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Rice-Based Cropping Systems for Enhancing Productivity and Sustainability of Food Grains in India

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Abstract

Rice-based cropping systems are central to food security and farm livelihoods in India, where rice is cultivated under diverse agro-ecological and production environments. However, increasing pressure on land and water resources, declining soil fertility, inefficient nutrient use and climate variability necessitate sustainable intensification of these systems. The present review synthesizes research on major rice-based cropping systems, with emphasis on system productivity, nutrient management, conservation agriculture and climate-resilient practices. Rice–rice, rice–wheat, rice–maize, rice–pulse and rice–oilseed systems are widely practiced across India. Multilocational studies indicated that rice–maize recorded the highest rice equivalent yield (10.2 t ha^{-1}) and gross return (Rs. 59,110 ha^{-1}) among the systems evaluated. In rice–wheat systems, transplanting produced higher system productivity than direct seeding, while integrated nutrient management involving recommended fertilizers, organic sources and micronutrients improved productivity. Application of green manure and farmyard manure generally increased system productivity compared with the control. Climate-resilient practices involving split nitrogen application, biofertilizers and crop-residue retention showed promise for maintaining productivity while improving resource-use efficiency. The review indicates that sustainable intensification of rice-based systems requires integrated management of crops, nutrients, water and residues, together with suitable crop diversification. Site-specific nutrient management, crop intensification, improved water-use efficiency, legume integration and stronger research– extension linkages are important for enhancing productivity and sustainability of rice-based agriculture in India.

Keywords: Rice-based cropping system, rice–wheat, rice–maize, nutrient management, conservation agriculture, climate resilience, system productivity

Introduction

Rice is one of the most important food crops in India and provides a major share of human food calories globally. India has one of the largest areas under rice cultivation, with much of the area being cultivated under multiple-cropping systems. Rice is grown during both *kharif* and *rabi* seasons, and the extent of irrigation varies considerably among states. Consequently, rice-based cropping systems differ widely according to climate, soil, water availability, market opportunities and farmers' needs. A rice-based cropping system comprises rice as the principal crop followed by or associated with other crops such as cereals, pulses, oilseeds, vegetables, fibre crops and sugarcane. Major systems include rice–rice, rice–wheat, rice–maize, rice–pulse and rice–oilseed, besides rice–fallow systems. The diversity of these systems provides opportunities for crop intensification and diversification, but also creates challenges related to soil fertility, water management, nutrient depletion and sustainability.

Earlier assessments showed considerable variation in the area under different rice-based systems. Rice–fallow and rice–other systems occupied substantial areas, while rice–rice and rice–rice–other systems were also important. Rice-based systems involving cereals, pulses and oilseeds are distributed across almost all rice-growing regions of India. The objective of this review is to synthesize research findings on productivity enhancement in rice-based cropping systems, particularly through crop diversification, nutrient management, conservation agriculture and climate-resilient management practices.

Methodology

This article is a synthesis of research findings reported in the supplied AICRIP/ICAR–Indian Institute of Rice Research material on rice-based cropping systems in India. Information was organized under four major themes: (i) diversity and distribution of rice-based cropping systems, (ii) system productivity and economics, (iii) nutrient management, and (iv) conservation and climate-resilient management. Reported results from multi-locational trials were compared using rice equivalent yield (REY), gross monetary return and system productivity. The effects of crop establishment, organic amendments, fertilizer management, micronutrients and tillage practices were summarized using the values presented in the source material. No additional experimental data were introduced.

Results and Discussion

Diversity of rice-based cropping systems

Rice-based cropping systems vary considerably among Indian states. Rice–wheat is particularly important in northern India, whereas rice–rice is common in southern and eastern regions. Rice may also be combined with groundnut, pulses, oilseeds, vegetables, potato, sugarcane, maize and other crops. Relay or *utera/paira* cropping, intercropping and sequential cropping provide additional opportunities for increasing land-use intensity. Intercropping rice with blackgram, greengram, sesame, maize and millets is practiced particularly under upland conditions. Relay cropping of lentil, gram, pea, lathyrus, berseem and linseed in standing rice helps save land-preparation time and utilize residual soil fertility. These approaches can contribute to greater resource use and cropping intensity when appropriately matched with local conditions. These results are in conformity with earlier reported by Brajendra et al. (2016), Sharma et al. (2020), Sharma et al. (2022), Patel et al. (2025) and Kumar et al. (2025), Tuli et al. (2022) and Brajendra et al. (2025).

Productivity of rice–cereal systems

Rice–rice, rice–wheat and rice–maize are important cereal-based systems. The rice–wheat system occupies a major area of the Indo-Gangetic Plains and is important for national food security. Multilocational trials indicated that transplanting resulted in higher rice equivalent yield than direct seeding under puddled conditions, with REY values of 11.7 and 10.8 t ha^{-1}, respectively. Nutrient management also influenced system productivity. Among the treatments reported, recommended NPK with zinc sulphate followed by the residual effect of green manure and foliar manganese application produced 11.8 t ha^{-1} REY. The results demonstrate the importance of combining balanced fertilization with organic nutrient sources and micronutrient management. Across different rice-based rotations, rice–maize produced the highest REY (10.2 t ha^{-1}) and gross return (Rs. 59,110 ha^{-1}), followed by rice–pulse (8.5 t ha^{-1}) and rice–wheat (8.4 t ha^{-1}). Rice–rice produced 7.8 t ha^{-1}, while rice–oilseed recorded 7.0 t ha^{-1}. These results are in conformity with earlier reported by Sharma et al. (2022), Patel et al. (2025) and Kumar et al. (2025), Brajendra et al. (2025) and Zoureen et al. (2025).

Integrated nutrient management

Continuous cultivation of intensive cropping systems can accelerate nutrient depletion. The source emphasizes that balanced nutrient management is therefore essential for sustaining productivity. Integrated nutrient management combines mineral fertilizers with organic manures,

Table 1: Productivity and gross return of major rice-based cropping systems

Cropping system	REY (t ha^{-1})	Gross return (Rs. ha^{-1})
Rice–rice	7.8	45,124
Rice–wheat	8.4	48,882
Rice–maize	10.2	59,110
Rice–pulse	8.5	49,152
Rice–oilseed	7.0	40,472

crop residues, green manures and biofertilizers. Organic materials improve soil physical, chemical and biological properties, whereas chemical fertilizers supply nutrients in readily available forms. Application of green manure and farmyard manure increased productivity across the rice-based systems compared with the control. Green manure increased productivity in rice–rice from 7.51 to 7.67 t ha^{-1} and in rice–maize from 9.50 to 10.79 t ha^{-1}. FYM further increased rice–rice productivity to 8.18 t ha^{-1} and rice–oilseed productivity to 8.09 t ha^{-1}. These results are in conformity with earlier reported by Srilatha et al. (2019), Kale et al. (2021), Rathod et al. (2021), Parmar et al. (2022) and Patel et al. (2025).

Seasonal nutrient management

Seasonal nutrient management had a marked effect on productivity. The highest reported productivity was generally obtained with 150% recommended fertilizer dose (RFD) of potassium and recycling treatments, although the response varied among cropping systems. For example, rice–wheat productivity increased from 4.67 t ha^{-1} under the control to 11.60 t ha^{-1} under 150% RFD of potassium and recycling. Similarly, rice–maize increased from 7.30 to 12.01 t ha^{-1}. These findings high light the importance of considering nutrient carry-over and residual effects between crops rather than managing each crop independently. Such system-based nutrient management can improve overall nutrient-use efficiency and productivity.

Micronutrient management

Micronutrients are important components of balanced nutrition in intensive rice-based systems. The reported trials showed positive responses to micronutrient application in rice–wheat systems, particularly where organic matter was included. The source indicates that organic matter applied during the preceding *kharif* season had a positive residual effect on the succeeding wheat crop, while micronutrient application through soil or foliar methods further influenced productivity. However, the reported micronutrient table contains substantial variation among treatments and should be interpreted in relation to the experimental conditions before making generalized recommendations. The values ranged from 3.95 to 8.84 t ha^{-1} across treatments. These results are in conformity with earlier reported by Brajendra et al. (2016) Bharamappanavara et al. (2020), Kale et al. (2021), Gorlapalli et al. (2022), Sahoo et al. (2022) and Gobinathet al. (2026).

Conservation agriculture and tillage

Conservation agriculture has considerable potential for reducing soil disturbance and improving resource-use efficiency. However, the reported rice-based trials showed that conventional tillage produced greater system productivity than zero or minimum tillage under the conditions evaluated. In rice–rice, conventional tillage with hybrid rice produced 13.15 t ha^{-1} compared with 8.96 t ha^{-1} under zero tillage with hybrid rice. Rice–linseed showed a similar trend. These findings suggest that conservation practices should not be promoted uniformly across all rice-based environments. Tillage

Table 2: Effect of organic nutrient sources on rice-based system productivity

Treatment	Rice–rice	Rice–wheat	Rice–maize	Rice–pulse	Rice–oilseed
Control	7.51	8.02	9.50	5.23	7.06
Green manure	7.67	8.65	10.79	6.05	7.54
FYM	8.18	8.64	10.29	5.82	8.09

recommendations need to be adapted to soil type, crop sequence, residue conditions, establishment method and local climate.

Climate-resilient management

Climate variability represents a major challenge to sustainable rice production. The source identifies water and nutrient management as key entry points for improving resilience. Non-puddled rice establishment was found to be promising at Coimbatore and other locations, particularly when combined with split nitrogen application, biofertilizers and crop-residue retention. These practices-maintained productivity while providing opportunities for saving nitrogen and improving resource-use efficiency. Climate-resilient rice-based systems therefore require an integrated approach rather than dependence on a single technology. Efficient fertilizer application, biological nutrient sources, residue management, improved establishment methods and appropriate crop diversification can collectively contribute to system resilience.

Future Research Priorities

Future research should focus on increasing the number of crops grown per year without compromising soil and water resources. Short-duration varieties, improved water management, minimum or appropriate tillage, supplementary irrigation and inclusion of legumes can facilitate crop intensification. Greater emphasis is also required on site-specific nutrient management, water-use efficiency and integrated use of mineral fertilizers, organic manures, crop residues and biological inputs. Crop and livestock integration, improved market access and stronger collaboration among research institutions, universities, KVKs and state agricultural departments are also important for sustainable intensification.

Conclusion

Rice-based cropping systems provide major opportunities for enhancing food production, farm income and resource-use efficiency in India. The reviewed evidence demonstrates that crop diversification, balanced nutrient management, organic amendments, micronutrient application and climate-resilient practices can substantially improve system performance. Among the systems evaluated, rice–maize recorded the highest rice equivalent yield and gross monetary return. Green manure and FYM generally improved system productivity, while integrated nutrient management enhanced the benefits of mineral fertilizers through residual and complementary effects. At the same time, the performance of conservation agriculture and crop-establishment practices varied with the production environment, indicating the need for location-specific recommendations. Sustainable intensification of rice-based systems should therefore combine crop diversification with efficient water and nutrient management, appropriate tillage, residue recycling and climate-resilient technologies. Future research should emphasize system-level assessment of productivity, profitability, soil health and resource-use efficiency to develop locally suitable and economically viable rice-based production systems for India.

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