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Evaluation of different nitrogen management protocols for yield, nutrient uptake and economics under various establishment methods in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system under Trans-Gangetic Plains of India

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ABSTRACT

The study was carried out during 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi to investigate the effects of precision nitrogen (N) management, including nano-urea under various crop establishment approaches on productivity and N uptake in rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.). The experiment was laid out in split-plot design (SPD) with three replications. The treatments involved 3 main-plots with establishment M_1, Vattar direct-seeded rice (VDSR) followed by conventional till-wheat (CTW) + rice residue at 3 t/ha; M_2, Dry direct seeded rice (DDSR) followed by zero till-wheat (ZTW) + rice residue at 3 t/ha; and M_3, Puddled transplanted rice (PTR) followed by CTW without residue and five sub-plots with variable N management practices [N_0, No N; N_1, Modified N application (No Basal + 3 Split N (33% each @15–20; 40–45 and 60–65 DAT/DAS); N_2, LCC-guided N application at LCC (≤3) for rice @30 kg/ha from 15–65 DAS and in wheat N use at LCC (≤4) @40 kg/ha from 20–65 DAS; N_3, 25% N as Basal + 25% N at 30 DAS/DAT + 2 Nano-urea sprays at maximum tillering (MT) and panicle initiation (PI) in rice and in wheat 25% N as Basal + 25% N at 30 DAS + 2 Nano-urea sprays at MT and peak flowering (PF); N_4, 25% N as Basal + 25% N at 25 DAS/DAT + 25% N at 40 DAS/DAT + 2 Nano-urea sprays @ MT and PI in rice and in wheat 25% N as Basal + 25% N at 25 DAS/DAT + 25% N at 45 DAS/DAT + 2 Nano-urea sprays @MT and PF].The study showed that leaf colour chart (LCC)-guided balanced N application led to higher grain yield and N uptake in all establishment techniques for both rice and wheat. It was followed by 3 split applications of N (farmer's practice), which remained on par with 75% N in splits + 2 nano-urea sprays. The highest rice grain yield and N uptake were recorded under PTR during both years. In the first year, rice grain yield and N uptake in PTR were 4.5 t/ha and 109.3 kg/ha, respectively which remained statistically on par with VDSR (4.3 t/ha and 103.1 kg/ha, respectively). It was followed by DDSR with grain yield and N uptake of 4.05 t/ha and 90.7 kg/ha, respectively. The rice grain yield obtained under PTR was 4.6 t/ha, which was 5.6% and 11.1% higher than VDSR and DDSR, respectively. However, this increase was 8.1% and 17.7% for N uptake in TPR over VDSR and DDSR. In the first year of the experiment, the highest wheat grain yield and N uptake were recorded with ZTW + rice residue @3 t/ha (4.5 t/ha and 131.9 kg/ha), respectively which was found on par with CTW + rice residue @3 t/ha (4.4 t/ha and 125.4 kg/ha). It was followed by CTW without residue (4.2 t/ha and 115.3 kg/ha, respectively) and a similar trend was observed in the second year also. A respective increase of 8.1% and 5.3% in wheat grain yield and 13.1% and 9.1% in N uptake was recorded under ZTW + rice residue and CTW + rice residue over CTW without residue.

Keywords: Direct-seeded rice, Leaf colour chart, Precision nutrient management

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system (RWS) is the major cereal production system which spans around 24 million hectares in the Asian sub-tropics. Nearly14 million hectares of it remains in Indo-Gangetic Plains of South Asia, 11 million hectares of which lies in India alone (Alam *et al.* 2016). This system is predominantly followed in the states of Punjab, Haryana, Bihar, Uttar Pradesh and Madhya Pradesh contributing around 75% of the national food grain production. The RWS plays a crucial role, accounting for about 32% and 42% of the total rice and wheat cultivation areas, respectively (Memom *et al.* 2018). Approximately 58% of the total agricultural land and 77% of the food grain production in the country is dedicated to these two crops. Besides, India also exports rice (both basmati and non-basmati) to other countries, the exports being up to 22 Mt for rice and 2.5 Mt wheat in 2022 (Kaur *et al.* 2022). This is an essential and potential system contributing towards the national food security and farmer's income. However, several concerns have been raised about the sustainability

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of RWS, viz. yield stagnation, extensive tillage, residue removal/burning, imbalanced fertilizer use and poor crop management practices, etc. (Saurabh *et al.* 2021). The faulty practices in field preparation, nutrient and water management have resulted in soil compaction, decreased soil organic carbon, loss of soil nutrients, reduced soil resilience and compromised ecosystem services (Babu *et al.* 2020). These challenges with PTR under non-traditional rice growing areas suggest that the use of traditional farming methods is no longer sufficient to sustain productivity of RWS as it demands significant labour, water, and energy inputs. Thus, a paradigm shift is necessary to improve the system's productivity and sustainability.

Dry direct-seeded rice (DDSR) offers advantages like efficient water usage, mechanization suitability, and higher net economic returns over PTR. Additionally, DDSR may enhance yield, quality, stand establishment, and maturity timing (Ishfaq *et al.* 2018), especially when followed by ZTW. The ZTW along with residue retention is a widely embraced agricultural approach aiming to address climate change and soil organic carbon sequestration (Das *et al.* 2022). Thus, the alternate establishment methods such as DDSR and ZTW along with residue retention offer a potential solution for enhancing input use efficiency, saving important resources like water and labour with more ecosystem services.

Over the past few years these techniques have been in practice, but the other agronomic interventions like real-time N management, synchronous N supply as per the plant demand, alternative N fertilizer sources and the pattern of N uptake in response to the supply need to be standardized. We hypothesize that converting PTR-CTW to DDSR-ZTW and applying nutrients on a site-specific basis using the LCC with the inclusion of Nano-urea may improve productivity, N uptake and use efficiency of RWS.

MATERIALS AND METHODS

The study was carried out during 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi. The mean highest temperature in *kharif* 2022 and 2023 was 33.1°C and 31.3°C, respectively. However, it was 27°C and 28.2°C, respectively during winter (*rabi)* 2022–23 and 2023–24. The sunshine hours during both the years remained 5.91 and 5.35, respectively. The maximum relative humidity was 76.6% and 81.2% during the two respective crop cycles. The total rainfall in both the years 2022 and 2023 was 1,051 mm and 1,201 mm, respectively.

The experimental soil was clayey-loam in texture and the physico-chemical properties included soil *p*H of 8.01, low organic carbon (0.35%) and available N (274.3 kg/ha), but had medium available P_2O_5 (25.3 kg/ha) and high available K_2O (456.5 kg/ha). The experiment was laid out in split-plot design (SPD) with three replications. The treatments involved 3 main-plots with establishment options and five sub-plots with variable N management practices. The establishment methods in rice and wheat were, M_1, Vattar direct-seeded rice (VDSR) followed by conventional till-wheat (CTW) + rice residue at 3 t/ha; M_2, Dry direct seeded rice (DDSR) followed by zero till-wheat (ZTW) + rice residue at 3 t/ha; and M_3, Puddled transplanted rice (PTR) followed by CTW without residue. The N management treatments remained similar in both rice and wheat, viz. N_0, No N; N_1, Modified N application (No Basal + 3 Split N (33% each @15–20, 40-45 and 60–65 DAT/DAS); N_2, LCC-guided N application at LCC (≤3) for rice @30 kg/ha from 15–65 DAS and in wheat N use at LCC (≤4) @40 kg/ha from 20–65 DAS; N_3, 25% N as Basal + 25% N at 30 DAS/DAT + 2 Nano-urea sprays at maximum tillering (MT) and panicle initiation (PI) in rice and in wheat 25% N as Basal + 25% N at 30 DAS + 2 Nano-urea sprays at MT and peak flowering (PF); N_4, 25% N as Basal + 25% N at 25 DAS/DAT + 25% N at 40 DAS/DAT + 2 Nano-urea sprays @MT and PI in rice and in wheat 25% N as Basal + 25% N at 25 DAS/DAT + 25% N at 45 DAS/DAT + 2 Nano-urea sprays @MT and PF. Nano-urea (2%) formulation of the commercial product obtained from IFFCO was used in the experiment.

In VDSR, pre-sowing irrigation was given and weeds were allowed to grow and then incorporated through tillage before direct sowing. In DDSR, sowing was done followed by irrigation. Under PTR, conventional puddling was carried out followed by transplanting seedlings. Under CTW, the land was prepared by using a cultivator and a rotavator to bring the soil into good tilth. Under (ZTW) no land preparation was done. For VDSR and DDSR plots in rice and CTW and ZTW plots in wheat, sowing was done by using a 9-tyne zero-till drill.

The N fertilizers were applied as per schedule in LCC plots, the application varied depending on the response of the crop. The full doses of phosphorus (P) and potassium (K) were applied as basal as per the RDF (Rice: 120:60:60 and wheat 150:80:60 (NPK). The source of NPK was urea, single super phosphate and muriate of potash, respectively. In rice, pre-emergence application of pendimethalin at 1 kg ai/ha was sprayed in VDSR and DDSR plots, whereas in PTR butachlor 1kg ai/ha was applied after 2-3 DAT. After 20-25 DAS, bispyribac sodium @25 g ai/ha was applied in all 3 establishment methods in rice. Likewise, the ready-mix herbicide (sulfosulfuron 75% + metsulfuron 5% WG; 40 g/ha commercial product) was applied after 30-35 DAS of wheat. Irrigation in VDSR and DDSR plots was given when there was a hairline crack in the soil and in PTR it was ponded. Concerning wheat, the irrigation was given at critical irrigation periods depending on climatic data.

$$\text{Nitrogen uptake in grain (kg/ha)} = \text{N content in grain (\%)} \times \text{Grain yield (kg/ha)} \times 10^{-2}$$

$$\text{Nitrogen uptake in straw (kg/ha)} = \text{N content in straw (\%)} \times \text{Yield (kg/ha)} \times 10^{-2}$$

$$\text{Total nitrogen uptake (kg/ha)} = \text{Uptake in grain (kg/ha)} + \text{Uptake in straw (kg/ha)}$$

Statistical analysis: The technique of analysis of variance was used for statistical analysis and conclusion. At probability levels of 0.05, the Fisher-Snedecorst "F" test error mean square was utilized to evaluate the importance of various causes of variation (Cochran and Cox 1955). The Fisher and Yates table was used to compare 'F' tables and compute important differences.

RESULTS AND DISCUSSION

Grain and straw yield of rice and wheat: The establishment methods have a significant impact on grain yield and straw yield of both rice and wheat during both consecutive years i.e. 2022–23 and 2023–24. In the first year, the highest rice grain yield was recorded in PTR (M_3; 4.52 t/ha), which was statistically on par with VDSR (M_1; 4.30 t/ha) and it was followed by DDSR (M_3; 4.05 t/ha) and the similar trend was seen in the second year with higher rice grain yield in M_3 (4.58 t/ha), which remained on par with M_1 (4.34t/ha) and followed by M_2 (4.09 t/ha) (Table 1). The maximum average rice grain yield (4.55 t/ha) was obtained under PTR which was 10.5% higher than DDSR. During the first year of wheat, the ZTW + rice residue @3 t/ha (M_2) recorded the highest grain yield (4.51 t/ha) and it remained on par with CTW + rice residue @3 t/ha (M_1, 4.40 t/ha), followed by CT-wheat without residue M_3 (4.22 t/ha). A similar trend was seen in the second year with higher grain yield in M_2 (4.64 t/ha) which was on par with M_1 (4.50 t/ha), followed by M_3 (4.26 t/ha).The highest average wheat grain yield 4.57 t/ha was observed under ZTW + R which was 7.33% higher than CTW-R. The higher grain yield received in PTR was possibly due to the selection of healthy seedlings for initial establishment; whereas DSR faced difficulty in initial establishment due to weed competition, bird damage, poor soil-seed contact under VDSR and DDSR (Mondal *et al.* 2016). Also, wheat grown under ZT has an added advantage over CT due to a higher infiltration rate and more soil organic carbon. Furthermore, crop residue retention in no-till soils with higher C and K substrates promotes microbial development and increases soil microbial biomass and activity than CT which indirectly enhances the yield of both rice and wheat (Singh *et al.* 2013).

For nutrient management options, N_2 where LCC-based N application was carried out recorded higher grain yield in rice (5.14 t/ha and 5.17 t/ha) in 2022 and 2023 respectively, followed by N_1 (3 splits i.e. farmers practice) with grain yield of (4.63 t/ha and 4.78 t/ha) in both years and it remained on par with N_4 (75%N in 3 splits, followed by 2 Nano-urea sprays) with the grain yield of (4.43 t/ha and 4.54 t/ha) in both the years and which was followed by N_3 (50% N in 3 splits, followed by 2 Nano-urea sprays) with grain yield of (4.11 t/ha and 4.17 t/ha) in both the years. A similar response was recorded in the wheat grain yield, where N_2 (LCC) outperformed all other N treatments with grain yield of (5.16 t/ha and 5.40 t/ha during 2022–23 and 2023–24, respectively). It was followed by N_1 (3 splits i.e. farmers practice) with grain yield of 4.57 t/ha and 4.75 t/ha during both years and remained on par with N_4 (75%N as 3 splits, followed by 2 Nano-urea sprays) with grain yield of (4.51 t/ha and 4.61 t/ha) in both the years. It was followed by N_3 (50% N as 3 splits, followed by 2 Nano-urea sprays) with grain yield of 4.28 t/ha and 4.30 t/ha in both years. Rice and wheat grain yield under LCC-guided N application remained at 40.1% and 37.2%, respectively higher compared to No N application and 7.1% and 11.7%, respectively higher over farmer's practice. The real-time and optimum N dose application under LCC-guided stewardship allowed the crop to utilize more N efficiently than the conventional application (Singh *et al.* 2014). N application in 3 splits as farmers practice was comparable to N_4 with 3 splits of N at a low dose and two additional Nano-urea sprays. Nano-urea sprays have been found to be more efficient than traditional urea in terms of absorption, translocation and metabolism resulted in higher yield in N_4, although N_1 remained on par with it. Since Nano-urea is having higher specific surface area to volume ratio, the N use efficiency goes as high as 80% which increased yield in N_4, despite 25% reduction in conventional N. Similar results have been reported by (Singh *et al.* 2023 Bhargavi and Sundari 2023).

Nitrogen uptake in rice and wheat: The highest N uptake in rice main plots was seen in M_3 (109.2 kg/ha) which remained on par with M_1 (103.0 kg/ha) and it was followed by M_2. A similar trend was seen in the second season, viz. the highest N uptake was seen with M_3 (111.0 kg/ha) which was on par with M_1 (102.0 kg/ha), followed by M_2 (Fig. 1). In wheat, the highest N uptake was recorded with M_2 (132.0 kg/ha) which remained on par with M_1 (128.0 kg/ha), followed by M_3 and a similar trend was observed in the second season, viz. the highest N uptake was seen with M_2 (137.0 kg/ha) which remained on par with M_1 (131.0 kg/ha) and followed by M_3. Since the grain yield, straw yield and nutrient content in M_3 were higher in rice, the total uptake was also higher in M_3 (PTR). However, in wheat due to higher grain yield, straw yield and nutrient content in M_2 resulted in higher N uptake in M_2. Higher yields and nutrient uptake in wheat under zero till and residue management have been reported by Midya *et al.* 2021.

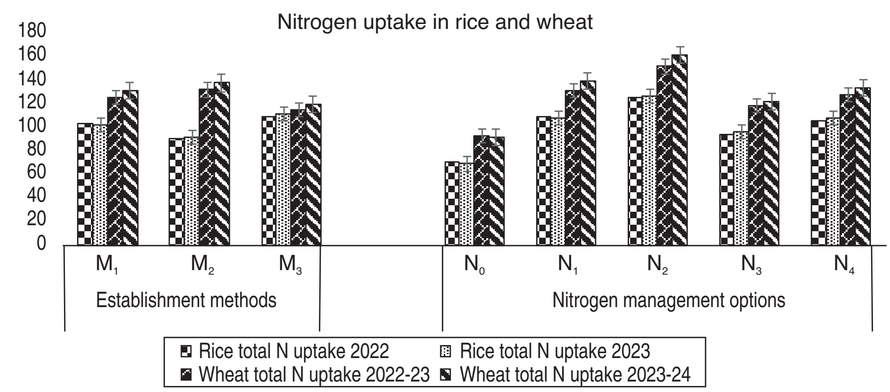

Fig. 1 Nitrogen Uptake as effected by establishment methods and nitrogen management. Treatment details are given under Materials and Methods.

Table 1 Effect of establishment methods and nitrogen management on grain and straw yield of rice and wheat

Treatment	Grain yield (t/ha)				Straw yield (t/ha)			
	Rice		Wheat		Rice		Wheat	
Establishment methods	2022	2023	2022–23	2023–24	2022	2023	2022–23	2023–24
M_1	4.30	4.34	4.40	4.50	7.48	7.23	7.18	7.24
M_2	4.05	4.09	4.51	4.64	6.80	6.71	7.36	7.44
M_3	4.52	4.58	4.22	4.26	7.63	7.55	6.90	6.89
SEm±	0.11	0.12	0.06	0.09	0.18	0.18	0.11	0.13
LSD (*P*=0.05)	0.43	0.45	0.24	0.34	0.72	0.70	0.42	0.50
Nitrogen management								
N_0	3.14	3.03	3.37	3.28	5.24	5.18	5.83	5.90
N_1	4.63	4.78	4.57	4.75	7.81	7.65	7.62	7.58
N_2	5.14	5.17	5.16	5.40	8.41	8.21	7.94	7.98
N_3	4.11	4.17	4.28	4.30	7.35	7.26	7.01	7.05
N_4	4.43	4.54	4.51	4.61	7.72	7.51	7.32	7.44
SEm±	0.10	0.11	0.07	0.09	0.20	0.18	0.11	0.13
LSD(*P*=0.05)	0.30	0.21	0.59	0.32	0.59	0.53	0.32	0.39

Treatment details are given under Materials and Methods.

Among the sub-plots in rice, N_2 with LCC-guided N application showed the highest N uptake (125 and 126 kg/ha) for both the years 2022 and 2023, respectively. It was followed by N_1 (farmers' practice) with N uptake of 109 kg/ha and 108 kg/ha and it remained on par with N_4 with N uptake of 105 kg/ha and 106 kg/ha for both years. In wheat, a similar trend was observed and the highest N uptake was seen with N_2 (151.2 and 161.0 kg/ha for both years, respectively), which was followed by N_1 (farmers' practice) and the N uptake remained 130 and 139 kg/ha. The N uptake under N_1 remained on par with N_4 with 127.4 and 133.1 kg/ha uptake during both the years, respectively, followed by N_3. The higher uptake in LCC-guided plots can be attributed to precise N scheduling as and when needed, which raised growth and yield attributes. This, in turn, raised the N content of rice and straw with a strong source-to-sink relationship that increased total N uptake. Similar results were reported by (Gurupadappa *et al.* 2018, Singh *et al.* 2011).

Economics: Among different establishment technique in rice, a higher cost of cultivation was recorded in PTR plots (₹65.3 × 10^3/ha) due to higher cost incurred for puddling and more water requirement over VDSR and DDSR. However, the higher net returns were recorded

Table 2 Effect of establishment methods and nitrogen management on economics in rice and wheat

Treatment	Economics											
Establishment methods	Rice						Wheat					
	Cost of cultivation (₹ × 10^3/ha)		Net returns (₹ ×10^3/ha)		Net B:C		Cost of cultivation (₹ × 10^3/ha)		Net returns (₹ × 10^3/ha)		Net B:C	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
M_1	54.4	54.4	124.0	124.9	2.27	2.28	50.3	50.3	74.3	81.4	1.47	1.61
M_2	51.8	51.8	115.6	117.0	2.22	2.25	44.3	44.3	83.3	91.4	1.86	2.05
M_3	65.3	65.3	121.6	123.8	1.86	1.89	44.3	44.3	75.2	80.6	1.69	1.81
SEm±	-	-	5.9	6.2	0.10	0.08	-	-	2.3	3.2	0.04	0.05
LSD (*P*=0.05)	-	-	17.7	18.6	0.32	0.33	-	-	6.9	9.8	0.14	0.20
N management												
N_0	55.0	55.0	74.8	70.5	1.37	1.29	43.9	43.9	53.1	55.1	1.22	1.26
N_1	57.3	57.3	134.1	139.5	2.36	2.45	46.6	46.6	83.5	92.2	1.80	1.99
N_2	57.8	57.8	154.4	155.0	2.69	2.70	47.1	47.1	96.5	107.4	2.05	2.28
N_3	57.7	57.7	113.1	115.3	1.98	2.01	46.7	46.7	74.5	79.9	1.59	1.72
N_4	58.0	58.0	125.7	129.3	2.18	2.25	47.2	47.2	80.2	87.9	1.71	1.87
SEm±	-	-	4.3	4.5	0.08	0.07	-	-	1.9	2.5	0.03	0.04
LSD (*P*=0.05)	-	-	12.6	13.2	0.22	0.21	-	-	5.7	7.4	0.10	0.13

Treatment details are given under Materials and Methods.

with VDSR, i.e. ₹124 × 10^3/ha and ₹124.9 × 10^3/ha, during both the years respectively. It was followed by PTR with net returns of ₹121.6 × 10^3/ha and ₹123.8 × 10^3/ha, during both the years. A higher net B-C ratio was seen in VDSR (2.27 and 2.28), followed by DDSR (2.22 and 2.25) for the both years, respectively. Since, the cost of cultivation was lower in DDSR and yield obtained was on par with PTR, hence the net BC ratio was higher as compared to PTR. And among different N management in rice, the higher net returns and B-C ratio was recorded in LCC-guided N application N_2 (₹154.4 × 10^3/ha and 2.69; and ₹155 × 10^3/ha and 2.70, respectively) for both the year. It was followed by N_1 (3 splits i.e. farmers practice) and N_4 (75% N as conventional and 2 Nano-urea sprays). With respect to establishment methods in wheat, the higher cost of cultivation was seen in M_1 (CTW + residue, ₹50.3 × 10^3/ha) due to additional cost for land preparation and residue used as compared to that CTW - R (M_3) and ZTW + R (M_2). The higher net returns and B-C ratio was recorded with ZTW + R (₹83.3 × 10^3 ₹/ha and 1.86) and (₹91.4 × 10^3/ha and 2.05) in both the years 2022–23 and 2023–24 respectively, which was followed by M_1 and M_3. Since, ZTW recorded higher yield and incur less cost, the net returns and B-C ratio was higher as compared to CTW. Among different N management treatments in wheat, the higher net returns and B-C ratio was recorded in LCC-guided N application (N_2) which remained ₹96.5 × 10^3/ha and 2.05) and (₹107.4 × 10^3/ha and 2.28, respectively) for both the years. It was followed by N_1 (3 splits i.e. farmers practice) and N_4 (75% N as splits with 2 Nano-urea sprays). Similar findings were reported with (Mohanta *et al.* 2021, Gurupadappa *et al.* 2018).

The results of the present study indicated that a higher yield, nutrient uptake and economics of rice and wheat can be obtained with VDSR and ZTW + R, respectively. The LCC-guided N management protocol under these establishment methods can enhance yields on a sustainable basis offering a climate-resilient solution for rice-wheat system.

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