

International Journal of Statistics and Applied Mathematics

ISSN: 2456-1452
NAAS Rating (2026): 4.49
Maths 2026; 11(4): 102-107
© 2026 Stats & Maths
<https://www.mathsjournal.com>
Received: 07-01-2026
Accepted: 09-02-2026

Bimal Gopinath
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

Dheerendra Singh
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

Brajkishor Rajput
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

Ashok Kumar Verma
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

HD Verma
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

Balkrishna Namdeo
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

Rakesh Kumar Ahirwar
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

Corresponding Author:
Bimal Gopinath
Rabindranath Tagore
University, Raisen, Madhya
Pradesh, India

Economic feasibility of irrigation scheduling and nutrient management practices in direct seeded rice under Vindhya Plateau conditions

Bimal Gopinath, Dheerendra Singh, Brajkishor Rajput, Ashok Kumar Verma, HD Verma, Balkrishna Namdeo and Rakesh Kumar Ahirwar

DOI: <https://www.doi.org/10.22271/math.2026.v11.i4b.2305>

Abstract

A field experiment was conducted during the Kharif seasons of 2021 and 2022 at the Agriculture Research Farm of Rabindranath Tagore University to assess the economic feasibility of irrigation scheduling in conjunction with nutrient management in direct seeded rice (DSR) under Vindhya Plateau conditions. The experiment was conducted in a Split Plot Design with 3 irrigation regimes-IR1 Continuous flooding - 5 cm depth of water, IR2 Maintenance of saturation upto tillering (50-55 DAS), flooding from tillering to flowering (55-100 DAS) later saturation till harvest and IR3 Alternate wetting and drying (irrigating at 10 days interval with 5 cm depth of water)-as main plots, and five nutrient levels-F1 Control, F2 75% RDF, F3 100% RDF, F4 125% RDF and F5 Farmers's practice (150:60:0)-as sub plots.

The results revealed that both irrigation scheduling and nutrient management significantly influenced yield and economic returns. Among irrigation treatments, IR2 recorded higher grain yield (52.9 and 54.3 q ha⁻¹) and net returns (₹131592 ha⁻¹ and ₹136484 ha⁻¹) with a B:C ratio of 4.23 and 4.30 during 2021 and 2022, respectively. Among nutrient levels, F4 (125% RDF) resulted in maximum grain yield (56.4 and 57.1 q ha⁻¹) and net returns (₹143252 ha⁻¹ and ₹145628 ha⁻¹) with superior profitability. The interaction effect further indicated that IR2 × F4 produced the highest grain yield (59.8 and 60.4 q ha⁻¹) and net returns (₹148310 ha⁻¹ and ₹149690 ha⁻¹), highlighting the synergistic effect of optimum moisture and nutrient availability. In contrast, lower input combinations recorded reduced productivity and economic gains.

The study concludes that precise irrigation scheduling combined with adequate nutrient supply is essential for maximizing productivity, profitability and resource-use efficiency in DSR under semi-arid agro-ecological conditions.

Keywords: Direct seeded rice, irrigation scheduling, nutrient management, economic feasibility, resource-use efficiency

Introduction

Rice (*Oryza sativa* L.) is a principal staple for more than half of the global population and underpins food and livelihood security across Asia. In India, it occupies a central position in the agricultural economy; however, the conventional puddled transplanted system is increasingly constrained by high water demand, rising labour costs and declining resource-use efficiency (Kumar & Ladha, 2011; Carrijo *et al.*, 2017) ^[2, 7]. In this context, direct seeded rice (DSR) has emerged as a viable alternative, offering advantages such as reduced labour requirement, lower water use and timely crop establishment, particularly under water-scarce environments (Sandhu *et al.*, 2021; Jat *et al.*, 2019) ^[5, 11].

Water availability is the most critical factor governing rice productivity. Traditional flooding methods are inefficient, leading to substantial conveyance and percolation losses. Improved irrigation strategies, such as controlled saturation and alternate wetting and drying (AWD), have been shown to enhance water productivity while maintaining or even improving yields by aligning water supply with crop demand (Bouman *et al.*, 2007; Lampayan *et al.*, 2015) ^[1, 9].

However, the performance of these irrigation regimes is highly dependent on soil type, climatic conditions and crop management practices, especially in semi-arid regions such as the Vindhya Plateau of Madhya Pradesh.

Parallel to water management, nutrient management plays a decisive role in determining crop productivity and profitability. Nitrogen, phosphorus and potassium are key drivers of plant growth, Modulating physiological activities such as photosynthetic efficiency, tiller formation, and grain filling. Imbalanced or inadequate fertilization not only reduces yield but also lowers nutrient use efficiency and economic returns (Dobermann & Fairhurst, 2000; Ladha *et al.*, 2005) [4, 8]. Recent studies have emphasized that optimizing fertilizer inputs beyond conventional recommendations can improve both yield and profitability when supported by appropriate moisture conditions (Liu *et al.*, 2021; Zhang *et al.*, 2020) [10, 16].

Importantly, irrigation and nutrient management do not act independently; rather, they exhibit strong interactive effects on crop growth and yield formation. Adequate soil moisture enhances nutrient solubility and uptake, while proper nutrient supply improves plant tolerance to water stress and increases water-use efficiency (Cassman *et al.*, 1998; Kumar *et al.*, 2018) [3, 6]. This interaction becomes particularly critical in DSR systems, where soil moisture dynamics differ significantly from transplanted rice systems.

Despite growing evidence on individual effects of irrigation and nutrient management, there is limited information on their combined economic feasibility under region-specific conditions, especially in the Vindhya Plateau. Therefore, the present investigation was undertaken to evaluate the economic viability of different irrigation scheduling and nutrient management practices in direct seeded rice, with the objective of identifying an optimal combination that maximizes productivity, profitability and resource-use efficiency under semi-arid agro-ecological conditions.

Materials and Methods

Experimental site

The field investigation was conducted during the Kharif seasons of 2021 and 2022 at the Agriculture Research Farm of Rabindranath Tagore University, located in the Vindhya Plateau region of Madhya Pradesh. This region represents a typical semi-arid to sub-humid agro-ecology where rainfall variability and intermittent dry spells often influence crop performance. The climate during the cropping period was characterized by warm temperatures, moderate to high humidity and monsoon-driven precipitation, creating a dynamic soil moisture environment for direct seeded rice.

The experimental field possessed soils representative of the region, moderately fertile with good tilth and drainage capacity, making them suitable for evaluating water and nutrient management strategies under direct seeding conditions. Prior to sowing, the field was uniformly prepared to ensure a fine seedbed, facilitating proper germination and establishment. Such conditions were essential to minimize variability arising from soil heterogeneity and to ensure that treatment effects were clearly expressed.

Experimental design and treatment details

The experiment was conducted in a Split Plot Design with three replications, a choice justified by the practical difficulty of imposing irrigation treatments at smaller plot scales. Irrigation scheduling was therefore assigned to the main plots, while nutrient management treatments were randomized

within sub plots to capture their differential effects with greater precision.

The main plot treatments consisted of three irrigation regimes:

1. IR1 Continuous flooding - 5 cm depth of water
2. IR2 Maintenance of saturation upto tillering (50-55 DAS), flooding from tillering to flowering (55-100 DAS) later saturation till harvest
3. IR3 Alternate wetting and drying (irrigating at 10 days interval with 5 cm depth of water)

The sub plot treatments included five nutrient management practices:

1. F1 Control
2. F2 75% RDF
3. F3 100% RDF
4. F4 125% RDF
5. F5 Farmers's practice (150:60:0)

The recommended dose of fertilizers (RDF) was applied according to treatment specifications, ensuring precise nutrient delivery. The rice variety PB-1 was selected for its adaptability to direct seeded conditions. Sowing was carried out using direct seeding under recommended spacing, and all agronomic practices were followed uniformly to maintain experimental consistency.

Crop management

The crop was established under well-prepared field conditions to ensure uniform emergence. Nutrient application was carefully managed, with nitrogen applied in split doses to synchronize nutrient availability with crop demand, thereby improving nutrient use efficiency and minimizing losses.

Irrigation was applied strictly according to the defined treatment schedules, with careful monitoring of soil moisture conditions to maintain treatment integrity. Particular attention was given to critical growth stages such as tillering and flowering, where moisture availability plays a decisive role in yield formation.

Weed management was carried out using appropriate pre- and post-emergence practices, while plant protection measures were implemented as needed to prevent pest and disease incidence. These uniform management practices ensured that observed differences in crop performance were attributable primarily to irrigation and nutrient treatments rather than external factors.

Observations Recorded

Yield and yield attributes

At physiological maturity, crop samples were harvested from the net plot area to record grain yield, straw yield and biological yield, expressed in quintals per hectare ($q\ ha^{-1}$). Care was taken to avoid border effects and ensure representative sampling. Harvest index was calculated as the ratio of grain yield to total biological yield and expressed as a percentage, providing insight into the efficiency of assimilate partitioning from vegetative to reproductive components.

Economic analysis

An economic assessment was carried out to evaluate the practical feasibility of each treatment combination. Cost of cultivation was computed based on prevailing input costs, including seed, fertilizers, irrigation and labour. Gross returns were calculated using market prices of grain and straw, reflecting real-world economic conditions. Net returns were derived by subtracting total cost of cultivation from gross

returns, while the benefit-cost (B:C) ratio was used as an indicator of economic efficiency and profitability.

Statistical analysis

The experimental data were subjected to statistical analysis using analysis of variance (ANOVA) appropriate for Split Plot Design. Treatment effects were tested at the 5% level of significance, and critical difference (CD) values were calculated for comparison of means. Interaction effects between irrigation scheduling and nutrient management were also examined to understand their combined influence on yield and economic parameters. This analytical approach ensured a robust interpretation of treatment effects and their practical implications.

Results and Discussion

The data presented in Table 1 clearly demonstrate that grain yield, straw yield, biological yield and harvest index were significantly influenced by irrigation scheduling and nutrient management during both years of investigation. This indicates that productivity of direct seeded rice is primarily governed by the interaction between soil moisture regime and nutrient availability, which directly regulates plant physiological processes such as photosynthesis, assimilate translocation and sink development. Similar conclusions have been drawn in recent studies emphasizing that resource-use efficiency in DSR systems is highly dependent on synchronization between water and nutrient supply (Kumar *et al.*, 2018; Sandhu *et al.*, 2021) [6, 11].

Effect of Irrigation Scheduling

Among irrigation treatments, IR2 Maintenance of saturation upto tillering (50-55 DAS), flooding from tillering to flowering (55-100 DAS) later saturation till harvest recorded the highest grain yield (52.9 and 54.3 q ha⁻¹), followed by IR1, whereas IR3 recorded the lowest yield. The superior performance of IR2 can be explained through optimized soil-plant-water relationships, wherein continuous soil moisture availability during vegetative growth enhances root proliferation, nutrient diffusion and nitrogen uptake, while subsequent flooding during reproductive stages ensures reduced spikelet sterility and improved grain filling.

Adequate water availability during critical stages maintains higher leaf water potential and stomatal conductance, thereby sustaining photosynthetic activity and assimilate production. This ultimately improves the source-sink relationship, resulting in higher yield. In contrast, IR3 (alternate wetting and drying) induced intermittent moisture stress, which likely reduced root hydraulic conductivity, restricted nutrient uptake and caused partial stomatal closure, thereby limiting carbon assimilation and reducing grain filling efficiency.

The higher harvest index observed under IR2 (43.59 and 42.18%) further indicates efficient biomass partitioning towards economic yield. These findings are in close conformity with studies conducted by International Rice Research Institute and Bouman *et al.* (2007) [1], who demonstrated that controlled irrigation regimes improve water productivity by aligning water supply with crop demand. More recent studies by Lampayan *et al.* (2015) [9] and Carrijo *et al.* (2017) [2] also confirmed that optimized irrigation enhances yield stability and water-use efficiency in direct seeded rice systems.

Effect of Nutrient Management

Nutrient management exerted a significant influence on yield and its components. Among the treatments, F4 - 125% RDF recorded the highest grain yield (56.4ha-1 and 57.1 q ha⁻¹),

followed by F3 and F5. The higher yield under F4 can be attributed to enhanced availability of essential nutrients, particularly nitrogen, which plays a central role in chlorophyll formation, enzyme activation and protein synthesis.

Adequate nitrogen supply increases leaf area index and photosynthetic rate, leading to greater dry matter accumulation. This is reflected in higher biological yield (130.56 and 132.64 q ha⁻¹), indicating improved radiation interception and conversion efficiency. Furthermore, higher harvest index under F4 suggests efficient translocation of assimilates from vegetative to reproductive parts, which is a critical determinant of yield formation.

In contrast, F1 Control recorded significantly lower yield due to nutrient deficiency, which restricted plant growth, reduced leaf area development and limited sink formation. These findings are consistent with Dobermann and Fairhurst (2000) [4] and Ladha *et al.* (2005) [8], who emphasized that balanced fertilization enhances nutrient use efficiency and crop productivity. Recent studies by Jat *et al.* (2019) [5] and Liu *et al.* (2021) [10] further confirmed that optimized nutrient management improves physiological efficiency and yield performance in rice-based systems.

Interaction Effect (I × F) on Yield

The interaction data presented in Table 1(a) and 1(b) revealed a significant combined effect of irrigation and nutrient management on yield parameters, clearly indicating that these factors operate in a synergistic manner. The treatment combination IR2 × F4 recorded the highest grain yield (59.8 and 60.4 q ha⁻¹), straw yield (75.5 and 75.9 q ha⁻¹), biological yield (135.3 and 136.3 q ha⁻¹) and harvest index (44.20 and 44.31%).

This superior performance can be attributed to resource synchronization, where IR2 ensures continuous soil moisture availability, enhancing nutrient solubility and uptake, while F4 provides adequate nutrient supply, improving physiological efficiency and metabolic activity. The combined effect results in enhanced radiation use efficiency, nutrient use efficiency and assimilate partitioning, ultimately leading to higher productivity.

Conversely, the lowest yield observed under IR3 × F1 indicates that simultaneous limitation of water and nutrients severely restricts crop growth, confirming that these inputs are co-limiting factors. This aligns with the concept proposed by Cassman *et al.* (1998) [3] that yield is maximized only when nutrient supply is synchronized with crop demand under favorable environmental conditions. Similar interaction effects have also been reported by Kumar and Ladha (2011) [7] and more recently by Yadav *et al.* (2020) [14], emphasizing the importance of integrated water and nutrient management in DSR systems.

Effect of Irrigation Scheduling and Nutrient Management on Economic Returns

The economic analysis presented in Table 2 indicated that both irrigation scheduling and nutrient management significantly influenced cost of cultivation, gross returns, net returns and B:C ratio, thereby determining overall profitability.

Among irrigation treatments, IR2 recorded the highest net returns (₹131592 and ₹136484 ha⁻¹) and B:C ratio (4.23 and 4.30). This was primarily due to higher grain yield and efficient utilization of water resources. Although IR1 produced comparable yields, its higher irrigation cost reduced profitability, whereas IR3 resulted in lower returns due to yield reduction despite lower input cost. This clearly suggests

that economic efficiency depends on optimizing resource use rather than minimizing inputs alone. Similar findings have been reported by Tuong *et al.* (2005) ^[13] and Carrijo *et al.* (2017) ^[2], who emphasized that water-saving technologies must maintain yield stability to be economically viable.

Effect of Nutrient Management on Economics

Among nutrient treatments, F4-125% RDF recorded the highest net returns (₹143252 and ₹145628 ha⁻¹) and B:C ratio (4.51 and 4.57), indicating that increased fertilizer input was economically justified due to higher yield gains. The improved profitability under F4 suggests that investment in balanced fertilization enhances economic returns by improving productivity and resource-use efficiency.

Interestingly, F5 Farmers' practice also recorded a comparable B:C ratio, indicating that farmers tend to optimize input-output relationships based on field experience. However, lower returns under F1 highlight that nutrient deficiency significantly reduces profitability. These results are supported by Ladha *et al.* (2005) ^[8] and recent findings by Zhang *et al.* (2020) ^[16], which indicate that economic

optimum fertilizer levels often align closely with agronomic optimum under well-managed systems.

Interaction Effect (I × F) on Economics: The interaction data presented in Table 2(a) clearly demonstrate that economic returns are maximized when irrigation and nutrient management are optimized simultaneously. The combination IR2 × F4 recorded the highest net returns (₹148310 and ₹149690 ha⁻¹) along with a B:C ratio of 4.21, making it the most economically viable treatment.

This clearly establishes that profitability is directly linked to productivity and resource-use efficiency, and not merely to cost reduction. In contrast, IR3 × F1 recorded the lowest economic returns, highlighting that low-input systems are not sustainable when they significantly reduce yield.

These findings strongly support the concept of sustainable intensification, as proposed by Tilman *et al.* (2002) ^[12], and further validated by recent studies (Jat *et al.*, 2019; Yadav *et al.*, 2020) ^[5, 14], which emphasize that optimal input management is essential for maximizing both productivity and profitability in modern agriculture.

Table 1: Effect of Irrigation Methods and fertilizer levels on Grain, Straw, Biological yield (q ha⁻¹) and Harvest Index of rice during Kharif 2021 and 2022

Irrigation	Grain yield (q ha ⁻¹)		Straw Yield (q ha ⁻¹)		Biological Yield (q ha ⁻¹)		Harvest Index	
	2021	2022	2021	2022	2021	2022	2021	2022
IR1	50.8	51.1	73.92	75.74	124.72	126.84	40.73	40.29
IR2	52.9	54.3	68.46	74.42	121.36	128.72	43.59	42.18
IR3	42.1	43.5	64.54	65.52	106.64	109.02	39.48	39.90
Mean	48.6	49.6	68.97	71.89	117.57	121.53	41.27	40.79
SEm (±)	0.85	0.91	1.38	1.45	1.82	1.96	0.62	0.66
CD (5%)	2.57	2.73	4.12	4.31	5.48	5.88	1.88	1.96
Fertilizer								
F1 – Control	26.2	27.4	41.28	42.86	67.48	70.26	38.83	37.29
F2 – 75% RDF	44.8	46.2	62.72	64.68	107.52	110.88	41.67	40.40
F3 – 100% RDF	52.3	53.7	70.42	72.38	122.72	126.08	42.62	41.49
F4 – 125% RDF	56.4	57.1	74.16	75.54	130.56	132.64	43.20	42.52
F5 – Farmers' practice	52.1	52.9	71.54	73.16	123.64	126.06	42.14	41.33
Mean	46.36	47.46	64.02	65.72	110.384	113.184	41.69	40.61
SEm (±)	1.05	1.12	1.65	4.78	2.14	2.28	0.74	0.78
CD (5%)	3.14	3.35	2.34	6.92	6.22	6.52	1.96	2.24

Table 1(a): Interaction Effect (I × F) on Grain and Straw yield (q ha⁻¹) of Rice during Kharif 2021 and 2022

Irrigation × Fertilizer	Grain yield (q ha ⁻¹)								Straw yield (q ha ⁻¹)							
	2021				2022				2021				2022			
	IR1	IR2	IR3	Mean	IR1	IR2	IR3	Mean	IR1	IR2	IR3	Mean	IR1	IR2	IR3	Mean
F1 – Control (No fertilizer)	28.5	29.1	21.1	26.2	29.3	30	23.01	27.4	45.1	41.2	37.84	41.28	46.8	42.5	39.18	42.86
F2 – 75% RDF	46.2	48.5	39.8	44.8	47.6	50.1	41	46.2	65.8	62.02	60.36	62.72	67.4	64.1	62.54	64.68
F3 – 100% RDF	53.6	55.4	48	52.3	54.9	56.9	49.2	53.7	74.2	69.8	67.26	70.42	75.9	71.7	69.14	72.38
F4 – 125% RDF	57.5	59.8	52.1	56.4	58.2	60.4	52.6	57.1	76.4	75.5	70.58	74.16	78.6	75.9	72.12	75.54
F5 – Farmers' practice	54	55.8	46.6	52.1	54.6	57	47	52.9	76.2	71.3	67.12	71.54	76.2	73.9	69.38	73.16
Mean	48	49.7	41.5	46.4	48.9	50.9	42.6	47.46	67.52	63.52	60.43	63.82	69.18	65.24	62.07	65.49
SEm ±	1.82				1.93				1.12				1.18			
CD (P=0.05)	5.44				5.79				3.41				3.59			

Table 1(b): Interaction Effect (I × F) on Straw yield (q ha⁻¹) and Harvest Index (%) of Rice during Kharif 2021 and 2022

Irrigation × Fertilizer	Biological Yield (q ha ⁻¹)								Harvest Index (%)							
	2021				2022				2021				2022			
	IR1	IR2	IR3	Mean	IR1	IR2	IR3	Mean	IR1	IR2	IR3	Mean	IR1	IR2	IR3	Mean
F1 – Control (No fertilizer)	73.5	70.1	58.8	67.5	76.1	72.5	62.18	70.26	38.78	41.51	35.69	38.83	38.5	41.38	36.99	39
F2 – 75% RDF	112	110.5	100	108	115	114	103.54	110.9	41.25	43.89	39.74	41.67	41.39	43.87	39.6	41.67
F3 – 100% RDF	127.8	125.2	115	123	131	129	118.34	126.1	41.94	44.25	41.64	42.62	41.97	44.25	41.58	42.59
F4 – 125% RDF	133.9	135.3	123	131	137	136	124.72	132.6	42.94	44.2	42.42	43.2	42.54	44.31	42.17	43.05
F5 – Farmers' practice	130.2	127.1	114	124	131	131	116.38	126.1	41.47	43.9	40.98	42.14	41.74	43.54	40.38	41.96
Mean	115.5	113.2	102	110	118	116	104.67	113	41.55	43.9	40.71	42.08	41.41	43.83	40.7	42.02
SEm ±	3.71				3.95				1.28				1.35			
CD (P=0.05)	10.81				11.34				3.39				3.87			

Table 2: Effect of Irrigation Methods and fertilizer levels on Cost of cultivation (₹ ha⁻¹), Gross returns (₹ ha⁻¹), Net returns (₹ ha⁻¹) and B:C of rice during Kharif 2021 and 2022

Treatments	Cost of cultivation (₹ ha ⁻¹)		Gross returns (₹ ha ⁻¹)		Net returns (₹ ha ⁻¹)		B:C	
	2021	2022	2021	2022	2021	2022	2021	2022
Irrigation								
IR1	43800	44800	167184	168448	123384	123648	3.82	3.76
IR2	40800	41300	172392	177784	131592	136484	4.23	4.30
IR3	37800	38300	139208	143604	101408	105304	3.68	3.75
Mean	40800	41466.67	159594	163178	118794	121711.33	3.91	3.94
SEm (±)			2875.3	2958.6	2444.1	2581.2	0.092	0.097
CD (5%)			8591.4	8832.4	7304.3	7716.2	0.27	0.29
Fertilizer								
F1 – Control	31800	31800	86856	90772	55056	58972	2.73	2.85
F2 – 75% RDF	37190	37190	146944	151536	109754	114346	3.95	4.07
F3 – 100% RDF	38985	38985	170984	175576	131999	136591	4.39	4.50
F4 – 125% RDF	40780	40780	184032	186408	143252	145628	4.51	4.57
F5 – Farmers' practice	37190	37190	170608	173332	133418	136142	4.59	4.66
Mean	37189	37189	151884	155524	114695	118335	4.08	4.18
SEm ±			2631.7	2712.3	2278.4	2391.5	0.086	0.091
CD (P=0.05)			7863.2	8107.3	6806.5	7131.4	0.26	0.27

Table 2(a): Interaction Effect (I × F) on Cost of cultivation (₹ ha⁻¹), Gross returns (₹ ha⁻¹), Net returns (₹ ha⁻¹) and B:C of rice during Kharif 2021 and 2022

Irrigation × Fertilizer	Cost of cultivation (₹ ha ⁻¹)		Gross returns (₹ ha ⁻¹)		Net returns (₹ ha ⁻¹)		B:C	
	2021	2022	2021	2022	2021	2022	2021	2022
IR1F1	43800	44800	94500	97260	50700	52460	2.16	2.17
IR1F2	49190	50190	151760	156280	102570	106090	3.09	3.11
IR1F3	50985	51985	175640	179880	124655	127895	3.44	3.46
IR1F4	52780	53780	187780	190320	135000	136540	3.56	3.54
IR1F5	49190	50190	177240	179040	128050	128850	3.60	3.57
IR2F1	40800	41300	95500	98500	54700	57200	2.34	2.38
IR2F2	46190	46690	157900	163120	111710	116430	3.42	3.49
IR2F3	47985	48485	180160	185040	132175	136555	3.75	3.82
IR2F4	46190	46690	194500	196380	148310	149690	4.21	4.21
IR2F5	46190	46690	181660	185780	135470	139090	3.93	3.98
IR3F1	37800	38300	70568	76836	32768	38536	1.87	2.01
IR3F2	43190	43690	131472	135508	88282	91818	3.04	3.10
IR3F3	44985	45485	157452	161428	112467	115943	3.50	3.55
IR3F4	46780	47280	170116	172224	123336	124944	3.64	3.64
IR3F5	43190	43690	153224	154876	110034	111186	3.55	3.54
Mean	45949.67	46616.33	151964.80	155498.13	106015.13	108881.80	3.27	3.31
SEm ±			4559.6	4677.2	3948.2	4140.6	0.149	0.156
CD (P=0.05)			13630.1	13976.2	11803.3	12373.5	0.45	0.47

Conclusion

The study demonstrates that productivity and profitability of direct seeded rice are strongly governed by the synergistic interaction between irrigation scheduling and nutrient management. The irrigation regime IR2, coupled with F4 (125% RDF), consistently optimized yield attributes, grain yield and economic returns, indicating superior resource-use efficiency. Conversely, sub-optimal input combinations resulted in marked yield and profit reductions. Thus, precise synchronization of water and nutrient supply is essential for achieving sustainable intensification and maximizing economic viability of DSR under Vindhya Plateau conditions.

References

1. Bouman BAM, Humphreys E, Tuong TP, Barker R. Rice and water. *Adv Agron.* 2007;92:187-237.
2. Carrijo DR, Lundy ME, Linquist BA. Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. *Agric Water Manag.* 2017;182:1-12.
3. Cassman KG, Peng S, Olk DC, Ladha JK, Reichardt W, Dobermann A, *et al.* Opportunities for increased nitrogen-use efficiency from improved resource management in irrigated rice systems. *Field Crops Res.* 1998;56(1-2):7-38.
4. Dobermann A, Fairhurst T. Rice: Nutrient disorders and nutrient management. International Rice Research Institute; 2000.
5. Jat ML, Saharawat YS, Gupta R, Kumar V. Conservation agriculture in cereal systems of South Asia: Nutrient management perspectives. *Field Crops Res.* 2019;232:1-15.
6. Kumar R, Singh Y, Chauhan BS. Water productivity of rice under different irrigation regimes in South Asia. *Field Crops Res.* 2018;218:1-10.
7. Kumar V, Ladha JK. Direct seeding of rice: Recent developments and future research needs. *Adv Agron.* 2011;111:297-413.
8. Ladha JK, Pathak H, Krupnik TJ, Six J, van Kessel C. Efficiency of fertilizer nitrogen in cereal production: Retrospects and prospects. *Adv Agron.* 2005;87:85-156.
9. Lampayan RM, Rejesus RM, Singleton GR, Bouman BAM. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Res.* 2015;170:95-108.
10. Liu Q, Zhou X, Li J, Wang X. Nitrogen management improves yield and nitrogen use efficiency of rice under different water regimes. *Agron J.* 2021;113(1):1-12.

11. Sandhu SS, Mahal SS, Vashistha M. Irrigation scheduling and water productivity in direct seeded rice systems. *Agric Water Manag.* 2021;243:106432.
12. Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. Agricultural sustainability and intensive production practices. *Nature.* 2002;418:671-677.
13. Tuong TP, Bouman BAM, Mortimer M. More rice, less water—Integrated approaches for increasing water productivity in irrigated rice-based systems. *Plant Prod Sci.* 2005;8(3):231-241.
14. Yadav GS, Lal R, Meena RS, Datta M, Babu S. Resource conservation technologies for sustainable management of rice-based systems. *Agronomy.* 2020;10(1):123.
15. Yoshida S. *Fundamentals of rice crop science.* International Rice Research Institute; 1981.
16. Zhang X, Davidson EA, Mauzerall DL, Searchinger TD, Dumas P, Shen Y. Managing nitrogen for sustainable development. *Sci Total Environ.* 2020;712:136532.