

Basmati rice (*Oryza sativa*) performance with varying irrigation and nitrogen control

Rahul. Vikram.Ch, Dhanun Jai

Department of Rural Development and Agricultural Extension,

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ABSTRACT

At the ICAR-Indian Agricultural Research Institute research farm in New Delhi, a field experiment was carried out during the rainy seasons (kharif) of 2021 and 2022 to investigate the impact of irrigation schedules and the combined use of prilled urea and nano-urea as a source of N on the productivity and profitability of basmati rice (*Oryza sativa* L.). Three irrigation regimes—irrigation at 1, 3, and 6 days after disappearance of surface water (DADSW) assigned to main-plots—and four N-management variations—100% RDN (recommended dose of N, 120 kg/ha); 75% RDN + 4% nano-urea (NU) 2 sprays (75% RDN + 2 NU); 50% RDN + 2 NU; and no-N (control) in sub-plots—were used in the experiment. In comparison to 3 and 6 DADSW, irrigating basmati rice 1 DADSW showed the greatest panicle weight (2.67–3.09 g) and number of grains/panicle (115.9, 109.8) over the years. Grain production was significantly reduced by the most delayed irrigation at 6 DADSW; the decline was 13–19% over irrigation at 3 DADSW and significantly by 23–28% over irrigation at 1 DADSW. The yield attributes and grain yield of rice crops fertilized with 100% RDN and 75% RDN + 2 NU were statistically similar, but both were significantly better than 50% RDN + 2 NU and no-N. Net returns, benefit cost (B:C) ratio, and monetary efficiency were significantly higher when the crop was irrigated 1 DADSW compared to 3 and 6 DADSW. For all examined economic factors, the N-management alternatives followed the trend of RDN>75% RDN + 2 NU >50% RDN > no-N.

Keywords: Basmati rice, yield, nitrogen, irrigation, economics, and nano-urea

Introduction

In order to tackle food insecurity, particularly in economically fragile countries, rice (*Oryza sativa* L.), which provides half of the world's population with nourishment, is essential (Dass et al. 2016, Wasaya et al. 2022). India, which produces 21% of the world's rice, must fulfill a projected demand of 130 million tons by 2025 for both national food security and the UN's sustainable development objectives (Choudhary et al. 2022). India is the world's top exporter of rice, but increased output is necessary due to dietary changes and population growth (Mohidem et al. 2022). However, with dwindling resources—most notably water scarcity—achieving increased yields is difficult.

A major problem in water-scarce countries like China and India is rice production, which uses 34–43% of the world's irrigation water (Surendran et al. 2021). Due to decreasing water availability, India is expected to have a 50% supply-demand mismatch by 2030 (Gulati et al. 2019). Traditional transplanting uses a lot of water.

1ICAR: Indian Agricultural Research Institute, New Delhi; 2ICAR: National Rice Research Institute, Cuttack, Odisha; and 3ICAR: Indian Institute of Soil Science, Bhopal, Madhya Pradesh. * Corresponding author email: anchal_d@rediffmail.com However, research revealed that a 2-3 day watering interval had no discernible effect on basmati rice output (Mahajan et al. 2006, Singh et al. 2008).

Crop yields are impacted by nitrogen (N), a critical nutrient (Zhang et al. 2020). Nano-fertilizers, such as those that improve nutrient transport via nanoscale channels (Mahanta et al. 2019), have the potential to increase plant biomass and yield (Khalid et al. 2022). By encouraging meristematic activity, cell elongation, photosynthate assimilation, and effective resource translocation within plants, nano-urea improves agricultural outcomes when combined with urea (traditional N-source). This leads to improved yield attributes and economics (Sahu et al. 2022, Kanno et al. 2022, Attri et al. 2022, Ranjan et al. 2023). In light of this, field experiments were carried out with the primary goal of examining the impact of irrigation schedules and the combined use of prilled urea and nano-urea as a source of N on basmati rice production and profitability.

METHODS AND MATERIALS

During the rainy (kharif) seasons of 2021 and 2022, a field experiment was carried out at the ICAR-Indian Agricultural Research Institute research farm (28°38' N; New Delhi (77°09' E; 229 m msl). During kharif 2021 and 2022, the average monthly maximum and minimum air temperatures were 33.8 and 24.5°C and 33.6 and 23.9°C, respectively. Using standard procedures, the initial soil chemical characteristics (0–15 cm depth) were recorded as Walkley-Black soil organic carbon (SOC) 0.5%, alkaline KMnO₄ oxidizable-N, 0.5 M NaHCO₃ extractable phosphorus (P), and 1 N NH₄OAc extractable potassium (K) contents of 254.2 kg/ha, 14.4 kg/ha, and 222.6 kg/ha, respectively (Rana et al. 2014). The experiment included four sub-plot N-management treatments: 100% recommended dose of N, or 120 kg/ha in split doses (RDN); 75% RDN + nano urea (NU) with two sprays (75% RDN + NU); 50% RDN + nano urea spray (50% RDN + NU); and a control plot where N was left out (N₀). The three main-plot treatments were irrigations applied 1, 3, and 6 days after surface water disappeared (1, 6 DADSW). The experiment was set up in 36 panels with three replications using a split-plot design (SPD). The newly created semi-dwarf Pusa Basmati 1692, which has extra-long and thin grains and is high yielding, early ripening, non-lodging, non-shattering, and somewhat resistant to blast disease, was chosen as the test variety (basmati rice). The plots were plowed, then harrowed to create a fine seed bed. Pre-germinated seeds were nursery-raised on well-fertilized, well-irrigated beds final week in June, and in mid-July, two seedlings per hill were transplanted into the main field at a distance of 20 cm by 10 cm. At 1, 3, and 6 days after surface water disappeared from the tillering to milking phases, the crop was watered (6 cm depth); irrigations were thereafter applied consistently. The total number of irrigations varied by treatment (1 DADSW-11, 15; 3 DADSW: 7, 11; 6 DADSW: 5, 7 during 2021 and 2022, respectively), and the quantity of rainfall received in each year had an impact on the number of irrigations. The crop was fertilized in accordance with the treatments; three split doses of 120 kg/ha N were administered as RDN in the form of urea, followed by two nano-urea sprays and 75% of RDN (90 kg/ha N) and 50% of RDN (60 kg/ha N). One-third of RDN (40 kg/ha), 60 kg/ha P₂O₅, and 40 kg/ha K₂O in the form of urea, single superphosphate (SSP), and muriate of potash (MOP) were applied as the basal dose. The remaining N and 4% nano-urea spray were applied at a rate of 500 ml/acre at approximately 25–30 and 45–50 DAT (days after transplanting). Butachlor 1.5 kg a.i./ha was used before to emergence in addition to two-hand weeding at 30 and 60 DAT for weed control. For yield characteristics, a 1 m² quadrat was used to randomly count the number of panicles/m² from three places in each plot at harvest. Ten randomly chosen panicles from each plot were counted to determine the average number of individuals loaded grains/hill. In order to determine the test weight (g), 1000 grains were randomly selected from each net-plot's bulk yield, counted, and weighed at 14% moisture content. Grain yield (t/ha) at 14% moisture content was recorded after the rice crop was harvested from a net-plot, sun-dried, threshed, winnowed, and manually cleaned each plot individually. The cost of cultivation (COC) was calculated by adding the costs of all the inputs and resources, including labor, equipment, irrigation, fertilizers, land preparation, seed, and transplanting. The economic production (grain + straw) was multiplied by the current market price of rice (₹3700/q in 2021 and ₹4000/q in 2022, and ₹2/kg for straw) to get the gross returns. The net returns were then deducted from the COC. The net returns were divided by the cultivation costs to get the net benefit-cost (B:C) ratio. Net returns were divided by crop duration to calculate monetary efficiency (ME). The conventional process was used to apply the Analysis of Variance technique for a split-plot design to year-wise data on all observations. The F-test was used to determine if there was a significant difference between the various treatments, and the parameters that showed significant differences had their least significant difference (LSD) values calculated. A 5% significance threshold was used to compare the treatment means.

OUTCOMES AND TALK

Irrigation schedules and N-management had a significant impact on the yield-attributing characteristics (Table 1). When rice was irrigated at 1 DADSW, the panicle length was much longer; this was closely followed by 3 DADSW with no discernible differences. With a delayed interval at 6 DADSW, the panicle length was considerably shortened (12–15%). The RDN had the longest panicle length among the N-management alternatives, followed by 75% RDN + NU, with no discernible variations. In comparison to irrigation regimes at 3 and 6 DADSW, the irrigation at 1 DADSW also showed the largest panicle weight (2.67 to 3.09 g) during the course of the years. However, changing irrigation from 3 DADSW to 6 DADSW had no effect on panicle weight. RDN produced the greatest panicle weight (3.0, 2.67 g) when N-management was taken into account in 2021, although it was statistically comparable to 75% RDN + NU and showed noticeably greater results than other treatments. In comparison to delayed irrigation, which further decreased it by 3–9% (3 DADSW) and 11–

15% (6 DADSW) over the years, irrigation at 1 DADSW resulted in much larger numbers of grains/panicle (115.9 and 109.8). RDN generated the most grains per panicle (115.1 and 113.03) across N treatments, and it was statistically comparable to 75% RDN + NU. Over the years, RDN generated around 10–11% more grains per panicle than 50% RDN + NU and 21–24% more than control.

Grain filling was superior to other treatments when the crop was watered at 1 DADSW, fertilized with 75% of the authorized nitrogen dosage, and sprayed twice with nano-urea. Irrigation schedule at 1 DADSW produced the highest test weight (27.7, 27.67 g) across all regimens; however, in the second year, the difference was comparable to 3 DADSW. However, further deferring the irrigation up to 6 DADSW resulted in a significant decrease in test weight (24.97, 24.32 g), which was around 9–12% over the years, with the second year showing the greatest drop.

Table 1 Effect of irrigation regimes and nitrogen management on yield attributes and yield of basmati rice

Treatment	Panicle length (cm)		Panicle weight (g)		Grains/panicle		Un-filled grains/panicle		1000-grain wt. (g)		Grain yield (t/ha)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation regimes												
1 DADSW	27.17	27.14	3.09	2.67	115.9	109.75	6.50	7.59	27.70	27.67	5.01	4.92
3 DADSW	26.20	25.37	2.54	2.23	105.4	106.22	9.56	12.22	26.77	26.05	4.43	4.35
6 DADSW	23.82	23.20	2.31	1.98	98.3	97.66	13.00	17.35	24.97	24.32	3.84	3.54
SEm ±	0.49	0.51	0.05	0.04	2.38	2.22	0.19	0.19	0.44	0.54	0.10	0.09
CD (P=0.05)	1.93	2.00	0.19	0.15	9.33	8.71	0.74	0.76	1.74	2.11	0.38	0.34
N-management												
RDN	28.12	27.44	3.00	2.69	115.1	113.03	7.73	10.01	27.36	27.02	5.19	5.05
75% RDN	+27.14	26.75	2.94	2.64	113.2	112.21	6.89	8.96	27.84	27.58	4.99	4.81
NU												
50% RDN	+25.27	24.52	2.58	2.15	104.3	101.83	9.92	12.23	26.20	25.76	4.48	4.31
NU												
N0	22.39	22.24	2.08	1.69	93.4	91.10	14.20	18.33	24.52	23.69	3.05	2.92
SEm ±	0.39	0.37	0.06	0.03	2.34	2.82	0.23	0.31	0.33	0.57	0.07	0.08
CD (P=0.05)	1.16	1.09	0.17	0.10	6.98	8.41	0.69	0.94	0.99	1.69	0.22	0.25
Interaction (I × N)	S	NS	S	S	NS	NS	S	S	S	NS	S	S

Days after surface water disappears (DADSW); Recommended dosage nitrogen (RDN); and nano-urea (NU). When compared to the other N treatments, the administration of 75% RDN + NU and RDN produced a considerably greater test weight. Over the years, the application of 75% RDN + NU produced the greatest 1000-grain weight (27.84, 27.58 g), which was 6–7% higher than 50% RDN + NU and around 13–16% higher than control treatment. All of the irrigation regimes examined in 2021 and 2022 showed significant variations in grain output (Table 1). The highest grain production was obtained by fertilizing with RDN and irrigating at 1 DADSW. However, there was no discernible decrease in grain production when 25% N was replaced with two sprays of 4% nano-urea. Conversely, the lowest grain yield (3.84, 3.54 t/ha) was produced by the most delayed irrigation at 6 DADSW; this drop was 13–19% higher than irrigation at 3 DADSW and significantly higher than irrigation at 1 DADSW throughout the course of the years. Frequent irrigation may have improved the soil-water ecosystem, reduced evapotranspiration (ET) losses by lowering water stress, improved soil and applied nutrient solubilization, absorption, and assimilation, which improved crop growth by moving more photosynthates to the sink, improving grain filling, and ultimately improving yield attributes and yield (5.01, 4.92 t/ha) (Parihar 2004, Kumari et al. 2017, Pratap et al. 2022). Stunted plant growth, reduced leaf area, fewer tillers, decreased dry matter production, fewer and shorter panicles, lower 1000-grain weight, insufficient grain filling, and smaller and lighter grains were all likely consequences of delayed irrigation-induced stress, which ultimately led to lower straw and grain yields (Rahman et al. 2002). The application of RDN yielded the greatest

grain production among the N treatments (5.19, 5.05 t/ha), which was statistically equivalent to 75% RDN + NU (4.99, 4.81 t/ha) and much better than other treatments in both years. RDN yielded 14–15% and 41–42% more than 50% RDN + NU and control (N0) during the course of the research years. This may be explained by the fact that adequate N application promotes cell division and elongation, increases the leaf area index, increases tiller production, and enhances panicle growth, which results in the synthesis and transfer of carbohydrates to the grains, improving yield attributes and yield. N 120 kg/ha has also been observed to boost grain output and yield characteristics (Jaiswal and Singh 2001). Because of its nano-scale particle size, which offers a higher surface area, quick absorption, penetration, and slow release of nano-nutrients allowing plants to fully utilize them, supplementing 25% N with nano-urea may have also compensated for the yield loss (Khalid et al. 2022). This would have increased plant biomass and consequently increased yield. Additionally, Chandana et al. (2021) and Sahu et al. (2022) observed that the combination of nitrogen and nano-urea resulted in improved yield qualities such as the maximum number of panicles/m² and the number of filled grain/panicle simultaneously led to improved grain production. Irrigation and nitrogen management has a significant impact on the economic returns on agricultural production, which include a variety of factors such as crop yield, quality, market price, input costs, and water availability. Frequent irrigation treatment produced the highest gross returns, net returns (143,699 ₹/ha, 150,019 ₹/ha), net B:C ratio (2.47, 2.41), and monetary efficiency (1218, 1271 ₹/ha/day) in 2021 and 2022, according to the economic analysis of the applied irrigation and nitrogen (Table 2). In general, throughout time, comparing

Table 2 Effect of irrigation regimes and nitrogen management on economic return in basmati rice

Treatment	Gross return (₹/ha)		Net return (₹/ha)		Net B:C ratio		Monetary efficiency (₹/ha/day)	
	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation regimes								
1 DADSW	201687	212007	143699	150019	2.47	2.41	1218	1271
3 DADSW	177579	186480	123591	128492	2.28	2.21	1056	1120
6 DADSW	152796	151111	100808	97123	1.93	1.79	908	883
SEm ±	3979	4318	2490	3623	0.06	0.06	23.3	25.6
CD (P=0.05)	15620	16950	9775	14222	0.24	0.25	91.6	100.6
N management								
RDN	208796	216927	153807	158605	2.78	2.70	1325	1369
75% RDN + NU	199989	206130	144618	147426	2.60	2.49	1246	1273
50% RDN + NU	178456	184623	123265	126099	2.22	2.14	1063	1115
N0	122176	125118	69108	68716	1.30	1.21	609	609
SEm ±	2710	3328	2241	3207	0.04	0.05	18	26.4
CD (P=0.05)	8085	9929	6687	9568	0.13	0.14	53.7	78.7
Interaction (I × N)	S	S	S	S	S	S	S	S

DADSW stands for days after surface water disappears; RDN is for recommended nitrogen dosage; NU stands for nano-urea; and B:C stands for benefit cost.

RDN, lowering N-dose by 75% RDN + NU; and 50% RDN + NU decreased net return by 19–20% and 6-7%, respectively. According to Attri et al. (2022), 75% RDN with Nano-urea was the most cost-effective combination in this situation. However, it has also been shown that 100% RDN with nano spray provides the optimum B:C ratio and economic return (Ranjan et al. 2023). Net returns and crop length were the primary determinants of monetary efficiency (Dass et al. 2022, Pratap et al. 2022); frequent irrigation and RDN improved monitoring efficiency. Adoption of 75% RDN + nano-urea may be encouraged for the purpose of environmental sustainability when considering its benefits over RDN, particularly in terms of energy conservation and greenhouse gas emissions reduction (Upadhyay et al. 2023).

It may be inferred from the two-year experiment that greater yield characteristics, yield, and economic return resulted from fertilizing rice with RDN and irrigating it at 1 DADSW. RDN and 75% RDN + 2 nano-urea sprays did not significantly vary in yield characteristics or yield; nevertheless, further optimization of nano-urea usage is necessary to increase basmati rice productivity and quality.

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