THE AGRI PUBLICATION
THE FUTURE OF AGRICULTURE
Grow With Every Page
e-Magazine for Agricultural Articles
Volume 01 | Issue 04 | September 2026
Available online at https://agripublication.com/
UDYAM REGISTERED NUMBER UDYAM-MP-06-0043239
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ISSN (Online): 3139-6127
Scan to Visit Our Website

Volume: 01 Issue No: 04

Sustainable Management Practices for Rice-Fallow Areas to Enhance Nutrient Use Efficiency

Article ID: AP-V01-I04-02

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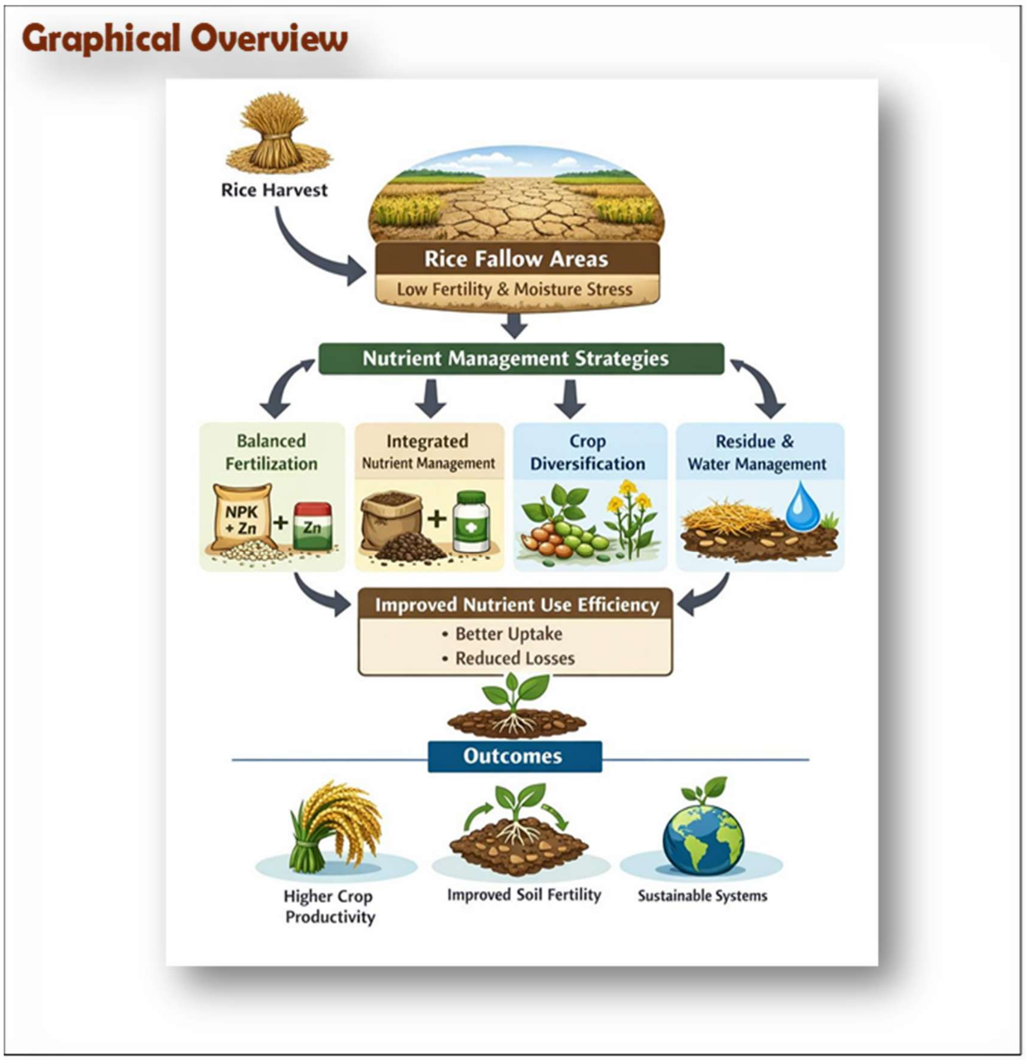
Abstract

Rice-fallow areas are an important yet under-utilised component of rice-based farming systems, particularly in eastern India, where large areas of land remain uncultivated after the *kharif rice* harvest. These fallows are characterised by low residual soil moisture and inappropriate management, leading to low system productivity. Enhancing nutrient use efficiency (NUE) in rice-fallow systems is essential to improve crop yields, minimize nutrient losses and ensure long-term soil sustainability. This review discusses the importance of sustainable nutrient management practices for improving NUE in rice-fallow areas. Practices such as balanced fertilisation, integrated nutrient management (INM), crop diversification with short-duration legumes, residue management and microbial bioaugmentation to rice and subsequent

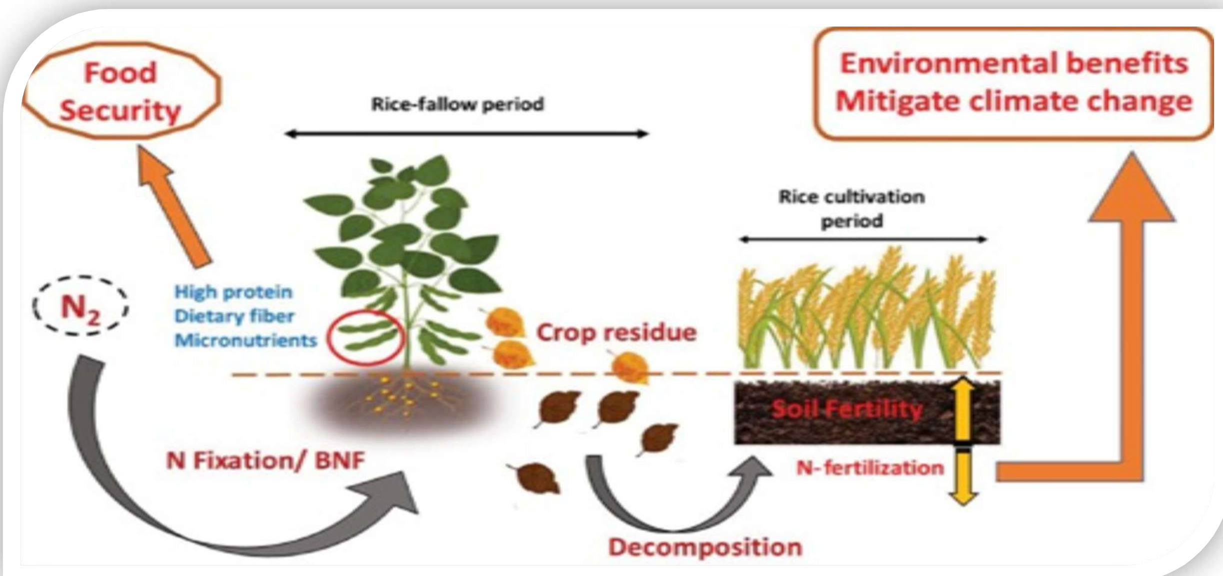
crop in sequence contribute to improved nutrient cycling, soil health and resource use efficiency with higher yield. Adopting these approaches can transform rice fallow lands into productive systems while preserving environmental integrity and supporting sustainable agricultural intensification.

Keywords- Rice-fallow, Nutrient use efficiency, Integrated nutrient management, Sustainability, Soil fertility



Introduction

Rice is the staple food crop for a large proportion of the world's population and rice-based cropping systems play an important role in ensuring food security and sustaining rural livelihoods. In India, particularly in the eastern and northeastern regions, vast areas of agricultural land remain uncultivated after the *kharif* rice harvest. These rice fallow lands are a major opportunity to augment agricultural productivity without expanding the cultivated area. However, rice fallows are generally characterised by poor soil fertility, nutrient depletion, limited soil moisture and poor crop management practices. Hence, enhancing NUE is essential for achieving sustainable intensification, improving crop productivity and mitigating environmental risks associated with nutrient losses.



Efficient utilisation of rice-fallow

Challenges in rice-fallow nutrient management

1. Declining soil fertility: Rice-fallow soils tend to lose productivity over time because rice plants continuously deplete large quantities of nutrients from the soil. Every season, essential nutrients such as nitrogen, phosphorus, potassium and important micronutrients are removed through harvest, but in many cases, they are not adequately replenished.

2. Moisture scarcity after rice harvest: Rice-fallow areas usually experience moisture deficit after the rice crop is harvested. Insufficient soil moisture limits the dissolution and movement of nutrients in the root zone, thereby reducing nutrient uptake by plants during the subsequent crop season.

3. Reduction in beneficial soil microorganisms: Continuous application of chemical fertilisers with minimal or no organic manure negatively affects beneficial soil microorganisms. Reduced microbial activity slows the mineralization process and the breakdown of organic matter, ultimately making fewer nutrients available to crops.

4. Weak rhizosphere environment: The rhizosphere is the zone of active nutrient transformation in the vicinity of plant roots, where interactions between roots and microorganisms occur. These interactions are weakened in degraded rice-fallow soils due to low root activity and poor microbial diversity, leading to decreased nutrient mobilisation and uptake efficiency.

5. Poor recycling of crop residues: In many areas, crop residues are removed from the field or burnt post-harvest. This results in less return of nutrients and organic carbon to the soil. Consequently, over time, soil fertility and biological activity degrade gradually.

Sustainable practices to enhance nutrient use efficiency

1. Optimizing water management

In case of rice-based cropping systems, efficient water management practices play a crucial role for enhancing nutrient use efficiency. Over irrigation leads to leaching, runoff and denitrification while under irrigation restricts nutrient uptake due to reduced root activity and poor mobility of nutrients. According to recent studies employing machine learning and remote sensing, water stress may be reduced, irrigation planning can be enhanced, and climate-resilient agriculture can be encouraged in rice-fallow areas by maintaining ideal soil moisture and groundwater levels (Singha et al., 2025).

Effective water management techniques like Alternate wetting and drying (AWD), laser land levelling, precision irrigation and soil moisture-based irrigation scheduling that helps to match crop demand with water and nutrient availability. Different practices that will help to enhance water use efficiency are,

A. Practices for Rice Crop

Alternate wetting and drying (AWD): During rice season, irrigation is to be applied only after water level falls a set threshold level. It will help to save water and improve residual moisture for succeeding crop.

ISSN (Online): 3139-6127

Laser land levelling: It helps in maintaining uniform distribution of irrigation water in the rice field and reduces unnecessary water application.

Precision irrigation: It helps to apply water according to crop demand, thereby improving water-use efficiency and reducing unnecessary water losses.

Soil moisture-based irrigation scheduling: Irrigation can be scheduled based on the soil moisture status and crop requirement, which helps to match crop demand with water and nutrient availability.

B. Practices for Fallow Crop

Mulching: Rice crop residues are kept on the soil surface to reduce evaporation and moisture loss.

Organic matter addition: This helps to enhance the moisture retention and nutrient availability.

Zero-tillage sowing: Immediately after rice harvest, seeds are sown into the undisturbed soil to retain residual soil moisture in the field.

Timely sowing after rice harvest: Sowing should be done within 7-10 days after rice harvest to use residual soil moisture efficiently before it evaporates.

Short duration and drought tolerant varieties: Higher yield can be achieved with less water by proper selection of crops and varieties.

Advantages:

• Fertilizer use efficiency increases due to reduced nutrient losses through leaching, runoff and denitrification.

• Maintains optimum soil moisture, improving root development.

• Improves utilization of residual soil moisture by the succeeding crop.

• Helps in improving water use efficiency and supports better nutrient uptake.

2. Balanced fertilization

A balanced supply of macro and micronutrients is an important strategy to enhance NUE in rice based-systems. Long term studies have shown that integrated use of nitrogen, phosphorus, potassium and micronutrients like zinc can greatly enhance nutrient uptake, crop yield and overall system productivity. Balanced fertilisation also reduces nutrient antagonism and increases physiological efficiency through improved root growth and nutrient uptake (Jacob *et al.*, 2025).

A. Practices for Rice Crop

Balanced NPK application: Nitrogen, phosphorus and potassium should be applied in appropriate amounts and proportions according to soil-test results and crop requirements. This helps to avoid excessive application of one nutrient while limiting the availability of others.

Site-specific nutrient management: Fertilizer application can be adjusted according to soil fertility status, crop requirement and expected yield. This helps in applying nutrients at the right rate and reduces unnecessary nutrient losses.

Split application of nitrogen: Nitrogen fertilizer should be applied in suitable splits, particularly at important growth stages of rice, instead of applying the entire quantity at once. This improves synchronization between nitrogen supply and crop demand and reduces losses.

B. Practices for Fallow Crop

Residual nutrient management: The succeeding crop should be selected and managed by considering the nutrients remaining in the soil after rice harvest. Efficient use of residual nutrients can reduce the need for additional fertilizer inputs.

Soil-test-based fertilization: Fertilizer application to the fallow crop should be based on soil fertility status and crop requirement. This avoids unnecessary fertilizer application and improves nutrient recovery.

Efficient recycling of rice residues: Retaining and properly managing rice residues can help recycle part of the nutrients contained in the residues back into the soil. As the residues decompose, these nutrients become available to the succeeding crop and contribute to better nutrient cycling.

Advantages:

- Increased nutrient uptake efficiency
- Reduced nutrient losses
- Stable yields and improved crop growth

3. Integrated nutrient management (INM)

Integrated Nutrient Management is the combined use of organic manures, crop residues, bio-fertilizers and chemical fertilisers to optimise nutrient availability and soil health. The combination of organic amendments and inorganic fertilisers has been shown to provide benefits such as improved soil organic carbon, microbial activity and nutrient cycling, resulting in higher yields and better nutrient recovery compared to chemical fertilisers alone (Bilkis *et al*., 2018).

Studies under aerobic and rice-fallow conditions also indicated that addition of organic inputs supplemented with micronutrients improved soil nutrient balance and crop performance, especially under limited water availability (Karthika *et al*., 2025).

Advantages:

- Increased agronomic efficiency
- Improved soil biological activity
- Sustained soil fertility and productivity
- Improves crop yield and sustainability under moisture stress

4. Crop diversification and residue management

Crop rotation: The use of short duration crops like pulses, oilseeds or legumes during post-rice fallow period by utilising the residual soil moisture and nutrients greatly increases the NUE. Pulses act as biological tillers for the strong deep tap root system making the soil loose improving water infiltration and soil aeration.

Biological nitrogen fixation: Pulses work as biological pump where the N-fixing bacteria in roots pull inert N from air and convert it to usable form ammonia.

Crop residue retention and organic matter addition helps improve soil structure and further reduces nutrient losses.

Field research carried out in eastern India has shown that the use of conservation tillage and residue retention techniques for crops such as safflower, lentils and chickpeas improves system productivity and soil moisture conservation (Rakesh *et al*., 2020).

Advantages:

- Biological nitrogen fixation for improved soil fertility
- Protective cover over the soil surface, maintaining better soil moisture conditions

5. Microbial bioaugmentation and rhizosphere enhancement

Recent advances in soil microbiology have highlighted the potential of beneficial microorganisms in enhancing nutrient availability and NUE. Bioaugmentation with microbial consortia, including rhizobia and non-rhizobial endophytes, has been shown to improve crop growth, nutrient uptake, and soil nutrient dynamics in rice fallow systems even with reduced chemical fertilizer inputs (Debnath *et al.*, 2025).

Beneficial microbes, including rhizobia, endophytes, and other plant growth promoting microbes, enhance root growth and rhizosphere activity in rice-fallow systems under conditions of moisture and nutrient limitation. These microorganisms assist crops in developing stronger and deeper root systems to efficiently absorb residual soil moisture and available nutrients after rice harvest. Roots are the pathways for nutrients, water and oxygen and their enhanced activity provides the better nutrient uptake efficiency, leading to improved crop establishment, healthier plant growth and higher productivity in rice fallow areas.

Advantages:

- Enhanced soil health & biological activity
- Healthier rhizospheric interactions resulting in better nutrient uptake and plant tolerance
- Increased soil nutrient availability

Indicators and Evaluation of nutrient use efficiency

NUE can be measured using several metrics, including:

- Agronomic efficiency (yield per unit of nutrient applied)
- Physiological efficiency (biomass per unit of nutrient uptake)
- Partial factor productivity and recovery efficiency

Improved management practices (balanced fertilisation + organic amendments) invariably enhance NUE and yield relative to conventional management approaches as demonstrated by different studies.

Conclusion

Improved nutrient use in rice-fallow areas offers a pathway to sustainable intensification - enhancing soil fertility, productivity and farmer profitability. Integrated nutrient management, balanced fertilization, crop rotation and improved water management strategies are important means to improve nutrient use efficiency and environmental sustainability. Future research should focus on local adaptation of nutrient management strategies, digital innovations for precision nutrient management and participatory approaches for scaling up adoption.

ISSN (Online): 3139-6127

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