Plant Archives Vol. 25, No. 2, 2025 pp. 2119-2126 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.304

COMPARATIVE PERFORMANCE OF ESTABLISHMENT METHODS AND NITROGEN PRACTICES ON YIELD AND PROFITABILITY IN RICE–RICE CROPPING SYSTEM

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(Date of Receiving : 15-08-2025; Date of Acceptance : 18-10-2025)

ABSTRACT

Sustaining productivity in irrigated rice–rice systems is increasingly constrained by labour scarcity, rising input costs, and declining resource-use efficiency. A field experiment was conducted during *kharif* 2023 and *rabi* 2023–24 at ICAR–Indian Institute of Rice Research, Rajendranagar, Telangana, to assess the effects of crop establishment methods and nitrogen management practices on yield and profitability. The split-plot design comprised three establishment methods normal transplanting (M_1), mechanical transplanting (M_2), and wet direct-seeded rice (M_3) and five nitrogen strategies: 100% recommended dose (RDN), LCC-based management, 75% RDN + nano urea sprays, 100% RDN through slow-release urea, and control. Both factors significantly influenced yield attributes, grain and straw yield, and economic returns (p = 0.05). Wet DSR (M_3) and mechanical transplanting (M_2) achieved higher grain yields (6.0–6.5 t ha^{-1}) and straw yields (7.1–7.4 t ha^{-1}) than normal transplanting, due to improved establishment and lower labour inputs. Among nitrogen treatments, slow-release urea (S_4) and LCC-based management (S_2) produced the highest grain yields (up to 7.4 t ha^{-1}) and net returns (>≠1.1 lakh ha^{-1}) with B:C ratios >2.9. No significant interaction between establishment and nitrogen factors was found, indicating independent effects. The integration of wet DSR or mechanical transplanting with slow-release or LCC-based nitrogen management proved most productive, profitable, and resource-efficient for sustainable intensification of irrigated rice systems in South Asia.
***Keywords* :** Wet direct-seeded rice, Mechanical transplanting, Normal transplanting, Slow-release urea, Leaf Colour Chart (LCC), Rice–rice system.

Introduction

Rice (*Oryza sativa* L.) is the primary staple food for more than half of the global population and plays a vital role in global food security, especially in Asia, where nearly 90% of the world's rice is produced and consumed (FAO, 2023). India ranks second among rice-producing nations, contributing significantly to both national and global food supply (Government of India, 2022). The rice–rice cropping system is widely practiced in irrigated regions of southern and eastern India to maintain a continuous grain supply. However, its sustainability is increasingly constrained by rising input costs, labour scarcity, declining productivity, and water shortages (Ladha *et al.*, 2015; Saharawat *et al.*, 2010).

Conventional rice cultivation through normal transplanting (NTP) remains the most prevalent establishment method under irrigated conditions. It ensures uniform crop stands and stable yields but requires high labour and water inputs, accounting for a major share of total cultivation costs (Kumar and Ladha, 2011). To overcome these limitations, mechanical transplanting (MTR) using mat-type nurseries has emerged as an effective alternative to reduce labour dependence and improve operational timeliness while maintaining comparable yields (Mahajan and Chauhan, 2011).

Wet direct-seeded rice (DSR) offers another promising establishment method by eliminating nursery raising and puddling, thereby reducing water and labour use and shortening crop duration (Haefele *et al.*, 2016; Ladha *et al.,* 2015**).** Studies have demonstrated that DSR can achieve yields similar to transplanted rice while lowering production costs and improving resource-use efficiency (Dey *et al.*, 2025). However, challenges such as uneven crop stands, increased weed pressure, and variable nutrient dynamics necessitate location-specific assessments before large-scale adoption (Mishra, 2017).

Nitrogen (N) management plays a pivotal role in enhancing rice productivity and profitability (Cassman *et al*., 2002; Majumdar *et al*., 2013). Conventional nitrogen application practices are often inefficient, leading to substantial N losses through volatilization, leaching, and denitrification. The Leaf Colour Chart (LCC) developed by the International Rice Research Institute (IRRI, 2009) has proven effective for real-time nitrogen management by synchronizing N application with crop demand, thereby improving nitrogen-use efficiency **(**Singh *et al.,* 2012**).** Recently, innovations such as nano urea foliar sprays and coated or controlled-release urea formulations have gained attention for their potential to enhance nutrient uptake and reduce environmental losses **(**Azeem *et al.,* 2014**).**

Therefore, the present study was conducted to evaluate the effects of different crop establishment methods (normal transplanting, mechanical transplanting, and wet direct seeding) and nitrogen management strategies (recommended dose, LCC-based management, nano urea substitution, coated urea, and control) on grain yield and profitability of rice–rice systems under irrigated conditions at the Indian Institute of Rice Research, Rajendranagar, Telangana. The findings aim to provide scientific evidence to support sustainable and economically viable rice-based cropping systems in irrigated agroecosystems.

Materials and Methods

Experimental Site and Soil Characteristics

The field experiment was carried out during the kharif seasons of 2023 and rabi season of 2023–24 at the Agronomy Research Farm, ICAR–Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telangana, India (17.32° N, 78.38° E; 542 m above mean sea level). The experimental site represents the semi-arid tropical climate with hot summers, mild winters, and an average annual rainfall of about 850 mm, the majority received through the southwest monsoon. The soil at the site was clay loam, slightly alkaline (pH 7.8–7.9), low in organic carbon and available nitrogen, medium in available phosphorus, and high in available potassium, typical of intensively cultivated irrigated ecosystems.

Weather conditions during the crop growth period

During kharif 2023, the crop experienced mean weekly maximum and minimum temperatures of 27.7–33.2°C and 16.1–23.7°C, respectively, with about 330 mm of irregularly distributed rainfall. Limited rainy days and low sunshine (1.0–8.9 h day^{-1}) led to intermittent moisture stress and reduced photosynthetic activity, particularly during crop establishment and tillering. Relative humidity ranged between 55.3% and 86.2%, while wind speed and evaporation varied from 2.5–7.7 km h^{-1} and 2.8–5.1 mm day^{-1}, respectively. In rabi 2023-24, weather conditions were hotter and drier, with maximum and minimum temperatures of 30.6–41.9°C and 15.3–26.8°C, relative humidity between 44.1% and 64.9%, and only a few light showers. Sunshine hours remained high (5.1–10.3 h day^{-1}), accompanied by strong winds (3.4–9.6 km h^{-1}) and higher evaporation (4.1–8.5 mm day^{-1}). Overall, kharif 2023 was humid with erratic rainfall and poor sunshine, whereas rabi 2024 was hot, dry, and characterized by high evaporative demand.

Experimental Design and Treatments

The trial was laid out in a split-plot design with three replications, with establishment methods assigned to main plots and nitrogen management practices to subplots. The main plot factor included three establishment methods: M_1–normal transplanting (NTP), M_2–mechanical transplanting (MTP), and M_3 – wet direct-seeded rice (WDSR). The subplot factor comprised five nitrogen management practices: S_1 – 100% recommended dose of nitrogen (RDN, 120 kg N ha^{-1} in three splits), S_2–real-time N management based on Leaf Color Chart (LCC), S_3–75% RDN applied basally with nano urea sprays (4 mL L^{-1}) at active tillering, panicle initiation and flowering, S_4–100% RDN applied through hydrophobic silicon-coated slow-release urea, and S_5–control (no nitrogen application). Phosphorus at 60 kg P_2O_5 ha^{-1}, potassium at 40 kg K_2O ha^{-1}, and farmyard manure at 10 t ha^{-1} were applied uniformly across treatments.

Crop Establishment and Management

The medium-duration rice variety DRR Dhan 55 (≈125 days) was used for all seasons. For normal transplanting, seedlings were raised in conventional nurseries, while mat-type nurseries were prepared for mechanical transplanting. In WDSR plots, pre-germinated seeds were sown directly after puddling. The gross plot size was 5.8 m × 6.4 m, and spacing was maintained at 20 × 10 cm for NTP and WDSR, and 23.5 × 15 cm for MTP. All recommended agronomic practices were followed for irrigation, weed management, and plant protection, ensuring uniform management across treatments.

Data Collection

Data were recorded on yield attributes (effective tillers m^{-2}, panicle weight, filled grains $panicle^{-1}$, and test weight), and yield (grain and straw yield in kg ha^{-1}). Economic parameters included cost of cultivation, gross returns, net returns, and benefit–cost ratio (B:C). Costs were computed based on prevailing prices of inputs and labour, while returns were estimated using market prices of grain and straw.

Statistical Analysis

All recorded data were subjected to analysis of variance (ANOVA) appropriate for the split-plot design as described by Gomez and Gomez (1984). Treatment means were compared using the critical difference (CD) at 5% probability, and the standard error of mean (SEm) was computed. Seasonal and pooled analyses were carried out to assess both temporal variability and overall treatment performance.

Results and Discussion

Yield Components

Panicle Weight

Panicle weight differed significantly (p = 0.05) among establishment and nitrogen management practices. Both wet direct-seeded rice (M_3) and mechanical transplanting (M_2) recorded heavier panicles than normal transplanting (M_1) (Table 1). The higher panicle weight in these systems may be attributed to better crop establishment, efficient tiller survival, and improved nutrient uptake under reduced transplanting shock and enhanced soil aeration. Similar findings were reported by Liang *et al.* (2023), who observed that mechanical transplanting and direct seeding improved panicle development due to better canopy structure and source–sink balance.

Among nitrogen management practices, slow-release urea (S_4) and LCC-based management (S_2) resulted in the highest panicle weights across both seasons. These treatments likely ensured sustained N availability during panicle initiation and grain-filling stages, leading to better assimilate translocation to developing grains. Comparable results were reported by Yang *et al.* (2020), who demonstrated that gradual nitrogen supply enhances panicle mass and grain filling efficiency in rice. Conversely, the control (S_5) recorded the lowest panicle weight, reflecting limited assimilate availability under N deficiency (Hussain *et al.* 2023).

Table 1 : Panicle weight, filled grains per panicle, productive tillers of rice-rice system as influenced by establishment methods and nitrogen management practices

Treatments	Panicle weight (g)		Filled grains per panicle		Productive tillers (m^{-2})	
	Kharif 2023	*Rabi* 2024	*Kharif* 2023	*Rabi* 2024	*Kharif* 2023	*Rabi* 2024
Establishment methods (M)						
M_1 - Normal transplanting	3.34	3.68	136	138	432	445
M_2 - Mechanical transplanting	4.13	4.45	151	154	475	489
M_3 - Wet direct seeded rice	4.20	4.48	155	158	477	496
SEm ±	0.12	0.08	2.64	3.12	9.91	9.85
CD (P = 0.05)	0.48	0.31	10.38	12.25	38.89	38.68
Nitrogen management practices (S)						
S_1 – 100 % RDN	4.03	4.35	159	162	503	516
S_2 – LCC based N management	4.46	4.82	174	177	534	552
S_3 – 75 % RDN as basal + nano urea spray @ 4ml L^{-1} at active tillering, panicle initiation and flowering stages	4.00	4.32	155	158	498	514
S_4 – 100 % RDN through slow-release urea (Hydrophobic silicon coated urea)	4.59	4.84	178	180	535	553
S_5 – Control	2.37	2.69	71	74	236	248

SEm ±	0.12	0.13	4.34	4.52	9.02	10.27
CD (P = 0.05)	0.36	0.39	12.66	13.20	26.33	29.99
Interaction						
M at S						
SEm ±	0.21	0.23	7.51	7.83	15.62	17.80
CD (P = 0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
S at M						
SEm ±	0.26	0.19	6.26	7.15	17.13	18.72
CD (P = 0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Filled Grains per Panicle

The number of filled grains per panicle also varied significantly (p = 0.05) among treatments. Wet DSR (M_3) and mechanical transplanting (M_2) produced a greater number of filled grains than normal transplanting (M_1) (Table 1), which may be linked to enhanced pollination success and reduced spikelet sterility under better crop vigor. Liang *et al.* (2023) reported that improved plant architecture in mechanized and direct-seeded systems promotes higher spikelet fertility.

Nitrogen management further influenced this trait: S_4 and S_2 yielded significantly more filled grains per panicle, indicating that a continuous or real-time N supply supports panicle differentiation and grain filling. Adequate N availability during booting and flowering enhances carbohydrate accumulation in panicles, which directly contributes to grain filling (Yang *et al.* 2020). The lowest number of filled grains occurred under S_5, confirming the adverse impact of N omission on spikelet fertility and sink development (Hussain *et al.,* 2023).

Productive Tillers per m²

Productive tillers per unit area increased markedly under M_3 and M_2 compared with M_1 (p = 0.05). Enhanced root proliferation, better nutrient capture, and uniform crop stand establishment likely contributed to the higher tiller density in DSR and mechanically transplanted plots. Liang *et al.* (2023) also found that mechanized planting improves tiller emergence due to optimum plant spacing and less mechanical stress on seedlings.

Among nitrogen practices, S_4 and S_2 maintained the highest number of productive tillers, suggesting that controlled or synchronized N release supported sustained tiller emergence and survival throughout vegetative growth. Yang *et al.* (2020) and Liu *et al.* (2025) emphasized that continuous N supply during early tillering enhances panicle-bearing tiller formation and maintains leaf photosynthetic activity. In contrast, the N-omission control showed sparse tiller production and poor stand vigor, corroborating the essential role of nitrogen in tiller initiation (Hussain *et al.,* 2023).

Grain and Straw Yield

Grain and straw yields of rice were significantly influenced by both establishment methods and nitrogen management practices (p = 0.05). Among the establishment methods, wet direct-seeded rice (M_3) and mechanical transplanting (M_2) produced significantly higher grain yields than normal transplanting (M_1) in both *kharif* 2023 and *rabi* 2024 seasons (Table 2). The improved performance of M_3 and M_2 can be attributed to better stand establishment, reduced transplanting shock, and enhanced root activity that facilitated superior nutrient uptake and photosynthate accumulation. These physiological advantages promote higher panicle initiation and grain formation, leading to improved yields. Similar results were reported by Mahajan and Chauhan (2011) and Kumar and Ladha (2011), who observed that mechanical transplanting and direct seeding promote timely crop establishment and improve yield through enhanced nutrient use efficiency. Liang *et al.* (2023) also demonstrated that mechanized transplanting and wet DSR systems enhance canopy light interception and optimize tiller dynamics, resulting in improved grain productivity.

Straw yield followed a similar pattern to grain yield, with DSR and mechanical transplanting recording significantly higher straw production than normal transplanting. The greater straw biomass reflects vigorous vegetative growth, improved tiller survival, and enhanced photosynthetic area maintenance throughout the crop duration. Ladha *et al.* (2015) emphasized that enhanced root development and greater resource-use efficiency under improved establishment systems contribute to higher total biomass and straw yield. Similarly, Haefele *et al.* (2016) found that well-managed DSR systems produced comparable or higher biomass than conventional transplanting due to better root–shoot balance and reduced transplanting stress.

Among nitrogen management practices, slow-release urea (S_4) and LCC-based nitrogen management (S_2) consistently produced the highest grain and straw yields during both seasons. These results indicate that a gradual and synchronized nitrogen release, or application guided by crop demand, effectively sustains N availability throughout vegetative and reproductive stages. Controlled-release fertilizers minimize volatilization and leaching losses, ensuring a continuous nutrient supply and promoting steady growth and grain filling (Azeem *et al.*, 2014; Tao *et al.*, 2024). Similarly, Singh *et al.* (2012) and IRRI (2009) confirmed that LCC-based nitrogen management significantly enhances yield by improving nitrogen-use efficiency and synchronizing N supply with plant demand.

The beneficial effects of slow-release and real-time N management are consistent with findings of Yang *et al.* (2020), who reported that controlled N availability promotes efficient assimilate partitioning to reproductive organs and improves harvest index. Liu *et al.* (2025) conducted a meta-analysis across multiple rice systems and showed that optimized N management practices increase yield by 5–10% and N-use efficiency by 17–21%, supporting the yield advantage observed under S_2 and S_4 in this study.

Table 2 : Grain yield (kg ha^{-1}) and straw yield (kg ha^{-1}) of rice-rice system as influenced by establishment methods and nitrogen management practices

Treatments	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})	
	Kharif	***Rabi***	***Kharif***	***Rabi***
	2023	**2024**	**2023**	**2024**
Establishment methods (M)				
M_1 - Normal transplanting	5350	5617	6596	6807
M_2 - Mechanical transplanting	5998	6375	7065	7317
M_3 - Wet direct seeded rice	6091	6505	7137	7382
SEm ±	135.37	130.26	107.43	123.66
CD (P = 0.05)	531.52	511.45	421.81	485.55
Nitrogen management practices (S)				
S_1 – 100 % RDN	6311	6644	7627	7844
S_2 – LCC based N management	6933	7359	8072	8321
S_3 – 75 % RDN as basal + nano urea spray @ 4ml L^{-1} at active tillering, panicle initiation and flowering stages	6213	6528	7596	7830
S_4 – 100 % RDN through slow-release urea (Hydrophobic silicon coated urea)	7053	7439	8114	8333
S_5 – Control	2554	2858	3254	3517
SEm ±	169.37	201.66	137.42	145.16
CD (P = 0.05)	494.34	588.60	401.11	423.69
Interaction				
M at S				
SEm ±	293.35	349.29	238.03	251.42
CD (P = 0.05)	**NS**	**NS**	**NS**	**NS**
S at M				
SEm ±	295.24	338.48	238.47	256.64
CD (P = 0.05)	**NS**	**NS**	**NS**	**NS**

Table 3 : Gross returns (≠ ha^{-1}), net returns (≠ ha^{-1}) and B:C of rice- rice system as influenced by establishment methods and nitrogen management practices

Treatment details	Gross returns (≠ ha^{-1})		Net returns (≠ ha^{-1})		B:C ratio	
	Kharif	***Rabi***	***Kharif***	***Rabi***	***Kharif***	***Rabi***
	2023	**2024**	**2023**	**2024**	**2023**	**2024**
Establishment methods (M)						
M_1 - Normal transplanting	126675	132827	68850	73603	2.18	2.23
M_2 - Mechanical transplanting	141538	150140	85714	92916	2.52	2.61
M_3 - Wet direct seeded rice	143665	153081	88041	95757	2.57	2.66
SEm ±	2099.86	2075.74	2099.86	2075.74	0.04	0.04
CD (P = 0.05)	8245.08	8150.38	8245.08	8150.37	0.15	0.16

Nitrogen management practices (S)						
S_1 – 100 % RDN	149200	156797	93188	99284	2.67	2.73
S_2 – LCC based N management	163463	173136	106986	115158	2.90	2.99
S_3 – 75 % RDN as basal + nano urea spray @ 4ml L^{-1} at active tillering, panicle initiation and flowering stages	147027	154260	87906	93639	2.49	2.55
S_4 – 100 % RDN through slow-release urea (Hydrophobic silicon coated urea)	166143	174885	109479	116721	2.94	3.01
S_5 – Control	60630	67670	6783	12323	1.13	1.22
SEm ±	2674.71	3476.51	2674.71	3476.51	0.05	0.06
CD (P = 0.05)	7806.93	10147.21	7806.93	10147.21	0.14	0.18
Interaction						
M at S						
SEm ±	4632.74	6021.49	4632.74	6021.49	0.08	0.10
CD (P = 0.05)	NS	NS	NS	NS	**NS**	**NS**
S at M						
SEm ±	4645.34	5771.95	4645.34	5771.95	0.08	0.10
CD (P = 0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

In contrast, the control treatment (S_5) recorded the lowest grain and straw yields in both seasons, highlighting the crucial role of nitrogen in rice productivity. Nitrogen deficiency restricts tiller formation, reduces leaf chlorophyll concentration, and limits carbohydrate translocation to grains, leading to smaller panicles and poor grain filling (Cassman *et al.*, 2002; Majumdar *et al.*, 2013; Hussain *et al.*, 2023).

No significant interaction (M × S) was observed, indicating that the effects of establishment method and nitrogen management were additive rather than synergistic. This suggests that the benefits of improved nitrogen strategies are consistent across establishment systems.

Overall, the results indicate that wet direct-seeded rice or mechanical transplanting, in combination with LCC-based or slow-release nitrogen management, is most effective in enhancing both grain and straw yields in irrigated rice–rice systems. These findings are in close agreement with previous studies demonstrating that integrating improved establishment methods with precision N management enhances productivity, profitability, and resource-use efficiency (Saharawat *et al.*, 2010; Ladha *et al.*, 2015; Haefele *et al.*, 2016).

Economic Returns

Gross Returns

Gross returns were significantly affected by both crop establishment and nitrogen management practices (p = 0.05). Among establishment methods, wet direct-seeded rice (M_3) and mechanical transplanting (M_2) recorded markedly higher gross returns in both *kharif* 2023 and *rabi* 2024 compared to normal transplanting (M_1). The higher returns under M_3 and M_2 are primarily attributable to superior grain yield coupled with lower operational and labour costs. These results align with those of Mubarak *et al.* (2025), who demonstrated that DSR consistently achieves higher gross margins than conventional transplanting when irrigation and weed management are optimized. Similarly, Liang *et al.* (2023) found that mechanized planting reduces drudgery and labour dependency while maintaining yield stability, thereby improving overall revenue generation.

Net Returns

Net returns followed a similar pattern, with M_3 producing the highest profitability, followed closely by M_2. The improved economic performance under these methods stems from reduced input use (especially water, seed, and labour) and timely crop establishment, which collectively enhance system productivity. These findings agree with the results of Haefele *et al.* (2016), who reported that well-managed direct-seeded rice can reduce production costs by 15–25 % relative to conventional transplanting. The reduction in puddling and transplanting operations also contributes to energy savings, further strengthening the cost advantage (Ladha *et al.*, 2015).

Across nitrogen management practices, both slow-release urea (S_4) and LCC-based N management (S_2) yielded the highest net returns in both seasons. These treatments enhanced yield without a proportional rise in fertilizer or labour costs. Controlled-release urea reduced application frequency and nitrogen losses, resulting in improved nutrient-use efficiency and profitability (Tao *et al.*, 2024; Azeem *et al.*, 2014). Likewise, real-time N application guided by the Leaf Colour Chart (LCC) minimized excess fertilizer use while maintaining optimum N availability, thereby lowering input expenditure (IRRI, 2009; Singh *et al.*, 2012).

Benefit–Cost Ratio (B:C Ratio)

The B:C ratio also differed significantly among treatments (p = 0.05). Wet DSR (M_3) and mechanical transplanting (M_2) achieved higher B:C ratios than normal transplanting, confirming their superior cost efficiency and economic viability. DSR, in particular, demonstrated the highest profitability due to savings in labour, water, and fuel, along with reduced turnaround time between crops. Mubarak *et al.* (2025) and Liang *et al.* (2023) similarly highlighted the economic feasibility of DSR and mechanized planting systems under intensive rice production environments.

Among N treatments, S_4 and S_2 produced the maximum B:C ratios (≈ 3.0), reflecting improved input-use efficiency and higher net profit margins. The gradual nutrient release from coated urea and the timely application of N under LCC-based management both contributed to efficient resource use and higher economic returns (Yang *et al.*, 2020; Liu *et al.*, 2025). The control treatment (S_5), lacking N supplementation, consistently recorded the lowest returns and B:C ratio, illustrating the critical role of nitrogen in maintaining profitability (Cassman *et al.*, 2002; Hussain *et al.*, 2023).

Conclusion

The study revealed that both crop establishment methods and nitrogen management practices significantly influenced the productivity and profitability of irrigated rice–rice systems. Among establishment methods, wet direct-seeded rice (DSR) and mechanical transplanting produced higher yields and economic returns than conventional transplanting due to improved stand establishment, root activity, and reduced labour cost.

Among nitrogen strategies, slow-release urea and Leaf Colour Chart (LCC)-based management enhanced yield attributes, grain and straw yields, and profitability by ensuring better nitrogen availability and use efficiency. The absence of significant interaction between factors indicates that their effects were independently beneficial.

Overall, integrating labour-saving establishment methods with precision nitrogen management offers a viable approach for improving yield stability, profitability, and resource-use efficiency, contributing to the sustainable intensification of irrigated rice systems.

Acknowledgement

The author expresses sincere gratitude to the Major Advisor, Co-advisor, and Advisory Committee members of the research programme at the ICAR–Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad, for their constant guidance, constructive suggestions, and encouragement throughout the course of the investigation and preparation of the manuscript. The author also acknowledges the technical staff and field assistants of the Crop Production Division, ICAR–IIRR, for their valuable help during field experimentation and data collection.

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