



Productivity and Economic Assessment of Diverse Rice (*Oryza sativa* L.) Varieties with Varied Nitrogen Levels in Eastern Indo-Gangetic Plains

Mohammad Hashim, Man Mohan Deo¹ and Sanjeev Kumar²

ICAR- Indian Agricultural Research Institute, Regional Station Pusa Samastipur -848 125, India

¹ICAR- Indian Institute of Pulses Research, Kanpur-208 024, India

²ICAR- National Dairy Research Institute, Karnal -132 001, India

E-mail: hashimagronomy@gmail.com

Abstract: During the *Kharif* seasons of 2020 and 2021, a field experiment was performed at the Indian Agricultural Research Institute (ICAR), Regional Station, Pusa, Bihar, to investigate the impact of different rice varieties and nitrogen levels on growth, yield, and economic aspects. Five varieties of rice, namely PNR 381, Rajendra Sweta, Sugandha-5, Pusa Sambha-1850, and Pusa-44, along with five nitrogen levels (0, 60, 120, 180, and 240 kg N/ha), were assessed. A progressive improvement in growth parameters and yield as nitrogen levels increased from the control to 200% recommended dose of nitrogen (RDN) equivalent to 240 kg/ha. The application of nitrogen at 240 kg N/ha resulted in significantly elevated plant height (102.1 cm), panicle length (27.1 cm), 1,000 grain weight (21.3 g), grains per panicle (200.9), grain yield (4.94 t/ha), net returns (₹ 61104/ha), and B:C ratio (2.27), as well as increased gross energy output, net energy return, energy use efficiency, and energy productivity. The Pusa-44 variety demonstrated superior performance compared to the other varieties tested. In conclusion, for the calcareous soil of the Indo-Gangetic Plains, cultivating the Pusa-44 rice variety along with the application of 150% RDN (180 kg N/ha) emerges as the optimal strategy to improve productivity, profitability and energetic.

Keywords: Economics, Energetics, Nitrogen levels, Rice, Varieties, Yield

Rice (*Oryza sativa* L.) constitutes a fundamental dietary staple for over half of the South Asian population and serves as a principal energy source in the North-Eastern Plain Zone of India (Hashim et al 2021). Despite being a water-intensive crop, it is cultivated across diverse ecosystems in the Indo-Gangetic Plains of India. The demand for rice continues to escalate, with projections estimating a requirement of approximately 140 million tons by 2025 (Singh et al 2019). In order to endure current food production and meet future demands, India must enhance rice productivity by approximately 3% annually (Kumar et al 2017). Rice is highly responsive to nutrient management, and the judicious application of fertilizers is critical for achieving sustainable and increased rice production. Improper nutrient use, particularly the indiscriminate application of major nutrients and intensive cropping, can result in a negative nutrient balance (Nadeem and Farooq, 2019). The sustainability and productivity of the rice-wheat cropping system are jeopardized by declining soil health, leading to diminished grain yields (Kumar et al 2016, Singh et al 2015).

The continuous cultivation of intensive rice-wheat sequences, coupled with discriminatory nutrient application, has contributed to the degradation of soil fertility, including the depletion of primary, secondary, and micronutrients (Prasad et al 2019). Given rice's substantial reliance on

nitrogenous fertilizers, it is imperative to address the varied nitrogen (N) requirements in transplanted rice due to continuous flooding during cultivation. Substantial losses, exceeding 40–50% of applied nitrogen, occur through mechanisms such as ammonia volatilization, denitrification, leaching, and runoff after fertilizer application (Hakeem et al 2012, Fu et al 2023, Kumari et al 2022). These losses not only diminish yield and economic efficiency but also pose severe environmental ramifications (Houlton et al 2019, Xu et al 2020, Cowan et al 2021).

Therefore, it is imperative to ascertain optimal nitrogen levels and identify high-yield varieties. Limited research has been conducted on determining the ideal nitrogen levels for diverse rice varieties cultivated in calcareous lowland soil. Consequently, this study aims to evaluate the performance of different rice varieties in calcareous soil within the Indo-Gangetic Plains under varying nitrogen levels.

MATERIAL AND METHODS

Experimental site: Two-year field experiment, encompassing the consecutive rainy seasons of 2020 and 2021, was executed at the ICAR-Indian Agricultural Research Institute, Regional Station, Pusa, Samastipur, Bihar, India. The experimental site is characterized by geographical coordinates of 25°58'49" N latitude, 85°40'48"

E longitude, and an elevation of 52.12 meters above mean sea level. The region experiences a subtropical, humid climate characterized by hot summers and cold winters. The recorded rainfall during 2020 and 2021 was 1633.2 mm and 1883.6 mm, respectively (Fig. 1). The soil at the experimental site exhibited a sandy loam texture, low organic carbon content (0.36%), a pH of 8.3, an electrical conductivity (EC) of 0.25 dS/m, and an available nitrogen content of 185 kg/ha.

Treatment details and crop management: Twenty-five treatment combinations, involving five levels of nitrogen application (control, 50% RDN, 100% RDN, 150% RDN, and 200% RDN) in the main-plot and five rice varieties (PNR-381, Rajendra Sweta, Sugandha-5, Pusa Sambha-1850, and Pusa-44) in the sub-plot, were examined using a split-plot design with three replications. The experiment spanned two consecutive years, with rice planted in a fixed plot and treatments superimposed on the same plot each year. Seedlings, grown in a well-prepared nursery bed and transplanted after 21 days in the main field with spacing of 20 cm × 15 cm. The recommended nitrogen doses was applied, with half as basal and the remaining half top-dressed in two equal split doses at active tillering and panicle initiation stage. Uniform doses of phosphorus and potassium were applied at 60 kg P₂O₅ and 40 kg K₂O, respectively, as basal doses.

Growth parameters, yield and economics: Upon reaching maturity, one border row surrounding the experimental plots was harvested, and the remaining net plot area was manually harvested using sickles to determine grain and straw yields. Dry matter efficiency (DME) was calculated using the methodology proposed by Kumar et al (2017). By multiplying the grain yield with the minimum support price (MSP) and incorporating the market value of by-products (such as straw) for the specific year, the gross return was determined. Net income, denominated in ₹/ha, was then computed as the

disparity between gross returns and cultivation costs.

Energy calculation: Energy-use efficiency (EUE) was subsequently calculated as per Mittal and Dhawan (1988).

$$EUE = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

Net energy (MJ/ha) = Energy Output (MJ/ha) - Energy input (MJ/ha)

Statistical analysis: The data were analyzed by analysis of variance using OPSTAT Software (Sheoran et al 1998).

RESULTS AND DISCUSSION

Growth parameters: Diverse nitrogen levels exerted a pronounced influence on the height of rice plants, exhibiting a range from 72 cm to 102.1 cm across the various treatments (Table 1). Specifically, plots treated with 200% of the recommended dose of nitrogen (RDN) dosage, equivalent to 240 kg/ha of nitrogen, demonstrated the greatest plant height at 102.1 cm. This elevation in height was comparable to those observed with 100 and 150% nitrogen application, signifying a statistically significant increase compared to both the control and the 50% RDN treatment. The observed augmentation in plant height, attributed to the application of nitrogen, can be attributed to the efficient uptake and concentration of nitrogen, thereby enhancing rice growth and facilitating the production of dry matter. Comparable findings were reported by Hasanuzzaman et al (2012), Ritesh et al (2014), Nayak et al (2022), Zidan (2017). Conversely, control plots, characterized by an insufficient supply of nitrogen, exhibited the lowest plant height at 72.0 cm significantly lower than all other treatments. Rice varieties exhibited distinct variations in plant height at the maturity stage. Pusa Sugandha 5 manifested the tallest plants at 99.7 cm, followed by Pusa Sambha 1850 at 93.7 cm, both significantly surpassing the plant heights of other tested rice varieties. These differences are likely attributable to genetic variations influencing growth attributes, particularly plant height. In contrast, the PNR-381 variety displayed the lowest plant height at 86.3 cm, with Pusa-44 following closely at 87.7 cm.

Yield attributing characters: The panicle length demonstrated increase with elevated nitrogen levels, particularly at 200% RDN, suggesting a potential augmentation in nutrient availability conducive to panicle development (Bahuguna et al 2023, Mondal et al 2013). Panicle length exhibited a range from 21.3 cm in the control group to 27.1 cm at 200% RDN. Furthermore, distinct rice varieties displayed variability in panicle length, with Pusa Sugandha-5 exhibiting the longest panicles (28.0 cm), followed by Pusa-44, while Rajendra Sweta presented the shortest panicles (22.5 cm). Genetic variations likely

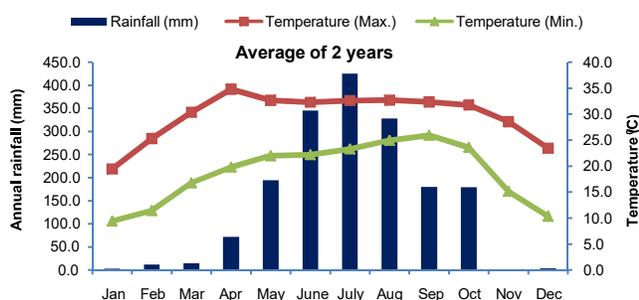


Fig. 1. Monthly average rainfall (mm), average maximum and minimum temperature (°C) in study locations (Pusa). Data were collected from the weather stations of the IARI, RS Pusa Bihar. Lines with filled triangles and squares represent the average minimum and maximum monthly temperatures, respectively, and bars represent the monthly average total rainfall

contribute to the observed differences in panicle length among diverse genotypes, corroborating findings in distinct genotypes (Sultana et al 2014). Similar trend was observed in earlier research (Bahuguna et al 2023, Sultana 2014, Mondal et al 2013, Nayak et al 2022 and Mohapatra et al 2024).

The influence of varying nitrogen levels on grain weight (1,000 grain weight) was notably apparent, with an increase from 18.1 g in the control to 21.3 g at 200% RDN, a value significantly higher than the control and equivalent to other nitrogen levels. The augmentation in panicle length, 1,000 grain weight, filled and total grains was particularly pronounced with elevated nitrogen levels up to 240 kg N/ha. This implies that nitrogen fertilization led to heightened metabolite synthesis in rice plants, contributing to the superior outcomes in terms of the number of filled grains per panicle, panicle length, and 1,000 grain weight. Conversely, control plots exhibited the highest number of chaffy or unfilled grains (47.2), whereas plots treated with 200% N/ha displayed the lowest count (Table 1). These findings resonate with previous studies (Hasanuzzaman et al 2012, Ritesh et al 2014, Zidan 2017, Ninju et al 2018, Bahuguna et al 2023). The rice genotypes exerted a substantial impact on both grain weight and the number of grains per panicle. Pusa Sugandha-5 demonstrated the highest grain weight (24.5 g/1000 grain), a statistically significant difference from other varieties, while Rajendra Sweta exhibited the lowest grain weight (15.7 g/1000 grain). This opinion aligns with the

research of Renuka et al (2013), underscoring the role of genetics in determining rice test weight. Pusa Sambha-1850 documented the significantly maximum total number of grains per panicle (230.8/panicle), coupled with the highest count of unfilled or chaffy grains, surpassing even Rajendra Sweta. Pusa-44 displayed the lowest number of unfilled grains (27.2). This divergence in unfilled grain counts may contribute to the superior yield observed in Pusa-44.

Productivity: The influence of varying nitrogen levels on rice productivity is discernible through the data presented here. The augmentation in grain yield with the elevation of nitrogen levels, reaching its zenith at 200% of the recommended dose, registering at 4.94 t/ha (Table 2). Application of 200% RDN (240 kg N/ha) exhibited substantial elevated yield of grain (4.94 t/ha), straw (9.12 t/ha), and biological yield (14.05 t/ha), respectively, on par with 150% RDN (180 kg N/ha). The application of 200% RDN resulted in a 64.59, 31.42, 10.65, and 4.00% increased grain yield compared to control, 50%, 100%, and 150% RDN, respectively. The application of 150% RDN yielded 58.38, 26.36, and 6.39% higher grain yields compared to control, 50%, and 100% RDN, primarily attributed to heightened growth yield attributes with amplified levels of nitrogen application, as reported by Kumar et al (2018). The 4% increment in yield was with the fertilization of 200% RDN in comparison to 150% RDN and may be due to efficient vegetative growth and sink development, in alignment with earlier studies (Salahuddin et al 2009, Nayak et al 2022, Kumar et al 2014). Consequently, overall yield

Table 1. Effect of nitrogen rates on growth and yield attributing characters of rice genotypes under transplanted condition in calcareous soil (Pooled data of 2 years)

Treatment	Plant height (cm)	Panicle length (cm)	1000-grain weight (g)	Grains/panicle			Harvest Index
				Filled	Un-filled	Total	
Nitrogen level							
Control	72.0	21.3	18.1	130.8	47.2	178.0	36.21
50% RDN	85.0	23.6	19.9	148.2	41.2	189.4	35.08
100% RDN	96.8	25.6	20.6	158.4	40.4	198.8	35.12
150% RDN	99.4	26.5	20.9	161.2	38.2	199.4	35.19
200% RDN	102.1	27.1	21.3	166.8	34.1	200.9	35.11
CD (p=0.05)	7.7	1.1	1.5	9.4	7.9	12.2	0.07
Varieties							
PNR-381	86.3	23.9	21.6	133.5	41.3	174.9	35.39
Rajendra Sweta	88.1	22.5	15.7	139.5	44.3	183.7	35.24
Pusa Sugandha-5	99.7	28.0	24.5	131.8	42.9	174.7	35.34
Pusa-44	87.7	25.2	21.8	175.2	27.2	202.4	35.35
Pusa Sambha-1850	93.7	24.4	17.3	185.4	45.4	230.8	35.40
CD (p=0.05)	3.5	1.2	0.9	12.9	5.7	14.8	0.04

Control (0 kg N), 50% RDN (60 Kg N), 100% RDN (120 Kg N), 150% RDN (180 Kg N), 200% RDN (240 Kg N)

increased as a result of an augmented number of panicles per unit area and heavier grains per panicle.

Similar to grain yield, straw yield exhibited an increase up to 200% RDN, leading to taller plants, augmented tiller density, and increased biomass production, consistent with the observations of Kumar et al (2018, 2019). Significantly heightened crop productivity (36.73 kg/ha/day) and DME (104.60 kg/ha/day) were recorded with the application of 200% RDN, comparable with 150% RDN, and significantly surpassed the remaining treatments. Incremental levels of nitrogen correspondingly improved crop productivity and DME up to the maximum applied nitrogen levels (200% RDN) due to higher yields within the same treatment.

In addition to nitrogen rates, rice varieties also exerted a significant influence on rice yields. Pusa-44 demonstrated substantial increased yield of grain (5.21 t/ha), straw (9.56 t/ha), and biological yield (14.77 t/ha) compared to remaining varieties tested. Pusa Sambha 1850 emerged as the second-highest yielding variety. These findings align with the results reported by earlier researchers (Danish et al 2022, Nayak et al 2022, Bahuguna et al 2023).

Economics: The aggregated data from two consecutive years indicates that the highest cultivation cost was observed in the 200% RDN treatment, amounting to ₹ 48,004/ha, followed by the 150% RDN. Conversely, the control plots, devoid of nitrogen application, exhibited the lowest cultivation cost., the application of 200% RDN resulted in significantly elevated gross returns (₹ 109,108/ha) and net

returns (₹ 61,104/ha) with a corresponding benefit-cost (B: C) ratio of 2.27, a performance that was on par with the 150% RDN treatment (Table 2). The 150% RDN application demonstrated 26.27 and 6.35% higher gross returns and 10.60 and 54.52% higher net returns compared to the 50% and 100% RDN treatments, respectively. However, the 200% RDN application yielded only a 5.84% increase in net returns compared to the 150% RDN treatment, possibly attributable to the higher yield achieved under the same treatment conditions. Similar inclination was previously reported by Kumar et al (2019). Significant disparities were evident among rice varieties concerning gross returns, net returns, and the B: C ratio. Pusa-44 exhibited notably higher gross returns (₹ 115,090/ha), net returns (₹ 68,602/ha), and a B: C ratio of 2.47, followed by Pusa Sambha-1850. The net returns of Pusa-44 surpassed those of Pusa Sambha-1850, Pusa Sugandha 5, Rajendra Sweta, and PNR-381.

Energetics: Combined data from two years demonstrated an escalating trend in input energy consumption corresponding to increasing nitrogen levels. The minimum input energy consumption was at lower nitrogen levels, and this increased progressively in the order of control <50% RDN <100% RDN <150% RDN <200% RDN, primarily attributed to heightened input requirements, notably nitrogen fertilization (Table 3). The highest energy input was registered at 200% RDN, followed by 150% RDN. Kumar et al (2018, 2019) also observed similar trend. The application of 200% RDN resulted in the highest net energy returns

Table 2. Effect of nitrogen levels on yields and economics of rice genotypes under transplanted condition in calcareous soil (Pooled data of 2 years)

Treatment	Productivity (t/ha)			Crop productivity (kg/ha/day)	Dry matter efficiency (kg/ha/day)	Cost of Production (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)						
Nitrogen level									
Control	3.00	5.29	8.28	22.36	61.79	45235	65748	20513	1.45
50% RDN	3.76	6.95	10.70	27.95	79.65	45681	83045	37364	1.82
100% RDN	4.46	8.24	12.70	33.26	94.69	46390	98597	52207	2.13
150% RDN	4.75	8.74	13.49	35.38	100.54	47128	104862	57734	2.23
200% RDN	4.94	9.12	14.05	36.73	104.60	48004	109108	61104	2.27
CD (p=0.05)	0.21	0.39	0.61	1.62	4.61	-	4735	4735	0.10
Varieties									
PNR-381	3.55	6.50	10.05	30.86	87.41	46487.6	78364	31876	1.68
Rajendra Sweta	3.67	6.78	10.45	26.62	75.74	46487.6	81196	34708	1.74
Pusa Sugandha-5	4.12	7.56	11.68	32.46	91.96	46487.6	91021	44533	1.95
Pusa-44	5.21	9.56	14.77	35.22	99.79	46487.6	115090	68602	2.47
Pusa Sambha-1850	4.34	7.93	12.27	30.53	86.38	46487.6	95690	49203	2.05
CD (p=0.05)	0.30	0.55	0.84	2.25	6.39	-	6542	6542	0.14

Table 3. Effect of nitrogen levels on energetics of rice genotypes under transplanted condition in calcareous soil (Pooled data of 2 years)

Treatment	Energy input (MJ/ha)	Energy output (MJ/ha)			Net energy returns (MJ/ha)	Energy ratio (Energy use efficiency)	Energy productivity (kg /MJ/ha)
		Grain	Straw	Total			
Nitrogen level							
Control	13210	44044	66080	110124	96914	8.34	0.227
50% RDN	16870	55203	86818	142022	125152	8.42	0.223
100% RDN	20506	65557	102950	168507	148001	8.22	0.217
150% RDN	24142	69752	109270	179022	154880	7.42	0.197
200% RDN	27778	72543	113954	186497	158719	6.71	0.178
CD (p=0.05)	-	3150	4927	8077	8077	0.56	0.015
Varieties							
PNR-381	20501	52173	81283	133457	112956	6.60	0.176
Rajendra Sweta	20501	53993	84733	138726	118225	6.87	0.182
Pusa Sugandha-5	20501	60593	94464	155058	134557	7.80	0.208
Pusa-44	20501	76614	119459	196074	175573	9.67	0.258
Pusa Sambha-1850	20501	63725	99133	162857	142356	8.16	0.218
CD (p=0.05)	-	4351	6823	11173	11173	0.58	0.015

Table 4. Renewable and non-renewable input energy of rice genotypes under different nitrogen levels (Pooled data of 2-years)

Source of energy	Renewable and non-renewable input energy (MJ/ha)					Percentage				
	N ₁	N ₂	N ₃	N ₄	N ₅	N ₁	N ₂	N ₃	N ₄	N ₅
Direct renewable (Human & water)	4547	4571	4571	4571	4571	34	27	22	19	16
Direct non-renewable (Diesel)	5321	5321	5321	5321	5321	40	32	26	22	19
Indirect renewable (Seed)	625	625	625	625	625	5	4	3	3	2
Indirect non-renewable (Machinery, fertilizer, chemicals)	2717	6353	9989	13625	17261	21	38	49	56	62

N₁: Control, N₂: 50% RDN, N₃: 100% RDN, N₄: 150% RDN, N₅: 200% RDN

(158719 MJ/ha) and gross energy output (186497 MJ/ha), comparable to 150% RDN and significantly superior to other nitrogen levels. Comparing 200% RDN with 150% RDN, the latter exhibited the highest EUE (7.42) and energy productivity (0.197 kg/MJ/ha), signifying a more judicious utilization of energy. This discrepancy is attributed to the intensified energy input consumption at higher nitrogen levels.

Within the array of rice varieties examined, Pusa-44 stood out with significantly elevated gross energy output (196074 MJ/ha), net energy returns (175573 MJ/ha), energy use efficiency (9.67), and energy productivity (0.258 kg/MJ/ha). This superiority is attributed to the variety's higher grain and straw yields coupled with lower energy utilization, consistent with findings reported by Kumar et al (2019). Examining different energy sources, the distribution among direct renewable, direct non-renewable, indirect renewable and indirect non-renewable sources varied across nitrogen levels. The percentage share of direct renewable, direct non-

renewable and indirect renewable energy sources decreased from control to 200% RDN. However, the share was increasing from control to 200% RDN (Table 4).

CONCLUSION

Based on the findings of the two-year investigation, it is deduced that cultivating the Pusa-44 rice variety in conjunction with 150% recommended dose of nitrogen (RDN) application proves to be a more advantageous and optimal strategy for attaining heightened levels of productivity, profitability, and energetic efficiency in the context of calcareous soils prevalent in the Indo-Gangetic Plains of India.

AUTHOR'S CONTRIBUTIONS

Mohammad Hashim: Conceptualization, writing-original draft; Man Mohan Deo: Statistical Analysis; Sanjeev Kumar: Writing, reviewing and editing. The final version was approved by all authors.

references

- Bahuguna A, Singh DK, Supriya, Kumar A, Garg K, Verma P, Patel S and Sudarshan S 2023. Agronomic evaluation of rice (*Oryza sativa*) genotypes under varying fertility levels. *Indian Journal of Agricultural Sciences* **93**(11): 1258-1261.
- Cowan N, Bhatia A, Drewer J, Jain, N, Singh R, Tomer R, Kumar V, Kumar O, Prasanna R, Ramakrishnan B, Kumar D, Bandyopadhyay S K, Suttan M and Pathak M 2021. Experimental comparison of continuous and intermittent flooding of rice in relation to methane, nitrous oxide and ammonia emissions and the implications for nitrogen use efficiency and yield. *Agriculture, Ecosystem & Environment* **319**: 107571.
- Danish M, Kumar M, Pramanick B, Singh SK and Hashim M 2022. Enhancing crop productivity, water and nitrogen use efficiency of *kharif* maize through planting methods, mungbean intercropping and nitrogen management practices. *Journal of Cereal Research* **14**(1): 97-102.
- Devasenapathy P, Senthil Kumar G and Shanmugam PM 2009. Energy management in crop production. *Indian Journal of Agronomy* **54**(1): 80-90.
- Fu Z, Zhang K, Zhang J, Zhang Y, Cao Q, Tian Y, Zhu, Y, Cao W and Liu X 2023. Optimizing nitrogen application and sowing date can improve environmental sustainability and economic benefit in wheat-rice rotation. *Agricultural Systems* **204**(C): 103536.
- Hakeem K R, Chandna R, Altaf A and Muhammad I 2012. Physiological and molecular analysis of applied nitrogen in rice genotypes. *Rice Science* **19**: 213-222.
- Hasanuzzaman M, Ali MH, Karim MF, Masum SM and Mahmud JA 2012. Response of hybrid rice to different levels of nitrogen and phosphorus. *International Research Journal of Applied and Basic Sciences* **3**(12): 2522-2528.
- Hashim M, Singh VK, Singh KK, Dhar S and Rathore SS 2021. Effect of foliar application of iron and zinc on performance of transplanted rice in middle gangetic plains of Bihar. *Journal of AgriSearch* **8**(2): 72-78.
- Houlton BZ, Almaraz M, Aneja V, Austin AT, Bai E, Cassman KG, Compton JE, Davidson EA, Erisman JW, Galloway JN, Gu B, Yao G, Martinelli LA, Scow K, Schlesinger WH, Tomish TP, Wang C and Zhang X 2019. A world of cobenefits: Solving the global nitrogen challenge. *Earth's Future* **7**: 865-872.
- Kumar A, Choudhary AK, Pooniya V, Singh VK, Singh U, Singh U, Praharaj CS, Singh SS and Singh N 2016. *Soil factors associated with micronutrient acquisition in crops-biofortification perspective* (New Delhi: Springer), pp 159-176.
- Kumar R, Mishra JS, Kumar S, Hans H, Bhatt BP, Srivastava AK and Singh S 2019. Production potential, economics and energetics of rice (*Oryza sativa*) genotypes as influenced by varying levels of nitrogen. *Indian Journal of Agricultural Sciences* **89**(11): 94-97.
- Kumar R, Mishra JS, Dwivedi SK, Kumar R, Rao KK, Samal SK, Choubey AK and Bhatt BP 2017. Nutrient uptake and content in sorghum cultivars (*Sorghum bicolor* L.) under summer environment. *Indian Journal of Plant Physiology* **22**(3): 309-315.
- Kumar S, Kumar R, Mishra JS, Dwivedi SK, Prakash V, Rao KK, Singh, AK, Bhatt BP, Singh SS, Haris AA, Kumar V, Srivastava AK, Singh S and Yadav A 2018. Productivity and profitability of rice (*Oryza sativa*) genotypes as influenced by crop management practices under middle Indo-Gangetic Plains. *Indian Journal of Agronomy* **63**(1): 45-49.
- Kumar S, Srinivasa G, Raju M and Mahendra Kumar R 2014. Growth characteristics, yield attributes, grain yield and quality of rice hybrids as influenced by nitrogen fertilization. *Progressive Agriculture* **14**(1): 125-129.
- Kumari P, Devi LL, Kumar, A, Pandey A, Sinha SK and Singh A P 2022. Differential response of rice genotypes to nitrogen availability is associated with the altered nitrogen metabolism and ionic balance. *Environmental and Experimental Botany* **198**(3691369):104847.
- Mittal JP and Dhawan KC 1988. *Research manual on energy requirements in agricultural sector*. ICAR, New Delhi. pp. 20-23.
- Mohapatra SS, Behera SD, Behera B, Sahu G, Jena J, Giri KS, Behera SD, Sahoo RK, Mishra S and Panda M 2024. Yield and quality of aromatic rice (*Oryza sativa*) varieties under nutrient management in organic environment of Coastal Odisha. *Indian Journal of Ecology* **51**(3): 552-558.
- Mondal S, Bauri A, Pramanik K, Ghosh M, Malik GC and Ghosh D C 2013. Growth, productivity and economics of rice as influenced by fertility level and plant density. *International Journal of Bio-resource and Stress Management* **4**(4): 547-554.
- Nadeem F and Farooq M 2019. Application of micronutrients in rice-wheat cropping system of South Asia. *Rice Science* **26**(6): 356-371.
- Nayak K, Sar K and Mishra G 2022. Growth and yield of rice (*Oryza sativa* L.) varieties as influenced by nutrient management practices under irrigated-aerobic condition. *Indian Journal of Ecology* **49**(5): 1710-1713.
- Njinju SM, Samejima H, Katsura K, Kikuta M, Gweyi-Onyango J P, Kimani JM, Yamauchi A and Makihara D 2018. Grain yield responses of lowland rice varieties to increased amount of nitrogen fertilizer under tropical highland conditions in central Kenya. *Plant Production Science* **21**(2): 59-70.
- Prasad S, Agrawal KK and Kumar R 2019. Productivity, profitability, quality and nutrient uptake of heat tolerant wheat (*Triticum aestivum*) cultivars as influenced by staggered sowing and nutrition levels. *Indian Journal of Agricultural Sciences* **89**(4): 670-677.
- Renuka DK, Sudhakar P and Sivasankar A 2013. Evaluation of physiological efficiency and yield potential of rice under aerobic condition. *Bioinfolet* **10**(1B): 209-213.
- Ritesh S, Gangwar RK, Yadav V and Kumar R 2014. Response of Basmati (*Oryza sativa*) cultivars to graded nitrogen levels under transplanted conditions. *International Journal of Research in Applied, Natural and Social Sciences* **2**(9): 33-38.
- Salahuddin KM, Chowdhury SH, Muniram S, Islam M and Parvin S 2009. Response of nitrogen and plant spacing of transplanted aman rice. *Bangladesh Journal of Agriculture Research* **34**: 279-285.
- Sheoran OP, Tonk DS, Kaushik LS, Hasija RC and Pannu RS 1998. *Statistical Software Package for Agricultural Research Workers. Recent Advances in information theory, Statistics & Computer Applications* by D.S. Hooda & R.C. Hasija Department of Mathematics Statistics, CCSHAU, Hisar (139-143).
- Singh A, Singh Y, Singh R, Upadhyay PK and Kumar R 2019. Effect of cultivars and weed management practices on weeds, productivity and profitability in ZT direct seeded rice. *Indian Journal of Agricultural Sciences* **89**(2): 353-359.
- Singh SS, Singh AK, Kumar S, Mishra JS, Haris AA, Sangle UR, Bhatt BP, Singh SK, Yadav A, Singh US and Singh S 2015. Performance of lentil under rice-lentil under different tillage in drought-prone rainfed ecosystem of Bihar. *Journal of AgriSearch* **2**(4): 263-268.
- Sultana R and Islam MK 2014. Performance evaluation of two rice varieties under different levels of salinity stress. *Bangladesh Research Publication Journal* **2**: 61-64.
- Xu P, Chen A, Houlton BZ, Zeng Z, Wei S, Zhao C, Lu H, Liao Y, Zheng Z, Luan S and Zheng Y 2020. Spatial variation of reactive nitrogen emissions from China's croplands codetermined by regional urbanization and its feedback to global climate change. *Geophysical Research Letter* **47**, 10.1029/2019GL086551.
- Zidan AA 2017. Performance of some rice genotypes to various nitrogen levels. *Journal of Plant Production, Mansoura University* **8**(1): 103-109.