transducers to improve detection sensitivity. Advanced techniques such as Surface Enhanced Raman Spectroscopy (SERS) have been employed to identify contaminants in various food samples, including fish and melamine in milk. This method was further enhanced by synthesizing standing AuNR (gold nanorod) arrays, which generated strong electromagnetic fields, enabling the analysis of milk, orange juice, and grapefruit juice for carbaryl contamination. With this modified approach, contaminants as low as 50 parts per billion (ppb) can be detected. Magnetic nanoparticles have also been extensively studied for diverse applications, including glucose sensing, rhodamine quantification and removal, malaria diagnosis, and enzyme-linked immunosorbent assay (ELISA) for atrazine detection.

a) **Electrochemical Biosensors**

Electrochemical biosensors detect changes in electrical signals or other properties influenced by biochemical reactions associated with food spoilage. These biosensors utilize electrodes and transducers to convert biological interactions into electrical impulses. They can identify early signs of spoilage, such as pH fluctuations, redox reactions, and the release of specific ions.

b) **Mechanical Biosensors**

Mechanical biosensors measure the deflection of a mass-sensitive sensor surface when target

analytes bind to its functionalized surface. They are categorized into four main types based on sensor-analyte interactions: affinity-based assays, finger-print assays, separation-based assays, and spectrometric assays. Quartz Crystal Microbalance (QCM) is a widely used mechanical biosensor due to its ability to detect minute mass changes in sub-nanogram amounts. QCM biosensors recognize mass alterations by monitoring the resonant frequency shifts of quartz crystals, making them highly sensitive for quantifying entire microbial cells.

## Conclusions

Food spoilage contributes to food insecurity in various regions worldwide, causing significant economic losses for everyone in the supply chain, from producers to consumers. Detecting spoilage can be highly beneficial for food producers by minimizing waste and ensuring the delivery of high-quality products, ultimately improving consumer satisfaction. Various methods and strategies have been developed to detect contaminants in food samples. Among them, biosensor-based techniques are considered reliable, safe, and precise, making them suitable for monitoring food manufacturing processes in real time. These innovations not only reduce waste but also strengthen food security, benefiting consumers, farmers, and the environment alike. However, despite remarkable progress in biosensor technology, several challenges remain. Practical considerations such as cost, scalability, and user-friendliness must also be addressed for their effective implementation in real-world applications.

## References

Kumar, A., Kulshreshtha, S., Shrivastava, A. and Saini, A. (2024). Biosensors for food spoilage detection: a comprehensive review of current advances. *Journal of Food Chemistry and Nanotechnology*, 10(S1): S73-S82.

Ali, A. A., Altemimi, A. B., Alhelfi, N. and Ibrahim, S. A. (2020). Application of biosensors for detection of pathogenic food bacteria: a review. *Biosensors*, 10(6): 58.

Saini, R. V., Vaid, P., Saini, N. K., Siwal, S. S., Gupta, V. K., Thakur, V. K. and Saini, A. K. (2021). Recent advancements in the technologies detecting food spoiling agents. *Journal of Functional Biomaterials*, 12(4): 67.

# Climate Resilient Agriculture: Farming for a Changing Climate

**Nayana H. N., Shruthi G. S., Supriya M. E. and Dayanandanaik S.**


## Abstract

Agriculture is increasingly affected by climate change through rising temperatures, erratic rainfall and soil degradation, leading to reduced productivity and farmer income. Climate Resilient Agriculture (CRA) offers a sustainable approach by enhancing the adaptive capacity of farming systems. It includes practices such as efficient water management, climate-smart crop selection, diversification, agroforestry and soil health improvement. These strategies reduce production risks, improve resource use efficiency and ensure stable yields under stress conditions. CRA also promotes the use of weather-based advisories for better decision-making. By combining scientific innovations with traditional knowledge, it strengthens resilience to climate variability. Overall, CRA provides a viable pathway for sustainable agriculture and long-term livelihood security.


## Introduction

Agriculture has always depended on nature- but today, nature is becoming increasingly unpredictable. Farmers are noticing that rains no longer arrive on time, summers are hotter than before and extreme events like droughts and floods are becoming more common. These changes are not temporary; they are part of a larger global phenomenon known as climate change. To deal with these challenges, scientists and farmers have come together to promote a new way of farming called Climate Resilient Agriculture (CRA)- an approach that helps agriculture survive, adapt and even thrive under changing climatic conditions. Climate Resilient Agriculture (CRA) is a proactive and sustainable approach to farming that helps agricultural systems adapt to climate variability and extreme weather events. It focuses on adopting improved farming practices such as efficient water management, climate-adapted crop varieties and enhanced soil health management to reduce production risks. These measures enable crops to withstand stresses such as drought, high temperatures, irregular rainfall and temporary flooding while maintaining stable productivity. By strengthening the resilience of farming systems, CRA helps protect farmer livelihoods, minimize losses and ensure sustainable agricultural production under changing climatic conditions (Rao *et al.*, 2016).


**Nayana H. N.**
Research Scholar, Department of Soil Science and Agricultural Chemistry, UAS, GKVK, Bengaluru, Karnataka

**Shruthi G. S.**
Senior Research Fellow, AICRP on MSPE, UAS, GKVK, Bengaluru, Karnataka

**Supriya M. E.**
Assistant Professor, GPS Institute of Agriculture Management, Bengaluru, Karnataka

**Dayanandanaik S.**
Research Scholar, Department of Agronomy, UAS, GKVK, Bengaluru, Karnataka

Climate change affects agriculture through rising temperatures, erratic rainfall, extreme weather events and soil degradation, all of which reduce crop productivity and stability. Higher temperatures can cause heat stress, reduce photosynthesis and increase soil moisture loss, while irregular rainfall disrupts sowing schedules and water availability. Frequent droughts and floods further threaten crop growth, damage soil structure and increase production risks. In addition, soil degradation through erosion, nutrient depletion and loss of organic matter reduces the soil's capacity to support healthy crop growth. Climate Resilient Agriculture addresses these challenges by improving the ability of farming systems to absorb shocks, adapt to changing conditions and maintain sustainable productivity (Lal, 2011).

## Key Strategies of Climate Resilient Agriculture

Efficient water management is a key component of Climate Resilient Agriculture (CRA), helping farmers address water scarcity caused by erratic rainfall and rising temperatures. Practices such as rainwater harvesting through farm ponds and check dams improve water availability, while micro-irrigation systems like drip and sprinkler irrigation enhance water-use efficiency by reducing losses. Proper irrigation scheduling based on crop requirements further optimizes water use and minimizes both water stress and over-irrigation, thereby supporting sustainable crop production under changing climatic conditions (FAO, 2013). Another crucial strategy is climate-smart crop selection, which involves choosing crop varieties that are better adapted to stress conditions such as drought, heat or salinity. Drought-tolerant and short-duration varieties allow crops to complete their life cycle even under limited moisture conditions, while selecting crops suited to local agro-climatic zones improves survival and productivity. This approach significantly reduces the risk of crop failure under unpredictable weather conditions (ICAR, 2016).

**Table 1: Drought-Tolerant Crops and Varieties**

| Crop | Drought-Tolerant Variety/Hybrid |
|---|---|
| Pearl millet | HHB 67 Improved, ICTP 8203 |
| Finger millet | GPU-28, GPU-67, Indaf-9 |
| Sorghum | M 35-1, CSV 15, CSV 27 |
| Foxtail millet | DHFt-109-3, HMT-100-1 |
| Pigeon pea | Asha (ICPL 87119), Maruti |
| Chickpea | JG 11, JAKI 9218 |
| Groundnut | ICGV 91114, Kadiri 6 |
| Sunflower | KBSH-44, DRSH-1 |
| Castor | DCH-177, GCH-7 |
| Cotton | AKA-7, Suraj |
| Maize | DHM-117, Vivek Hybrid-9 |

Crop diversification is equally important in building resilience. By growing multiple crops through intercropping or mixed cropping systems, farmers spread risk across different species. Inclusion of crops like pulses, millets and oilseeds not only enhances nutritional security but also improves soil fertility and reduces dependency on a single crop. In case one crop fails due to adverse weather, other crops can still provide yield and income, ensuring livelihood security. In addition, agroforestry and integrated farming systems play a vital role in stabilizing agricultural production. The integration of trees with crops creates a favourable microclimate by reducing temperature extremes and wind speed, while tree roots help in improving soil structure and nutrient cycling. Similarly, combining

crops with livestock, poultry or fisheries diversifies income sources and enhances overall farm efficiency, making the system more resilient to climate shocks. Maintaining soil health is another fundamental component of CRA. Practices such as application of farmyard manure (FYM), compost and green manures increase soil organic matter, which improves water-holding capacity and nutrient availability. Mulching helps conserve soil moisture and regulate temperature, while reduced tillage preserves soil structure and minimizes erosion. Healthy soils act as a buffer against both drought and heavy rainfall, supporting consistent crop growth (IPCC, 2022). Finally, the use of weather-based advisory services has become an essential tool in modern climate-resilient farming. Farmers can access real-time weather forecasts through mobile applications and extension services, enabling them to make informed decisions regarding sowing, irrigation, fertilization and pest management. This timely information helps reduce losses caused by unexpected weather events and improves overall farm management efficiency.

**Table 2: Major Climate Challenges and Corresponding CRA Adaptation Strategies**

| Climate Challenge | CRA Practice | Benefit |
|---|---|---|
| Drought | Drip irrigation | Water saving |
| Heat stress | Heat-tolerant varieties | Stable yield |
| Soil degradation | Organic manures | Improved soil health |
| Flooding | Raised beds | Better drainage |

Together, these strategies form a comprehensive approach that strengthens the resilience of agricultural systems, helping farmers adapt to climate change while ensuring sustainable productivity and long-term food security.

Fig. 1: Climate-Smart Agriculture Pillars

## Role of Climate Resilient Agriculture in Supporting Farmers

Climate Resilient Agriculture (CRA) enhances the stability, productivity and adaptability of farming systems under changing climatic conditions. By adopting practices such as crop diversification, drought-tolerant varieties and efficient water management, farmers can reduce the risk of crop failure and maintain stable yields even during adverse weather conditions. Improved soil health, moisture conservation and climate-adapted crops further support productivity under heat and water stress while reducing input costs through efficient use of resources. It also contributes to long-term soil fertility and farm sustainability. Practices such as the application of organic manures, mulching and reduced tillage improve soil structure, increase organic matter content and enhance water-holding capacity. These measures strengthen resilience against drought and heavy rainfall, resulting in more consistent yields and improved livelihood security

for farmers. Simple and cost-effective practices such as drip irrigation, intercropping and agroforestry demonstrate the practical benefits of CRA. For example, intercropping millets with pulses reduces production risks during drought, while agroforestry improves soil fertility and creates a favourable microclimate. Overall, CRA provides an effective pathway for enhancing farm resilience, ensuring sustainable production and improving farmer income under changing climatic conditions.

## Conclusion

Climate change poses significant challenges to agriculture through rising temperatures, erratic rainfall, extreme weather events and soil degradation, all of which adversely affect crop productivity and farmer livelihoods. Climate Resilient Agriculture (CRA) offers a sustainable solution by integrating efficient water management, climate-adapted crops, diversification and improved soil health practices. These strategies enhance the ability of farming systems to withstand and recover from climatic stresses while ensuring stable yields and efficient resource utilization. The adoption of CRA is particularly important in vulnerable and dryland regions where climate variability is high. Overall, CRA provides a practical pathway for sustainable agricultural production, environmental conservation and long-term livelihood security.

## References

Lal, R. (2011). Sequestering carbon in soils of agro-ecosystems. *Food Policy*, 36(S1): S33-S39.

Rao, C. S., Prasad, J. V. N. S., Mishra, P. K. and Rao, K. V. (2016). Climate resilient agriculture in India. *Indian Journal of Agronomy*, 61(4): 1-11.

FAO. (2013). *Climate-Smart Agriculture Source-book*. Food and Agriculture Organization of the United Nations, Rome, Italy.

ICAR. (2016). *Climate Resilient Agriculture in India: Initiatives and Approaches*. Indian Council of Agricultural Research, New Delhi, India.

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge University Press, Cambridge, United Kingdom.

# 3D Food Printing Technologies and their Potential

**Lad P. A., V. P. Kad and G. M. Chavan**


## Abstract

3D food printing, an emerging application of additive manufacturing, is transforming the way food is designed, produced and consumed. By depositing edible materials layer by layer, this technology enables unprecedented customization of food shape, texture, nutritional composition and appearance. This article explores the fundamental principles of 3D food printing, reviews the major printing technologies currently in use including extrusion-based printing, inkjet printing, binder jetting and selective laser sintering and examines the diverse range of edible materials compatible with each. Furthermore, the article highlights the vast potential of this technology across sectors such as personalized nutrition, the hospitality industry, space food systems and sustainable food production. Challenges including printing speed, food safety, consumer acceptance and scalability are also discussed. The future of 3D food printing holds remarkable promise in redefining food engineering and nutrition science.


## Introduction

Imagine walking into a restaurant and receiving a meal designed precisely for your nutritional needs, shaped into any form your imagination can conceive and prepared without human hands touching the ingredients. This is no longer science fiction it is the promise of 3D food printing, one of the most exciting frontiers in modern food engineering. The concept of additive manufacturing, popularly known as 3D printing, was first introduced in the 1980s for industrial applications. It works on a simple principle: building a three-dimensional object by adding material layer by layer based on a digital design file.

In recent years, this same principle has been adapted for use with edible materials, giving rise to the field of 3D food printing. Food engineers and food scientists around the world are increasingly recognizing the transformative potential of this technology. From hospitals seeking to improve patient nutrition to space agencies exploring food solutions for long-duration missions, 3D food printing is capturing the attention of researchers, chefs and industrialists alike. This article aims to provide a comprehensive yet accessible overview of 3D food printing technologies. It covers the working principles of various printing methods, the types of food materials used, the key sectors where this techn-


**Lad P. A. and G. M. Chavan**
Research Scholar, Department of Agricultural Processing Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri, Ahilyanagar, Maharashtra

**V. P. Kad**
Associate Professor, Department of Agricultural Processing Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, MPKV, Rahuri, Ahilyanagar, Maharashtra

ology is being applied and the challenges that must be overcome before it becomes mainstream.

## What is 3D Food Printing?

3D food printing is a process in which food ingredients in liquid, paste, gel, or powder form are deposited in successive layers to construct a three-dimensional edible product. The process is controlled by a computer program that reads a digital blueprint similar to a recipe encoded in geometry and instructs the printer on where and how to deposit each layer of material. The key components of a 3D food printing system include:

- ✓ A digital design file (CAD model) specifying the structure of the food item
- ✓ A printing mechanism suited to the type of food material being used
- ✓ Edible ink or food-grade printing material (called feedstock)A printing platform or build surface on which the food is constructed
- ✓ Post-processing equipment such as ovens or cooling units for finishing

Unlike conventional food manufacturing where food is shaped by moulds or cutting, 3D printing builds structure from scratch, offering unmatched freedom in design and composition.

## Types of 3D Food Printing Technologies

Several distinct printing technologies have been adapted for food applications, each suited to different types of ingredients and final products. The major technologies are described below.

**Extrusion-Based Printing:** Extrusion-based printing is the most widely used and commercially advanced 3D food printing method. It operates much like a hot glue gun a food paste or semi-solid material is loaded into a cartridge and pushed through a nozzle onto a printing surface. The nozzle moves in precise patterns as directed by a computer to build up the food layer by layer. This technology is highly compatible with a wide range of food materials including chocolate, cheese, mashed potatoes, cake batter, hummus, dough and meat pastes. Its simplicity and adaptability make it the preferred choice for culinary applications and food product development. Commercial machines such as the Foodini by Natural Machines and the by Flow Focus printer use this extrusion approach to create complex food structures in professional kitchens.

**Inkjet Printing:** Inkjet food printing works on the same principle as a standard office inkjet printer but uses edible inks instead of conventional dyes. Tiny droplets of liquid food colorants or flavour solutions are precisely deposited onto food surfaces. This technology is primarily used for decoration and surface detailing printing edible images on cake tops, biscuits, chocolates and pharmaceutical tablets. It offers excellent resolution and is capable of reproducing photographic quality images on food surfaces. However, inkjet printing is generally limited to two-dimensional surface applications and is not yet suitable for creating full three-dimensional food structures.

**Binder Jetting:** Binder jetting involves spreading a thin layer of powdered food material (such as sugar, starch, or flavoured powder) and then selectively

**Table 1: Summary of 3D food printing technologies and their compatible materials**

| Printing Technology | Compatible Food Materials | Primary Applications |
|---|---|---|
| Extrusion-Based | Chocolate, cheese, dough, meat paste, mashed vegetables, icing, hummus | Restaurant dishes, bakery products, confectionery |
| Inkjet Printing | Edible dyes, food colorants, flavour liquids | Cake decoration, biscuit printing, pharmaceutical tablets |
| Binder Jetting | Sugar powder, starch powder, flavoured powders | Sugar sculptures, confectionery decorations |
| Selective Laser Sintering | Sugar, starch, fat-based powders | High-precision confectionery, research applications |
| Hot Melt Extrusion | Chocolate, fats, lipid-based materials | Chocolate art, functional food dosage forms |

applying a liquid binding agent using a print head. The binder causes the powder to solidify in specific regions and after each layer is complete, another layer of powder is added. This process is particularly popular for creating intricate sugar sculptures, confectionery pieces and decorative food items. The famous 3D-printed sugar structures by ChefJet (now under 3D Systems) were produced using this technique. The primary limitation is that the resulting food often has a slightly grainy or porous texture.

**Selective Laser Sintering (SLS):** Selective Laser Sintering uses a focused laser beam to heat and fuse powdered food materials typically sugar or starch at specific points defined by the digital design. The unfused powder is removed after printing, leaving behind the desired 3D food structure. SLS produces food items with very fine resolution and complex geometries that would be impossible with other methods. However, it is expensive, requires significant safety measures due to laser use and is currently limited to a narrow range of food powders.

**Hot Melt Extrusion:** Hot melt extrusion (HME) is a variant of extrusion-based printing where the food material is heated to a molten state before being extruded through the nozzle. Chocolate printing is the most common application of this technology, where cocoa butter is melted and precisely deposited to create elaborate chocolate sculptures. HME has also found applications in pharmaceutical food products, where active nutrients are embedded within a food matrix to create functional edible dosage forms.

## Edible Materials Used in 3D Food Printing

The selection of printing material also called food ink or feedstock is critical to the success of 3D food printing. Not all food materials are printable; they must have specific rheological properties that allow them to flow through a nozzle while also maintaining their shape once deposited (Table 1). Proteins (such as meat pastes and insect protein powders), carbohydrates (such as starch gels and dough), fats (such as cocoa butter and dairy fats) and hydrocolloids (such as agar, gelatin and methyl-cellulose) are among the most commonly used categories of food inks. Researchers are also exploring the use of algae, fungi-based materials and plant-based protein isolates as sustainable feedstocks for 3D food printing.

## Applications and Potential of 3D Food Printing

**Personalized Nutrition:** One of the most significant and transformative potentials of 3D food printing is its ability to deliver precisely tailored nutritional

content in every meal. Hospitals, care homes and clinical nutrition centres can leverage this technology to create meals that meet exact caloric, protein, vitamin and mineral requirements for individual patients. For elderly patients with dysphagia (difficulty swallowing), 3D printing can create soft, pureed food that is moulded into realistic-looking food shapes such as a carrot or a piece of fish while retaining the required texture and nutritional profile. This significantly improves the dignity and appetite of patients who would otherwise consume unappealing pureed food.

**Culinary Creativity and the Food Service Industry:** Chefs and food artists are using 3D food printing to push the boundaries of culinary design. Intricate geometric chocolate pieces, lattice sugar structures, personalized wedding cake toppers and multi-flavour confectionery that would take hours to handcraft can be produced in minutes using a 3D food printer. High-end restaurants around the world, including those with Michelin stars, have experimented with 3D food printing as both a practical tool and a theatrical element of dining experience. The technology allows for unprecedented repeatability every plate can be an exact replica of a designer's vision.

**Space Food and Extreme Environment Applications:** NASA and other space agencies have shown interest in 3D food printing as a solution for long-duration space missions. In space, transporting large volumes of pre-prepared food is impractical. Instead, a compact 3D food printer loaded with shelf-stable ingredient cartridges could produce a wide variety of meals on demand. A 2013 NASA-funded project by Systems and Materials Research Corporation demonstrated a prototype that could 3D-print a pizza from ingredient powders. This concept of on-demand food production from compact, long-lasting ingredients is revolutionary for applications in space stations, Antarctic research bases and military field operations.

**Sustainable Food Production:** 3D food printing offers promising avenues for more sustainable food systems. By enabling the use of alternative protein sources such as insect flour, algae, single-cell proteins and plant-based proteins in printable food inks, the technology can help reduce dependence on conventional animal agriculture, which is a major contributor to greenhouse gas emissions. Additionally, 3D printing minimizes food waste by using precise quantities of ingredients, reduces the need for packaging through on-demand production and can incorporate by-products of food processing (such as vegetable pulp or fruit pomace) into nutritious printed food items.

**Pharmaceutical and Functional Foods:** The boundary between food and medicine is blurring in the context of 3D food printing. Researchers are developing edible dosage forms food items embedded with specific quantities of vitamins, minerals, probiotics, or even pharmaceuticals that can be produced with 3D printing. These functional food products can improve medication compliance, especially among children and the elderly, by making

drugs more palatable and personalized.

## Challenges and Limitations

Despite its immense potential, 3D food printing faces several significant challenges that must be addressed before it can achieve widespread commercial adoption.

**Printing Speed:** Current 3D food printers are slow compared to conventional food production methods. Printing a single complex food item can take several minutes to hours, making it unsuitable for high-volume food manufacturing. Advances in multi-nozzle printing systems and faster deposition mechanisms are being researched to address this bottleneck.

**Limited Range of Printable Materials:** Only food materials with specific viscosity, stiffness and rheological properties can currently be printed. Foods with high water content, fibrous textures, or chunky compositions such as salads, whole grains, or meat with visible muscle fibres cannot yet be replicated by 3D printing. Expanding the library of printable food inks remains an active area of research.

**Food Safety and Hygiene:** 3D food printers, with their numerous internal surfaces, tubes and nozzles, can be challenging to clean thoroughly, creating potential risks of microbial contamination. Regulatory frameworks for food-grade 3D printing materials and equipment are still developing in most countries. Ensuring the food safety of printed products throughout the supply chain is a critical concern for regulatory bodies and manufacturers.

**Consumer Acceptance:** Many consumers remain sceptical about the idea of eating food produced by a machine. Perceptions of 3D-printed food as artificial, processed, or less wholesome than traditionally prepared food pose a significant marketing and sociocultural challenge. Effective communication of the benefits especially in healthcare and sustainability will be essential to shift consumer attitudes.

**Cost and Accessibility:** High-quality 3D food printers remain expensive, limiting their use to research institutions, high-end restaurants and large food companies. For the technology to achieve broader societal impact particularly in addressing nutritional challenges in developing countries significant reductions in cost and improvements in ease of use will be necessary.

## Future Outlook

The future of 3D food printing is bright and rapidly evolving. Several key trends are expected to shape its trajectory over the coming decade:

**Integration with Artificial Intelligence (AI):** AI-powered systems will enable 3D food printers to automatically optimize nutritional content, adjust texture based on individual health profiles and generate new food designs based on available ingredients.

**Multi-material and multi-nozzle printers:** Future printers will simultaneously deposit multiple food materials, allowing complex multi-component foods such as complete balanced meals to be printed in a single operation.

**Bioprinting of cultured meat:** Researchers are exploring the bioprinting of cultured (lab-grown) meat cells arranged in muscle-like structures, which could revolutionize the meat industry and address ethical and environmental concerns.

**Home-use food printers:** Just as desktop computers moved from offices to homes, compact, affordable 3D food printers for household use are on the horizon, potentially transforming home cooking.

**Integration with supply chain technology:** Combining 3D food printing with precision fermentation, vertical farming and blockchain-based ingredient tracking could create fully sustainable and transparent food supply chains.

Industry analysts project the global 3D food printing market to grow substantially, driven by increasing demand for personalized nutrition, the rise of alternative proteins and growing interest in sustainable food systems.

## Conclusion

3D food printing is not a passing technological novelty it is a paradigm shift in the way humanity thinks about food design, production and consumption. By combining the principles of additive manufacturing with food science and engineering, this technology opens doors to applications that were previously unimaginable: from hospital meals customized for each patient's exact nutritional needs, to sustainable food systems powered by algae and insect proteins, to entire meals prepared in space from cartridges of shelf-stable powders. For food engineers, 3D printing represents a new frontier that demands interdisciplinary knowledge spanning rheology, food chemistry, materials science, digital design and nutrition. As research matures and technology becomes more accessible, 3D food printing is poised to move from the laboratory and the fine-dining kitchen to hospitals, homes and factories around the world. The plate of the future may well be printed and it will be more nutritious, more sustainable, more personalized and more beautiful than anything produced today.

## References

Sun, J., Peng, Z., Zhou, W., Fuh, J. Y. H., Hong, G. S. and Chiu, A. (2015). A review on 3D printing for customized food fabrication. *Procedia Manufacturing*, 1: 308-319.

Lipton, J. I., Cutler, M., Nigl, F., Cohen, D. and Lipson, H. (2015). Additive manufacturing for the food industry. *Trends in Food Science and Technology*, 43(1):114-123.

Godoi, F. C., Prakash, S. and Bhandari, B. R. (2016). 3D printing technologies applied for food design: Status and prospects. *Journal of Food Engineering*, 179: 44-54.

Liu, Z., Zhang, M., Bhandari, B. and Wang, Y. (2017). 3D printing: Printing precision and application in food sector. *Trends in Food Science and Technology*, 69: 83-94.

Moroni, L., Boland, T., Burdick, J. A., De Maria, C., Derby, B., Forgacs, G. and Vozzi, G. (2018). Biofabrication: A guide to technology and terminology. *Trends in Biotechnology*, 36(4): 384-402.

Dick, A., Bhandari, B. and Prakash, S. (2019). 3D printing of meat. *Meat Science*, 153: 35-44.

Dankar, I., Haddarah, A., Omar, F. E. L., Pujolà, M. and Sepulcre, F. 2018. 3D printing technology: The new era for food customization and elaboration. *Trends in Food Science and Technology*, 75: 161-174.

# Carbon Farming: An Emerging Strategy for Sustainable Crop Production and Climate Change Adaptation

**Anil Jakhar, Priyanka Choudhary, Rahul Jakhar and Nirmal Choudhary**

## Introduction

Agriculture plays a dual role in the global climate system. While it is one of the sectors most affected by climate change, it is also a significant source of greenhouse gas (GHG) emissions. Rising temperatures, erratic rainfall, prolonged droughts, floods and declining soil fertility have become major challenges for agricultural production across the world. At the same time, intensive cultivation practices, excessive tillage, residue burning and indiscriminate use of chemical fertilizers have accelerated the loss of soil organic carbon and increased carbon emissions. These challenges have highlighted the need for farming practices that improve productivity while protecting natural resources and reducing environmental impacts. Carbon farming has emerged as an innovative approach that addresses these concerns by integrating sustainable agricultural practices with climate change mitigation. Instead of viewing agricultural land only as a production system, carbon farming recognizes it as a valuable carbon sink capable of capturing atmospheric carbon dioxide and storing it in soil and vegetation. By increasing soil organic carbon, farmers can improve soil quality, enhance crop productivity and contribute to reducing greenhouse gas concentrations in the atmosphere.

**Carbon Farming:** Carbon farming refers to a group of land management practices designed to increase the storage of carbon in agricultural soils, crops, trees, and other vegetation while minimizing greenhouse gas emissions. The primary objective is to improve the natural capacity of agricultural ecosystems to absorb atmospheric carbon dioxide through photosynthesis and retain it as stable soil organic matter. Healthy soils naturally contain organic carbon derived from plant residues, roots, microorganisms and organic amendments. However, continuous intensive cultivation and poor soil management gradually deplete this carbon reserve. Carbon farming seeks to reverse this trend by adopting practices that increase organic matter inputs and reduce carbon losses from the soil. As soil organic carbon increases, soil fertility, structure,

**Anil Jakhar**
Research Scholar, Department of Agronomy, SKN College of Agriculture, SKNAU, Jobner, Jaipur, Rajasthan
**Priyanka Choudhary**
Research Scholar, Department of Biotechnology, MLSU, Udaipur, Rajasthan
**Rahul Jakhar**
Department of Agronomy, SKRAU, Bikaner, Rajasthan
**Nirmal Choudhary**
Research Scholar, Department of Soil Science, SAS, Nagaland University, Medziphema, Nagaland

water retention, and biological activity also improve, creating a more productive and resilient agricultural system.

## Important Carbon Farming Practices

The success of carbon farming depends on the adoption of scientifically proven management practices that promote carbon sequestration and improve soil health. Conservation tillage and zero tillage reduce soil disturbance, helping to preserve soil organic matter and prevent rapid oxidation of carbon. Cover crops grown during the fallow period protect the soil surface from erosion, improve nutrient cycling and contribute additional biomass that becomes part of the soil organic matter. Crop rotation and diversified cropping systems enhance microbial diversity and maintain balanced nutrient dynamics. Retaining crop residues on the soil surface instead of burning them adds organic carbon and protects the soil from moisture loss. Organic inputs such as farmyard manure, compost, green manure, vermicompost and crop wastes enrich the soil with stable organic matter while supporting beneficial microbial populations. Agroforestry is another important component of carbon farming. The integration of trees with agricultural crops increases carbon storage both above and below the ground. Tree roots stabilize soil, improve nutrient recycling, reduce erosion and create favorable microclimatic conditions that benefit crop growth. Similarly, biochar produced from agricultural biomass has gained considerable attention because of its ability to remain stable in soils for long periods, thereby enhancing carbon sequestration while improving nutrient retention and water-holding capacity.

## Benefits for Sustainable Agriculture

Carbon farming offers multiple benefits that extend beyond climate change mitigation. Increasing soil organic carbon improves soil aggregation, porosity and water infiltration, allowing crops to withstand periods of drought more effectively. Enhanced microbial activity promotes nutrient mineralization and improves nutrient use efficiency, reducing dependence on synthetic fertilizers.

Improved soil structure also minimizes runoff and soil erosion, helping conserve valuable topsoil. Greater biodiversity within the soil ecosystem strengthens natural pest suppression and supports ecosystem stability. These improvements ultimately contribute to higher and more stable crop yields, particularly under changing climatic conditions. For farmers, carbon farming can also reduce production costs by improving input-use efficiency. As international carbon markets continue to develop, farmers adopting verified carbon sequestration practices may receive financial incentives through carbon credit programmes, creating an additional source of farm income alongside conventional agricultural production.

**Carbon Farming in the Indian Context:** India has considerable potential to benefit from carbon farming because of its diverse agro-climatic regions and extensive agricultural land. Many sustainable farming practices already promoted under national programmes including conservation agriculture,

integrated nutrient management, agroforestry, natural farming and residue management align closely with the principles of carbon farming.

Improving soil organic carbon is particularly important for Indian agriculture, where continuous cultivation and imbalanced fertilizer use have contributed to declining soil health in many regions. Encouraging farmers to adopt residue recycling, organic amendments, cover crops and tree-based farming systems can simultaneously improve soil productivity and strengthen climate resilience. The gradual development of agricultural carbon markets may further encourage adoption by rewarding farmers for measurable environmental benefits.

## Challenges and Future Perspectives

Despite its promising potential, widespread adoption of carbon farming faces several practical challenges. Soil carbon sequestration varies with soil type, climate, cropping system and management practices, making its measurement technically demanding. Reliable monitoring and verification systems are essential for carbon credit programmes but remain expensive and inaccessible for many smallholder farmers.

Limited awareness, inadequate technical support, and insufficient policy incentives also restrict adoption. Future progress will require stronger collaboration among researchers, extension agencies, policymakers and farming communities. Advances in digital agriculture, remote sensing, geographic information systems and artificial intelligence are expected to improve carbon monitoring and facilitate large-scale implementation of carbon farming initiatives.

## Conclusion

Carbon farming represents a practical and science-based approach for achieving sustainable agriculture while addressing the global challenge of climate change. By restoring soil organic carbon through conservation tillage, crop residue management, cover cropping, agroforestry, organic nutrient management and biochar application, farmers can improve soil fertility, increase crop resilience, and reduce greenhouse gas emissions. In countries such as India, where agriculture supports millions of livelihoods, carbon farming offers an opportunity to combine environmental conservation with enhanced farm productivity and income. Continued investment in research, extension services, supportive policies and carbon financing mechanisms will play a crucial role in transforming carbon farming from an emerging concept into a mainstream agricultural practice capable of contributing to long-term food security and climate resilience.

## References

Arellano Vazquez, D. A., Gagliano, E., Del Borghi, A., Tacchino, V., Spotorno, S. and Gallo, M. (2024). Carbon farming of main staple crops: A systematic review of carbon sequestration potential. *Sustainability*, 16(18): 7907.

Singh, S., Kiran, B. R. and Mohan, S. V. (2024). Carbon farming: a circular framework to augment $CO_2$ sinks and to combat climate

change. *Environmental Science: Advances*, 3(4): 522-542.

Strauss, V., Paul, C., Dönmez, C. and Burkhard, B. (2024). Carbon farming for climate change mitigation and ecosystem services-Potentials and influencing factors. *Journal of Environmental Management*, 372: 123253.

Zheng, H., Ma, W. and He, Q. (2024). Climate-smart agricultural practices for enhanced farm productivity, income, resilience, and greenhouse gas mitigation: a comprehensive review. *Mitigation and Adaptation Strategies for Global Change*, 29(4): 28.

Kumara, K., Pal, S., Chand, P. and Kandpal, A. (2023). Carbon sequestration potential of sustainable agricultural practices to mitigate climate change in Indian agriculture: A meta-analysis. *Sustainable Production and Consumption*, 35: 697-708.

Khurana, A., Kajale, D., Cariappa, A. A. and Krishna, V. V. (2024). Shaping India's climate future: A perspective on harnessing carbon credits from agriculture. *Outlook on Agriculture*, 53(2): 113-130.

# Regenerative Agriculture: A Sustainable Solution for Soil Degradation

**Muneshwar Prasad Mandal**

Soil degradation has become a major global concern, threatening agricultural productivity and long-term food security. Intensive farming practices, excessive use of chemical fertilizers, deforestation, and improper land management have led to declining soil fertility, erosion, and loss of biodiversity. According to global estimates, a significant portion of the world's arable land is already degraded. In this context, regenerative agriculture has emerged as a promising and sustainable approach to restore soil health while maintaining agricultural productivity. Regenerative agriculture is a holistic farming system that focuses on rebuilding soil organic matter, enhancing biodiversity, and improving ecosystem resilience. Unlike conventional farming, which often prioritizes short-term yields, regenerative practices aim to restore the natural balance of agricultural systems. Key principles include minimal soil disturbance, continuous soil cover, crop diversification, and integration of livestock. One of the fundamental practices in regenerative agriculture is no-till or reduced tillage farming. Traditional plowing disturbs soil structure, accelerates erosion, and disrupts beneficial microbial activity. In contrast, no-till farming preserves soil integrity, improves water retention, and enhances carbon sequestration. Cover cropping is another essential practice, where crops such as legumes or grasses are grown between main crop cycles to protect the soil from erosion, suppress weeds, and add organic matter. Crop rotation and diversification also play a critical role in regenerative systems. Growing a variety of crops in sequence helps break pest and disease cycles, improves nutrient cycling, and promotes soil biodiversity. Additionally, integrating livestock into farming systems can further enhance soil fertility through natural manure deposition and improved nutrient recycling.

One of the most significant benefits of regenerative agriculture is its potential to combat climate change. Healthy soils act as carbon sinks, capturing and storing atmospheric carbon dioxide. By increasing soil organic carbon, regenerative practices not only mitigate greenhouse gas emissions but also improve soil structure and fertility. This dual benefit makes regenerative agriculture a key strategy in achieving sustainable development and climate goals. Moreover, regenerative agriculture contributes to improved water management. Soils rich in organic matter have better water infiltration and retention capacity, reducing the need for frequent irrigation and increasing resilience to drought conditions. This is particularly important in regions facing water scarcity and erratic rainfall patterns.

**Muneshwar Prasad Mandal**
Assistant Professor-cum-Junior Scientist, Department of Plant Physiology & Biochemistry, Bhola Paswan Shastri Agricultural College, Kasba Road, Purnea, Bihar

Despite its advantages, the transition to regenerative agriculture can be challenging for farmers. Initial yield fluctuations, lack of awareness, and limited access to technical knowledge may hinder adoption. However, growing global awareness, policy support, and market demand for sustainably produced food are encouraging more farmers to adopt regenerative practices. In conclusion, regenerative agriculture offers a viable pathway to address soil degradation while promoting sustainable and resilient farming systems. By restoring soil health, enhancing biodiversity, and mitigating climate change, it aligns agricultural productivity with environmental conservation. As the world seeks sustainable solutions for feeding a growing population, regenerative agriculture stands out as a transformative approach for the future of farming.

# RNA Interference (RNAi): A Natural Mechanism of Gene Silencing

**Vishal D. Pawar and Kishor T. Thakare**

## Introduction

RNA interference (RNAi) is a natural biological process in which the expression of a specific gene is suppressed or "silenced" by the presence of double-stranded RNA (dsRNA). It is an important gene regulation mechanism found in eukaryotic organisms, including plants, animals, and fungi. RNAi plays a crucial role in controlling gene expression, defending cells against viral infections, and maintaining genomic stability. The phenomenon of RNA interference was first discovered through studies in plants, where introduction of specific RNA molecules led to unexpected suppression of gene activity. Later, it was found that small RNA molecules are responsible for guiding this gene silencing process in a sequence-specific manner. Because of its precise and efficient mechanism, RNAi has become a powerful tool in molecular biology, biotechnology and plant pathology research.

## History of RNA Interference

The discovery of RNA interference is the result of several important scientific observations over time. In 1984, Stout and Caskey demonstrated that antisense RNA could suppress gene expression in mammalian systems. In 1990, Napoli and Jorgensen reported an unusual phenomenon called co-suppression in petunia plants, where the introduction of additional gene copies led to reduced gene expression instead of enhancement. In 1992, Romano and Macino observed a similar gene silencing phenomenon in the fungus *Neurospora crassa*, which was termed quelling. Later, in 1995, Guo and Kemphues demonstrated gene silencing in the nematode *Caenorhabditis elegans*, although the exact mechanism was not yet understood. A major breakthrough occurred in 1998 when Andrew Fire and Craig Mello demonstrated that double-stranded RNA (dsRNA) is responsible for sequence-specific gene silencing in C. elegans. This discovery clearly explained the mechanism of RNA interference. In recognition of their work, they were awarded the Nobel Prize in Physiology or Medicine in 2006.

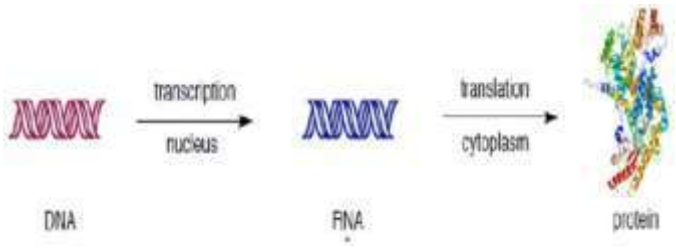
## Basic Concept of RNAi

✓ Protein synthesis in cells occurs in two main steps: transcription and translation. During trans-

**Vishal D. Pawar**
Assistant Professor, Plant Pathology Section, College of Agriculture, Nagpur, Maharashtra
**Kishor T. Thakare**
Young Professional-II, Hiwara, District-Gondia, Maharashtra

cription, DNA is converted into mRNA, and during translation, mRNA is used to synthesize proteins.

- ✓ RNA interference mainly acts at the post-transcriptional level by targeting mRNA and preventing its translation into proteins. Thus, RNAi effectively blocks protein synthesis by degrading or inhibiting mRNA molecules.




## Mechanism of RNA Interference (RNAi)

The mechanism of RNA interference is a multi-step, sequence-specific gene silencing process that occurs in eukaryotic cells. It is mainly triggered by the presence of double-stranded RNA (dsRNA), which can originate from viruses, transposons, or experimental introduction. The process involves the conversion of dsRNA into small RNA molecules that guide the silencing of complementary messenger RNA (mRNA).

**Introduction of Double-Stranded RNA (dsRNA):** The RNAi pathway begins when double-stranded RNA enters the cell or is produced within it. This dsRNA acts as the initiating signal for gene silencing.

**Processing by Dicer Enzyme:** The dsRNA is recognized and cleaved by an enzyme called Dicer, which belongs to the RNase III family. Dicer cuts the long dsRNA into short fragments of about 21-25 nucleotides known as small interfering RNA (siRNA).

**Formation of RNA-Induced Silencing Complex (RISC):** The siRNA is then incorporated into a protein complex called the RNA-induced silencing complex (RISC). Within this complex, the siRNA is unwound into two strands: the guide strand and the passenger strand. The guide strand remains bound to RISC and directs it to the target mRNA.

**Target Recognition and Binding:** The guide siRNA strand within RISC binds to a complementary sequence on the target messenger RNA (mRNA) through base pairing. This specificity ensures that only the correct gene transcript is targeted.

**Cleavage and Degradation of mRNA:** Once bound, the RISC complex (with the help of an enzyme called Argonaute) cleaves the target mRNA. The fragmented mRNA is then degraded by cellular enzymes, preventing it from being translated into a protein.

**Gene Silencing:** As a result of mRNA degradation, protein synthesis from that gene is blocked. This leads to effective gene silencing, which is the final outcome of RNA interference.

## Types of RNA Interference (RNAi)

RNA interference is mainly classified into two major types based on the nature and origin of small RNA molecules involved in gene silencing.

**siRNA (small interfering RNA):** siRNA is a class of double-stranded RNA-derived molecules that are typically 21-25 nucleotides in length. It is formed from long double-stranded RNA molecules that are cleaved by the enzyme Dicer.

siRNA is mainly involved in defense mechanisms against foreign genetic material such as viruses. In this pathway, the siRNA incorporates into the RNA-induced silencing complex (RISC) and guides it to a perfectly complementary messenger RNA (mRNA). This results in the cleavage and degradation of the target mRNA, leading to gene silencing. siRNA-mediated RNAi is highly specific and is widely used in research and biotechnology for gene knockdown studies.

**miRNA (micro RNA):** microRNAs are endogenous, single-stranded RNA molecules that are naturally produced within the cell from precursor transcripts. They are also processed by the Dicer enzyme, but unlike siRNA, miRNAs usually show partial complementarity with their target mRNA. miRNAs primarily function in regulating gene expression rather than completely destroying mRNA. They bind to target mRNA and either inhibit translation or cause mild degradation. miRNAs play an important role in controlling development, cell differentiation, and physiological processes in organisms.

## Applications of RNA Interference (RNAi)

RNA interference has wide applications in modern biology, agriculture, and medicine due to its ability to specifically silence gene expression.

**Plant Pathology and Crop Protection:** RNAi is used to develop disease-resistant plants by silencing genes of plant pathogens such as viruses, fungi, and insects. It helps in controlling crop diseases in an eco-friendly manner without using excessive chemical pesticides.

**Functional Genomics:** RNAi is widely used to study gene function by selectively silencing specific genes. This helps scientists understand the role of individual genes in growth, development, and disease processes.

**Medical Research and Disease Treatment:** RNAi is being explored for the treatment of human diseases such as cancer, viral infections (like hepatitis and HIV), and genetic disorders by targeting and silencing disease-causing genes.

**Pest Management:** In agriculture, RNAi technology is used to control insect pests by silencing essential genes required for their survival, feeding, or reproduction.

**Biotechnology and Genetic Engineering:** RNAi is an important tool in genetic engineering for creating genetically modified organisms (GMOs) with desirable traits such as improved yield, resistance, and stress tolerance.

## Advantages and Disadvantages of RNAi

### Advantages

- ✓ Highly specific gene silencing
- ✓ Efficient and rapid process
- ✓ Eco-friendly and biosafe
- ✓ Useful in research and crop improvement

### Disadvantages

- ✓ Does not achieve complete gene knockout
- ✓ Possibility of off-target effects
- ✓ High cost in some applications

## Conclusion and Future Prospects

RNA interference is a powerful and precise mechanism of gene regulation that has revolutioniz-

ed modern biology. It serves as an effective tool for gene silencing and has wide applications in agriculture, medicine, and biotechnology. RNAi technology is considered eco-friendly and biosafe, making it highly suitable for sustainable crop improvement and disease management. Future research is focused on developing more efficient RNAi-based tools with better specificity and control. A deeper understanding of RNAi mechanisms will further enhance its applications in improving crop productivity and managing plant diseases.

# Strategies to Restore Soil Health for Sustainable Production

**S. Teja, V. Boomika, S. S Masaye, A. I. Patel and J. Devika**


## Abstract

Soil is the living foundation of agriculture but intensive farming has contributed to soil fertility depletion and loss of organic matter as well as decreased soil resilience against climate stress. Soils are a non-renewable resource and healthy soils play important role not only in sustaining crop yields but also food security, farmer income and environmental stability. This article reviews the principal soil health issues, which include loss of nutrients, soil compaction and presence of pesticide residues and argues why enhancing soil health is vital for sustainable crop production. It discusses different practical methods to restore healthy soil to produce various crops. Through these methods, farmers can lower their input costs, increase their productivity and be more resilient against both droughts and floods. Building back soil health is more than science, it is the road to sustainable harvests and thriving rural communities.


## Introduction

Soil isn't just dirt; it's a living foundation that feeds our crops, supports our lives and keeps the environment healthy. But in the last few years, farmers all over India and the world had to deal with a growing problem as their soils are getting weaker, Fields are tired and less productive because they have been continuously cropped, used a lot of chemical fertilizers and not taken care of organic fertilizers. The key to long-term farming is healthy soil. It holds water, stores nutrients, supports helpful microbes and helps crops survive under floods and droughts. When the health of the soil goes down, the yields go down, the costs go up and farming becomes more dangerous. So, restoring the health of the soil is not just about getting better harvests; it's also about making sure that farmers can make that food is always available and balanced environment if maintained. In this article we can discuss farmer-friendly ways to bring life back to the soil. They show how farming can be both productive and environmentally friendly. Farmers can make sure they have healthy harvests and strong farming systems in the future by taking care of the soil today.


**S. Teja**
Department of Vegetable Science, ASPEE College of Horticulture, NAU, Navsari, Gujarat

**V. Boomika**
Department of Fruit Science, Dr. Y.S.R. Horticultural University, Venkataramannagudem, Andhra Pradesh

**S. S Masaye**
Department of Vegetable Science, Polytechnic in Horticulture, Paria, ASPEE College of Horticulture, NAU, Navsari, Gujarat

**A. I. Patel**
Department of Fruit Science, ASPEE College of Horticulture, NAU, Navsari, Gujarat

**J. Devika**
Department of Vegetable Science, Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal

**Soil health:** Soil health refers to the ability of soil to function as a living ecosystem that sustains plants, animals and humans. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive repercussions for soil water and nutrient holding capacity and ultimately improve crop production (Singh *et al*., 2024).

## Principles of soil health

- ✓ Keep the soil covered
- ✓ Disturb the soil less
- ✓ Grow diverse crops
- ✓ Keep living roots year-round
- ✓ Integrate livestock (Guo *et al*., 2021)

Fig. 1: Development of the science of soil health with concept, assessment, and management (Guo *et al*., 2021)

## Impacts of Poor Soil Health

- ✓ Declining crop yields
- ✓ Nutrient deficiencies
- ✓ Loss of soil organic matter
- ✓ Soil erosion
- ✓ Compaction and poor structure
- ✓ Reduced microbial activity
- ✓ Higher pest and disease pressure
- ✓ Water stress
- ✓ Accumulation of harmful residues
- ✓ Increased climate vulnerability

## Strategies to Restore Soil Health

**Enrich with Organic Matter:** Compost, manure and crop residues were added to increases soil fertility. Organic matter improves soil structure that helps retain moisture during dry spells, and provides food for beneficial microbes that keep soil alive and productive (Panda *et al.*, 2024).

**Reduce Soil Disturbance:** Too much ploughing or chemical use breaks soil aggregates and harms soil organisms. Conservation tillage (reduced or no-till) keeps soil intact, reduces erosion and allows water to soak in better. This makes soil stronger in the long run (Panda *et al.*, 2024).

**Diversify Cropping Systems:** Rotating crops or mixing legumes with cereals prevents pests and diseases from building up. Different crops use and return different nutrients so diversity keeps soil balanced and healthy. Intercropping also provides quick soil cover to reduce erosion (Rathi *et al.*, 2024)

**Smart Nutrient Use:** Fertilizers should be applied based on soil testing. Balanced use of nutrients improves crop yield and soil health. Following the 4R's approach (right source, right rate, right time, right place) ensures efficiency and avoids waste or pollution (Rathi *et al.*, 2024)

**Efficient Water Management:** Using drip or precision irrigation saves water and prevents soil compaction. Proper water management avoids probl-

ems like waterlogging (too much water) or drought stress (too little water), both of which damage soil structure and microbes (Panda *et al.*, 2024).

**Control Soil Erosion:** Keeping soil covered with residues or cover crops reduces erosion. Techniques like contour farming, strip cropping, and shelterbelts protect land from wind and water erosion, especially in hilly or dry regions (Panda *et al.*, 2024).

**Mulching Practices:** Spreading straw, dry leaves, or crop wastes on bare soil conserves moisture, reduces weed growth, and protects soil from erosion. Mulching also adds organic matter as it decomposes (Rathi *et al.*, 2024).

**Agroforestry Integration:** Planting trees or shrubs alongside crops provides shade, reduces wind erosion, and recycles nutrients from deeper soil layers. Leguminous trees fix nitrogen, improving fertility for nearby crops (Rathi *et al.*, 2024).

**Physical Protection Measures:** Structures like bunds, ridges or stone barriers slow down water flow, prevent soil loss, and store water for crops. These are especially useful in sloping or erosion-prone lands (Rathi *et al.*, 2024).

**Continuous Monitoring:** Soil health changes with climate, cropping and management. Regularly checking soil moisture, nutrient levels and microbial activity help farmers adjust practices quickly. Adaptive management ensures soil stays healthy over time (panda).

**Natural based solutions for soil restoration process (Rathi *et al.*, 2024)**

- ✓ Natural farming
- ✓ Organic manures
- ✓ Sheep penning
- ✓ Tank silt
- ✓ Zeolites
- ✓ Bentonite
- ✓ Biochar
- ✓ Fly ash

## Conclusion

Mismanagement, erosion and nutrient imbalance can all lead to poor soil health, which makes farming systems less productive and more fragile. Farmers can bring back the fertility and strength of their soil by doing things like adding organic matter, practicing conservation tillage, growing a variety of crops, using nutrients in a balanced way and controlling erosion. Continuous monitoring and adaptive management make sure that soils stay productive, sustainable and able to support farming for generations to come.

## References

Panda, N., Mohapatra, K. K., Mohanty, S., Padhan, K., Sahoo, S. K., Dash, P. K., Sethi, D. and Mishra, A. K. (2024). Soil health: Concepts, principles and road maps for management in regenerative agriculture. *Journal of Modern Agriculture and Biotechnology*, 3: 10.

Rathi, A., Kumar, P., Nangla, S., Sharma, S. and Sharma, S. (2024). Soil restoration strategies for sustaining soil productivity: A review. *Asian Research Journal of Agriculture*, 17 (1): 33-48.

Singh, N. K., Sachan, K., Bp, M., Panotra, N. and

Katiyar, E. (2024). Building soil health and fertility through organic amendments and practices: A review. *Asian Journal of Soil Science and Plant Nutrition*, 10(1): 175-197.

Guo, M. (2021). Soil health assessment and management: Recent development in science and practices. *Soil Systems*, 5(4): 61.

# Role of Marker-Assisted Selection in Pest Resistance

**Manisha Patel and Radheshyam Ramkrishna Dhole**


## Abstract

Insect pests are a major constraint to agricultural productivity, causing significant yield losses and increasing reliance on chemical pesticides. Developing pest-resistant crop varieties is a sustainable and eco-friendly solution to this problem. Marker-Assisted Selection (MAS) has emerged as a powerful tool in modern plant breeding, enabling precise and efficient selection of desirable traits based on molecular markers linked to genes of interest. MAS facilitates the identification and incorporation of pest resistance genes into elite crop varieties, reducing the time and effort required in conventional breeding. This article explores the principles of MAS, its applications in pest resistance breeding, advantages, challenges, and future prospects. The integration of MAS with advanced genomic tools is transforming crop improvement strategies and contributing to sustainable agriculture and food security.


## Introduction

Agricultural crops are constantly exposed to a wide range of insect pests that reduce yield and quality. The traditional approach to pest management has relied heavily on chemical pesticides, which pose environmental and health risks and often lead to the development of pesticide resistance in insect populations. Host plant resistance is considered one of the most effective and sustainable strategies for pest management. Conventional breeding for pest resistance is often time-consuming and challenging due to the complex genetic nature of resistance traits and the influence of environmental factors. The advent of molecular biology has provided new tools to enhance breeding efficiency. Among these, Marker-Assisted Selection (MAS) has gained prominence as a reliable method for selecting desirable traits based on DNA markers. MAS allows breeders to track the presence of specific genes or genomic regions associated with pest resistance without relying solely on phenotypic evaluation. This approach has significantly improved the precision and speed of crop improvement programs.

## Key Highlights

### Concept of Marker-Assisted Selection

Marker-Assisted Selection is a breeding technique that uses molecular markers to select plants carrying desirable traits. These markers are DNA sequences that are closely linked to genes controlling specific traits, such as insect resistance. Unlike traditional selection methods, which depend on visible traits, MAS enables indirect selection at


**Manisha Patel**
Research Scholar, Department of Genetics and Plant Breeding, Bihar Agricultural University, Sabour, Bhagalpur, Bihar
**Radheshyam Ramkrishna Dhole**
Assistant Professor, Department of Entomology, Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas, Bihar

the genetic level. This is particularly useful for traits that are difficult to evaluate, influenced by environmental conditions, or expressed at later stages of plant development.

**Types of Molecular Markers Used in MAS**

Several types of molecular markers are used in MAS:

**Simple Sequence Repeats (SSRs):** Highly polymorphic and co-dominant markers

**Single Nucleotide Polymorphisms (SNPs):** Abundant and widely used in high-throughput genotyping

**Amplified Fragment Length Polymorphisms (AFLPs):** Useful for detecting genetic variation

**Restriction Fragment Length Polymorphisms (RFLPs):** One of the earliest marker systems

These markers help in identifying and tracking resistance genes in breeding populations.

**Steps Involved in MAS**

The MAS process involves several key steps:

**Identification of Markers:** Detect markers linked to pest resistance genes through QTL mapping or association studies

**Validation of Markers:** Confirm the reliability of markers across different genetic backgrounds

**Selection of Parents:** Choose resistant and high-yielding parents for crossing

**Screening of Progeny:** Use markers to identify individuals carrying resistance genes

**Advancement of Selected Lines:** Develop improved varieties through successive generations

This approach ensures accurate and efficient selection.

**Applications in Pest Resistance Breeding**

MAS has been successfully applied in various crops for developing pest-resistant varieties:

**Rice:** Identification of genes for resistance to brown planthopper and gall midge

**Maize:** Development of varieties resistant to stem borers and fall armyworm

**Wheat:** Breeding for resistance against aphids and Hessian fly

**Cotton:** Improvement of resistance to bollworms and sucking pests

**Tomato:** Development of resistance against white-flies and leaf miners

These applications demonstrate the effectiveness of MAS in crop protection.

**Advantages of MAS**

**Precision:** Accurate selection of desired genes

**Speed:** Reduces breeding cycle time

**Early Selection:** Enables selection at seedling stage

**Environment Independence:** Not affected by environmental variability

**Gene Pyramiding:** Allows stacking of multiple resistance genes

These advantages make MAS a preferred tool in modern breeding programs.

**Gene Pyramiding for Durable Resistance**

One of the most important applications of MAS is gene pyramiding, which involves combining multiple resistance genes into a single variety. This approach provides:

- ✓ Broad-spectrum resistance
- ✓ Reduced risk of pest adaptation
- ✓ Long-lasting effectiveness

MAS facilitates the identification and combination of multiple genes, enhancing the durability of resistance.

**Integration with Other Technologies**

MAS is often integrated with other advanced technologies:

**Genomic Selection:** Uses genome-wide markers for prediction

**CRISPR-Based Genome Editing:** Enables precise gene modification

**High-Throughput Phenotyping:** Enhances trait evaluation

This integration improves the efficiency and effectiveness of breeding programs.

**Challenges and Limitations**

Despite its advantages, MAS faces certain challenges:

**High Initial Cost:** Requires investment in molecular laboratories

**Limited Marker Availability:** Suitable markers may not be available for all traits

**Complex Traits:** Traits controlled by multiple genes are difficult to manage

**Technical Expertise:** Requires skilled personnel and bioinformatics support

Addressing these challenges is essential for wider adoption.

**Recent Advances in MAS**

Recent developments have enhanced the potential of MAS:

**Next-Generation Sequencing (NGS):** Enables discovery of large numbers of markers

**High-Density Genetic Maps:** Improve accuracy of selection

**Automation and Robotics:** Increase efficiency of genotyping

**Bioinformatics Tools:** Facilitate data analysis and interpretation

These advances are making MAS more accessible and effective.

**Future Strategies**

The future of MAS in pest resistance breeding lies in its integration with emerging technologies and sustainable practices. Key strategies include:

- ✓ Expanding marker databases for diverse crops
- ✓ Developing cost-effective genotyping platforms
- ✓ Strengthening public–private partnerships
- ✓ Promoting capacity building and training
- ✓ Integrating MAS with integrated pest management (IPM)

These approaches will enhance the impact of MAS in agriculture.

**Conclusion**

Marker-Assisted Selection has transformed the field of plant breeding by enabling precise and efficient selection of pest-resistant traits. By utilizing molecular markers, MAS reduces the reliance on phenotypic selection and accelerates the development of improved crop varieties. Its ability to facilitate gene pyramiding and integrate with modern genomic tools makes it a powerful approach for sustainable pest management. Although challenges remain, continuous advancements in technology are

improving the accessibility and effectiveness of MAS. The adoption of MAS in breeding programs is essential for achieving sustainable agriculture, reducing pesticide use, and ensuring global food security.

## References

Collard, B. C. Y. and Mackill, D. J. (2008). Marker-assisted selection. *Philosophical Transactions of the Royal Society B*, 363: 557-572.

Xu, Y. and Crouch, J. H. (2008). Marker-assisted selection in plant breeding. *Molecular Breeding*, 22: 1-17.

Varshney, R. K., Graner, A. and Sorrells, M. E. (2005). Genomics-assisted breeding. *Trends in Plant Science*, 10: 621-630.

Moose, S. P. and Mumm, R. H. (2008). Molecular plant breeding. *Plant Physiology*, 147: 969-977.

Ribaut, J. M. and Hoisington, D. (1998). Marker-assisted selection. *Trends in Plant Science*, 3: 236-239.

# Genomic Selection Approaches in Crop for Pest Resistance Breeding

**Manisha Patel and Radheshyam Ramkrishna Dhole**


## Abstract

Insect pests are a major constraint to global agricultural productivity, causing substantial yield losses and increasing dependence on chemical pesticides. Developing pest-resistant crop varieties is a sustainable and eco-friendly solution to this challenge. Traditional breeding and marker-assisted selection (MAS) have contributed significantly to crop improvement; however, their effectiveness is limited for complex traits governed by multiple genes. Genomic Selection (GS) has emerged as an advanced breeding approach that utilizes genome-wide marker information to predict the performance of breeding lines. This technology enables faster and more accurate selection of pest-resistant genotypes. This article highlights the principles, methodologies, applications, advantages, and challenges of genomic selection in pest resistance breeding. The integration of GS with modern genomic tools offers immense potential for accelerating crop improvement and ensuring sustainable agricultural production.


## Introduction

Agricultural systems across the world are under constant pressure from insect pests that reduce crop yield and quality. Conventional pest control methods, particularly chemical pesticides, have led to environmental pollution, pest resistance, and health concerns. Therefore, breeding crops with inherent pest resistance has become a key strategy for sustainable agriculture. Traditional breeding methods rely on phenotypic selection, which is often influenced by environmental conditions and may not accurately reflect the genetic potential of a plant. Marker-assisted selection (MAS) improved precision by targeting specific genes; however, it is less effective for complex traits like pest resistance that are controlled by multiple genes with small effects. Genomic Selection (GS) has emerged as a transformative approach that overcomes these limitations. By using genome-wide markers, GS predicts the breeding value of plants without identifying individual genes. This approach enables breeders to select superior genotypes at an early stage, significantly accelerating breeding programs and enhancing genetic gain.

## Key Highlights

**Concept of Genomic Selection:** Genomic selection is a modern breeding technique that uses dense genome-wide markers to predict the performance of individuals. Unlike MAS, which focuses on a few markers linked to major genes, GS considers the


**Manisha Patel**
Research Scholar, Department of Genetics and Plant Breeding, Bihar Agricultural University, Sabour, Bhagalpur, Bihar
**Radheshyam Ramkrishna Dhole**
Assistant Professor, Department of Entomology, Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas, Bihar

effects of all markers across the genome simultaneously. The key concept in GS is the estimation of Genomic Estimated Breeding Values (GEBVs), which represent the genetic potential of an individual. These values are calculated using statistical models trained on a reference population with known genotypic and phenotypic data.

**Components of Genomic Selection**

Genomic selection involves three main components:

**Training Population:** A set of individuals with both genotypic and phenotypic data

**Prediction Model:** Statistical models used to estimate marker effects

**Selection Candidates:** Individuals genotyped but not phenotyped, selected based on predicted performance

This framework allows efficient selection without extensive field testing.

**Methodology of Genomic Selection**

The process of GS typically involves the following steps:

**Development of Training Population:** Select a diverse population representing genetic variability

**Phenotyping:** Evaluate pest resistance under controlled and field conditions

**Genotyping:** Use high-density markers such as SNPs to capture genome-wide variation

**Model Development:** Apply statistical models like BLUP, Bayesian methods, or machine learning algorithms

**Prediction of GEBVs:** Estimate breeding values for new individuals

**Selection and Advancement:** Choose superior lines for further breeding

This methodology significantly reduces the breeding cycle time.

**Types of Genomic Selection Models**

Different statistical models are used in GS:

**Genomic Best Linear Unbiased Prediction (GBLUP):** Assumes equal contribution of markers

**Bayesian Models (Bayes A, B, C):** Allow variable marker effects

**Machine Learning Models:** Include random forests, support vector machines, and neural networks

Each model has its own strengths depending on the trait and dataset.

**Application in Pest Resistance Breeding**

Genomic selection has been widely applied in developing pest-resistant crop varieties:

**Rice:** Prediction of resistance to brown planthopper and stem borers

**Maize:** Selection for resistance against fall armyworm and stem borers

**Wheat:** Improvement of resistance to aphids and Hessian fly

**Soybean and Cotton:** Enhanced resistance to various insect pests

GS enables simultaneous improvement of pest resistance along with yield and quality traits.

**Advantages of Genomic Selection**

**Higher Accuracy:** Captures small effects of multiple genes

**Faster Breeding Cycles:** Reduces need for repeated phenotyping

**Early Selection:** Enables selection at seedling stage

**Cost-Effective in Long Term:** Reduces field evaluation costs

**Simultaneous Trait Improvement:** Allows selection for multiple traits

These advantages make GS highly suitable for complex traits like pest resistance.

## Comparison with Marker-Assisted Selection

| Feature | Marker-Assisted Selection (MAS) | Genomic Selection (GS) |
|---|---|---|
| Target genes | Few major genes | Genome-wide markers |
| Trait type | Simple traits | Complex traits |
| Efficiency | Moderate | High |
| Selection stage | Later stages | Early stages |
| Genetic gain | Limited | Higher |

This comparison highlights the superiority of GS for complex breeding objectives.

## Challenges and Limitations

Despite its potential, GS faces several challenges:

**High Initial Cost:** Genotyping and infrastructure requirements

**Data Complexity:** Requires advanced statistical and computational tools

**Model Accuracy:** Depends on quality of training population

**Limited Adoption:** Lack of expertise in developing countries

Overcoming these challenges is essential for widespread adoption.

## Integration with Modern Technologies

Genomic selection is increasingly integrated with other advanced tools:

**Next-Generation Sequencing (NGS):** Provides high-density marker data

**High-Throughput Phenotyping:** Improves accuracy of trait measurement

**CRISPR Genome Editing:** Enables precise modification of selected genes

**Artificial Intelligence (AI):** Enhances prediction models

This integration enhances the efficiency of crop improvement programs.

## Role in Sustainable Agriculture

GS contributes to sustainability by:

- ✓ Reducing reliance on chemical pesticides
- ✓ Promoting eco-friendly pest management
- ✓ Enhancing crop productivity and resilience Supporting climate-smart agriculture

These benefits make GS a key tool for future agriculture.

## Future Strategies

The future of genomic selection in pest resistance breeding is highly promising. Key strategies include:

- ✓ Expanding genomic databases for diverse crops
- ✓ Developing low-cost genotyping platforms
- ✓ Enhancing training populations for better prediction accuracy
- ✓ Integrating GS with precision agriculture tools
- ✓ Promoting capacity building and interdisciplinary research

Additionally, the use of AI and big data analytics will further improve prediction accuracy and decision-making in breeding programs.

## Conclusion

Genomic selection represents a revolutionary advancement in plant breeding, offering a powerful

approach for improving pest resistance in crops. By utilizing genome-wide marker information, GS overcomes the limitations of traditional breeding and marker-assisted selection, enabling faster and more accurate selection of superior genotypes. Its ability to handle complex traits and integrate with modern technologies makes it an indispensable tool for sustainable agriculture. Despite certain challenges, ongoing advancements in genomics and data science are making GS more accessible and effective. The adoption of genomic selection in crop improvement programs will play a crucial role in ensuring food security and reducing the environmental impact of agriculture.

## References

Meuwissen, T. H. E., Hayes, B. J. annd Goddard, M. E. (2001). Prediction of total genetic value using genome-wide markers. *Genetics*, 157: 1819-1829.

Heffner, E. L., Sorrells, M. E. and Jannink, J. L. (2009). Genomic selection for crop improvement. *Crop Science*, 49: 1-12.

Crossa, J., Pérez, P., Hickey, J., *et al.* (2014). Genomic prediction in plant breeding. *Heredity*, 112: 48-60.

Varshney, R. K., Singh, V. K., Hickey, J. M., *et al.* (2021). Genomic selection for crop improvement. *Trends in Plant Science*, 26: 941-956.

Desta, Z. A. and Ortiz, R. (2014). Genomic selection in plant breeding. *Plant Breeding Reviews*, 38: 153-193.

# Application of RNA Interference Technology in Plant Breeding for Insect Pest Suppression

**Manisha Patel and Radheshyam Ramkrishna Dhole**


## Abstract

Insect pests are among the most significant challenges to global agriculture, causing severe crop losses and increasing dependence on chemical pesticides. RNA interference (RNAi) technology has emerged as a revolutionary tool for targeted pest management and crop improvement. RNAi is a gene-silencing mechanism that enables the suppression of specific genes in insects, thereby affecting their growth, development, or survival. In plant breeding, RNAi offers a precise, eco-friendly, and sustainable approach for developing insect-resistant crop varieties. This article explores the principles of RNAi technology, its application in pest suppression, methodologies, advantages, challenges, and future prospects. The integration of RNAi into plant breeding programs has the potential to transform pest management strategies and contribute significantly to sustainable agriculture and food security.


## Introduction

Agricultural productivity is heavily influenced by insect pests that damage crops and reduce yield and quality. Conventional pest control methods rely on chemical pesticides, which pose environmental hazards, lead to resistance development in insect populations, and negatively affect beneficial organisms. As a result, there is an increasing demand for sustainable and targeted pest management strategies. RNA interference (RNAi) is a natural biological process found in eukaryotic organisms, where double-stranded RNA (dsRNA) molecules inhibit gene expression by degrading messenger RNA (mRNA). This mechanism has been harnessed as a powerful tool in plant biotechnology to develop crops with enhanced resistance to insect pests.

RNAi-based pest control involves silencing essential genes in insect pests, thereby disrupting their physiological processes. Unlike traditional approaches, RNAi offers species-specific targeting, minimizing off-target effects and environmental risks. The application of RNAi in plant breeding represents a promising advancement in modern agriculture.

## Key Highlights

**Principle of RNA Interference Technology:** RNA interference is a sequence-specific gene-silencing mechanism. It is triggered by the introduction of double-stranded RNA (dsRNA) into the cell. The dsRNA is processed into small interfering RNAs (siRNAs) by an enzyme called Dicer. These siRNAs are incorporated into the RNA-induced silencing


**Manisha Patel**
Research Scholar, Department of Genetics and Plant Breeding, Bihar Agricultural University, Sabour, Bhagalpur, Bihar

**Radheshyam Ramkrishna Dhole**
Assistant Professor, Department of Entomology, Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas, Bihar

complex (RISC), which binds to complementary mRNA sequences and degrades them, preventing protein synthesis.

This process effectively "turns off" specific genes, allowing researchers to target genes essential for insect survival or reproduction.

**Types of RNAi Approaches in Pest Management**

RNAi technology can be applied in different ways:

**Host-Induced Gene Silencing (HIGS):** Plants are genetically engineered to produce dsRNA targeting insect genes.

**Spray-Induced Gene Silencing (SIGS):** dsRNA is applied externally as a spray, which is taken up by insects feeding on the plant.

**Virus-Induced Gene Silencing (VIGS):** Plant viruses are used as vectors to deliver gene-silencing constructs.

These approaches provide flexibility in implementing RNAi for pest control.

**Mechanism of Insect Pest Suppression**

When insects feed on RNAi-expressing plants or ingest dsRNA, the following occurs:

- ✓ dsRNA enters the insect gut
- ✓ It is processed into siRNAs Target mRNA is degraded
- ✓ Essential proteins are not produced
- ✓ Insect growth, development, or survival is impaired

This targeted mechanism ensures effective pest suppression with minimal impact on non-target organisms.

**Target Genes for RNAi-Based Control**

RNAi technology targets critical genes in insect pests, such as:

**Genes involved in digestion:** Affect nutrient absorption

**Genes regulating development:** Disrupt molting and metamorphosis

**Reproductive genes:** Reduce fertility and population growth

**Detoxification genes:** Increase susceptibility to plant defenses

Selection of appropriate target genes is crucial for effective pest control.

**Applications in Crop Improvement**

RNAi has been successfully applied in several crops:

**Maize:** Control of rootworms through gene silencing

**Cotton:** Suppression of bollworms and other lepidopteran pests

**Rice:** Resistance against planthoppers and stem borers

**Potato:** Protection against Colorado potato beetle

These applications demonstrate the potential of RNAi in developing pest-resistant varieties.

**Advantages of RNAi Technology**

**High Specificity:** Targets specific insect species without affecting beneficial organisms

**Eco-Friendly:** Reduces reliance on chemical pesticides

**Versatility:** Can target multiple genes simultaneously

**Reduced Resistance Development:** Lower chances of resistance compared to conventional methods

**Compatibility with IPM:** Integrates well with other

pest management strategies

## Comparison with Conventional Methods

| Feature | Chemical Pesticides | RNAi Technology |
|---|---|---|
| Specificity | Low | High |
| Environmental impact | High | Low |
| Resistance development | Rapid | Slower |
| Target precision | Limited | Highly precise |

This comparison highlights the superiority of RNAi as a sustainable pest management tool.

## Challenges and Limitations

Despite its potential, RNAi technology faces several challenges:

**Stability of dsRNA:** Degradation under environmental conditions

**Delivery Efficiency:** Ensuring uptake by target insects

**Variable Response:** Different insect species show varying sensitivity

**Regulatory Issues:** Approval processes for RNAi-based crops

**Cost:** High initial development costs

Addressing these challenges is essential for large-scale adoption.

## Recent Advances in RNAi Technology

Recent developments have improved RNAi applications:

**Nanotechnology based Delivery:** Enhances stability and uptake of dsRNA

**Improved Gene Targets:** Identification of highly effective genes

**Combination Strategies:** Integration with *Bt* crops and other technologies

**Genome Sequencing:** Facilitates identification of target genes

These advances are increasing the effectiveness of RNAi-based pest control.

## Role in Sustainable Agriculture

RNAi technology contributes to sustainability by:

- ✓ Reducing chemical pesticide use
- ✓ Protecting beneficial insects and biodiversity
- ✓ Enhancing crop productivity
- ✓ Supporting eco-friendly farming practices

## Future Strategy

The future of RNAi in plant breeding is highly promising. Key strategies include:

- ✓ Developing cost-effective dsRNA production methods
- ✓ Enhancing delivery systems for field applications
- ✓ Expanding research to a wider range of crops and pests
- ✓ Integrating RNAi with genomic selection and genome editing tools
- ✓ Strengthening regulatory frameworks and public awareness

The use of artificial intelligence and bioinformatics will further improve target gene identification and prediction of RNAi efficiency.

## Conclusion

RNA interference technology represents a groundbreaking advancement in plant breeding and pest management. Its ability to precisely target insect genes offers a sustainable and environmentally friendly alternative to conventional pest control methods. By integrating RNAi into crop improvement programs, breeders can develop pest-resistant varieties that reduce reliance on chemical pesticides

and enhance agricultural productivity. Although challenges remain, ongoing research and technological innovations are addressing these limitations. RNAi has the potential to play a pivotal role in ensuring food security and promoting sustainable agriculture in the future.

## References

Baum, J. A., *et al.* (2007). Control of coleopteran insect pests through RNA interference. *Nature Biotechnology*, 25: 1322-1326.

Zotti, M., *et al.* (2018). RNA interference technology in crop protection. *Pest Management Science*, 74: 1239-1250.

Christiaens, O., *et al.* (2020). The use of RNAi for insect pest control. *Nature Reviews Insect Science*, 1: 1-18.

Dubrovina, A. S. and Kiselev, K. V. (2019). Exogenous RNA interference in plants. *International Journal of Molecular Sciences*, 20: 2282.

Mamta, B. and Rajam, M. V. (2017). RNAi technology in crop protection. *Plant Cell Reports*, 36: 1625-1642.

# Breeding Climate-Resilient Crops with Pest Resistance Traits

**Manisha Patel and Radheshyam Ramkrishna Dhole**


## Abstract

Climate change poses a significant threat to global agriculture by altering temperature, precipitation patterns, and the distribution of insect pests. These changes not only affect crop growth but also intensify pest incidence and severity, leading to substantial yield losses. Developing climate-resilient crops with enhanced pest resistance is essential for ensuring food security and sustainable agriculture. Modern plant breeding approaches, integrating conventional methods with advanced genomic tools, are enabling the development of crop varieties that can withstand both environmental stresses and pest pressures. This article discusses the concept of climate-resilient breeding, mechanisms of pest resistance, and strategies for developing resilient crops, recent advancements, challenges, and future prospects. The integration of climate adaptation and pest resistance in breeding programs is a crucial step toward sustainable agricultural systems.


## Introduction

Agriculture is highly sensitive to climate variability, and recent changes in global climate patterns have significantly impacted crop production systems. Rising temperatures, erratic rainfall, increased frequency of extreme weather events, and shifting agro-ecological zones are influencing crop growth and productivity. At the same time, climate change is altering the biology, distribution, and population dynamics of insect pests, often leading to more frequent and severe pest outbreaks. Traditional crop varieties are often not equipped to cope with these combined stresses. Therefore, there is a growing need to develop crop varieties that are resilient to climatic stresses while also possessing strong resistance to insect pests. Climate-resilient crops are those that can maintain productivity under adverse environmental conditions such as drought, heat, salinity, and flooding. Plant breeding plays a central role in developing such crops by integrating traits for abiotic stress tolerance and pest resistance. Advances in molecular biology, genomics, and biotechnology are accelerating the breeding process and improving the efficiency of developing resilient crop varieties.

## Key Highlights

**Concept of Climate-Resilient Crops:** Climate-resilient crops are varieties that can withstand environmental stresses caused by climate change while maintaining stable yields.


**Manisha Patel**
Research Scholar, Department of Genetics and Plant Breeding, Bihar Agricultural University, Sabour, Bhagalpur, Bihar
**Radheshyam Ramkrishna Dhole**
Assistant Professor, Department of Entomology, Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas, Bihar

These crops possess traits such as drought tolerance, heat tolerance, flood tolerance, and resistance to pests and diseases.

The integration of pest resistance into climate-resilient crops is critical because changing climate conditions often increase pest pressure, making crops more vulnerable.

## Impact of Climate Change on Insect Pests

Climate change influences insect pests in several ways:

**Increased Reproduction Rates:** Higher temperatures accelerate insect life cycles

**Expanded Geographic Range:** Pests spread to new regions

**Altered Pest-Plant Interactions:** Changes in plant physiology affect pest behavior

**Increased Overwintering Survival:** Mild winters allow more pests to survive

These factors highlight the importance of incorporating pest resistance into climate-resilient crops.

## Mechanisms of Pest Resistance in Crops

Pest-resistant crops employ various defense mechanisms:

**Antixenosis (Non-Preference):** Plants deter insect feeding or egg-laying

**Antibiosis:** Plants adversely affect insect growth and survival

**Tolerance:** Plants withstand damage without significant yield loss

These mechanisms can be combined to provide durable and broad-spectrum resistance.

## Breeding Approaches for Climate Resilience and Pest Resistance

Several breeding approaches are used to develop resilient crops:

**Conventional Breeding:** Selection and hybridization of tolerant and resistant varieties

**Marker-Assisted Selection (MAS):** Identification and transfer of resistance genes using molecular markers

**Genomic Selection (GS):** Prediction of breeding values using genome-wide markers

**Transgenic Approaches:** Introduction of genes for pest resistance

**Genome Editing (CRISPR):** Precise modification of genes associated with stress tolerance and resistance

These approaches complement each other in modern breeding programs.

## Role of Genetic Resources

Genetic diversity is essential for breeding resilient crops. Sources include:

**Wild Relatives:** Provide genes for stress tolerance and pest resistance

**Landraces:** Adapted to local environments

**Gene Banks:** Preserve diverse genetic material

Utilizing these resources enhances the adaptability and resilience of crops.

## Trait Integration and Pyramiding

Combining multiple traits in a single variety is a key strategy:

**Gene Pyramiding:** Stacking multiple resistance genes

**Trait Integration:** Combining abiotic stress tolerance with pest resistance

**Multi-Environment Testing:** Ensuring stability across diverse conditions

This approach ensures long-term effectiveness and adaptability.

## Advantages of Climate-Resilient Pest-Resistant Crops

**Reduced Crop Losses:** Protection against both environmental and biological stresses

**Lower Pesticide Use:** Environmentally friendly pest management

**Improved Yield Stability:** Consistent performance under variable conditions

**Economic Benefits:** Increased profitability for farmers

**Sustainability:** Supports eco-friendly agricultural practices

## Challenges and Limitations

Despite their potential, several challenges exist:

**Complex Genetics:** Traits are controlled by multiple genes

**Environmental Interactions:** Trait expression varies across environments

**Breeding Time:** Developing multi-trait varieties is time-consuming

**Resource Constraints:** Limited access to advanced technologies in developing regions

**Regulatory Issues:** Approval of genetically modified crops

Addressing these challenges is crucial for successful implementation.

## Recent Advances in Breeding Technologies

Recent developments have enhanced breeding efficiency:

**Next-Generation Sequencing (NGS):** Enables identification of stress-related genes

**High-Throughput Phenotyping:** Accurate measurement of traits

**Artificial Intelligence (AI):** Predicts plant performance under different conditions

**Precision Agriculture:** Optimizes crop management

These technologies are transforming crop improvement strategies.

## Case Examples

**Rice:** Development of drought-tolerant and pest-resistant varieties

**Wheat:** Breeding for heat tolerance and resistance to aphids

**Maize:** Improved varieties resistant to drought and fall armyworm

**Pulses:** Enhanced tolerance to drought and resistance to pod borers

These examples demonstrate the practical application of climate-resilient breeding.

## Future Strategy

The future of breeding climate-resilient and pest-resistant crops lies in integrating multidisciplinary approaches. Key strategies include:

- ✓ Strengthening genomic research and data integration
- ✓ Expanding the use of wild germplasm and landraces

- ✓ Developing cost-effective breeding technologies
- ✓ Enhancing collaboration between research institutions and farmers
- ✓ Promoting climate-smart agricultural practices

Additionally, policy support and public awareness are essential for the adoption of improved crop varieties.

## Conclusion

Breeding climate-resilient crops with pest resistance traits is a critical strategy for ensuring sustainable agriculture in the face of climate change. By integrating traits for abiotic stress tolerance and pest resistance, plant breeders can develop crop varieties that are capable of maintaining productivity under challenging conditions. Advances in molecular biology, genomics, and biotechnology are accelerating the breeding process and improving the precision of trait selection. Although challenges remain, continued research and innovation will enable the development of resilient crops that contribute to food security, environmental sustainability, and economic stability for farmers. The future of agriculture depends on the successful integration of climate resilience and pest resistance in crop improvement programs.

## References

Lesk, C., Rowhani, P. and Ramankutty, N. (2016). Influence of extreme weather on crop production. *Nature*, 529: 84-87.

Varshney, R. K., *et al.* (2018). Can genomics deliver climate-change ready crops? *Current Opinion in Plant Biology*, 45: 205-211.

Lobell, D. B., *et al.* (2011). Climate trends and global crop production. *Science*, 333: 616-620.

Reynolds, M., *et al.* (2016). Improving global integration of crop research. *Nature Climate Change*, 6: 56-60.

Savary, S., *et al.* (2019). The global burden of pathogens and pests on crops. *Nature Ecology & Evolution*, 3: 430-439.

# The Nutritional Powerhouse: Exploring the Benefits of Black Rice

**Gurpreet Kaur, Kanik Kumar Bansal and Komal**

**Abstract**

Black rice (*Oryza sativa* L.), commonly referred to as "forbidden rice," has gained increasing attention in nutritional science due to its exceptional phytochemical composition and health-promoting properties. Rich in anthocyanins, phenolic compounds, dietary fiber, and essential micronutrients, black rice is recognized as a functional food with potential roles in preventing chronic diseases such as diabetes, cardiovascular disorders, and cancer. This article critically examines the nutritional composition, bioactive compounds, physiological benefits, and emerging applications of black rice, drawing upon evidence from high-impact scientific journals.

## Introduction

Rice is a staple food for nearly half of the global population, yet its nutritional quality varies significantly among different varieties. While white rice is widely consumed, it undergoes extensive milling that removes essential nutrients. In contrast, pigmented rice varieties such as black rice retain their bran layer and are rich in bioactive compounds. Black rice has been cultivated for over 4,000 years, particularly in East and Southeast Asia, where it was historically reserved for royalty due to its rarity and perceived health benefits (Thilavech *et al.*, 2025). Today, it is increasingly recognized in modern nutrition as a nutrient-dense grain with therapeutic potential. Recent research highlights black rice as a "nutraceutical" food, meaning it provides health benefits beyond basic nutrition, including disease prevention and metabolic regulation.

## Nutritional Composition of Black Rice

**Macronutrients:** Black rice is a rich source of complex carbohydrates, dietary fiber, and plant-based protein. Compared to white rice, it contains significantly higher protein and fiber levels, contributing to improved satiety and metabolic health (Nutrition and Food Science, 2021). Dietary fiber plays a crucial role in regulating digestion, lowering cholesterol levels, and maintaining glycemiccontrol. The presence of resistant starch further enhances its functional properties, particularly in glucose metabolism.

## Micronutrients

Black rice contains essential vitamins and minerals, including:

- ✓ Iron
- ✓ Zinc
- ✓ Magnesium
- ✓ Potassium
- ✓ B-complex vitamins

These micronutrients are vital for enzymatic functions, oxygen transport, and immune regulation

**Gurpreet Kaur, Kanik Kumar Bansal and Komal**
Faculty of Agriculture, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab

(Nutrition and Food Science, 2021).

**Bioactive Compounds:** The defining feature of black rice is its high concentration of bioactive compounds, including:

- ✓ Anthocyanins
- ✓ Flavonoids
- ✓ Phenolic acids
- ✓ γ-oryzanol and tocopherols

These compounds contribute to its antioxidant, anti-inflammatory and disease-preventive properties (Nutrition and Food Science, 2021). Notably, black rice has been reported to contain significantly higher levels of anthocyanins compared to other rice varieties, making it one of the richest plant-based sources of these compounds.

**Anthocyanins and Antioxidant Capacity**

- ✓ Anthocyanins are water-soluble pigments responsible for the deep purple-black color of black rice. These compounds exhibit strong antioxidant activity by neutralizing free radicals and reducing oxidative stress (Thilavech *et al*., 2025).
- ✓ Studies indicate that black rice contains up to six times more antioxidants than white or brown rice. This high antioxidant capacity plays a critical role in preventing cellular damage and slowing the progression of chronic diseases (Thilavech *et al*., 2025).
- ✓ Oxidative stress is implicated in aging, cancer, cardiovascular diseases, and neurodegenerative disorders. By scavenging reactive oxygen species (ROS), anthocyanins help maintain cellular integrity and function (Ou *et al*., 2023).

**Health Benefits of Black Rice**

**Anti-Diabetic Properties:** Black rice has demonstrated significant potential in regulating blood glucose levels. Anthocyanins inhibit carbohydrate-digesting enzymes such as α-amylase and α-glucosidase, thereby slowing glucose absorption in the intestine. Clinical and in vitro studies show that black rice consumption can reduce postprandial hyperglycemia and improve insulin sensitivity, making it beneficial for diabetes management (Ou *et al.*, 2023).

**Cardiovascular Protection:** Cardiovascular diseases remain a leading cause of mortality worldwide. Black rice contributes to heart health through multiple mechanisms:

- ✓ Reduction of LDL cholesterol
- ✓ Improvement of lipid metabolism
- ✓ Prevention of oxidative damage to blood vessels

Anthocyanins also interfere with cholesterol absorption and bile acid metabolism, further supporting cardiovascular health (Nutrition and Food Science, 2021).

**Anti-Inflammatory Effects:** Chronic inflammation is a key contributor to metabolic disorders and degenerative diseases. Bioactive compounds in black rice, particularly phenolics and flavonoids, exhibit anti-inflammatory properties by modulating inflammatory pathways (Nutrition and Food Science, 2021). These compounds reduce the production of pro-inflammatory cytokines, thereby lowering the risk of conditions such as arthritis, obesity, and meta-

bolic syndrome.

**Anti-Cancer Potential:** Emerging evidence suggests that black rice may possess anti-cancer properties. Anthocyanins have been shown to inhibit tumor growth, induce apoptosis (programmed cell death), and prevent DNA damage. Although most findings are based on in vitro and animal studies, they highlight the potential of black rice as a complementary dietary component in cancer prevention strategies (Ou *et al.*, 2023).

**Gut Health and Microbiome Regulation:** The dietary fiber and resistant starch in black rice support gut health by promoting beneficial gut microbiota. A healthy gut microbiome is associated with improved digestion, enhanced immunity, and reduced risk of gastrointestinal disorders. Additionally, fermentation of fiber in the colon produces short-chain fatty acids (SCFAs), which contribute to intestinal health (Food Chemistry Advances, 2025).

**Neuroprotective Effects:** Recent research suggests that anthocyanin-rich foods, including black rice, may support cognitive function and reduce neuro inflammation. These compounds can cross the blood-brain barrier and exert protective effects on neuronal cells. Although further clinical studies are needed, preliminary findings indicate potential benefits in preventing neurodegenerative diseases such as Alzheimer's (Food Chemistry, 2019).

**Weight Management and Metabolic Health:** Black rice is beneficial for weight management due to its high fiber and protein content, which promote satiety and reduce overall calorie intake. Its low glycemic index also prevents rapid spikes in blood sugar, helping to regulate appetite and energy balance (ICAR, 2025).

## Black Rice as a Functional Food

Functional foods are defined as foods that provide health benefits beyond basic nutrition. Black rice fits this category due to its rich composition of bioactive compounds and therapeutic effects. It has been increasingly used in the development of:

- ✓ Functional beverages
- ✓ Nutraceutical products
- ✓ Fortified foods

The incorporation of black rice into food products enhances their antioxidant capacity and nutritional value (Food Chemistry Advances, 2023).

## Applications in Food Science and Industry

Black rice is gaining popularity in the food industry due to its versatility and health benefits. It is used in:

- ✓ Bakery products
- ✓ Dairy formulations
- ✓ Snack foods
- ✓ Gluten-free products

Additionally, anthocyanins extracted from black rice are used as natural food colorants, offering a safer alternative to synthetic dyes (Food Chemistry Advances, 2025).

## Comparison with Other Rice Varieties

Compared to white and brown rice:

- ✓ Black rice has higher antioxidant levels
- ✓ Contains more protein and fiber
- ✓ Offers superior micronutrient density

White rice, due to polishing, loses most of its nutrients, while brown rice retains some but lacks the high anthocyanin content found in black rice.

## Limitations and Challenges

Despite its benefits, black rice faces several challenges:

- ✓ Higher cost and limited availability
- ✓ Longer cooking time
- ✓ Lower agricultural yield compared to conventional rice

These factors may limit its widespread adoption, particularly in low-income populations.

## Future Perspectives

Ongoing research is focused on:

- ✓ Enhancing the yield and quality of black rice varieties
- ✓ Developing functional food products
- ✓ Conducting clinical trials to validate health claims

The integration of black rice into global diets could contribute significantly to improving public health outcomes.

## Conclusion

Black rice is a highly nutritious grain with immense potential in promoting health and preventing disease. Its rich composition of anthocyanins, phenolic compounds, and essential nutrients distinguishes it from other rice varieties.

Scientific evidence supports its role in managing diabetes, improving cardiovascular health, reducing inflammation, and providing antioxidant protection. As research continues to uncover its full potential, black rice is poised to become a key component of functional nutrition and sustainable diets.

## References

Thilavech, T., *et al*. (2025). Black rice (*Oryza sativa* L.) and its anthocyanins: mechanisms and clinical insights. Food Production, Processing and Nutrition.

Ou, S. J. L., *et al*. (2023). Postprandial glycemic and lipidemic effects of black rice anthocyanins. *NPJ Science of Food*.

Food Chemistry Advances. (2023). Black rice: bioactive compounds and health benefits.

Food Chemistry. (2019). Chemical composition and functional properties of black rice.

Nutrition and Food Science. (2021). Bioactive compounds and nutritional benefits of black rice.

Food Chemistry Advances. (2025). Functional properties and antioxidant richness of black rice.

ICAR (Indian Farming Journal). (2025) Nutritional advantage of black rice.

# Urban Fruit Gardening and Terrace Orchards: Bringing Nature Back to City Life

G. Bhrijavasi and P. Vinaya Kumar Reddy

## Introduction

Modern city life is becoming increasingly stressful and disconnected from nature. Rapid urbanization has reduced open spaces, and many people now live in apartments with very limited greenery around them. At the same time, concerns about food safety, pesticide residues, and rising prices of fruits and vegetables are increasing. In this situation, urban fruit gardening and terrace orchards are emerging as excellent solutions for healthy and sustainable living. Urban fruit gardening simply means growing fruit plants in small spaces such as terraces, balconies, rooftops, backyards, and kitchen gardens. Today, many city residents are successfully growing fruits like guava, lemon, papaya, strawberry, pomegranate, banana, and dragon fruit even in containers and grow bags. Terrace orchards not only provide fresh fruits but also create a peaceful and green environment in urban homes.

## Why Urban Fruit Gardening is Becoming Popular

Many people are now realizing the importance of consuming fresh and chemical-free fruits. Home-grown fruits provide confidence regarding food safety and quality. Urban gardening is also becoming popular because it:

- ✓ Utilizes empty terrace space
- ✓ Improves household nutrition
- ✓ Reduces stress
- ✓ Enhances environmental quality
- ✓ Encourages healthy lifestyles

For many families, gardening has become both a hobby and a healthy daily activity.

## Fruit Crops Suitable for Terrace Orchards

Several fruit crops can be grown successfully in urban conditions.

**Guava:** Guava is one of the easiest fruit plants to grow in containers. It tolerates pruning well and produces fruits regularly.

**Lemon and Citrus Fruits:** Lemon plants are highly popular because they require less space and are useful throughout the year.

**Papaya:** Dwarf papaya varieties can produce fruits quickly and grow well in terrace gardens.

**Banana:** Dwarf banana plants adapt well to grow bags and large containers.

**Strawberry:** Strawberries are attractive, easy to manage, and highly suitable for terrace cultivation.

**Dragon Fruit:** Dragon fruit is becoming increasingly popular because of its nutritional value and exotic appearance.

These crops not only provide fruits but also improve the beauty of home gardens.

## Basic Requirements for Terrace Orchards

G. Bhrijavasi and P. Vinaya Kumar Reddy
College of Horticulture, Dr. Y.S.R. Horticultural University, Venkataramannagudem, Andhra Pradesh

**Sunlight:** Most fruit plants require at least five to six hours of sunlight daily.

**Containers:** Plants can be grown in pots, drums, cement containers, or grow bags with proper drainage.

**Growing Medium:** A good potting mixture usually contains:

- ✓ Red soil
- ✓ Compost or farmyard manure
- ✓ Cocopeat
- ✓ Sand
- ✓ Vermicompost

**Water Management:** Container-grown plants require regular watering because the soil dries quickly during hot weather.

**Organic Nutrition:** Many urban gardeners prefer using organic manures such as vermicompost, neem cake, and kitchen compost.

## Environmental Benefits of Terrace Orchards

Urban fruit gardening contributes greatly toward environmental improvement. Plants absorb carbon dioxide and release oxygen, helping improve air quality in cities. Terrace gardens also:

- ✓ Reduce rooftop heat
- ✓ Improve biodiversity
- ✓ Attract pollinators like bees and butterflies
- ✓ Help in rainwater absorption
- ✓ Reduce urban pollution

In many cities, terrace gardens are helping create greener and cooler urban environments.

**Mental and Physical Health Benefits:** Gardening activities provide mental relaxation and emotional satisfaction. Many people feel peaceful while watering plants, pruning branches, and harvesting fruits from their own gardens. Gardening also encourages physical activity and reduces screen time, especially among children. Studies indicate that interaction with plants can reduce stress and improve mental well-being.

**Challenges in Urban Fruit Gardening:** Despite its benefits, terrace gardening also has some challenges. The major problems include:

- ✓ Limited space
- ✓ Water management issues
- ✓ Pest and disease attacks
- ✓ Lack of technical knowledge
- ✓ Structural load on rooftops

However, with proper guidance and planning, these challenges can be managed effectively.

## Modern Technologies Supporting Urban Gardening

Modern horticultural technologies are making urban fruit gardening easier and more efficient.

**Drip Irrigation:** Mini-drip systems help save water and reduce labour.

**Vertical Gardening:** Vertical systems allow gardeners to grow more plants in less space.

**Hydroponics:** Hydroponics enables cultivation without soil and is becoming popular for strawberries and leafy vegetables.

**Smart Gardening Tools:** Mobile applications and moisture sensors help gardeners monitor plant health and irrigation requirements.

These innovations are making urban horticulture more scientific and productive.

## Future Scope of Urban Fruit Gardening

The future of terrace orchards appears highly promising because urban populations are continuously increasing. Many experts believe that urban agriculture will become an important part of sustainable city development. Future trends may include:

- ✓ Smart rooftop farms
- ✓ Community fruit gardens
- ✓ Organic terrace orchards
- ✓ Hydroponic fruit cultivation
- ✓ IoT-based irrigation systems

Government agencies and horticultural universities are also promoting urban gardening through training and awareness programs.

## Conclusion

Urban fruit gardening and terrace orchards are reconnecting people with nature in the middle of busy city life. Even small spaces can be transformed into productive green areas capable of producing fresh and healthy fruits. Apart from improving household nutrition, terrace orchards contribute toward environmental conservation, stress reduction, and sustainable living. With increasing awareness regarding healthy lifestyles and food safety, urban fruit gardening is likely to become even more popular in the future. Growing fruits at home is no longer just a hobby it is gradually becoming a healthy and sustainable way of living.

## References

Government of India, Ministry of Housing and Urban Affairs. (2021). Urban Agriculture: Practices and Guidelines.

Lal, R. and Stewart, B.A. (2017). Urban Agriculture and City Sustainability. CRC Press.

Despommier, D. (2010). The Vertical Farm: Feeding the World in the 21st Century.

Choudhary, M. L. and Dikshit, S. N. (2019). Urban Horticulture and Terrace Gardening in India. Indian Horticulture, ICAR.

ICAR Handbook of Horticulture (2019).

Singh, H. P., Sharma, R. R. and Rao, V. K. (2018). Advances in Horticulture and Urban Gardening.

# Precision Irrigation Scheduling: A Pathway to Higher Water Use Efficiency in Rice-Wheat Cropping

**Navjot Kaur and Neha Kumawat**


## Abstract

Water scarcity has emerged as one of the most critical challenges threatening agricultural sustainability in South Asia, particularly in the Indo-Gangetic Plains. Punjab, which serves as the breadbasket of India with its rice-wheat cropping system, is confronting an unprecedented groundwater crisis. The state relies on groundwater for approximately 73% of its irrigation requirements, leading to an alarming depletion rate of nearly one meter per year. With an annual water demand of 66.12 billion cubic meters (BCM) across all sectors of which agriculture alone accounts for 62.58 BCM and a growing deficit increasingly met through over-exploitation of deep aquifers, the sustainability of current irrigation practices is severely compromised. Compounding this, monsoon rainfall over Punjab has shown a significant deficit in 80% of years over the last two decades, further stressing freshwater availability. The current water use scenario in Punjab, analyses the water budget of the state and discusses soil, climate and plant-based strategies for improving water use efficiency (WUE) through optimised irrigation scheduling. Identifying demand-supply gap and ensure long-term food and water security.


## Introduction

Agriculture is the backbone of India's economy, employing approximately half of the workforce and contributing significantly to national food security. Among Indian states, Punjab plays a disproportionately large role in national grain production owing to its fertile soils and the wide-spread adoption of the high-yielding rice-wheat cropping system. However, this agricultural product-ivity has been achieved at a substantial environ-mental cost, the rapid depletion of groundwater reserves. According to the Census of India and NITI Aayog, irrigation is virtually universal in Punjab, with 99.9% of agricultural land being irrigated. Of this, only 27% is served by canal water, while the remaining 73% depends on groundwater extracted through tubewells (Punjab Agricultural University, 2017; Groundwater Year Books, CGWB, Punjab). The Central Ground Water Board (2022) has documented that groundwater levels in the state are declining at an average rate of one metre per year (Kaur *et al.*, 2017), classifying large parts of Punjab as overexploited or critical zones. Simultaneously, monsoon rainfall, which replenishes groundwater, has been increasingly unreliable. Analysis of rainfall data spanning five decades (1971-2021) reveals that 80% of years in the last two decades have experienced below-normal monsoon precipitation

**Navjot Kaur and Neha Kumawat**
Research Scholar, Department of Soil Science, PAU, Ludhiana, Punjab

(Kumar *et al*., 2021). This convergence of accelerating groundwater extraction and declining natural recharge makes the current trajectory of water use unsustainable. Improving water use efficiency (WUE) through scientific irrigation scheduling is therefore not merely an agronomic recommendation but an ecological and economic imperative.

## Water Resource Status of Punjab

**Groundwater Depletion:** Punjab is one of the most groundwater-stressed regions in the world. The intensive cultivation of rice, a water-intensive crop, during the summer Kharif season has necessitated large-scale groundwater extraction. Tubewells, which supply 73% of irrigation water, have enabled year-round cultivation but have simultaneously triggered irreversible aquifer depletion. Data from the Central Ground Water Board (2022) confirm that the water table is falling at roughly one metre per year across large tracts of the state, with certain districts experiencing even steeper declines.

**Rainfall Variability:** Analysis of the monsoon rainfall departure from the long-term normal over the period 1971-2021 reveals a discernible trend of increasing rainfall deficits in Punjab. Over the last two decades, 17 out of 20 years (80%) have recorded deficit monsoon rainfall relative to historical normals. This reduction in natural precipitation not only diminishes direct soil moisture availability but also constrains the natural recharge of shallow aquifers, further widening the gap between water supply and agricultural demand (Kumar *et al*., 2021).

**State Water Budget:** A comprehensive water budget for Punjab, derived from the State Irrigation Plan and quantifies the precarious balance between supply and demand. Total water availability from renewable sources amounts to 53.06 BCM, comprising canal water from dams (14.80 BCM), rainfall (26.30 BCM), treated wastewater (1.26 BCM) and return flow from irrigation (10.70 BCM). An additional 13.06 BCM is sourced through drawdown of the water table (5.10 BCM) and withdrawal from deep aquifers (7.96 BCM) the latter representing non-renewable extraction that cannot be sustained indefinitely. Total water demand across all sectors reaches 66.12 BCM, with agriculture accounting for a staggering 94.6% of this total (62.58 BCM). Rural domestic, urban domestic, and industrial uses collectively demand only 3.54 BCM. The 13.06 BCM deficit is entirely met through unsustainable over-exploitation of groundwater, highlighting the urgency of demand-side management.

## Water Use Efficiency: Concepts and Principles

Water use efficiency (WUE) in agriculture is defined as the ratio of marketable crop yield produced to the quantity of water consumed, typically expressed as kg $ha^{-1}$ $mm^{-1}$ or kg $m^{-3}$. The FICCI (2021) framework identifies two overarching principles for improving WUE at the field scale:

- ✓ Increasing the marketable crop yield per unit of water transpired through the stomata (productive water use), achieved by optimising varietal selection agronomic management and crop nutr-

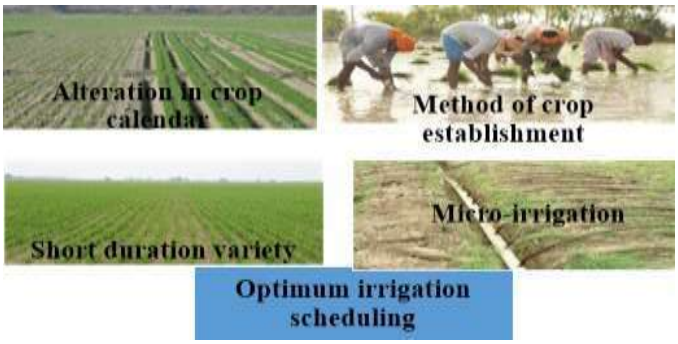
ition.

- ✓ Reducing all non-productive evaporative losses from the crop field, including soil evaporation, surface runoff and deep percolation, which represent water consumed without contributing to crop production.

Improving WUE therefore requires an integrated approach spanning soil, climate, and plant dimensions. Soil-based strategies include improving soil organic matter to enhance water retention, minimum or zero tillage to reduce evaporative surface exposure and adoption of micro-irrigation systems such as drip and sprinkler that deliver water directly to the root zone. Climate-informed strategies involve scheduling irrigation based on evapotranspiration (ET) demand estimated from meteorological data, thereby avoiding both deficit and excess irrigation. Plant-based approaches encompass breeding and selection of drought-tolerant, high-WUE cultivars and the use of crop physiological indicators such as leaf water potential and canopy temperature to guide irrigation timing.

## Irrigation Scheduling in Rice-Wheat System

**Scientific Basis of Irrigation Scheduling:** Irrigation scheduling refers to the decision-making process of determining when to irrigate (timing) and how much water to apply (quantity) to achieve optimal crop growth with minimal water wastage. In the rice-wheat system of Punjab, traditional irrigation practices are largely calendar-based or based on visual assessment of crop wilting, both of which are imprecise and often result in over-irrigation. Scientific irrigation scheduling relies on quantitative methods including soil water balance modelling, tensiometer-based soil moisture monitoring, and reference evapotranspiration ($ET_o$) calculations using the FAO Penman-Monteith equation.




**Strategies for the Rice Crop:** Rice cultivation under continuously flooded conditions, the conventional practice in Punjab, consumes between 1,200 and 1,500 mm of water per season. Water-saving irrigation technologies such as Alternate Wetting and Drying (AWD) and Saturated Soil Culture (SSC) have demonstrated potential for reducing water application by 15-30% without significant yield penalties. Under AWD, the field is allowed to dry to a threshold soil water potential (-15 to -20 kPa) before re-flooding, using perforated field water tubes for monitoring. Transplanting date modification delaying rice transplanting to align with the onset of the south-west monsoon can substantially reduce irrigation water requirements during the early crop growth stages.

**Strategies for the Wheat Crop:** Wheat, grown during the Rabi season from November to April, requires 4-6 irrigations under Punjab conditions, with critical growth stages being crown root initiation (CRI), tillering, jointing, booting, flower-

ing and grain filling. Soil-moisture-based irrigation scheduling using tensiometers or gypsum blocks can identify precise irrigation intervals, reducing water application by 1-2 irrigations per season compared to calendar-based scheduling. Research at Punjab Agricultural University has demonstrated that irrigating at 0.8 IW/CPE (Irrigation Water to Cumulative Pan Evaporation) ratio optimises both yield and water productivity in wheat.

## Conclusions

Improving water use efficiency through evidence-based irrigation scheduling offers the most immediate and scalable lever for reducing agricultural water consumption without compromising food production. By transitioning from flood-based, calendar-driven irrigation to demand-driven scheduling informed by crop evapotranspiration, soil moisture sensors and agronomic knowledge of critical growth stages, substantial water savings estimated at 20-35% in rice and 15-20% in wheat can be achieved at the farm level. Complementary strategies spanning soil health management, climate-adapted crop varieties and physical water conservation structures must accompany irrigation reforms to address the crisis comprehensively. Policy interventions are equally critical. Regulatory frameworks that discourage free or subsidised electricity for groundwater pumping, combined with farmer incentives for adopting water-saving technologies, can create the enabling conditions for widespread adoption of efficient irrigation practices. Long-term aquifer sustainability will ultimately depend on reducing the net extraction deficit of 13.06 BCM through a combination of demand reduction and managed aquifer recharge. Irrigation scheduling, grounded in the scientific principles of WUE maximisation, is an indispensable component of this broader water governance agenda for Punjab and analogous groundwater-stressed agricultural regions worldwide.

## References

Baweja, S., Aggarwal, R., Brar, M. and Lal, R. (2017). Groundwater depletion in Punjab, India. *Encyclopedia of Soil Science*, 3(3): 1-5

Central Ground Water Board. (2022). Ground Water Year Book-Punjab. Ministry of Jal Shakti, Government of India.

FICCI. (2021). Water Use Efficiency in Indian Agriculture: Status and Way Forward. Federation of Indian Chambers of Commerce and Industry, New Delhi.

Punjab Agricultural University. (2017). Package of Practices for Crops of Punjab-*Kharif*. PAU, Ludhiana.

Kumar, A., Giri, R. K., Taloor, A. K. and Singh, A. K. (2021). Rainfall trend, variability and changes over the state of Punjab, India 1981-2020: A geospatial approach. *Remote Sensing Applications: Society and Environment*, 23: 100595.

State Irrigation Plan & Mekorot Assessment. (2019). Punjab State Water Budget and Irrigation Plan. Government of Punjab, Chandigarh.

# Transcriptomics: A New Era of Vegetable Crop Improvement

**Teja S., S. S. Masaye and A. I. Patel**


## Abstract

Vegetables play a crucial role in global health and nutrition; however, enhancing their productivity and resilience necessitates a more profound understanding of gene functionality. Transcriptomics, the comprehensive study of RNA molecules within a cell, has emerged as a potent tool for elucidating gene expression patterns in vegetables. By identifying which genes are upregulated or downregulated during growth, stress and nutrient uptake in transcriptomics aids in identifying candidate genes for increased yields, disease resistance and improved nutritional quality. Recent advancements such as RNA sequencing (RNA-seq), single-cell RNA sequencing and spatial transcriptomics enable researchers to examine gene activity with unprecedented precision, ranging from individual cells to tissue-level distribution. Although these advanced methodologies are extensively utilized in medicine, they are beginning to revolutionize plant research, providing novel strategies for targeted breeding and genetic engineering. Through the mapping of intricate regulatory networks and environmental responses, transcriptomics offers a strategic framework for the development of vegetable varieties that exhibit enhanced resilience, nutritional value and farmer accessibility. This article underscores the transformative impact of transcriptomics on vegetable enhancement and delineates prospective pathways where genomics and breeding intersect to promote sustainable agricultural practices.


## Introduction

Transcriptomics involves the comprehensive analysis of gene transcription and regulatory networks within biological systems. This field was initiated by Velculescu *et al*. in 1997, marking the first systematic profiling of cellular mRNA populations. Broadly, the transcriptome encompasses the complete set of RNAs including messenger (mRNA), ribosomal (rRNA), transfer (tRNA) and non-coding (ncRNA) species expressed under specific physiological or environmental conditions. More narrowly, it refers to the protein-coding mRNA fraction, which remains the primary focus of most transcriptomic studies. By quantifying gene expression dynamics at the transcriptional level, transcriptomics elucidates the molecular mechanisms underlying biological processes, ranging from developmental programs to stress responses.


**Teja S.**
Department of Vegetable Science, ASPEE College of Horticulture, NAU, Navsari, Gujarat
**S. S Masaye**
Department of Vegetable Science, Polytechnic in Horticulture, Paria, ASPEE College of Horticulture, NAU, Navsari, Gujarat
**A. I. Patel**
Department of Fruit Science, ASPEE College of Horticulture, NAU, Navsari, Gujarat

Since its inception, technological advancements have established transcriptomics as a cornerstone of modern biological research (Yu *et al.*, 2025). The evolution of transcriptomics has progressed through three significant stages: Bulk RNA-Seq is high-throughput sequencing technique measures average gene expression across tissues, thereby uncovering pathways related to development and stress response. Single-cell RNA-Seq (scRNA-Seq) captures gene activity at the resolution of individual cells, revealing previously hidden cellular heterogeneity and intricate regulatory mechanisms. Spatial transcriptomics (ST) approach incorporates spatial context, identifying the precise locations of gene expression within tissues and linking molecular activity to plant structure (Wang *et al.*, 2024).

## Experimental Techniques in Transcriptomics

**Microarray analysis:** It represents one of the pioneering methodologies enabling researchers to simultaneously assess the expression of thousands of genes. This technique involves immobilizing DNA probes on a chip and hybridizing them with fluorescently labelled RNA or complementary DNA (cDNA) samples. The resultant signals indicate gene activity, facilitating gene expression profiling, biomarker discovery, and pathway analysis.

**RNA sequencing (RNA-Seq):** This technique has significantly advanced the field of transcriptomics by providing a more sensitive and comprehensive examination of the transcriptome. In contrast to microarrays, RNA-Seq is capable of detecting novel transcripts, alternative splicing events and non-coding RNAs. The procedure entails converting RNA into cDNA, sequencing it using high-throughput platforms, and analyzing millions of reads with bioinformatics tools. RNA-Seq offers an unbiased and detailed depiction of gene activity, rendering it essential for investigating crop development, stress responses and trait improvement (Vishwanath *et al.*, 2023).

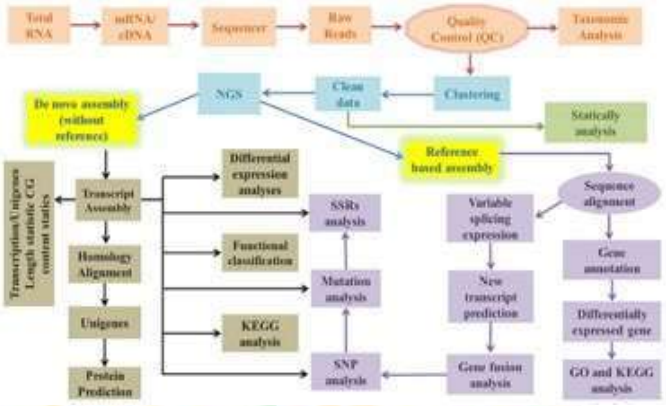



Fig. 1: Flow chart of transcriptome data analysis (Tyagi *et al.*, 2022)

## Transcriptome Alterations during Stress

Abiotic stressors, including drought, salinity, heat and cold, significantly disrupt normal plant physiological processes, thereby diminishing the conversion of energy into biomass. Transcriptomic analyses have demonstrated that thousands of genes and transcription factors (TFs) exhibit differential expression under these stress conditions. Common responses encompass alterations in genes associated with photosynthesis, secondary metabolite biosynthesis and the activation of TFs such as MYB. Each type of stress also induces the expression of distinct gene sets; for instance, salt stress may activate genes involved in ion transport, whereas heat stress may affect pathways related to protein folding.

Leaves, which play a crucial role in photosynthesis and carbon metabolism, exhibit pronounced transcriptomic changes, although studies focusing on roots are more prevalent. This underscores the necessity for more comprehensive investigations into leaf-specific responses to stress. Biotic stresses are induced by infections from fungi, bacteria and viruses. Plants respond to these challenges through a multi-layered immune system: pathogen-associated molecular pattern (PAMP)-triggered immunity (PTI) identifies pathogen signals, while effector-triggered immunity (ETI) addresses pathogen strategies designed to circumvent plant defenses. Transcriptomic analyses reveal the activation of genes involved in carbohydrate metabolism, defense responses, protein phosphorylation and ribosome biogenesis. Additionally, hormone signaling pathways, such as those involving salicylic acid and jasmonic acid, undergo reprogramming. WRKY transcription factors are consistently activated, coordinating the expression of defense-related genes. A characteristic feature of biotic stress is the oxidative burst, which leads to a hypersensitive response (HR) that limits pathogen proliferation (Rurek *et al*., 2024).

## Challenges in Transcriptomics

**Data complexity:** RNA-Seq produces large datasets that need advanced bioinformatics tools for proper analysis.

**Reference genome gaps:** Many vegetables (e.g. okra) lack high-quality reference genomes, which hampers accurate gene annotation.

**Sample design issues:** Careful consideration of tissue specificity, developmental stage and stress conditions is needed to avoid unreliable results.

**Standardization:** Study comparison is difficult due to lack of consistency in sample collection and analysis protocols.

**Functional validation:** Transcriptomics identifies candidate genes, but experimental validation (e.g., CRISPR/Cas9) is needed.

## Transcriptomic response of vegetable crops (Vishwanath *et al*., 2023)

| Vegetable | Transcriptomic results |
|---|---|
| **Tomato** | Resistant vs susceptible varieties for bacterial wilt showed contrasting gene expression. Down-regulation: *KCS6*, *CDPK1*, *MYB86*. Up-regulation: *RD19D*, *PR1*, *PR6*, *WRKY75*, *CNGC2*. Highlights defense pathways and pathogen resistance mechanisms |
| | JA/ABA signaling NAC TFs (*SlNAP1*, *SlNAC35*, *SlSRN1*) regulate defense genes under abiotic stress, linking hormone signaling to stress tolerance. |
| | Transcriptome atlas of fruit development revealed genes regulating ripening, flavour, colour, and texture**.** Identified candidate genes for lycopene biosynthesis and shelf-life improvement. |
| **Pepper** | Trichome formation RNA-Seq revealed DEGs linked to trichome development (protective against stress). Hairy genotype showed up-regulation of *SlCycB2*, *SlCycB3*, *H*. |
| **Okra** | Transcriptome analysis identified candidate genes for nutritional enrichment (vitamins, minerals, mucilage content) and textural quality traits**.** |
| **Cucumber** | Alternaria cucumerinae resistant vs susceptible genotypes showed DEGs. Up-regulated: phenylpropanoid, phenylalanine, glutathione pathways. Down-regulated: photosynthesis genes (*PsaD*, *PsaF*, *PsbO*, *PsbP*, *PsbR* etc.) in susceptible plants. |
| | High temp stress affected male flower development → pollen abortion and reduced viability. Transcriptome analysis revealed altered gene expression linked to reproductive stress tolerance. |
| Under-utilized vegetables | Transcriptomics helps uncover unique genes for taste, nutrition, and bioactive compounds in neglected vegetables, offering novel quality traits for crop improvement. |

**Underutilized crops:** There are many indigenous or traditional vegetables that are not explored and their unique genetic resources are lost.

## References

Vishwanath, P. P., Bidaramali, V., Lata, S. and Yadav, R. K. (2025). Transcriptomics: illuminating the molecular landscape of vegetable crops: a review. *Journal of Plant Biochemistry and Biotechnology*, 34: 349-364.

Rurek, M. and Smolibowski, M. (2024). Variability of plant transcriptomic responses under stress acclimation: A review from high throughput studies. *Acta Biochimica Polonica*, 71: 13585.

Yu, T., Ma, X., Zhang, J., Cao, S., Li, W., Yang, G. and He, C. (2025). Progress in transcriptomics and metabolomics in plant responses to abiotic stresses. *Current Issues in Molecular Biology*, 47: 421.

Wang, H., Xu, Y., Zhang, Z., Zhang, G., Tan, C. and Ye, L. (2024). Development and application of transcriptomics technologies in plant science. *Crop Design*, 3: 100057.

Tyagi, P., Singh, D., Mathur, S., Singh, A. and Ranjan, R. (2022). Upcoming progress of transcriptomics studies on plants: An overview. *Frontiers in Plant Science*, 13: 1030890.

# Chemical Diversity and Medicinal Potential of Millipede Defensive Secretions

**Yashwant Patne and Ravi Barde**


## Abstract

Millipedes are important terrestrial arthropods recognized not only for decomposition and nutrient cycling but also for their chemically diverse defensive secretions with emerging medicinal importance. These secretions are produced through specialized repugnatorial glands or stink glands and contain quinones, alkaloids, phenols, terpenoids, and cyanogenic compounds. Studies indicate antimicrobial, antifungal, antioxidant, and anti-inflammatory properties in several of these compounds. The growing global challenge of antibiotic resistance has further increased interest in natural bioactive compounds from arthropods. This article highlights the nature of millipede defensive secretions, their antimicrobial and medicinal significance, major bioactive compounds, and future pharmaceutical applications.


## Introduction

Millipede defensive secretions are composed of various chemically active substances, such as quinones, phenols, alkaloids, hydrogen cyanide, and terpenoids. Recent research has shown that many of these substances possess notable antimicrobial, antifungal, antioxidant and anti-inflammatory properties. With the rise of antimicrobial resistance, natural products from arthropods are being increasingly considered as potential sources for new therapeutic agents. Compared to bioactive compounds derived from plants and microbes, the medicinal and pharmaceutical potential of millipede defensive secretions is relatively underexplored. However, advancements in analytical methods like gas chromatography-mass spectrometry (GC-MS) and high-performance liquid chromatography (HPLC) have enhanced the ability to identify and characterize these compounds. This review focuses on the chemical makeup, biological activities, and growing medicinal significance of millipede defensive secretions, particularly emphasizing their antimicrobial and pharmaceutical uses.

## Defensive Secretions in Millipedes

**Repugnatorial Glands and Ozopores:** Millipedes possess specialized defensive glands called repugnatorial glands (stink glands) which produce and store defensive chemical secretions. These secretions are released through external openings known as ozopores, located along the lateral sides of the body segments. The secretions serve as an effective defense mechanism against predators and

**Yashwant Patne**
Department of Zoology, N.E.S. Science College, Nanded, Maharashtra
**Ravi Barde**
Department of Zoology, Shri Guru Buddhiswami Mahavidyalaya, Purna, Parbhani, Maharashtra

microbial pathogens. Depending on the species, the secretions may contain quinones, phenols, alkaloids, terpenoids and cyanogenic compounds with important biological activities.

**Chemical Nature of Defensive Secretions:** Millipede defensive secretions contain chemically diverse compounds that vary among taxonomic groups. Researchers have identified several important forms of compounds including Quinones, hydroquinones, Alkaloids, Phenolic compounds, Terpenoids, Cyanogenic compounds, Organic acids, Fatty acid esters. These compounds may occur individually or in complex mixtures reflecting evolutionary adaptation and ecological specialization.

**Quinones and Hydroquinones:** Quinones are among the most typically reported defensive compounds in millipedes (Tummanam *et al.,* 2023). Benzoquinones and hydroquinones are especially widely reported in several millipede groups. These compounds possess strong antimicrobial and repellent properties. Quinones can irritate skin and mucous membranes and contribute substantially to antibacterial and antifungal activity.

**Alkaloids:** Alkaloids are nitrogen-containing compounds with important biological activities. Certain millipedes produce alkaloid-based defensive compounds that exhibit strong chemical defense properties. Alkaloids contribute to antimicrobial activity and possess pharmacological importance. Recent chemical investigations have identified several structurally complex alkaloids from millipede secretions (Banks *et al.,* 2024). These compounds have attracted interest because of their possible therapeutic applications and unique chemical structures.

**Phenolic Compounds and Terpenoids:** Phenolic compounds and terpenoids contribute to antioxidant activity, antimicrobial defense, and chemical signaling. Terpenoids are particularly important because they are widely recognized for their medicinal and industrial applications.

**Cyanogenic Compounds:** Some millipedes produce cyanogenic compounds capable of releasing hydrogen cyanide under stress conditions. These compounds provide strong protection against predators. Although cyanogenic compounds can be toxic, controlled scientific investigations can help identify useful pharmaceutical applications.

## Antimicrobial and Biological Activities

**Need for Novel Antimicrobial Agents:** The rapid emergence of antimicrobial resistance has created an urgent need for the discovery of new therapeutic compounds. Natural products derived from animals, plants, and microorganisms are increasingly being explored as alternative sources of antimicrobial agents. In this context, millipede defensive secretions have received scientific attention due to their rich composition of bioactive compounds exhibiting antimicrobial and antifungal properties. These secretions represent promising leads for the development of future pharmaceutical agents (Idris *et al.,* 2025).

**Antibacterial Activity of Millipede Secretions:** Several investigations have demonstrated antibact-

**Table 1: Major Defensive Compounds and their Biological Importance**

| Major Compound Group | Biological Function | Potential Medicinal Importance |
|---|---|---|
| **Quinones** | Predator defense, antimicrobial activity | Antibacterial and antifungal applications |
| **Alkaloids** | Chemical defense and toxicity | Pharmaceutical and therapeutic potential |
| **Phenolic compounds** | Antioxidant and defensive role | Anti-inflammatory and antimicrobial uses |
| **Terpenoids** | Repellent and signaling functions | Drug discovery and medicinal chemistry |
| **Cyanogenic compounds** | Protection against predators | Potential biochemical research applications |
| **Fatty acid esters** | Enhancement of biological activity | Supportive pharmaceutical significance |

erial activity in millipede extracts and defensive secretions against both Gram-positive and Gram-negative bacteria (Billah *et al*., 2015; Tummanam *et al.*, 2023). Researchers have reported activity against bacterial pathogens such as *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Salmonella* species. The antimicrobial effects are believed to result mainly from quinones, alkaloids, and phenolic compounds present in the secretions. These compounds can damage bacterial cell membranes, interfere with metabolic pathways, or inhibit microbial growth.

**Antifungal Activity:** In addition to antibacterial properties, millipede secretions also exhibit anti-fungal activity (Tummanam *et al.*, 2023). Some studies have demonstrated inhibitory effects against fungal pathogens and yeast species. This antifungal activity assist to protect millipedes from fungal infections in humid soil habitats. From a pharmaceutical perspective, these findings indicate the possibility of developing novel antifungal compounds from arthropod-derived natural products.

**Mechanisms of Antimicrobial Action:** Although the precise mechanisms are still under investigation, researchers propose that millipede defensive compounds may act by disrupting microbial cell membranes, causing oxidative damage, interfering with enzyme systems, inhibiting protein synthesis, and disturbing essential metabolic pathways. The multifunctional nature of these compounds makes them attractive candidates for antimicrobial drug development.

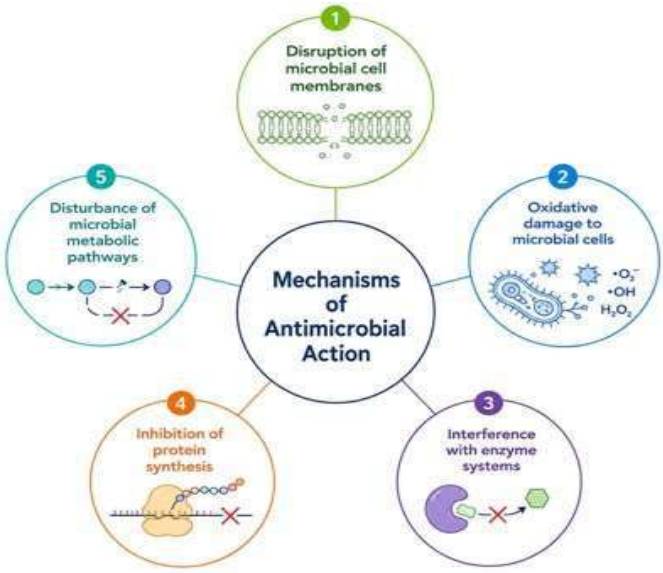



Fig. 1: Mechanisms of antimicrobial action of millipede defensive compounds

## Medicinal Significance of Millipede Secretions

**Anti-inflammatory and Therapeutic Potential:** Scientific studies suggesting some millipede compounds exhibit anti-inflammatory activity (Meyer-Rochow, 2017). Certain phenolic compounds and bioactive molecules can reduce oxidative stress and inflammatory responses. The anti-inflammatory potential of these compounds contribute to future therapeutic development. Researchers are increasingly exploring natural compounds with fewer side

effects compared to synthetic drugs.

**Biomedical Relevance:** The unique chemistry of millipede secretions has gained focus in biomedical research. Many of the identified compounds possess distinctive chemical structures that serve as templates for designing novel pharmaceuticals. Natural products from arthropods often exhibit diverse biological activities because they evolved as defense mechanisms over millions of years. Such compounds provide provide innovative approaches for treating infections and inflammatory disorders.

**Toxicological Considerations:** Although millipede secretions possess valuable biological activities, some compounds produce toxic or irritating effects. Contact with concentrated secretions can cause skin irritation, discoloration, burning sensations, and eye irritation. Therefore, proper toxicological evaluation is essential before medicinal or pharmaceutical applications can be developed. Controlled studies are necessary to determine safe concentrations, dosage levels, and possible side effects.

## Bioactive Compounds Identified from Millipedes

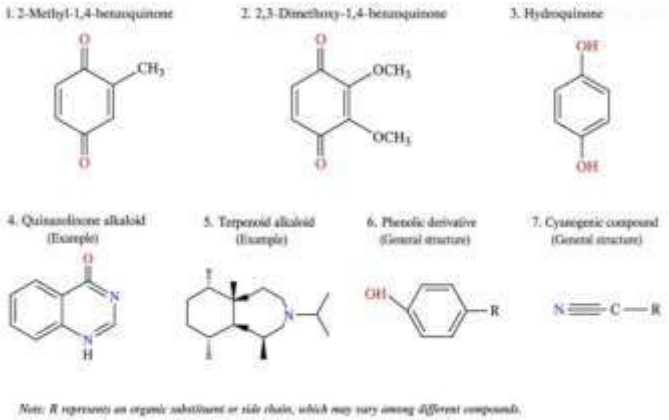



Fig. 2: Representative Structures of Bioactive Compounds

Researchers have identified numerous bioactive compounds from millipede secretions through chemical analysis techniques such as gas chromatography-mass spectrometry (GC-MS), nuclear magnetic resonance (NMR), and metabolomic studies (Banks *et al.*, 2024; Tummanam *et al.*, 2023).

**Pharmaceutical and Drug Discovery Potential:** Millipede defensive secretions have ga cod siderableine interest in pharmaceutical research because they contain a variety of bioactive compounds, including quinones, phenols, alkaloids and cyanogenic substances. Research has showing these compounds possess antimicrobial, antifungal, antioxidant and anti-inflammatory properties, highlighting their potential as natural therapeutic agents. With the increasing issue of antimicrobial resistance, there is a heightened focus on natural products as alternative sources for drug development. In this regard, millipede secretions could be promising candidates for creating new antibiotics and other pharmaceutical compounds. Some quinones and phenolic compounds have demonstrated inhibitory effects on pathogenic microorganisms, indicating their potential use in antimicrobial formulations. Beyond their antimicrobial effects, certain compounds found in millipede secretions might also exhibit cytotoxic and anti-inflammatory properties, which could be beneficial for future biomedical research. The progress in analytical and pharmacological methods has enhanced the ability to identify and assess these natural substances. Although the research is still in its early stages, existing evidence indicating millipede defensive secretions are a prom-

ising and largely untapped resource for pharmaceutical and drug discovery research.

**Modern Analytical Approaches:** Modern analytical techniques such as gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC) and spectroscopic methods have significantly improved the identification and characterization of millipede defensive compounds. These techniques facilitate in detecting bioactive molecules and evaluating their pharmaceutical potential.

**Table 2: Reported Biological Activities of Millipede Secretions**

| Biological Activity | Reported Importance |
|---|---|
| Antibacterial activity | Inhibition of pathogenic bacteria |
| Antifungal activity | Suppression of fungal growth |
| Antioxidant effects | Reduction of oxidative stress |
| Anti-inflammatory potential | Possible therapeutic applications |
| Chemical defense | Protection against predators |
| Cytotoxic effects | Potential biomedical research value |

## Future Research Directions and Challenges

Despite the promising antimicrobial and pharmaceutical potential of millipede defensive secretions, research in this area is still in its infancy. Most existing studies are preliminary, concentrating primarily on identifying chemical compounds, while comprehensive pharmacological research is lacking. More in-depth studies are necessary to isolate and identify bioactive molecules that contribute to antimicrobial, antifungal, antioxidant, and anti-inflammatory effects. A pronounced hurdle is assessing the toxicity, safety, and therapeutic dosage of these compounds before they can be used clinically. Advanced analytical and molecular methods could aid in elucidating the mechanisms of action and enhancing the pharmaceutical application of these natural substances. In addition, extensive screening of various millipede species might uncover new compounds with substantial medicinal promise.

## Conclusion

Millipede defensive secretions offer a rich yet largely untapped reservoir of bioactive natural compounds with notable medicinal potential. These secretions are composed of quinones, alkaloids, phenols, terpenoids, and cyanogenic compounds, each exhibiting antimicrobial, antifungal, antioxidant and anti-inflammatory effects. As antimicrobial resistance becomes an increasing concern, the focus on natural products as alternative therapeutic solutions has intensified, and millipede-derived compounds could serve as promising candidates for future drug development. Although advancements in analytical and pharmacological techniques have facilitated the identification and evaluation of these compounds, further toxicological, pharmacological, and clinical research is essential. In conclusion, the diverse chemical composition of millipede defensive secretions highlights their potential significance in pharmaceutical and biomedical research.

## References

Meyer-Rochow, V. B. (2017). Therapeutic arthropods and other, largely terrestrial, folk-medicinally important invertebrates: A comparative survey and review. *Journal of Ethnobiology and Ethnomedicine,* 13(9): 1-31.

Jung, M., Nieradko-Iwanicka, B. and Kania, G. (2023). Medical and economical significance of millipedes. *Polish Hyperbaric Research*, 82(1): 115-125.

Banks, P., Funkhouser, E. M., Macias, A. M., *et al.* (2024). The chemistry of the defensive secretions of three species of millipedes in the genus *Brachycybe*. *Journal of Chemical Ecology*, 50: 478-488.

Tummanam, A., Sutthisa, W., Radchatawedchakoon, W., *et al*. (2023). Composition and anti-microbial activity of defensive secretions of giant millipedes. *Tropical Natural History*, 23: 42-51.

Billah, M. K., Kwang, D., Adofo, C., *et al.* (2015). Antibacterial activities of millipede extracts against selected bacterial pathogens. *Journal of Microbiology and Antimicrobial Agents*, 1(2): 30-35.

Idris, Y. B., Sirajo, M., Hassan, L. G., *et al*. (2025). Millipede secretions as a potential source of antibiotics: A mini review. *Caliphate Journal of Science and Technology*, 1: 44-54.

# Jammu & Kashmir's Rural Innovation: Defining Agritech-Entrepreneurship-Scope, Challenges & Opportunities

**Tabasum Mushtaq, Mushtaq Ahmad Lone and Jameel Ahmad Khan**

## Introduction

In the lush green valley of Jammu & Kashmir the way of living has always been Agriculture. The Valley's well-to-do agri and horticulture endowment like saffron meadows in Pampore and apple garths in Sopore and Shopian have encouraged generations. Underneath this heap, still, is an irony: many farmers encounter low income, confined market access, and lesser value addition although producing high- value produce. Simultaneously young generation of literate people are at turning point because they are hesitating to seek traditional farming yet are looking for sustainable careers. In J&K, for many years production has been the main focus of agriculture. Farmers focused on cultivating crops, oftentimes selling them unrefined with no command over market kinetics or pricing. Due to the post-harvest losses, limited cold storage, unconnected supply systems, and dependence on middleman profitability has been further thwarted. Horticulture has the same story, especially with regard to apples, walnuts, and cherries. Although some of the best fruits are produced, the lack of branding, processing, and structured marketing confines revenue possibilities.

Present time's traditional practices are no longer sufficient to preserve agriculture. These must evolve into a system that embodies technology, entrepreneurship, and innovation. In terms of economic importance agriculture and horticulture contribute significantly to the J& K's economy, standing neck and neck with tourism. A diversified and wealthy agricultural ecosystem is found in J&K that comprises horticulture, fisheries, sericulture, apiculture, dairy, and livestock sectors. In unison, these build a vast economic network with new potential. Jammu & Kashmir must set up its development trajectory about its natural relative advantage agriculture contrary to the regions bestowed with industrial resources such as coal, iron and oil. There is an urgent need for a perspective change among youth because it is neither practical nor sustainable to count solely on public sector jobs due to limited government employment opportunities. In lieu, younger generation must adopt entrepreneurship as a feasible and satisfying career path. This opportunity is precisely offered by agritech entrepreneurship by revamping youth from job creators and making them competent of providing means of support not only for

**Tabasum Mushtaq**
Research Associate (Business Data Analyst), Rural Business Incubation Centre, SKUAST-K, UT of J&K
**Mushtaq Ahmad Lone**
Assistant Professor, Statistics Directorate of Planning & Monitoring, SKUAST-K, UT of J&K
**Jameel Ahmad Khan**
Chief Executive Officer, Rural Business Incubation Centre, SKUAST-K, UT of J&K

themselves but for others too.

In Jammu & Kashmir's rural economy, to modernise agriculture and improve farmer's sustenance, agritech entrepreneurship is budding as an evolutionary power and innovative pathway. In modern farming practices, Agri-tech startups are unifying advanced technologies such as data analytics, Internet of Things (IOT), artificial intelligence, and remote sensing hence enhancing crop productivity, cutting down on waste, and improve operational efficiency.

Agriculture sector in Jammu & Kashmir, grips tremendous judicious weight for economic development because almost 70 percent of the population is directly or indirectly dependent on it. Regardless of its rich agricultural heritage, Jammu & Kashmir keep to confide severely on traditional farming practices, facing constant challenges such as confined access to modern technologies, inadequate infrastructure, and constrained market linkages. Despite that, these very challenges create a fertile ground for agritech innovation and entrepreneurial interventions.

## Scope of Agritech Entrepreneurship

In Jammu & Kashmir, Agritech Entrepreneurship bears a vast and versatile potential and scope. There are tremendous possibilities for value addition and enterprise development in the sectors including meat production, fisheries, floriculture, dairy processing, honey production etc. For example, a very small portion of milk produced in J&K is processed, signalling a large gap and opportunity for entrepreneurs to develop value- added dairy products like clarified butter, khoya, cheese, butter etc. Likewise by extending the shelf life of flowers from three days to fifteen days by new innovations in packaging and storage emphasize how simple technological interventions open new markets and revenue streams. In nurturing this ecosystem government initiatives such as the Holistic Agriculture Development Programme (HADP), Jammu and Kashmir's Competitiveness Improvement of Agriculture & Allied Sectors Project (JKCIP), Mission YUVA etc are playing an important role. The modernisation of agriculture is aimed by these programmes by unifying technology, improving infrastructure, strengthening market linkages, and encouraging startup culture in rural areas. There is immense and largely undiscovered scope of agritech entrepreneurship in J&K. For managing soil health, irrigation, fertilise use, and crop productivity, precision farming technologies such as Global Positioning system (GPS) and Geographical Information System (GIS) mapping, drone-based monitoring, satellite imagery, IOT-enabled sensors, and Variable Rate technology (VRT) can play an important role in revolutionising the modern agriculture. These tools facilitate real-time inspection of field situations, thereby helping farmers to make data-driven decisions and optimal use of resources. In addition to this, emerging technologies like blockchain, artificial intelligence, and machine learning can further increase clearness, monitorability and productivity throughout agricult-

ure value-added chains. Through digital agri start-ups, farmers can be directly connected with consumers by smart market linkages thereby reducing the dependence on intermediaries and minimising post -harvest losses. There is a need for more user- friendly and accessible solutions in J& K, because of limited adoption of initiatives like Kisan Mandi and Kisan Survidha.

In agri-tech entrepreneurship educational and capacity -building initiatives also play a pivotal role. Startups can empower the farmers with knowledge of modern practices, climate- resilient techniques, and market trends by designing mobile applications, training platforms, and extension services. These interventions can largely enhance productivity and sustainability by bridging the knowledge gap. J&K's economy can be diversified by these agri-startups which provide a unique opportunity for reducing dependence on uncertain sectors, and generate rural employment. By backing innovation and entrepreneurship, agri- tech can switch the story from subsistence farming to enterprise-driven agriculture.

## Challenges in the Transition

Regardless its potential, agri-tech entrepreneurship in J&K confronts numerous structural and socio-economic challenges. The decreasing agricultural land, small and broken landholdings, climate variability, transportation and inadequate market access, lack of entrepreneurial skills and training, lack of value addition and processing, poor industry-academia linkages, marketing and branding challenges, political and economic uncertainty, lack of strtup ecosystem in rural areas continue to impede growth. Further, an age-old perspective of agriculture as a risky and less beneficial occupation has dispirited youth participation. The slip away from traditional farming practices further entangles the transition towards modern technology -driven agriculture. The ecosystem for startups though increasing still requires powerful organization support, better financial access, guidance, and market intelligence. For enabling rural entrepreneurs to scale their innovations into sustainable businesses bridging these gaps is essential. Also, the growth of agri-tech ventures is halted by limited awareness among farmers, resistance to adopting new technologies, financial constraints and inadequate organizational support. In order to overpower these obstacles, aspiring entrepreneurs must concentrate on building strong technical skills, nurturing creativity, and adopting an innovative mindset. There is also the need of collaborations with research institutions, incubation centres, various government agencies, and industry stakeholders in order to get access to mentorship, funding opportunities, investor networks, innovation labs, startup accelerators and critical resources through their partnerships. Despite the fact incubation support is getting better through institutions and government schemes, rural outreach remains restricted. For scaling agri-tech startups secure financial support through government schemes and private investment is another pivotal factor. The designing of affordable and practical solutions is also equally important for the tailored

unique socio-economic conditions. With reference to local needs technologies must not only be advanced but should be accessible also. In this connection, incubation ecosystems play an important role in nurturing agritech innovations.

Simply put, the process of nurturing ideas and turning them into successful businesses is known as incubation. In agriculture incubation means supporting and assisting young people move over farming with the aim of sustenance and hold it as an enterprise. Organizations like SKUAST-K with NABARD support are energetically operating incubation centres like SKUAST Kashmir Innovation, Incubation and Entrepreneurship Centre (SKIIE), Rural Business Incubation Centre (RBIC) SKUAST-K, to establish a handholding environment for startups by furnishing technical guidance infrastructure, and business development support and transforming ideas into business enterprises by creating ecosystems of innovation and funding, IP & TM; branding & marketing, data- driven decisions and most importantly confidence which is an important but often overlooked component of entrepreneurship. The fear of failure among youth must be addressed by encouraging entrepreneurship. Since innovation involves the inherent risk factor but it also brings learning and growth. Young Innovators in Jammu & Kashmir must be empowered to experiment the failure by trying again and again because failures are often considered the stepping stones tor success. Government has taken some initiatives such as the establishment of Kissan Khidmat Ghars, Farmers Producer Organizations etc in the proper direction towards strengthening innovations at grassroot level.

## Opportunities through Innovations and Value Addition

As India changes to a more powerful and independent rural economy the areas like Jammu & Kashmir have the capability to lead the way. With the correct support networks, vision and philosophy farmers can become agripreneurs and a new generation can find again agriculture as a means of innovation and expansion rather than an alternative plan. By adopting innovations, value addition and modern technology the future of Jammu & Kashmir's rural economy will push the boundaries. It is the need of an hour to enhance the productivity and profitability per unit of output because the land resources are shrinking drastically. The steps which can help in achieving so are; to do food processing, to develop cold chains, enhance agri-logistics, to do precision farming and adapt digital agricultural solutions. Significant economic gains can be seen from small innovative real-life examples of the region. The potential for scaling the ideas like improving packaging techniques in floriculture or branch out dairy products into successful enterprises is tremendous. With the existence of incubation centres, universities, and government- backed programmes such an innovative ecosystem is further boosted and empowered. The incubation is aiding in reframing the story by making the farmers as entrepreneurs from being producers, changing liveli-

hood to sustainability, and replacing uncertainty to opportunity. It is an essential step to take up agri-entrepreneurship for lifting production and profitability in agriculture and allied sectors, rather than being only an opportunity. For example, growing apples was considered a low-paying job by a young Pulwama graduate. With the right incubation support, the same individual could now launch a firm that focuses on apple grading, packing, and direct-to-market supply chains, significantly increasing value realization. Or consider the saffron growers in Pampore. Instead of selling raw produce, incubation enables efforts in branding, packaging, and export-oriented processing, targeting premium markets. Additionally, opportunities are emerging in; Walnut crackers and value-added products, logistics and storage solutions for the cold chain, agri-tech advancements including precision farming, organic certification and access to niche markets. Incubation ecosystems are beginning to open these real, scalable paths; they are not remote possibilities. Incubation centres are evolving into drivers for rural change rather than only providing support. Incubation initiatives at organizations such as SKUAST-K are concentrated on: finding and supporting agri-entrepreneurs in their early stages. Closing the gap between research and practical implementation, offering organized assistance from concept to business, promoting innovation in the fields of horticulture and agriculture. The way these centres' function has also undergone a significant change. They are increasingly using data-driven methods to monitor entrepreneurial journeys, assess program efficacy, and enhance decision-making. This guarantees that incubation is impact-oriented rather than merely activity-based. Although there has been positive progress, a number of issues still need to be resolved; Rural youngsters have little knowledge about incubation options, A pipeline of significant agri-startups that is still under development, cultural reluctance to take chances and pursue entrepreneurship, deficits in early-stage funding availability, stronger industrial ties and market integration are required. Institutions, legislators, and the corporate sector must work together to address these issues. Incubation must be incorporated into a broader ecosystem approach in order to genuinely alter agriculture in Jammu & Kashmir. This comprises; including instruction on business in agricultural studies, increasing cooperation between academic institutions, governmental organizations and business, encouraging regional innovation models adapted to local crops and difficulties, using technology to increase productivity, supply chain efficiency, and market knowledge, including analytics and data in decision-making procedures to improve results. The objective is to develop sustainable rural businesses that create jobs and stimulate economic growth, not merely startups.

## Conclusion

Jammu and Kashmir's innovative ecosystem is at crucial point. With the policy convergence support, organizational support and youthful enthusiasm the agri-tech entrepreneurship has the power to

modify its economy into a dynamic and inclusive system. The switching from subsistence farming to enterprise-driven agriculture will not only secure sustainable livelihoods but also arise as a model for rural innovation in India. In nut shell, the key for transforming agriculture in Jammu & Kashmir into a resilient, sustainable, and growth-oriented sector is held by agritech startups and Jammu & Kashmir can unlock its true agricultural potential by leveraging technology, fostering innovation, and strengthening institutional support. By embracing agritech innovation, Jammu & Kashmir stands tranquil to arise as a model for rural transformation, revealing how technology can reformulate agriculture and create new routes of prosperity.