Indian Journal of Agricultural Sciences **94** (6): 571–576, June 2024/Article
https://doi.org/10.56093/ijas.v94i6.145304

Precision nitrogen, irrigation and cultivation regimes for enhanced yield, and nutrient accumulation in direct-seeded basmati rice (*Oryza sativa*)

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Received: 15 November 2023; Accepted: 08 March 2024

ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of 2019 and 2020 at ICAR-Indian Agricultural Research Institute, New Delhi to monitor the effect of precision nitrogen (N) and water management options on yield and nutrient acquisition in grain and straw of direct-seeded rice (DSR, basmati) (*Oryza sativa* L.). Experiment was conducted under two cultivation methods, in a triplicate split-plot design (SPD). The main-plots were allocated to 6 combinations of 2 DSR cultivation approaches, viz. growing DSR in ploughed land (CT_{DSR}); and growing DSR without tilling the land (ZT_{DSR}); and 3 water regimes [adequate water; water supply at 20% available soil moisture exhaustion (ASME); and 40% ASME + silicon (Si) supply @80 kg/ha]. Sub-plots had 3 N supply decisions, viz. 100% recommended rate of N (RRN: 150 kg/ha); NutrientExpert (NE) + leaf colour chart (LCC); and NE + soil plant analysis development (SPAD) meter-based N scheduling. Conventional till-direct seeded rice produced 1.9, 3.1 and 5.7% greater grain yield, grain protein content and protein yield, respectively, over ZT_{DSR}; the respective improvement in grain N, P and K uptake was 5.9, 7.9 and 4.9%. Adequate water regime resulted in 11.5, 7.3 and 18.7% more grain yield, grain protein content and protein yield, respectively, over water supply at 20% ASME with concomitant enhancement in grain N, P and K uptake of 19, 24 and 23%, respectively. A significant improvement in grain yield (9.2%), grain protein (11.7%) content and protein yield (22.1%) was detected with NE® + SPAD meter-based N application over RRN; the N, P and K uptake in grain also spiked by 22.1, 42.1 and 31.7%, respectively. Hence, NE + SPAD-based N application and adequate water regime (irrigation at 72 h of drying of surface water) could be beneficial for improving yield and quality of both CA-based and conventionally cultivated DSR.

Keywords: Basmati, Direct-seeded rice, Irrigation regimes, Leaf colour chart, Precision N, SPAD meter, Water

Nitrogen (N) deficiency has been recognized as a significant issue in ensuring food security worldwide (Dass *et al.* 2015). Yield and quality of directed-seeded rice (DSR) (*Oryza sativa* L.) widely cultivated in Asia, are hindered by N-deficiency (Khan *et al.* 2012); also, the availability of P, S, Zn and Fe is limited (Dass *et al.* 2017). Moreover, the process of nitrification and de-nitrification upsurges due to alternating wetting and drying of soil as conditioned by DSR cultivation causing N loss as N_2O (Prasad 2011). Additionally, the DSR crop exhibits a relatively low N uptake under aerobic conditions, leading to a reduced recovery of fertilizer-N. In rice, the efficiency of applied N fluctuates between 30–40% mainly due to lack of synchrony between N supply and crop demand. Out of the 150 kg/ha of applied N, merely one-fourth is taken-up by the crop, with 31% remaining in the soil after the harvest (Beldar *et al.* 2005). To achieve the maximum grain output with enhanced NUE, it is imperative to optimize the N-supply specifically for DSR (Pratap *et al.* 2022), by using modern tools like Nutrient Expert, LCC, GreenSeeker, and SPAD meter. These tools facilitate improved synchronization between N-supply and crop demand, ultimately resulting in higher yields and environmental safety (Pratap *et al.* 2022). Generally, DSR produces lower yield than transplanted rice, due to inadequate plant population, nutrient and water stresses, spikelet sterility, higher incidences of weeds and root-knot nematodes, and have several impacts on subsequent wheat crop (Dass *et al.* 2017a, Pratap *et al.* 2021a, Pratap *et al.* 2021b, Pratap *et al.* 2023).

Water and nitrogen (N) management approaches in DSR system vary significantly with conventional cultivation practices. Nevertheless, there is a scarcity of information regarding the combined and individual impacts of irrigation regimes integrated with stress-tolerance-enhancing chemicals like silicon, N-applications guided by optical sensors, and the implementation of conservation agriculture practices. Therefore, the present study aimed to assess the

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impact of precision-N management strategies on grain yield, nutrient accumulation in grain and straw, grain protein content, and protein yield in conservation agriculture-based DSR (basmati) under varying irrigation regimes.

MATERIALS AND METHODS

Present study was carried out during rainy (*kharif*) seasons of 2019 and 2020 at the ICAR-Indian Agricultural Research Institute (28°38' N, 77°09'E, and 229 m amsl), New Delhi. The experimental site has a sub-tropical and semi-arid climate. During the crop period of 2019, a rainfall of 570 mm occurred, while in 2020, there was 623 mm rainfall. The sandy loam soil of the experimental field tested alkaline in reaction (*p*H of 8.3) and medium in organic C content (0.415%) with overall fertility status being low to medium. The fixed plot field study was set in a triplicate, split-plot design (SPD) wherein main-plots were allocated to 6 combinations of 2 DSR cultivation approaches, viz. growing DSR in ploughed land (CT_{DSR}); and growing DSR without tilling the land (ZT_{DSR}); and 3 water regimes, viz. adequate water; water supply at 20% available soil moisture exhaustion (ASME); and 40% ASME + silicon (Si) supply @80 kg/ha]. Sub-plots had 3 N supply decisions, viz. 100% recommended rate of N (RRN: 150 kg/ha); NutrientExpert (NE) + leaf colour chart (LCC); and NE + SPAD meter-based N scheduling. In conventional till (CT) plots, two cross-ploughings with a cultivator and subsequent harrowing were given, while for direct seeding in zero-till (ZT), plots were kept weed-free with the application of glyphosate (1.0 kg a.i./ha) 1 week prior to sowing. Basmati rice variety Pusa Basmati 1509 was sown on 4th July and 30th June during 2019 and 2020, respectively using a seed rate of 30 kg/ha with row spacing of 25 cm. One day after sowing (DAS), pendimethalin (1.0 kg a.i./ha) was applied to keep under control the early flushes of weeds; next day after the application of pendimethalin, residues of previous season wheat crop were applied @3.5 t/ha in ZT plots. For RRN, 150 kg N/ha was used, while in precision N management, the NE® based calculated dose of N, P_2O_5 and K_2O were 119, 28 and 54 kg/ha, respectively. Entire dose of N was apportioned into three equal parts and first 1/3rd of N and entire dose of P_2O_5 and K_2O were applied basally at the time of sowing through urea, single super phosphate (SSP) and muriate of potash (MoP); while remaining amount of N was top-dressed when the LCC and SPAD rating approached the threshold value (LCC: 3 and SPAD ≤ 37). Additionally, silicon (Si) at 80 kg/ha sourced from calcium silicate was also applied in the specified treatment only. Irrigations were applied as per treatments. At 20-days stage of DSR, bispyribac-sodium (25 g a.i./ha) was applied that was followed by a hand weeding 45 DAS to control weeds that emerged later stage. From net-plot (4 m × 3.5 m), DSR was harvested manually on 23rd October 2019 and 19th October 2020, left in the field for sun-drying for a week-time; thereafter carefully bundled, tagged and brought to the threshing yard separately. After sun-drying, individually crop bundle was weighed, threshed and grain yield was recorded. At harvest total N, P and K contents in grain and straw of DSR were determined using standard protocols. A conversion factor of 5.95 was multiplied with respective grain N content to obtain grain protein content (Juliano 1985). Protein yield was calculated as:

$$\text{Protein yield (kg/ha)} = \frac{\text{Grain protein content (\%)}}{100} \times \text{Grain yield (kg/ha)}$$

Nutrient uptake (N, P and K) by grain and straw of DSR was calculated as (Pratap *et al.* 2021b):

$$\text{Nutrient uptake in grain/straw (kg/ha)} = \frac{\text{Nutrient content in grain/straw (\%)}}{100} \times \text{Grain/straw yield (kg/ha)}$$

The data were subjected to "Analysis of Variance" (ANOVA) following the procedures applicable to a split-plot design (Rana *et al.* 2014). The significance of differences among treatments was tested by using 'F' test ($P \leq 0.05$). Treatment means were compared with the help of critical difference (CD) computed for the parameters which were significantly affected by studied factors.

RESULTS AND DISCUSSION

Grain yield: Conventional-tilled direct-seeded rice recorded on an average 2% advantage in grain yield in comparison to ZT_{DSR} (Table 1). This small improvement in grain yield of basmati rice is the resultant of robust crop stand supported by a fine-pulverized seed bed achieved through 4 tillage operations cultivator/harrow and planking. Tillage and harrowing created an ideal soil tilth suiting to germinating seeds and seedlings emerging from soil, destroyed weeds, facilitated root establishment and propagation, nutrient and water uptake; all these benefits of conventional tillage together enhanced crop growth, yield attributes and yield compared to ZT_{DSR} (Singh *et al.* 2017, Pratap *et al.* 2022).

Ensuring a consistent water supply through assured irrigation led to an approximately 11.4% increase in grain yield compared to water supply at 20% ASME. Further, irrigating at 20% ASME produced 24% increment in rice yield over 40% ASME+Si_{80}. Irrigating crop every 72 h of drying of surface water (assured irrigation) and under slight stress (re-watering at 20% ASME) led to improved and favourable soil-water status than 40% ASME + Si_{80}. Thus, rice crop grew vigorously consequent to the enhanced solubility of inherent soil and applied nutrients facilitating their greater uptake, re-mobilization, and metabolism by the plants, resulting into higher dry matter accumulation, tiller count, yield forming components, and finally larger grain turnover (Dass *et al.* 2017, Pratap *et al.* 2022).

The NE® + SPAD meter-based N schedule accrued ~8.5% more grain yield over RRN; the NE® + LCC-based N addition also produced 5.6% more grain yield than RRN. Higher yield with NE® + SPAD and NE® + LCC-based N schedules could be the resultant of better crop growth and thereby formation of larger yield attributes like effective tiller count, panicle size, grains/panicle and 1000-grain

Table 1 Effect of precision N, irrigation and cultivation regimes on grain yield and N, P and K content in grain and straw of DSR grown during rainy season

Treatment	Grain yield (t/ha)		N content (%)				P content (%)				K content (%)			
			Grain		Straw		Grain		Straw		Grain		Straw	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Cultivation regimes														
CT_{DSR}	3.75	3.02	1.40	1.39	0.49	0.48	0.40	0.38	0.17	0.14	0.46	0.43	1.47	1.43
ZT_{DSR}	3.70	2.95	1.37	1.35	0.47	0.45	0.39	0.35	0.16	0.13	0.45	0.42	1.42	1.39
SEm±	0.06	0.05	0.03	0.04	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03
CD (*P*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrigation regimes														
Assured irrigation	4.28	3.46	1.50	1.45	0.53	0.52	0.45	0.41	0.19	0.17	0.50	0.47	1.52	1.49
Irrigation at 20% ASME	3.87	3.08	1.40	1.37	0.50	0.48	0.40	0.38	0.17	0.14	0.45	0.43	1.44	1.42
Irrigation at 40% ASME+Si (80 kg/ha)	3.03	2.42	1.25	1.30	0.41	0.40	0.33	0.30	0.14	0.11	0.40	0.36	1.36	1.32
SEm±	0.07	0.06	0.04	0.04	0.02	0.01	0.02	0.01	0.004	0.01	0.02	0.01	0.03	0.04
CD (*P*=0.05)	0.23	0.18	0.11	0.14	0.05	0.04	0.06	0.04	0.014	0.02	0.05	0.04	0.09	0.12
Precision N regimes														
Recommended N	3.55	2.85	1.30	1.29	0.41	0.41	0.34	0.32	0.13	0.11	0.41	0.38	1.37	1.33
NutrientExpert + LCC	3.74	3.02	1.40	1.40	0.49	0.48	0.40	0.38	0.18	0.14	0.46	0.43	1.46	1.43
NutrientExpert + SPAD meter	3.89	3.10	1.46	1.43	0.54	0.50	0.44	0.40	0.19	0.16	0.49	0.45	1.50	1.48
SEm±	0.09	0.08	0.04	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.03
CD (*P*=0.05)	0.25	0.25	0.10	0.11	0.03	0.03	0.03	0.03	0.02	0.01	0.04	0.04	0.04	0.09

CT_{DSR}, Conventional till-direct seeded rice; ZT_{DSR}, Zero tilled-direct seeded rice; Si, Silicon; N, Nitrogen; P, Phosphorus; K, Potassium; LCC, Leaf colour chart; SPAD, Soil plant analysis development meter; NS, Non-significant.

Table 2 Effect of precision N, irrigation and cultivation regimes on nutrient uptake, grain protein content and protein yield of DSR grown during rainy season

Treatment	N uptake (kg/ha)				P uptake (kg/ha)				K uptake (kg/ha)				Grain protein content (%)		Protein yield (kg/ha)	
	Grain		Straw		Grain		Straw		Grain		Straw					
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Cultivation regimes																
CT_{DSR}	53.8	42.3	24.6	19.4	15.4	11.7	8.5	5.8	17.4	13.2	72.8	56.7	8.3	8.3	319.8	251.8
ZT_{DSR}	50.9	39.9	22.8	17.3	14.6	10.6	8.0	5.2	16.8	12.5	68.2	53.2	8.1	8.0	303.0	237.7
SEm±	1.47	0.86	0.81	0.46	0.44	0.42	0.25	0.24	0.58	0.40	2.06	1.35	0.17	0.21	8.73	5.10
CD (P=0.05)	NS	NS	NS	1.44	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrigation regimes																
Assured irrigation	64.8	49.9	29.7	23.1	19.6	14.4	10.7	7.4	21.6	16.4	84.3	65.8	9.0	8.6	385.6	296.8
Irrigation at 20% ASME	54.3	42.3	24.8	18.8	15.7	11.7	8.4	5.6	17.5	13.4	71.4	55.9	8.3	8.1	322.9	251.4
Irrigation at 40% ASME+Si (80 kg/ha)	37.9	31.3	16.7	13.0	9.8	7.3	5.7	3.6	12.2	8.6	55.9	43.1	7.4	7.7	225.7	186.0
SEm±	1.80	1.05	0.99	0.56	0.54	0.51	0.31	0.29	0.71	0.49	2.52	1.65	0.21	0.26	10.70	6.24
CD (P=0.05)	5.66	3.30	3.10	1.76	1.71	1.60	0.97	0.91	2.22	1.55	7.93	5.19	0.65	0.81	33.65	19.63
Precision N regimes																
Recommended N	46.3	36.8	19.6	15.3	12.1	9.2	6.2	4.2	14.6	11.0	65.3	50.2	7.7	7.7	275.4	219.2
NutrientExpert + LCC	53.2	42.4	23.6	18.8	15.3	11.6	8.4	5.6	17.2	13.2	70.3	54.8	8.3	8.3	316.2	252.5
NutrientExpert + SPAD meter	57.6	44.1	28.0	20.8	17.7	12.7	10.1	6.8	19.6	14.2	76.0	59.9	8.7	8.5	342.7	262.6
SEm±	1.96	1.13	0.77	0.64	0.56	0.42	0.37	0.23	0.71	0.49	1.54	1.02	0.21	0.22	11.65	6.72
CD (P=0.05)	5.72	3.30	2.25	1.86	1.62	1.22	1.09	0.67	2.08	1.43	4.51	2.98	0.62	0.63	34.01	19.60

CT_{DSR}, Conventional till-direct seeded rice; ZT_{DSR}, Zero tilled-direct seeded rice; Si, Silicon; N, Nitrogen; P, Phosphorus; K, Potassium; LCC, Leaf colour chart; SPAD, Soil plant analysis development meter; NS, Non-significant; ASME, Available soil moisture exhaustion.

weight. The better yield components in these treatments were owing to greater nutrient uptake resulting from combined effect of a balance nutrient supply mediated by NE® and regular need-based N addition in commensuration with crop needs by LCC and SPAD meter (Satyanarayana *et al.* 2012). Lesser nutrient uptake by crop due to mismatch between crop demand and N supply was the primary cause for lower grain yield with RRN.

Nutrient content in grain and straw of DSR: The CT_{DSR} showed marginally higher N, P and K concentrations in grain and straw over ZT_{DSR}. Tillage may accelerate the mineralization of organic matter, releasing nitrogen for plant uptake. This outcome may be attributed to enhanced nutrient absorption, facilitated by improved root development, favoured by a fine seedbed. Additionally, the accelerated mineralization of organic matter under CT could be contributing to improved N, P, and K dynamics, releasing a higher amount of nutrients for uptake by plants (Singh *et al.* 2017).

Assured irrigation led to higher nutrient contents in grain and straw which were significantly higher than those found with irrigation at 40% ASME + Si_{80}. Adequate water supply helps plants access nutrients in the soil solution, supporting their growth and development. Higher N, P and K contents in grain and straw with assured irrigation and irrigation at 20% ASME could be ascribed to better solubilisation of applied nutrients that led to greater availability in soil solution, and consequently higher uptake by the plants. Lower N, P and K content in grain and straw under irrigation at 40% ASME + Si_{80} could be explained by lesser nutrient uptake by crop roots as nutrients remained un-solubilised in the absence of favourable moisture regimes.

NutrientExpert® + soil plant analysis development meter-based N application resulted in higher N, P and K contents in both grain and straw, which was significantly superior to RRN but stood at par with NE+LCC based N application. This was attributed due to greater nutrient (N, P and K) uptake; favoured by ample supply of nutrients as NE optimize nutrient management, ensuring precise and balanced nutrient application coinciding with crop requirements all through the growing period (Satyanarayana *et al.* 2012). Lower N, P and K content in grain and straw of DSR under RRN resulted from lesser nutrient uptake as major chunk of applied N could have been lost by different processes beside lack of synchrony between crop demand and supply of nutrients.

N, P and K uptake by grain and straw of DSR: Different crop establishment methods did not exert a significant influence on N, P and K uptake by grain and straw of DSR during both the study years (Table 2). However, CT-DSR recorded ~5.9, 7.9, 4.9% and 10, 8.9 and 6.7% higher N, P and K in grain and straw, respectively, over ZTDSR. Higher grain and straw yields in CT_{DSR} could potentially make it possible for grain and straw to absorb more N, P, and K. Lower grain and straw yield within ZT_{DSR} contributed lesser N, P and K uptake by grain and straw. Pratap *et al.* (2021a) observed that ZT_{DSR} with *Sesbania* co-culture had lower N, P, and K uptake in grain and straw compared to ZT_{DSR} with residue addition and *Sesbania* co-culture.

Higher N, P and K uptake by grain and straw were observed within assured irrigation followed by irrigation at 20% ASME and irrigation at 40% ASME +Si_{80}. Greater N, P and K uptake by grain and straw under assured irrigation could be ascribed due to higher grain and straw yields. Lower N, P and K acquisition by grain and straw of DSR under mild stress (irrigation at 20% ASME) and severe stress (irrigation at 40% ASME+Si_{80}) resulted from reductions in grain and straw harvests.

NutrientExpert® + soil plant analysis development meter-based N application led to highest N, P and K uptake by grain and straw followed by NE + LCC and RRN. Higher N, P and K uptake by grain and straw under NE + SPAD meter or NE + LCC attributed to highest grain and straw yields. Lower N, P and K uptake by grain and straw with RRN is explained by lesser grain and straw yields.

Grain protein content and protein yield: Conventional till-direct seeded rice exhibited 3.1 and 5.7% higher grain protein content and protein yield respectively, over ZT_{DSR} due to higher grain N concentration and higher grain yield, respectively. Assured irrigation registered highest grain protein content and protein yield, which was closely, followed by irrigation at 20% ASME and 40% ASME+Si_{80}. Increased grain protein content and protein yield under assured irrigation conditions were attributed to elevated grain nitrogen content and higher grain yield. Conversely, lower grain protein content and protein yield observed with irrigation at 40% ASME+Si_{80} were primarily linked to lower grain nitrogen content and grain yield (Jagannath *et al.* 2021).

The NE + SPAD meter-based N schedule caused 3.6 and 6.2% greater protein content and protein yield over NE + LCC. Similarly, NE + SPAD meter caused 11.7 and 22.1% higher protein content and protein yield over RRN. Higher grain protein content and protein yield under NE + SPAD meter-guided N application was attributed largely to higher grain N content and grain yield. This could be achieved through more precise and timely application of nitrogen fertilizers, optimizing the nitrogen supply according to the actual crop demand. Applying nitrogen based on real-time data also led to reduction in nitrogen loss through leaching or volatilization, promoting better nitrogen-use efficiency that further enhanced the nutritional quality by increasing protein content (Ali *et al.* 2015).

In summary, the 2-year field investigation indicated that employing NE®+SPAD-based nitrogen application (119 kg/ha) and implementing irrigation after 72 h of surface water drying could enhance both yield and quality in both CA-based and conventionally cultivated DSR. Nevertheless, in situations with restricted water availability, it's suggested that DSR (basmati) can be irrigated at 20% ASME.

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