



SPUD REVOLUTION: *THE RISE OF THE MIGHTY POTATO*

FEBRUARY 2026

WWW.DIGITALAGRINEWS.COM

From the Desk of the Founder



At **Digital Agri News**, we understand that farming is not just a profession — it's a way of life. It is the heartbeat of our economy, the foundation of our food security, and the lifeline of millions of families. With this in mind, our mission is simple yet powerful: to bring timely, accurate, and actionable agricultural news right to your fingertips.



From market trends and crop prices to climate alerts and weather updates, from emerging technologies and sustainable practices to policy reforms and government schemes, we cover everything that matters to the agricultural community. Our goal is to empower you with knowledge that helps you make better decisions — in the field, in the marketplace, and for the future. We also believe in celebrating the spirit of farming. Through farmer success stories, expert interviews, and global agri innovations, we highlight the resilience and creativity that keep agriculture thriving even in challenging times. Every story we share is a step toward building a stronger, more connected, and more informed agri-ecosystem.

At Digital Agri News, we go beyond headlines — we provide insights, analysis, and solutions that matter. By bridging the gap between technology and tradition, policy and practice, local needs and global opportunities, we strive to create a platform where every voice in agriculture is heard and valued.

Thank you for trusting us as your partner in this evolving journey. Together, let's cultivate awareness, embrace innovation, and nurture a sustainable future for generations to come.

Dr. Mukesh Narwal

Warm Regards

Dr. Mukesh Narwal

Founder, Digital Agri News

From the Desk of the Chief Editor



Greetings to all the esteemed readers of Digital Agri News Magazine. We are pleased to present Volume 02, Issue 02 (February 2026), which brings together insightful discussions on emerging trends and innovations shaping the future of agriculture.

In this issue, we highlight the growing importance of advanced and sustainable agricultural practices such as vertical farming and hydroponics. With challenges like rapid urbanization, shrinking land resources, and climate change, these modern techniques offer practical solutions for ensuring food security while conserving natural resources. Their ability to produce high-quality

crops using limited space and water makes them highly relevant for the future of Indian agriculture.

We have also included articles that explore diverse and forward-looking topics such as space aquaculture, bioremediation in aquaculture wastewater, and the role of crop rotation in pest and disease management. These contributions reflect the integration of science, technology, and sustainability in modern farming systems. They emphasize the need for eco-friendly practices, efficient resource management, and innovation-driven growth in agriculture.

At Digital Agri News, our aim is to create awareness, share knowledge, and inspire farmers, students, researchers, and agri-entrepreneurs to adopt progressive agricultural practices. As agriculture continues to evolve, it is essential to combine traditional wisdom with modern technology to achieve sustainable and profitable farming. We hope this issue provides valuable insights and encourages you to explore new opportunities in the agricultural sector. Let us move forward together towards a smarter, greener, and more sustainable future.

Dr. Ankit Saini

Warm Regards

Editor-in-Chief

Digital Agri News Magazine



DR. ANKIT SAINI

*Assistant Professor and Head
Department of Agronomy*

Dr. KSG Akal College of Agriculture
Eternal university Baru Sahib Sirmour
HP

TABLE OF CONTENTS

01 Vertical farming & hydroponics

02 Space Aquaculture :A Sustainable Pathway for Next Generation Food Systems for Astronauts

03 Role of crop rotation in pest and disease management

04 Bioremediation in wastewater aquaculture

05 Export potential of horticultural crops from Himalayan states

06 Rainfed agriculture and watershed management: Integrating sustainable practices for environmental resilience

07 Rainfed agriculture: The silent backbone of global food security

EDITORIAL BOARD MEMBER



R. PUNGAVI
Assistant Professor,
Joy university, Raja Nagar,
Vadakangulam, Near Kanyakumari,
Tirunelveli Dist. – 627116 Tamil Nadu



DR SELVAKUMAR R
Scientist
Centre for Protected Cultivation Technology
ICAR – Indian Agricultural Research
Institute New Delhi – 110012



DR. NEHA THAKUR
Assistant professor
Department of Commerce and
Management Career Point
University, Hamirpur



DR. PRIYANSH RAHANGDALE
Assistant professor
Department of Agriculture science
Sam global University Bhopal



PRADEEP KUMAR
Scientific Officer
in the Department of Pearl
Millet Breeding at ICRISAT



DR PARTIBHA SHARMA
Assistant professor
Faculty of Agricultural Sciences,
DAV University Jalandhar



CHAITANYA TIWARI
Assistant Officer
Seed Quality Control and
Seed Testing, Star Agri
Seeds



DR SHIV KUMAR
Assistant professor
School of agricultural
sciences Geeta university
panipat



CHINMAYA SAHOO
Ph. D. Research Scholar
Department of Agronomy
Dr. Rajendra Prasad Central Agricultural
University, Pusa, Bihar



DR. AKASHDEEP SINGH

Assistant Professor,
Department of Agronomy Dr. Khem Singh
Gill Akal College of Agriculture, Eternal
University, Baru Sahib, Sirmaur (HP)



DR. PRANEET CHAUHAN

Assistant Professor (Plant Pathology)
Dr. K.S. Gill Akal College of
Agriculture, Eternal University, Baru
Sahib (H.P.)



BHAVNEET KOUR

Project associate -I
Sher-e-Kashmir University
of Agricultural Sciences &
Technology of Jammu , Rs Pura

EMPOWERING INDIA'S FERTILIZER SELF-RELIANCE...

FARMER-FIRST COMMITMENT

Affordable inputs. Timely delivery. Empowered farmers.

- Ensuring affordable, timely and effective fertiliser solutions for farmers
- Strengthening last-mile delivery across regions and geographies
- Providing timely farmer advisories for informed and sustainable farming practices

SUPPLY SECURITY & STRATEGIC SOURCING

Assured supply. Stable markets. Stronger India.

- Leveraging alternative sources, imports and efficient trading mechanisms
- Ensuring uninterrupted fertiliser availability and market stability
- Strengthening national fertiliser security for long-term resilience

ENERGY EFFICIENCY & RESPONSIBLE OPERATIONS

Efficient plants. Safe operations. Lower carbon footprint.

- Driving energy savings through efficiency-led plant operations
- Continuous improvement through adoption of energy-efficient technologies
- Maintaining the highest standards of operational safety and security

SUSTAINABILITY & POLICY ALIGNMENT

Balanced nutrition. Healthier soil. Sustainable future.

- Active implementation of PM-PRANAM initiatives
- Promoting balanced nutrient use and reducing chemical dependency
- Supporting policy reforms for sustainable and climate-smart agriculture

ADVANCING TOWARDS A SELF-RELIANT FUTURE

Atmanirbhar agriculture. Resilient tomorrow.

- Supporting Atmanirbhar Bharat in fertiliser and agriculture sectors
- Building a resilient, sustainable and farmer-centric ecosystem
- Aligned with national priorities and India's long-term growth vision

हर एक काम,
देश के नाम



Hindustan Urvarak & Rasayan Limited

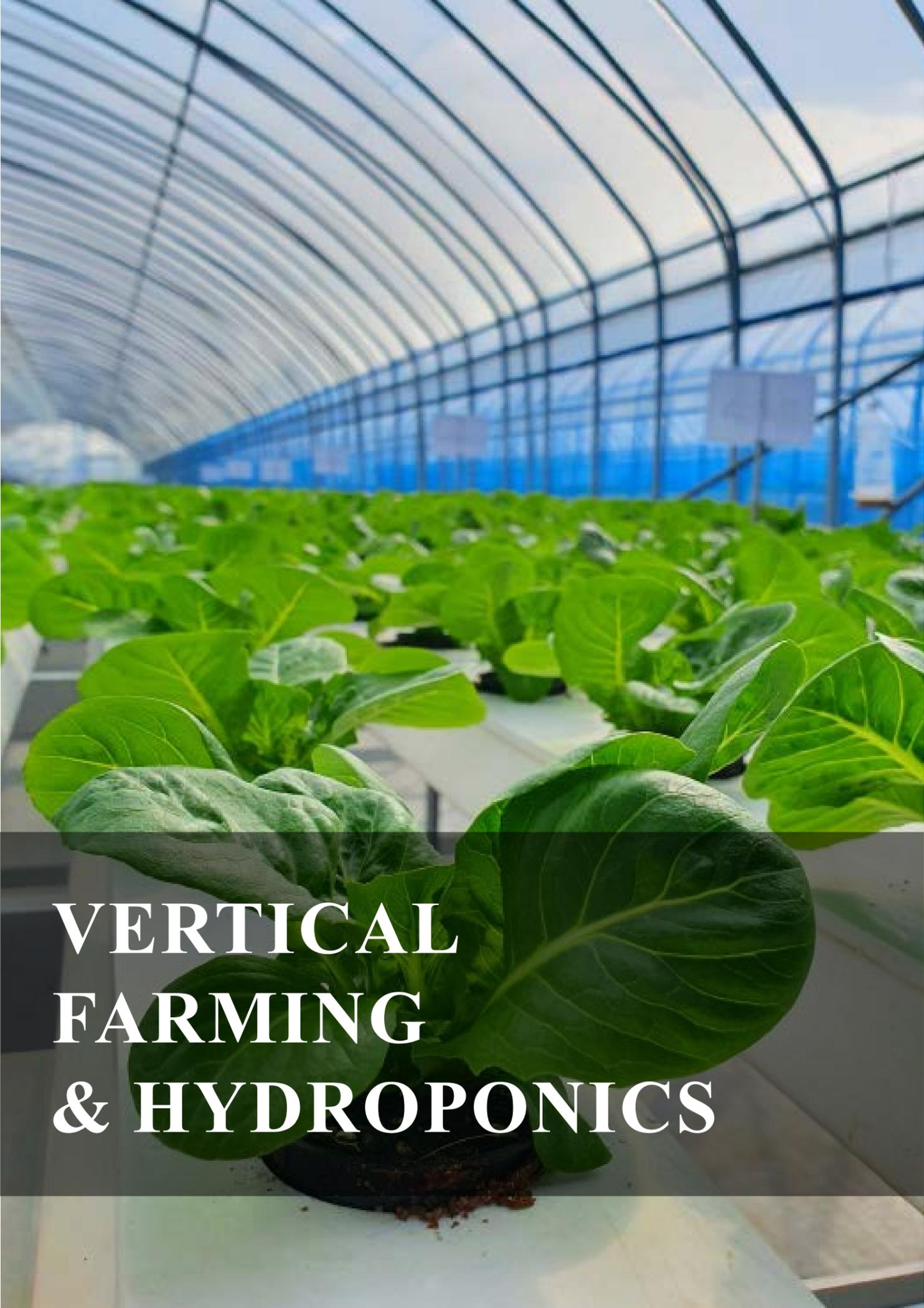
Corporate Office

Hindustan Urvarak & Rasayan Limited

Core 3 & 4, 9th Floor, SCOPE Minar, Laxmi Nagar District Centre, New Delhi-110092

Website: www.hurl.net.in | Email: contactus@hurl.net.in

Follow Us:



VERTICAL FARMING & HYDROPONICS

**Jaskaran Singh,
Arshdeep Singh &
Dr. Harmanpreet
Kaur Gill**

Khalsa College, Patiala

In terms of any communication
correspondence is pertained to:

jaskaransinghkaler2004gmail.com

Introduction

Vertical farming and hydroponics are innovative agricultural methods designed to meet the growing demand for food in a sustainable way. With rising population, shrinking farmland, and climate change challenges, traditional farming faces serious limitations. Vertical farming involves growing crops in stacked layers, often indoors, using controlled environments.

What exactly is vertical farming?

A Vertical farming is a modern method of growing crops in vertically stacked layers instead of spreading them across large fields. It is usually practiced indoors in controlled environments using artificial lighting, temperature control, and advanced irrigation systems. The concept was popularized in 1999 by Professor Dickson Despommier of Columbia University, who proposed growing food in tall urban buildings to solve food shortages. However, similar ideas existed earlier in greenhouse farming.



Now, what exactly we know about hydroponics and uses

Hydroponics is a method of growing plants without soil using nutrient-rich water solutions

- Plant roots receive essential minerals directly from water, allowing faster growth and higher yields.
- It uses less water compared to traditional farming because water is recycled within the

system

- Hydroponic systems can be set up indoors or outdoors under controlled environmental conditions.
- This technique reduces soil-borne diseases and is widely used in modern vertical farming practices..
- Hydroponics allows precise control over nutrients, pH levels, and water supply, helping plants grow healthier and more uniformly compared to traditional soil-based farming



- systems.
- Common hydroponic systems include nutrient film technique (NFT), deep water culture (DWC), and drip irrigation systems
- Hydroponics supports year-round cultivation since environmental factors like temperature and light can be artificially controlled
- It requires significantly less land area, making it suitable for urban farming, rooftops, greenhouses, and indoor agricultural production units
- Crops such as lettuce, spinach, tomatoes, cucumbers, and herbs grow especially well in hydroponic environments.
- Hydroponics supports year-round cultivation since environmental factors like temperature and light can be artificially controlled

Why we need vertical farming and hydroponics

1. Vertical farming and hydroponics help overcome land scarcity by producing more crops in limited space, making them ideal for urban areas where traditional farmland is not easily available.
2. These systems use significantly less water than conventional agriculture, as water is recycled efficiently, helping conserve resources in regions facing water shortage
3. Make. Controlled indoor environments reduce dependency on climate and weather changes, allowing year-round crop production with higher yields

Word Startups focus on vertical and hydroponics

iFarm – Finnish ag-tech company developing software and automated vertical farming systems for salads, strawberries, and other crops..

- **Eden green tech** – U.S. company building hydroponic vertical farming systems for commercial crops and research greenhouses
- **AppHarvest** – American hydroponic and vertical farming producer focused on large greenhouses..
- **Cityblooms** – Urban farming startup in California developing modular hydroponic systems for local distribution





Future Of vertical farming and hydroponics in India

The future of vertical farming and hydroponics in India appears highly promising as the country faces challenges like rapid urbanization, shrinking agricultural land, and water scarcity. With increasing demand for fresh, pesticide-free vegetables in cities, controlled environment farming offers a reliable solution. These systems use less water, require limited space, and allow year-round production regardless of climate conditions. Government support for agri-tech startups and rising interest among young entrepreneurs are further boosting this sector.

How may Indian farmer may adopt this technology

Farmers in India can learn vertical farming and hydroponics through agricultural universities, Krishi Vigyan Kendras (KVKs), government training programs, and online platforms like YouTube and agri-tech

courses. They can also visit successful model farms and attend agricultural expos. By adopting these technologies, farmers can achieve higher yields, better quality produce,

Challenges and Sensible Warnings

- Access & equity. Not all farm- ers have smartphones, internet, or trust in algorithmic advice. Solutions must be affordable, lo- cal-language, and human-centred.
- Technical knowledge is essential , as proper nutrient and ph managements
- Skills & support. Tech needs field technicians, training and mainte- nance. Without on-ground support, advanced machines can sit unused.
- Environmental trade-offs. Some in- tensification can harm biodiver- sity if not managed carefully— so the goal must be sustainable intensification (more yield, less harm).
- Regular monitoring and maintenance are required, since system failures like pump breakdowns can harm plants within a short period

How governments play crucial role in this sector to boost growth

- Subsidies and pilot programs that test tech with smallholder groups.
- Open data (weather, soil maps) paired with privacy protections.
- Training hubs and technician net- works so machines keep working.
- Finance models (rentals, machinery-as-a-service, pay-per-use) so farmers don't need heavy capital.

A FUTURE PLAN

In A strong future plan for vertical farming and hydroponics in India should focus on gradual expansion, skill development, and market connection. Farmers should begin with small pilot projects to understand system management and costs before scaling up. Training programs, partnerships with agri-tech companies, and government subsidies can support adoption. Building direct links with supermarkets, hotels, and online grocery platforms will ensure stable demand and better pricing. Investment in renewable energy like solar power can reduce electricity costs. Continuous research, innovation, and collaborations done.



CONCLUSION

Vertical farming and hydroponics offer sustainable, space-efficient, and water-saving solutions for modern agriculture. With proper knowledge, investment, and market planning, they can enhance food security, profitability, and environmental sustainability in the future.

REFERENCES

1. (FAO) – Publishes global reports on hydroponics, soilless cultivation, water efficiency, and sustainable agricultural technologies worldwide. https://www.fao.org/food-safety/news/detail/Modern-indoor-farming-opportunities-and-food-safety-challenges-highlighted-in-new-FAO-report/en?utm_source=chatgpt.com
2. (USDA) – Provides research, technical guides, and data on controlled environment agriculture and hydroponic crop production systems
3. (NASA) – Conducted early hydroponic and controlled-environment research for space food production experiments. https://www.nasa.gov/technology/tech-transfer-spinoffs/nasa-research-launches-a-new-generation-of-indoor-farming/?utm_source=chatgpt.com
4. Dickson Despommier – Discusses origin, scientific background, and global future of vertical farming concepts.

SPACE AQUACULTURE: A SUSTAINABLE PATHWAY FOR NEXT GENERATION FOOD SYSTEMS FOR ASTRONAUTS

Prathib P S^{1*}, Vanathi Venkatesan², Pavithran Kalaiselvan¹

¹Ph.D. Research Scholar, Department of Aquaculture, ICAR - Central Institute of Fisheries Education, Versova, Mumbai, India- 400061

²M.F. Sc Research Scholar, Department of Aquaculture, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Dr. MGR FC&RI, Ponneri, India- 601204

In terms of any communication correspondence is pertained to:
prathibsakthivel@gmail.com

Abstract

Space aquaculture is the cultivation of aquatic organisms in space under controlled conditions. Food energy requirements for humans during spaceflight and residing in space are similar to those on Earth. Astronauts experience physiological challenges in microgravity. If human energy intake decreases in space, it may lead to a 30% reduction in protein synthesis, and certain body problems may occur, including cardiovascular deconditioning, bone demineralization, muscle atrophy, and immune system deficiency. There is a need for a fresh animal-based food source to be included in the diet of space residents. Aquatic organisms have higher nutritional value than other food sources, making them an ideal food source for the human community who are there on the moon or Mars for long-term residence in space. Culturing aquatic organisms requires water, oxygen, and hydrogen, resources that may be available in extraterrestrial environments (Mars, Venus, the Moon). The use of innovative technologies, such as Recirculating Aquaculture Systems (RAS) and Integrated Multitrophic Aquaculture (IMTA), will be a valuable approach for culturing fish in space. However, culturing them in a constrained environment, such as microgravity, is difficult due to water management, waste recycling, and system stability. The successful Lunar Hatch program was conducted in France to assess the feasibility of space aquaculture through Earth-based space simulations. This article explores the potential of space aquaculture for sustainable food production to support astronaut nutrition.

Keywords: Space aquaculture, BLSS, astronauts, food security, astronaut nutrition

Introduction

The supply of energy and oxygen, and the recycling of biological waste, are considered major concerns for long-term manned stays outside the planet. The freeze-dried foods are currently used to meet human nutritional needs in space. However, freeze-dried foods, when stored for more than a year, may become unstable, leading to degradation of essential nutrients such as potassium, calcium, and vitamins, which are important for maintaining muscle and bone in altered gravity (Cooper et al., 2017). The production of plants, vegetables, and microalgae in altered gravity was studied, and space aquaculture was considered to meet the nutritional requirements of space residents. The International Space Station reports that the availability of fresh food (including farmed aquatic species) may have positive physiological effects on residents in space (Douglas et al., 2020). To achieve this, several research studies have been conducted, and the results indicate that fish embryos are more resistant to neutrons and gravity. Additionally, the growth period of fish in the space until it reaches an edible size has been studied. The recirculating aquaculture system was found to be superior for fish growth in such an environment (Przybyla, 2021).





Figure 1. First aquaculture farms in Mars (Source: <https://matkuling.com/news/first-aquaculture-farms-mars-space/>)

Need to culture fish in space

Fish, being an excellent source of protein, omega-3s, and vitamin B, is needed for the maintenance of muscle mass for astronauts. Further, keeping aquariums has also been demonstrated to lower heart rate and relieve psychological stress, which may have positive emotional effects on crew members. In addition, culturing fish in space is comparatively easier than farming other animals, such as poultry or cattle, because livestock require a large area for rearing, which would be a competing factor. Moreover, fish require less energy and oxygen (compared to mammals) and generate less carbon dioxide, which is an important factor for the survival of astronauts in space. Another important factor to consider is waste management. Compared to fish, other animals, such as pigs, chickens, cows, or goats, produce large amounts of waste that is very difficult to remove from the system. On the other hand, the waste excreted by the fish can be easily removed from the system. Another advantage of culturing fish in space is that they can experience gravity, as they possess a swim bladder and otoliths that help maintain buoyancy. So, it is very clear that the altered gravity will not be a disturbance factor for the swimming activity of fish.

Nutritional requirements of astronauts

For proper bone maintenance, cardiovascular function, iron metabolism, and muscle function, astronauts need specific nutrients. Balanced nutrients, such as carbohydrates, fats, proteins, and minerals, must be maintained. The composition of nutrients, or the proportions of the food, varies depending on the duration of stay and individual needs. The most important nutrients for bone health are calcium, vitamin D, and iron. Nowadays, technologies such as freeze drying and thermos stabilization are used to retain the flavor, texture, and nutritional composition of food.

Feasibility (Fish embryos to Moon)

Water in the celestial bodies is saline or hypersaline. Based on this, species selection for space culture depends on the fish's physiology, behaviour, and euryhaline nature. For the culture, fish embryos need to be sent to space for hatching. The Lunar Hatch program (2019) is investigating the shipping of fish eggs to space for hatching in a lunar bioregenerative life support system (BLSS). Rearing adults for reproduction will not be possible in the space. So, Eggs, as the biological stage for space travel are relevant mainly because of the low volume of water required for egg incubation (<1 kg

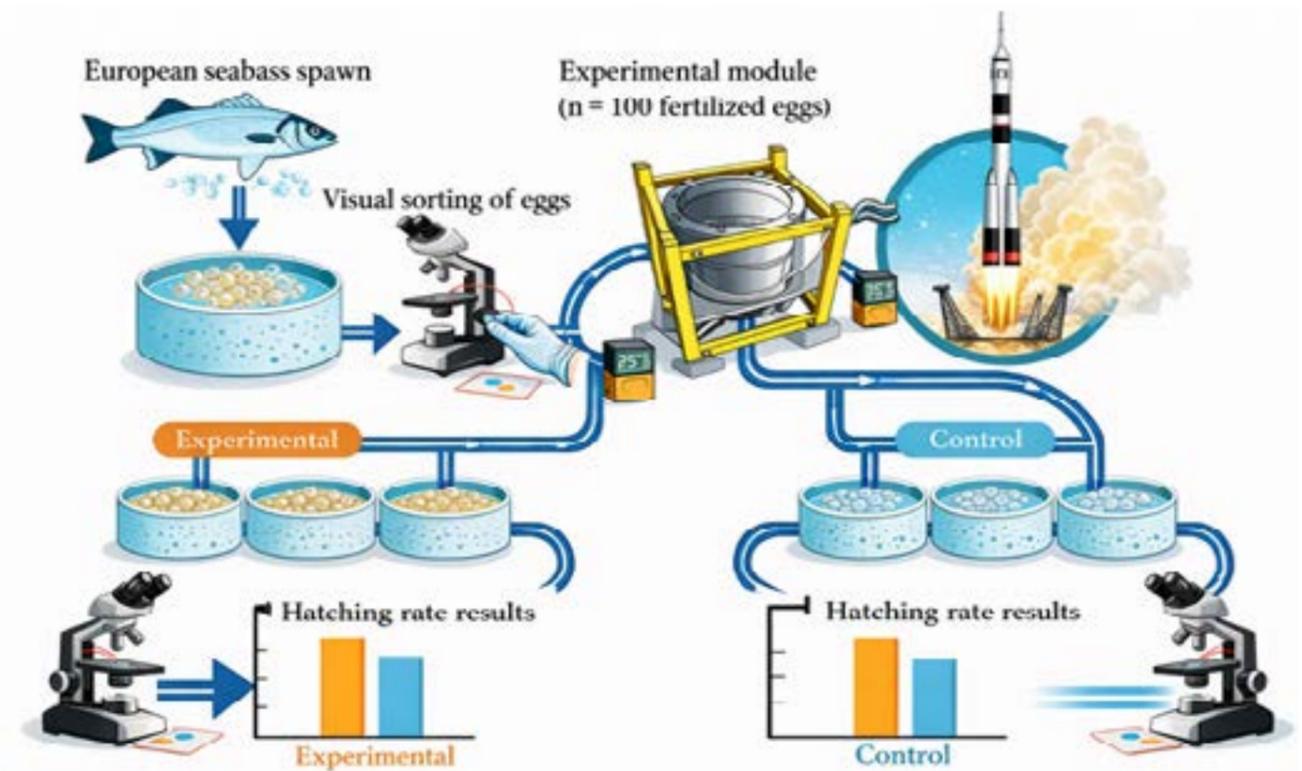


Figure 2. Protocol for Vibrations test on European seabass embryos (modified with Przybyla, 2021)

for about 900 future larvae). Fish eggs can be transported using an automated cargo ship. Culture in the land-based system will not have a serious impact on fish embryos, but when embryos are carried in space, they will be affected by higher acoustic levels, mechanical vibrations, hypergravity, microgravity, and radiation from the motors, as well as atmospheric acceleration. Experiments on simulated acoustic and mechanical vibrations (Fig. 2), hypergravity, microgravity, and radiation were conducted on European seabass embryos. Hatching rate and survival have no significant differences, with the control indicating that survival and hatchability of an aquaculture species will be the same on the Moon or Mars after space travel (Przybyla, 2021)

IMTA (Integrated Multitrophic Aquaculture) for feeding fish in Space

Farming fish in space requires feed to raise them, but it is not possible to send feed from Earth to the Moon or Mars. The aquatic organisms' food web is a complex cycle that starts with phytoplankton and ends with the conversion of fish biomass. Each species in the aquatic system has diverse feeding habits. So, IMTA could become an innovative method for aquatic system has diverse feeding habits. So, IMTA could become an innovative method for feeding fish on the Moon or Mars. Fish waste, or sourced from other sources such as byproducts from space agriculture or food waste released by astronauts, which acts as fertilizer, can act as a food source for aquatic organisms (from algae to invertebrates). The N/P ratio from fish waste fits the requirements of algae for invertebrates. Fish, feeds containing zooplankton grown (utilizing algae) in the IMTA system or microalgae (mostly marine) have been tested successfully, with no alteration in growth or organoleptic quality, in a fish feed containing 20–40% microalgae (Stuart et al., 2021). Molluscs and algae can also improve water quality, thereby increasing fish growth rates. From Figure 3, it is clearly evident that FCR for fish is very low when compared with other terrestrial animals. So, culturing fish in space will not be difficult to feed astronauts (Przybyla, 2021).

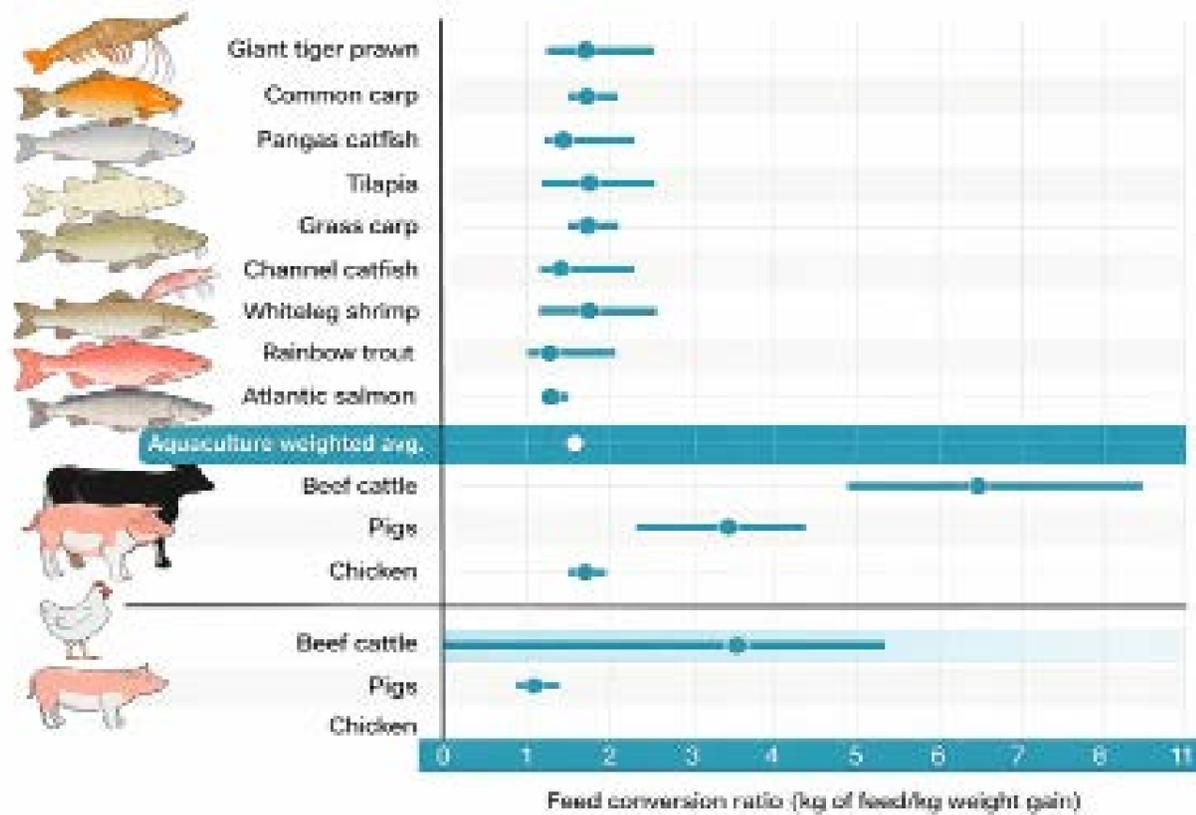


Figure 3. FCR for selected aquaculture species compared to terrestrial farmed species (Fry et al., 2018)

Limitations and future prospects

Various parameters need to be considered before designing the aquaculture system for space, including the number of astronauts/residents to feed, water availability, energy requirements, and the mission duration. The culture system requires water circulation, but this must be determined based on lunar gravity. For a week, a single person requires 250 g of fish to meet the recommended nutritional requirements. The thermal growth coefficient of the selected fish needs to be considered, as there will be 14 days of sunlight and 14 days of darkness in the space context. This will affect fish growth in BLSS. Depends on photosynthesis by algae, hydroxyl extraction, and oxygen from the regolith, which can be adjusted to meet the fish's biological demands (DO). Algal biomass extraction is a challenging process in space due to limited space. Extraction needs to be performed periodically to prevent water degradation and excessive O₂ consumption.

Conclusion

Space aquaculture will become a valuable food source for humans undertaking long-term space missions. Space aquaculture is nearing reality, but it depends on in situ water and energy availability. The nutrients in fish can provide valuable health benefits to humans, particularly in preventing cancer caused by long-term radiation exposure in space. An additional simulation experiment is needed on Earth to study interactions between organisms and gas flow management. Everything is based on research done on Earth using space simulations. However, a properly designed, scientifically grounded, manned space-based mission to culture fish in space is needed in the future to increase sustainability and meet the food requirements of humans and astronauts.



REFERENCES

1. Cooper, M., Perchonok, M., and Douglas, G. L. (2017). Initial assessment of the nutritional quality of the space food system over three years of ambient storage. *NPJ Microgravity* 3, 17.
2. Douglas, G. L., Zwart, S. R., and Smith, S. M. (2020). Space food for thought: challenges and considerations for food and nutrition on exploration missions. *J. Nutr.* 150, 2242–2244.
3. Li, M., Callier, M. D., Blancheton, J.-P., Galès, A., Nahon, S., Triplet, S., Geoffroy, T., Menniti, C., Fouilland, E., & Roque d'Orbcastel, E. (2019). Bioremediation of fishpond effluent and production of microalgae for an oyster farm in an innovative recirculating integrated multi-trophic aquaculture system. *Aquaculture*, 504, 314–325.
4. Przybyla, C. (2021). Space aquaculture: Prospects for raising aquatic vertebrates in a bioregenerative life-support system on a lunar base. *Frontiers in Astronomy and Space Sciences*, 8, 699097.
5. Stuart, K. R., Barrows, F. T., Silbernagel, C., Alfrey, K., Rotstein, D., & Drawbridge, M. A. (2021). Complete replacement of fish oil and fish meal in the diet of juvenile California yellowtail *Seriola dorsalis*. *Aquaculture Research*, 52(2), 655–665.

**Christina Mochary¹,
Ankit Saini^{1*} and
Neelakshi Sharma²**

¹Dr. KSG Akal College of Agriculture,
Eternal University, Baru Sahib,
Sirmaur, Himachal Pradesh, India

²Department of Soil Science, CSK
HPKV, Palampur, HP, India-176062

In terms of any communication
correspondence is pertained to:
ankitsaini970@gmail.com

Abstract

Crop rotation is a fundamental ecological strategy used in sustainable agriculture for reducing pest and disease pressure while improving soil health. By systematically alternating crops with different botanical families, rooting depths, and nutrient requirements, farmers can disrupt pest life cycles, suppress soil-borne pathogens, and reduce the reliance on chemical pesticides. This article discusses the mechanisms through which crop rotation influences pest and disease dynamics, reviews key benefits and examples of rotation systems, and highlights its role in integrated pest management (IPM) approaches. The different approaches suggest that crop rotation remains one of the most cost-effective, environmentally friendly, and practical methods for managing pests and diseases in agroecosystems.

Keywords- Crop rotation, ecology, integrated pest management, cost effective and agroecosystems.

Introduction

Pests and plant diseases pose significant threats to global food security, causing substantial yield losses and reducing crop quality (FAO, 2020). Historically, chemical pesticides have been widely used to manage these challenges; however, increasing concerns about resistance development, environmental contamination and human health risks have prompted a shift toward more sustainable approaches. Crop rotation, an ancient agricultural practice, has regained prominence as a core component of ecological farming systems.

Crop rotation involves the planned sequence of different crops on the same field over time. The practice directly influences the pest and disease ecosystem, often reducing populations by interrupting their life cycles and altering the environmental conditions necessary for their survival (Cook, 1991). This article explores the principles and benefits of crop rotation in pest and disease management and explains how it contributes to sustainable crop production.

Benefits and Advantages of Crop Rotation in pest and Disease Management:

Crop rotation is one of the most effective, eco-friendly, and long-term strategies used in modern agriculture to manage pests and plant diseases. By systematically changing the type of crops grown in a particular field every season or year, farmers can naturally interrupt pest life cycles, reduce disease pressure, and improve the overall health of the farming ecosystem (Altieri, 1995).



Below are the major benefits and advantages of crop rotation in pest and disease management:

1. Breaks Pest Life Cycles

Many pests are host-specific, meaning they depend on a particular crop for food and reproduction. When the same crop is planted continuously, pest populations grow quickly. Crop rotation disrupts this cycle by replacing the preferred host with a non-host crop (Liebman and Dyck 1993).

Advantages:

- i. Reduces the survival and reproduction of pests.

ROLE OF CROP ROTATION IN PEST AND DISEASE MANAGEMENT

ii. Minimizes pest buildup in the soil or on plant residues.

iii. Limits the need for chemical pesticides.

2. Reduces Soil-Borne Diseases

Diseases caused by fungi, bacteria, nematodes and viruses often remain in the soil for years when the same crop is grown repeatedly (Stevenson et al., 2001).

Rotating crops weakens these pathogens by removing their preferred host.

Benefits:

i. Lower incidence of soil-borne diseases like wilt, blight and root rot.

ii. Reduction in nematode populations.

iii. Healthier root systems and stronger plant growth.

3. Prevents Overpopulation of Specific Insects

Certain insects thrive in monoculture systems. By changing crop types, the habitat and food source for insect shifts, making it harder for them to survive.

Advantages:

i. Decreases insect pressure naturally.

ii. Helps control pests like borers, beetles and caterpillars.

iii. Reduces dependence on insecticides.

4. Minimizes the Need for Chemical Pesticides

With fewer pests and diseases, farmers can significantly reduce pesticide application.

Benefits:

i. Lower input costs.

ii. Less chemical residue on crops.

iii. Decreased environmental and groundwater contamination.

iv. Promotes beneficial insect populations such as predators and pollinators.

5. Promotes Biodiversity in the Field

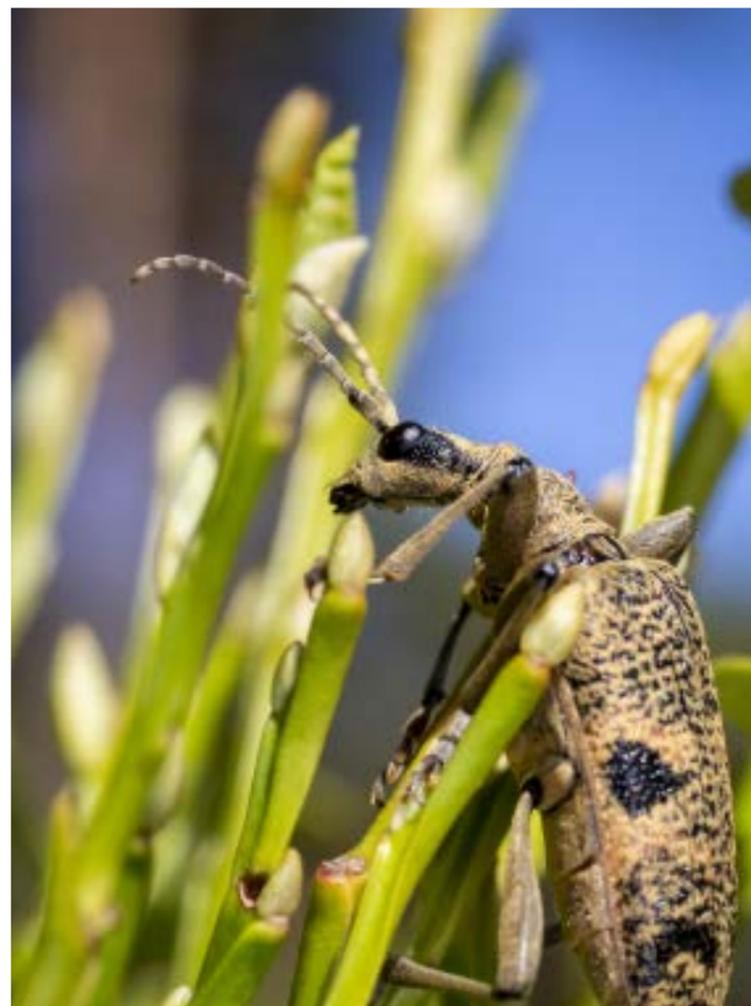
Crop rotation introduces diversity in plant species over time.

Advantages:

i. Creates a varied ecosystem that is unfavourable to pests and pathogens.

ii. Improves the natural balance of predator-prey interactions.

iii. Builds resilience against unexpected disease outbreaks.



6. Improves Soil Health, Making Plants More Resistant to Pests & Diseases

- Healthy soil is the foundation of strong plant immunity.
- Crop rotation enhances soil structure, fertility and microbial balance.

Benefits:

- Increased organic matter and nutrient availability.
- Stronger, healthier crops that can resist pest attacks.
- Reduced chances of disease infection.

7. Controls Weed Populations

- Many weeds are adapted to certain crop environments.
- Rotating crops disrupts weed growth by changing planting schedules and cultivation practices.

Advantages:

- Limits weed species dominance.
- Reduces herbicide use.
- Prevents weeds from serving as hosts for diseases and pests.

8. Supports Integrated Pest Management (IPM)

- Crop rotation is a central component of sustainable IPM programs.

Benefits:

- Complements biological and cultural pest control methods.
- Enhances long-term pest suppression.
- Promotes environmental sustainability and farm profitability.

CONCLUSION

Crop rotation remains one of the most practical and ecologically sound strategies for pest and disease management. By breaking pest and pathogen life cycles, improving soil health and enhancing overall farm biodiversity, rotation supports sustainable agricultural production while reducing dependency on chemical pesticides. When integrated with other IPM practices, crop rotation contributes significantly to long-term agricultural resilience and food security.

REFERENCES

1. Altieri, M. A. (1995). *Agroecology: The Science of Sustainable Agriculture*. CRC Press.
2. Cook, R. J., & Veseth, R. J. (1991). *Wheat Health Management*. APS Press.
3. Liebman, M., & Dyck, E. (1993). Crop rotation and intercropping strategies for weed, pest, and disease management. *Agronomy Journal*, 85(3), 301–309.
4. Stevenson, W. R., Loria, R., Franc, G. D., & Weingartner, D. P. (2001). *Compendium of Potato Diseases*. APS Press.
5. United Nations FAO (2020). *Sustainable Crop Production and Integrated Pest Management*. Food and Agriculture Organization



BIOREMEDIATION IN WASTEWATER AQUACULTURE

Prathib P S

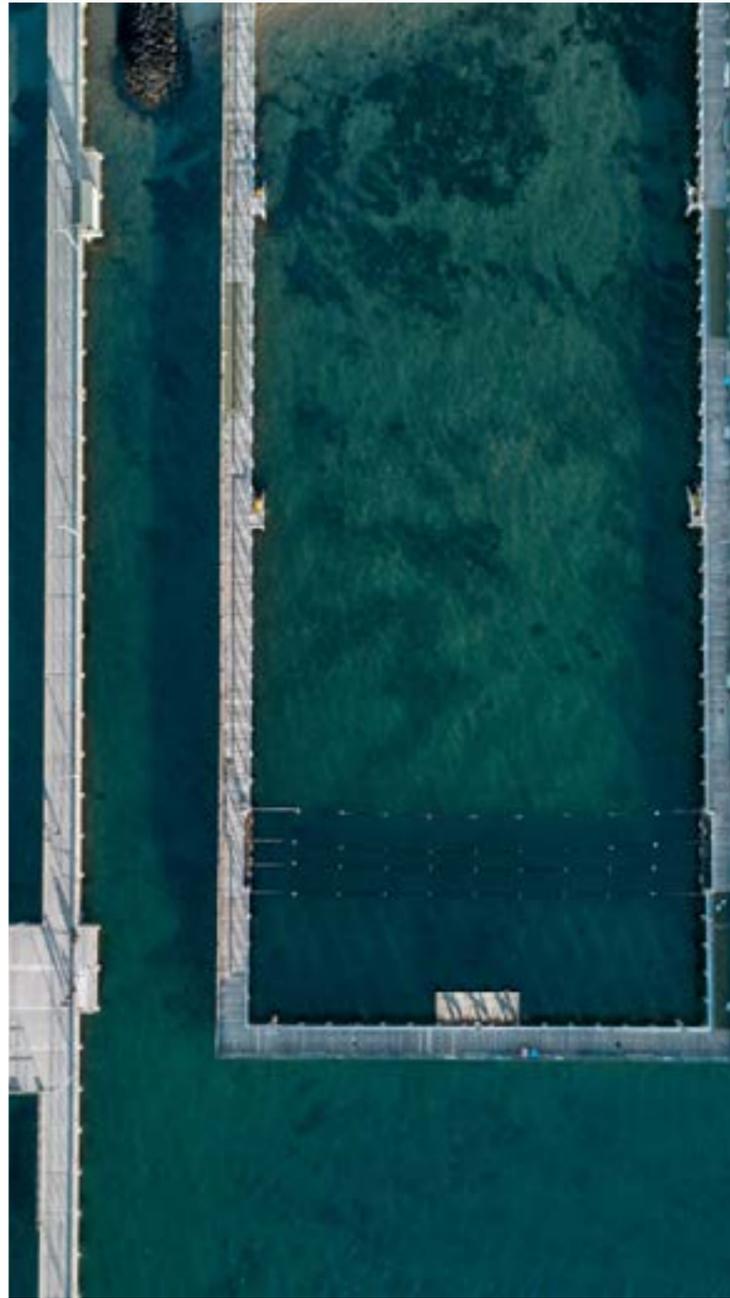
Ph.D. Research Scholar, Department of Aquaculture, ICAR - Central Institute of Fisheries Education, Versova, Mumbai, India- 400061

In terms of any communication correspondence is pertained to: prathibsakthivel@gmail.com

Abstract

Aquaculture intensification has generated large volumes of nutrient-rich wastewater containing organic matter, nitrogenous compounds, suspended solids, and other pollutants, posing serious environmental challenges. Bioremediation offers an eco-friendly, cost-effective approach to treating aquaculture wastewater by harnessing natural biological agents, including microorganisms, microalgae, aquatic plants, fungi, and filter-feeding organisms. This article discusses the principles, processes, and types of bioremediation techniques applied in wastewater aquaculture, including in-pond treatment, pre-discharge remediation, and water reuse systems. The role of bacteria in nitrogen transformation, microbial mats in integrated treatment systems, microalgae in nutrient removal and biomass production, and aquatic macrophytes and seaweeds in constructed wetlands is highlighted. Several case studies demonstrate the effectiveness of integrated bioremediation systems involving algae, bivalves, fungi, and plants in improving water quality and reducing pollution load. Economic analysis indicates favorable cost-benefit ratios, emphasizing the financial viability of such systems. Sewage-fed aquaculture and duckweed-based treatment models further illustrate the potential for sustainable resource recovery and a circular economy. Overall, bioremediation emerges as a sustainable, scalable, and environmentally sound solution for wastewater management in aquaculture, particularly in water-limited regions.

Keywords: Waste water, sewage, aquaculture, bioremediation



Introduction

Bioremediation is a biological treatment process that utilizes living organisms, primarily microorganisms, plants, and algae, to degrade, transform, or detoxify pollutants present in contaminated environments. George M. Robinson introduced the concept of bioremediation during the 1960s. It is the biological degradation of organic waste under controlled conditions, converting harmful substances into harmless end products. In aquaculture, bioremediation has gained importance as a cost-effective, environmentally friendly solution for

managing wastewater and improving water quality. Naturally occurring bacteria, fungi, microalgae, and aquatic plants play a key role in removing nutrients and toxic compounds, ensuring sustainable aquaculture practices.

Process of Bioremediation

The bioremediation process begins when microorganisms release specific enzymes into the environment. These enzymes break down complex organic contaminants into simpler, digestible molecules. The degraded substances are then taken up by microbial cells and utilized as energy and nutrient sources. Through this process, organic pollutants are mineralized into non-toxic end products such as carbon dioxide, water, and inorganic nutrients.

Types of Bioremediation Techniques

Bioremediation techniques are broadly classified into in situ and ex situ methods. In situ bioremediation involves treatment of contaminated soil or water at the site with minimal disturbance. This approach is highly dependent on site-specific conditions such as soil characteristics and environmental factors. Common in situ techniques include biosparging, bioventing, and bioaugmentation. Ex situ bioremediation involves removing contaminated material from the site for treatment. This method is primarily used for soil contamination and is less commonly used for wastewater remediation. Techniques include landfarming, composting, and biopiles. Both approaches require isolating and characterizing microorganisms, culturing them, studying their catabolic activity, and continuously monitoring remediation progress.

Bioremediation Organisms and Their Roles

Different biological agents are involved in bioremediation. Phytoremediation utilizes plants, macroalgae, and microalgae to absorb nutrients and contaminants. Species such as *Chlorella* and *Gracilaria* are widely used. Bacterioremediation employs beneficial bacteria to convert nitrogenous compounds and degrade organic waste; examples include *Bacillus subtilis* and ammonia-oxidizing bacteria. Mycoremediation

involves fungi such as *Trichoderma* and white-rot fungi that degrade toxic compounds. Zooremediation uses bivalves and other filter feeders, such as mussels, oysters, and clams, to remove suspended solids, algae, and organic matter from water.

In-Pond Bioremediation and Waste Generation

Aquaculture systems generate various types of waste, including uneaten feed, fecal matter, metabolic by-products, residues of biocides and fertilizers, molting waste in shrimp farming, and collapsing algal blooms. In-pond bioremediation focuses on the decomposition of internal waste using beneficial microorganisms and algae to maintain water quality. Biotechnological solutions involving microbes, microalgae, and bioprocessing methods support sustainable aquaculture development.



Bioremediation of Nitrogenous Compounds

Nitrogenous wastes, particularly ammonia, originate mainly from fish excretion and sediment mineralization. Ammonia-oxidizing bacteria, such as *Nitrosomonas*, *Nitrosococcus*, and *Nitrospira*, convert ammonia into nitrite, which is further oxidized to nitrate by nitrite-oxidizing bacteria, such as *Nitrobacter*. Denitrifying filters create anaerobic conditions that allow bacteria to convert nitrate into nitrogen gas, thereby reducing nitrogen load in aquaculture systems.

Bioremediation of Hydrogen Sulphide

Hydrogen sulphide is a toxic compound produced by sulphate-reducing bacteria under anaerobic conditions. In the presence of oxygen, sulphur-oxidizing bacteria convert sulphide into non-toxic sulphate. Photosynthetic benthic bacteria and purple non-sulphur bacteria play an essential role in decomposing hydrogen sulphide, nitrite, and organic wastes at the pond bottom, thereby maintaining a favorable aquaculture environment.

Bioremediation Before Discharge

Before releasing aquaculture wastewater into natural water bodies or reusing it, bioremediation is applied to reduce nutrient and organic load. Microalgae such as *Chlorella vulgaris*, *Nannochloropsis oculata*, and *Tetraselmis chuii* are effective in removing nitrogen and phosphorus while producing valuable biomass. However, wastewater must be free from heavy metals to prevent accumulation in algal cells.

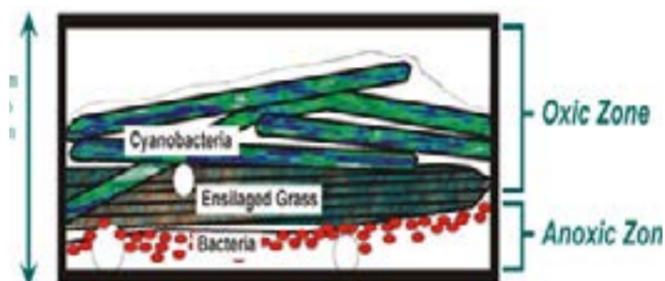


Figure 1. Layers of Microbial Mat

Microbial Mats and Integrated Systems

Microbial mats consist of layered microbial communities that simultaneously manage nitrogen and carbon. The surface layer of cyanobacteria produces oxygen, supporting nitrification. The middle layer contains nitrifying bacteria that reduce ammonia toxicity, while the lower layer consists of denitrifying microbes that remove nitrate. Integrated microbial mat bioreactor-constructed wetland systems enhance wastewater treatment efficiency.

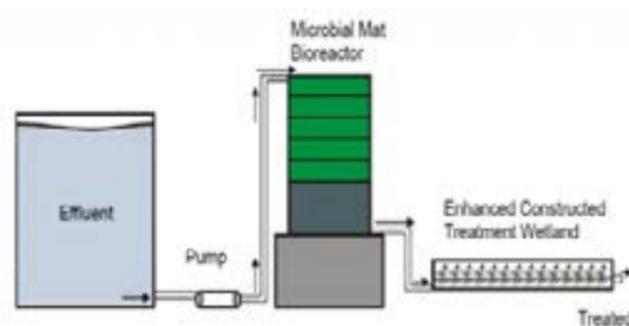


Figure 2. Integrated Microbial Mat Bioreactor

Aquatic Plants and Seaweeds in Nutrient Removal

Aquatic plants and seaweeds such as *Gracilaria*, *Caulerpa*, and *Sargassum* absorb nitrogen and phosphorus from aquaculture effluents. Constructed wetlands using macrophytes effectively remove organic matter and suspended solids, enabling safe discharge or reuse of treated water



Case Studies and Integrated Bioremediation

Several case studies demonstrate the effectiveness of integrated bioremediation systems. Papyrus-bivalve systems showed maximum removal of nutrients and total dissolved solids. Macroalgae combined with *Artemia* improved nitrogen removal, while mussel-microalgae-bacteria systems efficiently removed nutrients and organic pollutants. Fungal bioremediation using *Aspergillus* species significantly reduced phosphorus, nitrogen, and chemical oxygen demand

Economics and Water Reuse

Integrated bioremediation systems provide favorable economic returns through reduced water exchange, lower chemical use, improved fish growth, and the sale of biomass. Cost-benefit analysis indicates a ratio of 1.69:1, demonstrating economic and environmental sustainability. Treated wastewater can be reused for fish culture, addressing freshwater scarcity in India.

Sewage-Fed Aquaculture and Duckweed Systems

Sewage-fed aquaculture systems, particularly in Kolkata, utilize natural purification processes involving wetlands, macrophytes, sunlight, and microbial activity. Duckweed-based systems effectively remove nutrients, convert sewage into fish protein, and generate revenue, though they require large land areas and are best suited for domestic wastewater.

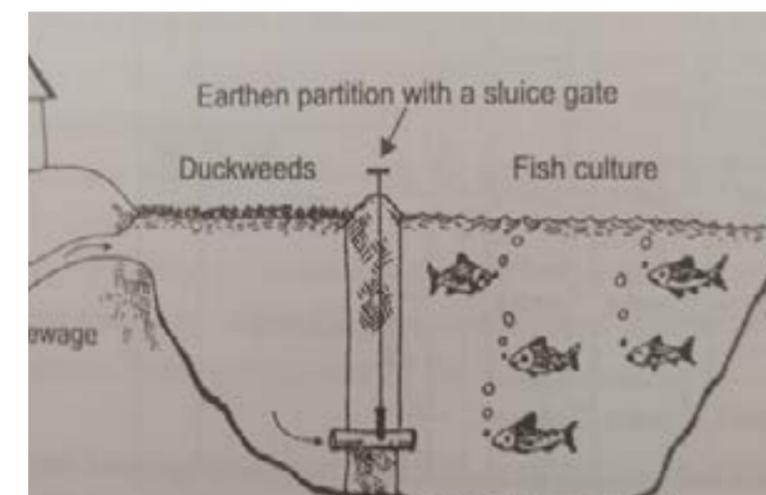


Figure 4. Duckweed-based sewage treatment for fish pond (Source: Handbook of Fisheries and Aquaculture)

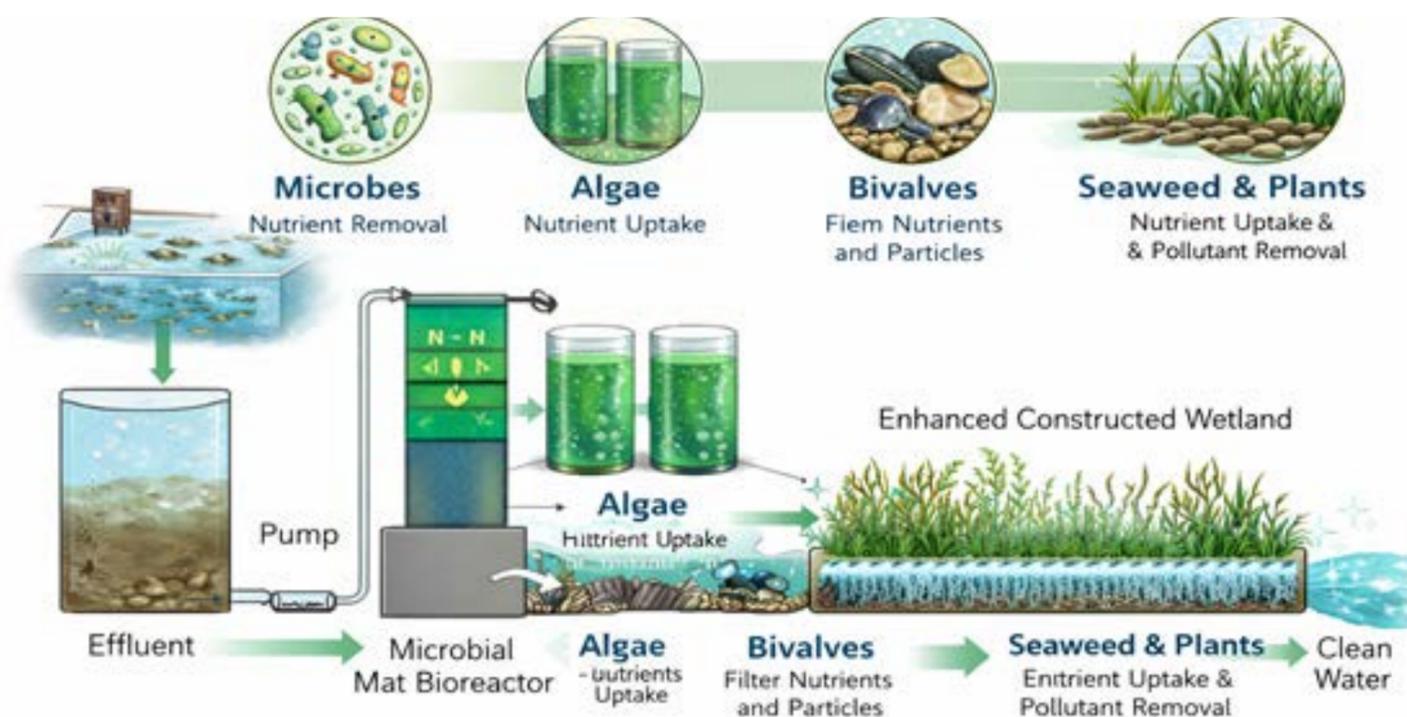


Figure 3. Integrated bioremediation of aquaculture wastewater using microbes, algae, bivalves, and plants (Self-designed conceptual diagram of bioremediation in aquaculture)

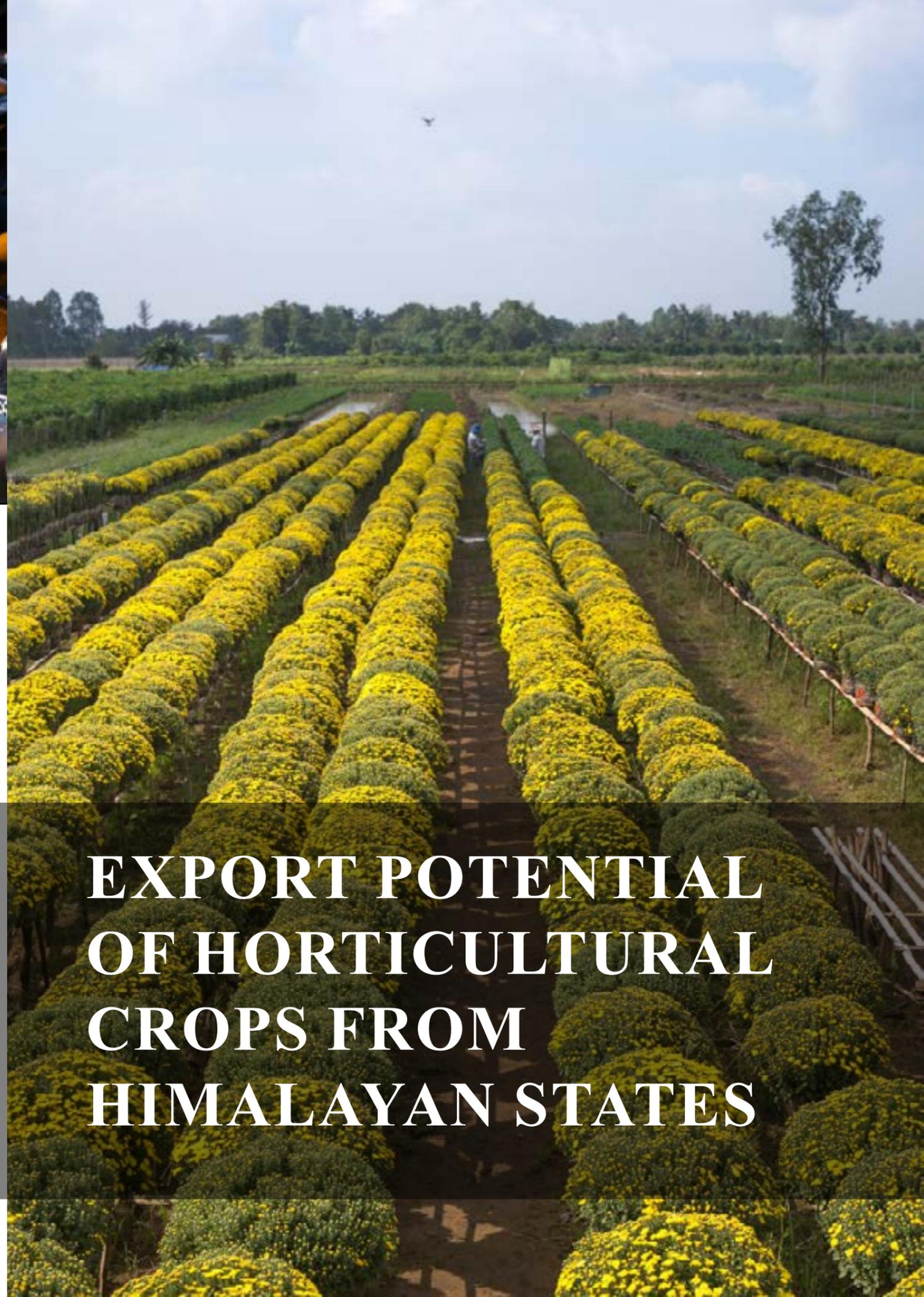


Conclusion

Bioremediation in wastewater aquaculture offers low-cost, eco-friendly treatment with effective nutrient removal and biomass production. However, it depends on climatic conditions and requires large land areas. With rising demand for sustainable wastewater solutions and government support, bioremediation holds strong potential. Overall, bioremediation supports circular economy principles and provides a sustainable solution.

REFERENCES

1. Ayyappan, S. (2000). Duckweed and fish-based aquaculture sewage treatment system: Status and prospects. In *Waste recycling and resources management in the developing world* (pp. 59–63). University of Kalyani & International Ecological Engineering Society.
2. Ayyappan, S., & Mishra, S. (2003). Bioamelioration in aquaculture with a special reference to nitrifying bacteria (pp. 89–107). In I. S. B. Singh, S. S. Pai, R. Philip, & A. Mohandas (Eds.), *Aquaculture medicine*. CFDDM, CUSAT.
3. Indian Council of Agricultural Research. (2019). *Handbook of fisheries and aquaculture*. ICAR.
4. McHugh, S., O'Reilly, C., Mahony, T., Colleran, E., & O'Flaherty, V. (2003). Anaerobic granular sludge bioreactor technology. Reviews in *Environmental Science and Biotechnology*, 2(2), 225–245.
5. Oron, G. (1994). Duckweed culture for wastewater renovation and biomass production. *Agricultural Water Management*, 26(1–2), 27–40.
6. Sarkar, D., Lahiri, S., & Jana, B. B. (2017). Responses of structure, function, and C-sequestration potential of microalgae to nutrient enrichment across the sewage effluent of a tropical waste stabilization pond system. *Ecology and Hydrobiology*, 5.



EXPORT POTENTIAL OF HORTICULTURAL CROPS FROM HIMALAYAN STATES



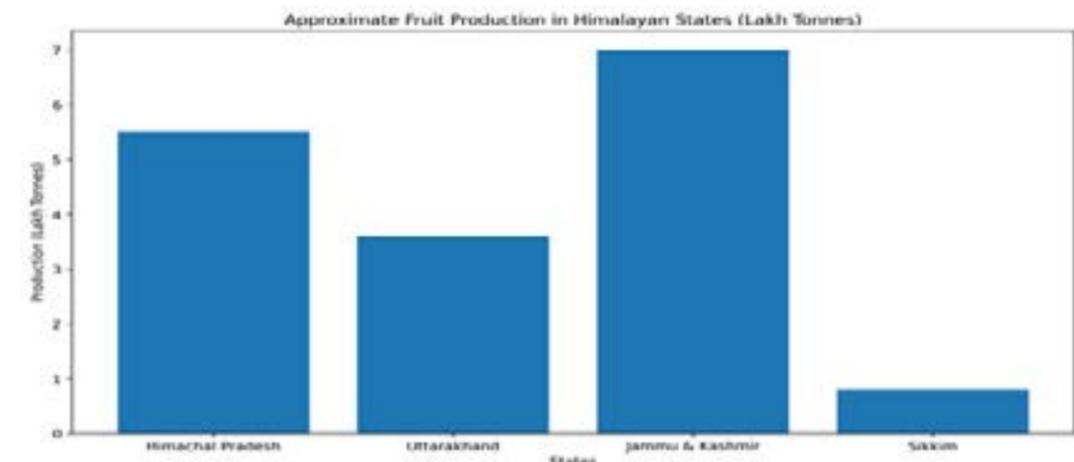
Introduction

The Himalayan states of Himachal Pradesh, Uttarakhand, Jammu and Kashmir and Sikkim hold tremendous potential in horticultural production due to their diverse agro-climatic conditions, altitude variations and relatively low chemical usage systems. These states are emerging as important contributors to India's high-value horticultural exports. According to the Ministry of Agriculture & Farmers Welfare, India's total horticulture production reached 354.74 million tonnes in 2023-24, surpassing food grain production [1]. Despite this large production base, India contributes only about 1% of global horticulture exports, indicating significant untapped export potential [2].

also produces walnuts and cherries, which have established international demand. Sikkim, declared India's first fully organic state in 2016, cultivates large cardamom, ginger, turmeric and organic vegetables, offering premium export potential in niche organic markets [6].

1. Horticultural Strength of Himalayan States

Himachal Pradesh has approximately 3.38 lakh hectares under horticulture, with fruits accounting for a major share [3]. The state contributes significantly to India's apple production, producing around 5-6 lakh tonnes annually depending on climatic conditions. Uttarakhand produces nearly 3.6 lakh tonnes of fruits annually, including citrus, peach, plum and kiwi [4]. The state is also expanding cultivation of off-season vegetables and aromatic plants, enhancing export diversification. Jammu & Kashmir is one of India's largest apple-producing regions, contributing nearly 75% of India's apple exports in some years [5]. The region



Vasundhra Negi¹ and Akshay Rana²

¹Ph.D Scholar
College of Horticulture and Forestry, Neri, Hamirpur
Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.)

²Ph.D Scholar
College of Horticulture and Forestry, Neri, Hamirpur
Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.)

In terms of any communication correspondence is pertained to:
vasundhraneggi@gmail.com & ranaakshay1769@gmail.com

2. Export Scenario and Market Trends

According to the Agricultural and Processed Food Products Export Development Authority (APEDA), India exported horticultural products worth approximately USD 3.8-4.0 billion in 2022-23, including fresh fruits and vegetables [7].

Major export destinations include:

- UAE, Saudi Arabia, Bangladesh, UK and Netherlands. The Gulf region remains a strong market for Indian apples and vegetables due to proximity and established trade channels [7].

Himalayan apples, especially from Himachal Pradesh and Jammu & Kashmir, fetch premium prices because of:

- Better colour development due to diurnal temperature variation
- Higher sugar content
- Longer shelf life under cold conditions. Off-season vegetables grown in hill regions also supply metropolitan markets and have growing export interest due to pesticide-residue compliance [2].

3. Climate Advantage & Comparative Edge

The Himalayan agro-climate provides natural advantages: • Cool temperatures suitable for temperate fruits • Low pest pressure in high altitudes • Potential for organic and residue-free production. The Horticulture Mission for North East & Himalayan States (HMNEH) has supported area expansion, nursery development, and post-harvest infrastructure in hill regions [8].

High-value crops suitable for export include:

Crop	Export Potential	Key States
Apple	GCC & EU markets	HP, J&K
Kiwi	Niche premium markets	Uttarakhand
Large Cardamom	Middle East & Southeast Asia	Sikkim
Walnut	Europe & USA	J&K
Medicinal Plants	Global nutraceutical industry	UKD, HP

4. Infrastructure & Policy Support

Government schemes such as:

- Mission for Integrated Development of Horticulture (MIDH)
- PM Formalisation of Micro Food Processing Enterprises (PM-FME)
- Operation Greens have strengthened cold chain infrastructure and processing capacity [1].
- However, India’s cold storage capacity remains unevenly distributed and hill states face transportation challenges due to mountainous terrain [2].

5. Challenges Limiting Export Growth

Despite strong potential, key constraints include:

1. Fragmented landholdings that limit export-scale aggregation
2. High logistics costs due to hilly terrains
3. Strict sanitary and phytosanitary (SPS) standards in EU markets
4. Inconsistent quality grading and packaging India ranks 14th in vegetable exports and 23rd in fruit exports globally. This highlights the potential for improving competitiveness [2].

6. Strategic Way Forward

To improve export prospects, Himalayan states need to concentrate on the following:

- Improving Farmer Producer Organizations (FPOs)



- Developing organic certification (particularly in Sikkim and Uttarakhand)
- Developing packhouses and reefer transport services
- Implementing digital traceability solutions
- Developing the “Himalayan Produce” brand as a high-end mark. Export clusters for apples, cardamom, walnuts and medicinal herbs could help increase export quality.



Summary

The Himalayan states of Himachal Pradesh, Uttarakhand, Jammu & Kashmir and Sikkim have a strong potential for export-oriented horticulture due to favourable agro-climatic conditions and the production of high-value temperate fruits and organic products. Although India has a large production of horticultural products, its share in the global export market is still small. Apples, walnuts, cardamom, kiwi, medicinal plants and off-season vegetables are some of the promising export products. Although the government has made efforts to improve infrastructure and support, the issues of logistics, fragmentation and quality standards continue to be challenges. Improvement in FPOs, certification, branding and post-harvest infrastructure can help make the Himalayan region a competitive export destination for horticultural products.

Conclusion

The Himalayan states have a strong comparative advantage in high-value horticultural crops. Although the contribution of India to the global export of horticulture is not substantial, with proper investment in infrastructure, certification and export development, these Himalayan states can become leading contributors to the growth of agri-exports in India. The Himalayas can change from being production centres to export powerhouses in the global horticulture market.

REFERENCES

1. Agricultural and Processed Food Products Export Development Authority (APEDA). (2023). Agricultural export statistics report 2022-23. Ministry of Commerce & Industry, Government of India, pp. 25-27.
2. Directorate of Horticulture, Jammu & Kashmir. (2023). Apple production and export report 2022–23. Government of Jammu & Kashmir, p. 18.
3. Government of India. (2025). India’s Exports of Major Horticulture Crops (Data up to 2023-24). Ministry of Commerce and Industry, Government of India, p. 12.
4. Government of Himachal Pradesh. (2024-2025). Economic survey of Himachal Pradesh 2024–25. Department of Economics & Statistics, Government of Himachal Pradesh, p. 67.
5. Government of Sikkim. (2016). Sikkim organic mission report: Organic state declaration and agricultural data. Government of Sikkim, p. 9.
6. Government of Uttarakhand. (2024). Horticulture production data report 2023–24. Department of Horticulture, Government of Uttarakhand, pp. 30-31.
7. Ministry of Agriculture & Farmers Welfare. (2023-2024). Horticulture statistics at a glance 2023. Government of India. p. 45.
8. Ministry of Agriculture & Farmers Welfare. (2024-25). Horticulture mission for North East and Himalayan States (HMNEH) guidelines. Government of India. p. 45.

RAINFED AGRICULTURE AND WATERSHED MANAGEMENT: INTEGRATING SUSTAINABLE PRACTICES FOR ENVIRONMENTAL RESILIENCE

Jahanvi Jublani ¹, Chinmaya Sahoo^{2*} and Ankit saini¹

¹Dr. KSG Akal College of Agriculture,
Eternal University, Baru Sahib,
Sirmaur, Himachal Pradesh, India

²Dr. Rajendra Prasad Central
Agricultural University, Pusa, Bihar,
India

In terms of any communication
correspondence is pertained to:
ankitsaini970@gmail.com

Abstract

Agriculture and watershed management are intricately linked, as agricultural activities significantly influence water resources, soil health, and ecosystem stability. This article explores the interplay between these domains, emphasizing the need for integrated approaches to mitigate environmental degradation. Key topics include the impacts of conventional farming on watersheds, such as soil erosion, nutrient runoff, and water pollution, alongside sustainable strategies like conservation tillage, agro-forestry, and riparian buffer zones. The article highlights successful implementations and challenges posed by climate change and urbanization. By adopting watershed-based management, agriculture can enhance productivity, ensure water security, and promote biodiversity. The discussion underscores policy recommendations and technological innovations, advocating for collaborative efforts among farmers, policymakers, and scientists. Ultimately, sustainable agriculture within watersheds is essential for global food security and environmental sustainability.

Keywords- Agriculture, watershed management, sustainable farming, soil erosion and nutrient runoff.

Introduction

Agriculture forms the backbone of human civilization, providing food, fibre and livelihoods

for billions. However, its expansion and intensification have often come at the expense of natural resources, particularly watersheds areas that drain into a common waterway, encompassing rivers, lakes, and groundwater systems. Watershed management involves the coordinated planning and implementation of practices to protect and restore these vital ecosystems, ensuring sustainable water flow, soil retention, and biodiversity. The relationship between agriculture and watersheds is symbiotic yet fraught with challenges. On one hand, watersheds supply irrigation water, nutrients, and fertile soils essential for crop production. On the other, agricultural practices like deforestation, excessive tillage, and chemical fertilizer use can lead to soil erosion, sedimentation of waterways, and pollution from pesticides and nutrients, resulting in eutrophication and degraded water quality. These issues are exacerbated by climate change, which alters precipitation patterns and increases the frequency of droughts and floods. This article aims to delve into the dynamics of agriculture and watershed management, highlighting their interconnections, challenges, and solutions. It begins by examining the environmental impacts of agriculture on watersheds, followed by sustainable management strategies, case studies, and future prospects. By integrating watershed principles into agricultural systems, we can foster resilience, enhance productivity, and safeguard ecosystems for future generations.

The Interplay Between Agriculture and Watersheds

Watersheds are dynamic systems where land use directly affects water quantity and quality. Agriculture occupies about 38% of the Earth's land surface making it a dominant force in watershed dynamics. Conventional farming practices, such as monoculture cropping and heavy machinery use, disrupt soil structure, leading to erosion rates that can exceed 10 tons per hectare annually in vulnerable areas. This eroded sediment clogs rivers, reduces reservoir capacity, and harms aquatic habitats. Nutrient runoff from fertilizers is another critical issue. Excess nitrogen and phosphorus from agricultural fields contribute to algal blooms in water bodies, as seen in the Gulf of Mexico's "dead zone," where hypoxic conditions kill marine life over thousands of square kilometres. Pesticides further contaminate groundwater, posing risks to human health and wildlife. Deforestation for farmland expansion reduces evapotranspiration, altering stream flows and increasing flood risks. Conversely, watersheds provide essential services to agriculture. They regulate water cycles, recharge aquifers, and deliver nutrients through natural processes. Effective management can



enhance these benefits, promoting sustainable intensification where yields increase without compromising environmental integrity.

Rainfed Agriculture: Growing of crops entirely under rainfed conditions by using rain water is called as rainfed agriculture.

Types of Rainfed Agriculture:

Dry farming: The cultivation of crops in regions with annual rainfall less than 750mm. Crop failure is most common due to prolonged dry spell during the crop period. These are arid regions with a growing season less than 75 days. Moisture conservation practices are necessary for crop production.

Dryland farming – cultivation of crops in the regions with annual rainfall more than 750 mm. In spite of prolonged dry spell crop failure is relatively less frequent. These are semi-arid tracts with a growing period between 75 to 120 days. Moisture conservation practices are necessary for crop production. However, adequate drainage is required especially for Vertisols.

Rainfed farming – Crop production in the regions with annual rainfall more than 1150 mm. Crops are not subjected to soil moisture stress during the crop period. These are humid regions with growing period more than 120 days.

Importance of Rainfed agriculture in India:

- About 70% of rural population lives in dry farming areas and their lives depends on success or failure of crop.
- Rainfed agriculture plays a distinct role in Indian agriculture occupying 49% of net cultivation area and supports 40% of human population and 60 % of livestock population.
- The contribution of rainfed agriculture in India is about 42% of total food grains,

75% of oilseeds, 90% of pulses and 70% of cotton.

- Drylands offer good scope for development of agroforestry, social forestry, horti-silvi-pasture and such other similar systems which will not only supply food, fuel to the village people and fodder to the cattle but forms a suitable vegetative cover for ecological maintenance.

Problems of dryland agriculture:

- Inadequate and uncertainty of rainfall and its erratic distribution. Expected rainfall in the year is 650mm but 80% of it is received in 75-90 days of the monsoon season.
- Late onset and early cessation of monsoon.
- Prolonged dry spells during the crop period.
- Low moisture retention capacity.
- Poor soil fertility conditions.
- Socio-economic constraints particularly because of predominance of small and marginal farmers, 54% of the holdings are less than 1 ha.
- Limited infrastructure development and improper and untimely availability of credits and agricultural inputs.

Challenges in Integrating Agriculture and Watershed Management

Several factors complicate the integration of agriculture with watershed management. Climate change intensifies these challenges by causing erratic rainfall, prolonged droughts, and extreme weather events. For instance, rising temperatures accelerate evaporation, reducing water availability for irrigation, while intensified storms heighten erosion and flooding (IPCC, 2021). Urbanization and industrialization encroach on agricultural lands, fragmenting watersheds and increasing impervious surfaces that exacerbate runoff. In developing regions, smallholder farmers often lack access to resources, leading to unsustainable practices like slash-and-burn agriculture, which degrades watersheds in tropical areas. Policy and institutional barriers also hinder progress. Fragmented governance, where agricultural and water management fall under different agencies, leads to uncoordinated efforts. Economic pressures prioritize short-



term yields over long-term sustainability, with subsidies for chemical inputs discouraging eco-friendly alternatives.

Sustainable Strategies for Watershed Management in Agriculture

To address these challenges, integrated watershed management emphasizes holistic approaches that align agricultural practices with ecosystem health. Key strategies include:

- **Conservation Tillage and Soil Management:** Reducing tillage minimizes soil disturbance, preserving organic matter and reducing erosion. Practices like no-till farming, combined with cover cropping, enhance soil infiltration and water retention. In the United States, conservation tillage has reduced soil loss by up to 50% on croplands.
- **Agro-forestry and Diversified Cropping:** Integrating trees and shrubs into farming systems, such as alley cropping or windbreaks, stabilizes soils and improves water cycling. Agro-forestry can increase biodiversity and provide additional income from timber or fruits, as demonstrated in Kenya's Mau Forest Complex, where

it has restored degraded watersheds (Nair, 2012).

- **Riparian Buffer Zones:** Planting vegetation along waterways filters runoff, traps sediments, and absorbs nutrients. Buffers of 10-30 m wide can reduce nitrogen runoff by 60-90% (Lowrance et al., 1997). In Europe, the EU's Common Agricultural Policy mandates such zones to protect rivers.
- **Precision Agriculture and Technology:** Using GPS, sensors, and drones enables targeted application of inputs, minimizing waste and pollution. Remote sensing helps monitor watershed health, while models like SWAT (Soil and Water Assessment Tool) simulate impacts and guide decisions (Arnold et al., 1998).
- **Water Conservation Techniques:** Rainwater harvesting, drip irrigation, and constructed wetlands manage water efficiently. In arid regions, these methods have boosted crop yields while conserving

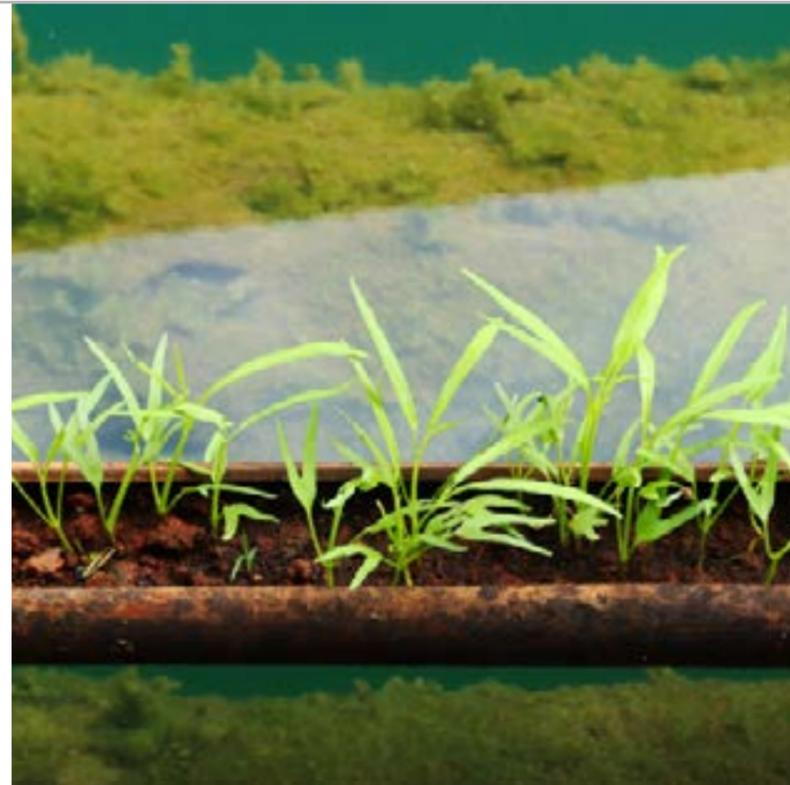
- watersheds (Pimentel et al., 1995).
- **Policy and Community Engagement:** Incentives like payments for ecosystem services encourage farmers to adopt sustainable practices. Participatory approaches, involving local communities in watershed planning, foster ownership and compliance.

Future Prospects and Innovations

Advancing technology, such as AI-driven predictive analytics for drought forecasting will enhance watershed resilience. Climate-smart agriculture, combining adaptation and mitigation, is crucial. Global initiatives like the UN's Sustainable Development Goals (SDGs) target zero hunger (Goal 2) and clean water (Goal 6), urging integrated approaches. Collaboration across sectors farmers, governments, NGOs, and researchers is essential. Education and capacity-building can empower communities, while international funding supports developing nations.

Conclusion

Agriculture and watershed management are interdependent pillars of sustainability. While conventional practices have degraded watersheds through erosion, pollution, and resource depletion, integrated strategies offer pathways to harmony. By embracing conservation tillage, agroforestry, and technological innovations, agriculture can thrive without compromising water quality, biodiversity, or resilience to climate change. Case studies from the Mississippi, Indo-Gangetic Plain, and Chesapeake Bay affirm that with policy support and community involvement, positive outcomes are achievable. Moving forward, prioritizing watershed-centric agriculture is imperative for global food security and environmental health. Policymakers must incentivize sustainable practices, researchers should innovate adaptable solutions, and farmers should adopt them for long-term prosperity. Ultimately, nurturing watersheds ensures a bountiful legacy for future generations.



REFERENCES

1. Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large area hydrologic modeling and assessment part I: Model development. *Journal of the American Water Resources Association*, 34(1), 73-89.
2. IPCC. (2021). *Climate change 2021: The physical science basis*. Cambridge University Press.
3. Lowrance, R., Altier, L. S., Newbold, J. D., Schnabel, R. R., Groffman, P. M., Denver, J. M., Correll, D. L., Gilliam, J. W., Robinson, J. L., Brinsfield, R. B., Staver, K. W., Lucas, W., & Todd, A. H. (1997). Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. *Environmental Management*, 21(5), 687-712.
4. Nair, P. K. R. (2012). *Agroforestry: The future of global land use*. Springer.
5. Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., & Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science*, 267(5201), 1117-1123.

RAINFED AGRICULTURE THE SILENT BACKBONE OF GLOBAL FOOD SECURITY

Amritendu Misra

Suresh Gyan Vihar
University, Jaipur,
Rajasthan

Abstract

Rainfed agriculture constitutes the dominant production system across the world's cultivated land, supporting the livelihoods of billions while contributing substantially to global food security. Despite its importance, it remains constrained by climatic variability, resource limitations, and technological gaps. This manuscript synthesizes the structural importance of rainfed systems, their productivity gaps, and modern scientific interventions required to transform them into resilient, high-efficiency production ecosystems. By integrating advances in plant breeding, climate-smart agronomy, soil-water management, and digital agriculture, rainfed farming can evolve from a vulnerable system into a sustainable and profitable enterprise. Policy and institutional convergence will be crucial in unlocking this transformation.

Keywords: Rainfed agriculture, climate resilience, dryland farming, crop improvement and water-use efficiency.



Introduction

Rainfed agriculture occupies approximately 80% of the global cultivated area and contributes nearly 60–70% of the world's staple food production. In countries like India, rainfed regions support a large proportion of smallholder farmers and account for a major share of pulses, oilseeds, millets, and coarse cereals production. However, rainfed agriculture is highly sensitive to climatic variability, particularly rainfall uncertainty, temperature stress, and soil degradation. The yield gap between rainfed and irrigated systems often ranges from 30–60%, highlighting both the vulnerability and the untapped potential of these systems.

Characteristics of Rainfed Agro-Ecosystems

Rainfed agricultural systems are characterized by:

Dependence on precipitation: No assured irrigation supply

High rainfall variability:

- Temporal and spatial fluctuations
- Low soil fertility and organic carbon levels
- High risk of droughts and crop failures
- Dominance of marginal and smallholder farmers
- These factors collectively contribute to unstable yields and income insecurity.

Productivity Constraints

Climatic Variability : Erratic monsoon patterns, delayed onset, early withdrawal, and extreme events (droughts, floods) severely impact crop growth stages, particularly germination and grain filling.

Soil Degradation

- Rainfed soils often suffer from:
- Low organic matter
- Poor water-holding capacity
- Nutrient deficiencies (N, P, S, Zn)

Limited Access to Technology

Farmers in rainfed areas frequently lack access to:

- Improved seed varieties
- Precision agronomy
- Mechanization
- Market linkages

Socio-economic Constraints

Fragmented landholdings, credit limitations, and price volatility further limit investment capacity in improved practices.

Scientific Strategies for Rainfed Transformation

Climate-Resilient Crop Breeding

Modern plant breeding offers solutions through:

- Drought-tolerant genotypes
- Early-maturing varieties
- Heat-resilient hybrids
- Root architecture optimization
- Integration of genomic selection, marker-assisted breeding, and doubled haploid technology can accelerate genetic gains under stress environments.

Water Management Innovations

- In-situ moisture conservation (mulching, contour bunding)
- Rainwater harvesting (farm ponds, check dams)
- Micro-irrigation (drip and sprinkler)
- Deficit irrigation strategies (Ceccarelli, S., 2015).
- These approaches enhance water productivity (kg grain per mm water).

Soil Health Restoration

- Integrated nutrient management (INM)
- Use of biofertilizers and compost
- Conservation agriculture (minimum tillage, residue retention)
- Cover cropping and crop rotation

Climate-Smart Agronomy

- Altered sowing windows based on monsoon prediction
- Intercropping systems (e.g., maize + pigeon-pea, sorghum + cowpea)

Agroforestry integration

- Stress-adaptive cropping sequences (Passioura, J., 2007).

Digital and Decision Support Systems

- Remote sensing for drought monitoring
- AI-based yield prediction
- Mobile-based agro-advisories
- Weather-indexed insurance



Case of India: Rainfed Potential and Challenges

India has nearly 52–55% of its net sown area under rainfed conditions. These regions contribute significantly to:

- 80% of pulses
- 90% of millets
- 70% of oilseeds

Despite lower productivity compared to irrigated areas, rainfed regions possess immense untapped potential due to large yield gaps and adaptability to climate-resilient crops (ICAR, 2021).



Policy and Institutional Interventions

For sustainable transformation, the following policy measures are essential:

- Investment in watershed development programmes
- Strengthening seed systems for stress-tolerant varieties
- Expansion of climate-smart extension services
- Crop insurance and risk-buffer mechanisms
- Market reforms ensuring MSP and procurement for dry land crops (FAO, 2019).

Future Outlook

Rainfed agriculture will play a decisive role in ensuring food and nutritional security under climate change. Future research must focus on:

- Systems biology for drought tolerance
- Root phenomics and soil-plant interactions
- Carbon-neutral rainfed farming
- Integration of AI and breeding pipelines

Conclusion

Rainfed agriculture is not merely a subsistence system but a strategic pillar of global food security. With targeted scientific innovations, improved governance, and farmer-

centric policies, rainfed ecosystems can transition into resilient, productive, and sustainable agricultural landscapes.

Acknowledgements

The author acknowledges contributions from the scientific community working in dryland agriculture, crop breeding, and climate resilience.

Conflict of Interest

The author declares no conflict of interest.

REFERENCES

1. Ceccarelli, S. (2015). Efficiency of plant breeding. *Agronomy for Sustainable Development*, 35, 1–14.
2. FAO (2019). *The State of Food and Agriculture*. FAO, Rome.
3. ICAR (2021). *Vision 2050 for Dryland Agriculture*. Indian Council of Agricultural Research.
4. Passioura, J. (2007). The drought environment. *Functional Plant Biology*, 34, 101–112.

हर एक काम,
देश के नाम

EMPOWERING INDIA'S FERTILIZER SELF-RELIANCE...

FARMER-FIRST COMMITMENT

Affordable inputs. Timely delivery. Empowered farmers.

- Ensuring affordable, timely and effective fertiliser solutions for farmers
- Strengthening last-mile delivery across regions and geographies
- Providing timely farmer advisories for informed and sustainable farming practices

SUPPLY SECURITY & STRATEGIC SOURCING

Assured supply. Stable markets. Stronger India.

- Leveraging alternative sources, imports and efficient trading mechanisms
- Ensuring uninterrupted fertiliser availability and market stability
- Strengthening national fertiliser security for long-term resilience

ENERGY EFFICIENCY & RESPONSIBLE OPERATIONS

Efficient plants. Safe operations. Lower carbon footprint.

- Driving energy savings through efficiency-led plant operations
- Continuous improvement through adoption of energy-efficient technologies
- Maintaining the highest standards of operational safety and security

SUSTAINABILITY & POLICY ALIGNMENT

Balanced nutrition. Healthier soil. Sustainable future.

- Active implementation of PM-PRANAM initiatives
- Promoting balanced nutrient use and reducing chemical dependency
- Supporting policy reforms for sustainable and climate-smart agriculture

ADVANCING TOWARDS A SELF-RELIANT FUTURE

Atmanirbhar agriculture. Resilient tomorrow.

- Supporting Atmanirbhar Bharat in fertiliser and agriculture sectors
- Building a resilient, sustainable and farmer-centric ecosystem
- Aligned with national priorities and India's long-term growth vision



Hindustan Urvarak & Rasayan Limited

Corporate Office

Hindustan Urvarak & Rasayan Limited

Core 3 & 4, 9th Floor, SCOPE Minar, Laxmi Nagar District Centre, New Delhi-110092

Website: www.hurl.net.in | Email: contactus@hurl.net.in

Follow Us: