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ORIGINAL ARTICLE

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Effect of Nano-Urea and Zinc Sulphate Foliar Spray on Crop Growth, Yield and Uptake of Rice Varieties in Alluvial Soils

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ABSTRACT

Among the major plant nutrients, excessive use of nitrogen (N) fertilizer in rice (*Oryza sativa* L.) cultivation results in significant nutrient losses and environmental degradation. Foliar nano fertilizers offer a promising solution to enhance nutrient use efficiency, reduce losses, and mitigate environmental impacts in rice production systems. This study aims to evaluate the effects of foliar fertilization of nano-urea and zinc sulphate on the performances of rice varieties in the new alluvial soils of West Bengal, India during *kharif* season. In this experiment, three rice cultivars of different duration viz. V_1- Shatabdi (110 days), V_2-Lalswarna (135 days) and V_3-Kataribhog (150 days) were kept in main plots and four nutrient managements like F_1-Prilled N_0 + FYM (@ 5t ha^{-1}) + Nano-urea @0.4%, F_2- Prilled N_{30} kg ha^{-1} + Nano-urea @0.4% dilution, F_3-Prilled N_{60} kg ha^{-1} + ZnSO4, $7H_2O$ @0.5% dilution and F_4- Only prilled N_{60} kg ha^{-1} were placed in sub-plots. Results revealed that rice cv. 'Lalswarna' recorded the highest grain yield followed by Shatabdi with harvest index. Supplementation of 50% prilled urea by N_{30} kg ha^{-1} + nano-urea 0.4% foliar application achieved at par grain yield of rice with 100% RDN as prilled urea @ N_{60} kg ha^{-1}. The application of 100% RDN as prilled urea by N_{60} kg ha^{-1} + ZnSO4 *foliar @ 0.5% dilution along with full 30 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} had the significant impact on grain yield of 4490 kg ha^{-1} accompanied by the highest numbers of effective tillers, more filled grains with low chaffs and the highest test weight. The interaction effects of variety and foliar application revealed the highest grain yield achievedby 'Lalswarna' variety with the application of prilled urea @ N_{60} kg ha^{-1} + foliar ZnSO4 at 20 and 40 DAT, and the lowest grain yield was noted in aromatic cultivar 'Kataribhog' by the application of no prilled urea (N0) + FYM @ 5.0 t ha^{-1} + foliar nano-urea. In post-harvest soil, residual NPK availability was better in 'Kataribhog than Lalswarna variety. Based on the results of experiment, foliar application of nano-urea and zinc may be advocated considering grain yield, nutrient use efficiency for the highest net returns and B:C ratio in low land rice ecosystem of lower Indo-Gangetic plains.*

1 | INTRODUCTION

The increasing reliance on nitrogen (N) fertilizers in modern rice cultivation has raised concerns about grain quality and environmental sustainability. Nano-fertilizers, particularly nano-urea, have been suggested as alternative use to conventional urea (Reddy *et al*., 2025). Rice is one of the most important food crops in India. Globally India ranks first in rice growing areas covering 52.8 m ha and second in rice production (18%) after China (27%) with total production of 154.02 million tons (paddy) with an average productivity of 2905 kg ha^{-1} by 2025-26 (USDA, 2026). The leading rice production states are West Bengal, UP, Punjab, Odisha, Andhra Pradesh, Bihar etc. In India, the majority of rice is grown during *kharif* season (~40 million ha) under rainfed condition, and a considerable fraction of the soils in these areas have a zinc (Zn) deficiency of 49% (Mondal *et al.,* 2020; Mandal and Ghosh, 2021). Nanotechnology has the potential to profoundly transform agriculture by effectively addressing the escalating demand for plant nutrients for increasing crop production with space of growing population, while also maintaining environmental sustainability and stability. Nanotechnology offers a promising solution to address the nutrient demands of cereals for inorganic fertilizers (Upadhyay *et al*., 2023b; Santosh *et al*., 2024). Using the foliar fertilizers like nano-urea and zinc sulphate in crop cultivation is an emerging concept in the field of nutrient management of crops for augmentation of crop yield and quality (Rawat *et al.,* 2024). Foliar fertilization, a technique involving the direct application of nutrients onto the leaves, has demonstrated the ability to enhance crop productivity and enhance the quality of food products (Singh and Singh, 2018). Nitrogen plays a vital role in crucial plant processes like photosynthe-

sis and protein synthesis and aiding nutrient transport. Nano-fertilizers show potential by enhancing nutrient efficiency and penetrating cell walls. They could reduce nutrient losses by synchronizing nutrient release with plant uptake (Lv *et al*., 2019, Nandy *et al*., 20223). Urea-based nanoparticles are now recommended for agricultural nitrogen supplementation (Kiran and Chandra, 2021).

Recently, in India, IFFCO has developed nano-urea, which has been tested at the field research scale to provide essential nitrogen and enhance the effectiveness of various crops (Upadhyay *et al*., 2023b). Spraying of nano urea at the rate of 2-4 ml per lit of water at the critical growth stages may lead to better crop response, better use efficiency of nutrient, minimizing nutrient loss and improves nutrient uptake from the rhizosphere. However, limited research has been conducted on studying the interaction effects of different levels of recommended dose of nitrogen with nano-urea in rice. The standardization of nano-urea for higher productivity, profitability and economics in rice, especially under new alluvial soil of West Bengal needs to be investigated. Validation of foliar fertilization of nano-urea and zinc sulphate on rice varieties of different duration under varying nutrient gradients in rainfed conditions is crucial and further research is required to evaluate how well it can be integrated with prilled nitrogen sources is a new field of inquiry.

2 | MATERIALS AND METHODS

2.1 | Experimental Site

The field experiment was conducted at the Agricultural Instructional Farm at Jaguli of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, situated in the new alluvial zone of West Bengal during the *kharif* season of 2023. The research station is situated at 22˚93´ N latitude and 88˚5´ E longitude with an elevation of approximately 9.75 m above the mean sea level. The experimental site also experiences a subtropical and sub-humid climate.

This experiment was conducted in split plot design with three replications comprising three main plots and four sub-plots. There were total 36 plots having each with the size of 4m × 3m and bunded with the border and a buffer of 0.6m was maintained for isolation. In this experiment, three rice cultivars of different duration viz. V_1- Shatabdi (110 days), V_2-Lal Swarna (135 days) and V_3- Kataribhog (150 days) were kept in main plots and four nutrient managements like F1-Prilled N_0 + FYM (@ 5t ha^{-1}) + Nano-urea (@0.4%), F_2-Prilled N_{30} kg ha^{-1} + Nano-urea @0.4% dilution, F_3- Prilled N_{60} kg ha^{-1} + ZnSO4, $7H_2O$ @0.5% dilution and F_4- Only prilled N_{60} kg ha^{-1} were placed in sub-plots. The recommended dose of N, P_2O_5 and K_2O was applied at the rate of 60:30:30 kg ha^{-1}. Nitrogen in the form of prilled urea was applied in three splits (½ + ¼ + ¼), full dose of phosphorus in the form of SSP as basal and of potassium in the form of MOP in two split (½ + ½). Nano-urea @4 ml lit^{-1} of water and $ZnSO_4$ @0.5% dilution were maintained in 500 lit ha^{-1} water twice at 20 DAT and 40 DAT of crop growth.

HIGHLIGHTS

- Rice cv. 'Lalswarna' recorded the highest grain yield (4490 kg ha^{-1}) followed by Shatabdi (3749 kg ha^{-1}) with harvest index of 40.07% in alluvial soils of West Bengal.
- Supplementation of 50% N by nano-urea foliar application achieved at par grain yield of rice with 100% RDN as prilled urea @ N_{60} kg ha^{-1}.
- The application of 100% RDN as prilled urea by N_{60} kg ha^{-1} + ZnSO4 foliar along with full 30 kgP_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} had the significant impact on the grain yield.
- The interaction effects of variety and foliar application revealed the highest grain yield of 4875 kg ha^{-1} was achieved by 'Lalswarna' variety with the application of prilled urea @ N_{60} kg ha^{-1} + foliar ZnSO4. This treatment had also the highest net income and B:C ratio.
- Nano-urea foliar fertilization helped to keep in-situ soil fertility, whereas, N_{60} + ZnSO4 application depleted NPK soil reserve more.

2.3 | Soil and Crop Managment

The seedlings of three different varieties like Shatabdi, Lalswarna and Kataribhog were raised in separate nurseries keeping one meter isolation distance among them during the 2nd week of July, 2023. The topography of land was medium land and the soil was sandy clay loam in texture (38-46:29-35:24-26%) belonging to the order Inceptisols of India and having pH value 7.1. Soil of this area is mostly fertile with an initial value of available NPK @ 227.12, 36.45 and 184.64 kg ha^{-1} respectively, deep and almost neutral in reaction developed from recent alluvial flood soils of the river Ganges. Intense puddling operation of soil was made by the tractor drawn rotavator two times one week ahead transplanting at the 1st week of August. At the time of transplanting similar age of seedling 4 weeks and crop spacing 20 cm × 15 cm were maintained for different duration of rice varieties. In the crop field, weeding was made manually at 20 and 40 DAS to make the plot weed free. Plant protection measures were taken care off from seedling to flowering with granular insecticide like Curbofuran (Furadon 3G @ 20 kg ha^{-1} against stem borer and soil nematode and fungicides like Carbendazim and Mancozeb WP mixture (Saaf @2g lit^{-1} water) were used against the leaf spot in per humid climate. Crop harvesting dates of Shatabdi, Lal swarna and Kataribhog were different on 2nd, 17th November and 10th December due to their varietal durations respectively.

2.4 | Agro-climatic Situation

The average annual rainfall received in this area is 1560 mm, which is essential for rice crop growth. During summer, the temperature in this place ranges from 26°C to 38°C while in winter the temperature ranges from 8°C to 26°C. Rainfall received during the crop-growing period from August to November of 2023 was 688.8 mm where the maximum rainfall was 252.9 mm received in October followed by August 230.4 mm, which were crucial for rice crop establishment and growth. Throughout growing period rice experimentation, the maximum relative humidity was consistently high ranging from 93.10 to 94.83% and the

lowest minimum relative humidity ranged from 50.80 to 71.50%. During the cropping season, the number of bright sunlight hours ranged between 3.38 and 6.60 (Table 1).

TABLE 1 Meteorological data during the crop growth period, 2023.

Period	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)	Total Evaporation (mm)	Bright Sunshine (hour)
	Max	Min	Max	Min			
August	32.53	25.88	93.55	83.68	230.4	71.5	3.38
September	32.91	25.84	94.83	85.21	199.5	63.8	3.82
October	31.88	22.75	94.32	81.87	252.9	61.7	6.23
November	29.96	17.83	93.10	79.93	6.0	50.8	6.60

Source: AICRP on Agro-Meterology, BCKV

2.5 | Data Collection

Agronomic traits such as plant height, dry matter production, crop growth rate (CGR) at different growth stages were recorded. Yield attributes including number of panicles at harvest, filled grains per panicle, chaffs, and thousand grain weights were recorded. Harvested grain yields were expressed on hectare basis at 14% moisture content. Post-harvest soil samples were analyzed for available NPK using standard laboratory procedures. Partial factor productivity (PFP) was estimated to assess the overall impact of nutrients applied in the form of fertilizers both as soil and foliar for each treatment as

$$PFP\ (kg\ kg^{-1}) = \frac{GY}{FA} \qquad (1)$$

where, GY =grain yield (kg ha^{-1}); FA- total fertilizer nutrients added (kg ha^{-1}) for each treatment.

Gross return, net benefits and B:C were computed based on prevailing local market price of respective yields as Net benefit = Gross returns minus total variable cost and B:C ratio value = Gross return divided by total cost of cultivation.

2.6 | Statistical Analysis

The collected data were analyzed using the statistical technique of analysis of variance, specifically the split plot design method, as outlined by Gomez and Gomez (1984). The analysis was conducted in MS excel. The significance of various sources of variation was assessed through Fisher and Snedecor's F test, considering the appropriate degrees of freedom. The significance of the 'F' statistics was determined and critical difference (CD) at a 5% level of significance was calculated following the Fisher and Yates table.

3 | RESULTS AND DISCUSSION

3.1 | Crop Growth

The plant growth in terms of plant height, leaf area index, tillering and dry matter production of rice varieties tested using nano-urea and zinc sulphate foliar fertilization exhibited significant variations (Table 2). Among the tested varieties, 'Lalswarna'(135 days duration) recorded the shorter plants (99.3 cm) at harvest along with more tillers (406 per m^2), high leaf area development (3.18), more dry matter production (421.6 gm^{-2}) and crop growth rate (9.02 gm^{-2} day^{-1}) at grand growth period (60 DAT) followed by 'Shatabdi' (110 days).

TABLE 2 Plant growth of rice varieties as influenced by foliar fertilizer management in new alluvial soil during *kharif*.

Treatment	Growth attributes of rice				
	Plant height at harvest (cm)	LAI at 60 DAT	Total tillers m^{-2} at 60 DAT	DM at 60 DAT (g m^{-2})	CGR at 60-harvest (g m^{-2}/day^{-1})
Variety (V)					
Shatabdi	107.2	3.30	377	405.9	8.20
Lalswarna	99.3	3.18	406	421.6	9.02
Kataribhog	153.9	3.07	321	424.8	8.41
S Em(±)	0.97	0.03	6.08	2.31	0.09
CD (p=0.5)	3.79	0.13	23.88	9.09	0.37
Fertilizer management (F)					
N_0 +FYM+ Nano-urea	115.3	3.11	345	462.4	9.81
N_{30}+Nano-urea	118.7	3.17	361	479.9	10.14
N_{60}+ $ZnSO_4$	124.7	3.25	390	504.3	10.62
N_{60}	122.9	3.21	377	490.5	10.26
S Em (±)	0.45	0.02	5.96	2.57	0.08
CD (p=0.5)	1.34	0.07	17.70	7.63	0.23

The aromatic 'Kataribhog' cultivar of long duration (150 days) recorded maximum plant height (153.9 cm) at harvest but lagging behind other varieties in total tillers (321 per m^2), LAI (3.07) and CGR at 60-harvest (8.41 g $m^{-2}day^{-1}$). Higher LAI under nano urea treatment indicates greater expansion of the photosynthetic surface, which enhances interception and utilization of solar radiation (Gautam *et al*., 2025). There was a significant variation in plant growth indices of aromatic variety and HYV varieties, amounting to 43.56 to 54.98%. This variation was due to their wide varietal duration (Golada and Debbarma, 2023; Kumar *et al*., 2023). The application of prilled N-fertilizers in four combinations with FYM, Nano-urea and Zinc Sulphate had the significant impact on plant height, LAI, total tillers, DM production and CGR of rice varieties. The maximum growth indices values like plant height (124.7 cm) at harvesting, more LAI 3.25, total tillers (390 m^{-2}), DM (504.3 per m^2) and CGR (10.62 gm^{-2} day^{-1}) were noticed with the application of prilled N_{60} + ZnSO4 followed by full prilled N_{60} kg ha^{-1}. Supplementation of 50% prilled RDN by the nano-urea i.e N_{30} + Nano-urea treatment was not found significant to increase growth attributes but at par with prilled N_{60}. This might be due to the fact that basal application of conventional prilled N fertilizers (N_{30}) along with foliar spray of nano-urea increased of enzyme activity and auxin metabolism in the plant, which in turn enhances cell enlargement and elongation thereby producing taller plants (Gaikwad *et al*., 2023; Reddy *et al*., 2024). Significantly poor growth attributes were observed with no prilled N application i.e N_0 + FYM + Nano-urea treatment. These results are in conformity with works of Arya *et al.,* 2022; Namasharma *et al*., 2023).

3.2 | Yield Attributes

The yield attributes in terms of number of effective tillers per m^2 area, panicle length, filled grains, chaffs and test weight of grains of different rice varieties grown in *kharif* season in the new alluvial zone of West Bengal were significantly influenced by variation in nitrogen fertilizer management. The variations ranged 7.39 - 4.25% among the high yielding and aromatic rice varieties of different durations. The medium duration (135 days) variety Lalswarna recorded the highest number of effective tillers (350.4 m^{-2}), maximum number of average filled grains (151.1) per panicle with less chaffs (15.9%) and the highest sink capacity of grains in terms of thousand seed weight (19.50g).Conversely, aromatic long duration Kataribhog (150 days) recorded the lowest number of effective tillers per m^2 (261) with longest panicle (25.5 cm), moderate number of grains per panicle (131.7) with moderate chaff per cent (18.2) and lowest thousand grain-weight (14.59 g). Application of N-fertilizers in four combinations with prilled urea @ N_0, N_{30} and N_{60} along with nano-urea, zinc sulphate and FYM had the significant impact on the number of effect tillers, panicle length, filled grains, chaffs and test weight of grains of rice varieties (Table 3). Application of N60 + ZnSO4 recorded the highest numbers of effective tillers (332.9), longest panicle length (25.0 cm), highest number of filled grains (141.9) with lowest chaffs (16.0%) and the highest thousand grain weight (17.63 g). Supplementation of 50%RDN by the nano-urea i.e N_{30} + Nano-urea treatment was not found significant to increase the yield attributes but at par with prilled N_{60}. The lowest number of effective tillers (287.8 m^{-2}), with shortest panicle length (23.2 cm), lowest number of grains per panicle (129.5) with low chaff per cent (16.3) and lowest thousand grain-weight (17.15 g) in combination with N_0 + FYM + nano-urea. This poor yield attributes might be associated with poor start of the plant growth at early stage as a result of no N at basal. These result are in conformity with report of Gaikwad *et al*., 2023; Arya *et al.,* 2022; Namasharma *et al*., 2023.

TABLE 3 Yield attributes of rice varieties as influenced by fertilizer management in new alluvial soils.

Treatment	Yield attributes of rice				
	Effective tillers m^{-2}	Panicle length (cm)	Filled grains $panicle^{-1}$	Chaffs $Panicle^{-1}$ (%)	Thousand grain weight (g)
Variety (V)					
Shatabdi	326.3	23.8	122.7	16.7	18.04
Lalswarna	350.4	22.7	151.1	15.9	19.50
Kataribhog	261.0	25.5	131.7	18.2	14.59
S Em (±)	7.18	0.27	1.46	0.19	0.10
CD (p=0.5)	28.20	1.05	5.73	0.75	0.37
Fertilizer management (F)					
N_0 +FYM+ n-urea	287.8	23.2	129.5	16.3	17.15
N_{30}+n-urea	309.3	23.7	132.4	18.0	17.31
N_{60}+ $ZnSO_4$	332.9	25.0	141.9	16.0	17.63
N_{60}	322.2	24.0	136.9	17.7	17.42
S Em (±)	5.26	0.28	0.90	0.12	0.16
CD (p=0.5)	15.63	0.83	2.68	0.35	0.47

RDF: NPK @ 60:30:30 kg ha^{-1}

3.3 | Yield and Harvest Index

Grain, straw and biological yield, and harvest index of rice varieties grown in *kharif* season in the NE New Alluvial Zone of West Bengal were significantly influenced by variation in nitrogen fertilizer management (Table 4). Wide variations (16.50 - 52.50%) were observed among the high yielding and aromatic rice varieties of different durations. The variety Lalswarna (135 days) recorded the highest grain yield (4490 kg ha^{-1}), straw yield (6682 kg ha^{-1}), biological yield (11193 kg ha^{-1}) and also the highest harvest index of 40.07%. On the contrary, aromatic long duration Kataribhog (150 days) recorded the lowest grain yield (2129 kg ha^{-1}), straw yield (5976 kg ha^{-1}), biological yield (8125 kg ha^{-1}) and also the lowest harvest index of 26.16%. Application of N-fertilizers in four combinations with prilled urea @ N_0, N_{30} and N_{60} along with nano-urea, zinc sulphate and FYM had the significant impact on the grain yield, straw yield, biological yield and also the harvest index of rice varieties. Application of N_{60} + ZnSO4 recorded the highest grain yield (3812 kg ha^{-1}), straw yield (6506 kg ha^{-1}), biological yield (10337 kg ha^{-1}) and also the highest harvest index of 36.13%. The higher uptake of soil nutrients along with foliar zinc results in optimal growth of plant parts and metabolic processes like photosynthesis that increase photosynthates accumulation and translocation to the economically productive parts of the plant which results in increased biomass, yield attributing characters and finally yield by amplifying the translocation of assimilates to sink grains (Reddy *et al.,* 2024). Supplementation of 50% prilled RDN by the nano-urea i.e N_{30} + Nano-urea treatment was not found significant to increase the yield but at par with prilled N_{60} i.e 100%RDN with full dose of PK. This result is corroborating the findings of Namasharma *et al*., 2023. Conversely, the application of no basal prilled nitrogen i.e N_0 + FYM+ Nano-urea recorded the poor yield performances like grain yield (3178 kg ha^{-1}), straw yield (6147 t ha^{-1}), biological yield (9337 kg ha^{-1}) with also the least harvest index of 33.31%. The lower efficacy of nano-urea foliar application might be attributed to poor start up by the crop and less development of foliage in the early growth stage due to devoid of prilled N at basal. This is in conformity with the works of Golada and Debbarma, 2023.

TABLE 4 Yield and harvest index of rice varieties as influenced by fertilizer management in new alluvial soil.

Treatment	Yield of rice (kg ha^{-1})			Harvest Index (%)
	Grain Yield	Straw Yield	Biological Yield	
Variety (V)				
Shatabdi	3749	6350	10089	37.11
Lalswarna	4490	6682	11193	40.07
Kataribhog	2129	5976	8125	26.16
S Em(±)	11.48	31.26	42.05	0.08
CD (*p*=0.5)	45.07	122.73	165.10	0.29
Fertilizer management (F)				
N_0 +FYM+ n-urea	3178	6147	9337	33.31
N_{30}+n-urea	3274	6254	9531	33.59
N_{60}+ $ZnSO_4$	3812	6506	10337	36.13
N_{60}	3561	6436	10004	34.75
S Em(±)	30.36	23.44	24.38	0.23
CD (*p*=0.5)	90.31	69.64	72.44	0.70

The interaction effects of rice variety and nano-urea and zinc foliar application on grain yield were found significant (Fig. 1). The results revealed that the highest grain yield was recorded of 4878 kg ha^{-1} in Lalswarna with 100% granular RDN i.e N_{60}+ ZnSO4 foliar but the lowest grain yield of 1969 kg ha^{-1} was noted in Kataribhog with N_0+ FYM + Nano-urea. Variation in prilled urea, nano-urea and zinc foliar application significantly influenceed the grain yield of Shatabdi and Lalswarna variety but as expected less impact was noted in aromatic Katabhog indigenous cultivar. Supplementation of 50% prilled N application as basal in Shatabdi and Lalswarna resulted at par yield increase with 2-times foliar feeding of nano-urea at 20 and 40 DAT of rice growth stages. In contrary, the lowest seed yield was noted when the plants were tested with no prilled urea, only with FYM @ 5 t ha^{-1}+ Nano-urea spray due to poor nutrient availability to the rice plant at early growth stage. Chandana *et al.,* 2021 and Gaikwad *et al*., 2023 reported the similar findings when nano-urea and zinc sulphate was applied as foliar spray with the supplementation of recommended dose of commercial fertilizer.

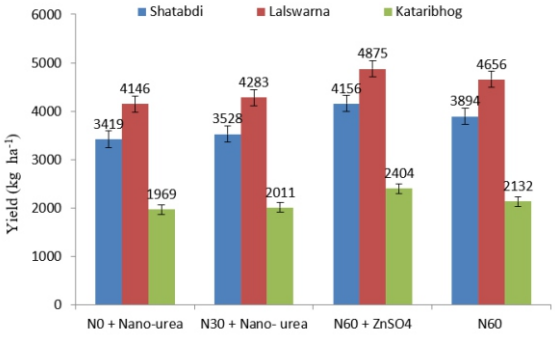

FIGURE 1 Interaction effects of variety and fertilizers management on grain yield of rice in new alluvial soils during *kharif* season.

3.4 | Association of Grain Yield

The association of grain yields in terms of correlation coefficients showed high level of statistical significance at p<0.01with growth indices like DM production at harvest (r=0.980**), effective tillers (r=0.967**), thousand grain weight (r=0.985**) and filled grains per panicle (r=0.540) but the relation with plant height (r= -0.908**), panicle length (r= -0.690*), chaffs percentage (r=-0.731**) had significantly negative correlation with the grain yield of rice varieties under different fertilizer management treatments (Table 5).

3.5 | Soil Available Nutrients

Different rice varieties and fertilizer management practices had significant impact on available nutrient status of the soil (Table 6). In post-harvest soil, available N (222.74 kg ha^{-1}), P (38.60 kg ha^{-1}) and K (180.28 kg ha^{-1}) was found highest in aromatic variety Kataribhog but the lowest available NPK status was observed in Lalswarna (MTU 7029). Application of nano-urea and zinc sulphate had the significant impact on available nutrients in post harvest soil. The highest availability of N, P and K was found from the plot treated with N_0 + Nano-urea and N_{30} + Nano-urea. This is due to smaller size and larger effective surface area of nano particles which can easily penetrate into the plant and lead to better uptake of nutrients but the lowest available nutrient status was noted from the treatment N_{60} + ZnSO4. It might be caused that foliar zinc spray enhanced the growth and yield of rice by improving nutrient uptake (Mondal *et al.,* 2020; Mandal and Ghosh, 2021). The interaction effects of variety and N-fertilizer application on the available soil NPK nutrients after harvesting was not found significant. Post harvest soil reserve of N, P and K was found maximum in cultivar 'Kataribhog' with nano-urea plots but the lowest available N, P and K was found from Lalswarna plots treated with ZnSO4. These results are in conformity with the works of Golada and Debbarma, 2023.

3.6 | Nutrient Use Efficiency by PFP

The overall assessment of nutrients used in this experiment was made through partial factor productivity (PFP) of added nutrients in table 7 to understand the efficacy of variety and nutrient use efficiency. Among the rice varieties, medium duration cv. 'Lalswarna' recorded the maximum mean PFP of 42.49 kg kg^{-1} followed by 'Shatabdi' variety and the least PFP-value was noted in long duration aromatic cv. 'Kataribhog' (20.13 kg kg^{-1}) as expected. Among four nutrient treatments, $N_0P_{30}K_{30}$ + FYM + Nano-urea foliar treatments had the maximum mean PFP (35.71 kg kg^{-1}) followed by $N_{30}P_{30}K_{30}$ + Nano-urea foliar application 2-times and the least mean value (29.67 kg kg^{-1}) was observed in $N_{60}P_{30}K_{30}$. Interactions of variety and nutrients applied revealed that Lalswarna variety had the maximum mean PFP value of 46.58 kg kg^{-1}in treatment $N_0P_{30}K_{30}$+ FYM_5 + Nano-urea application and least value was achieved by the Kataribhog with $N_{60}P_{30}K_{30}$. Foliar application of nano-urea and zinc, therefore, remained always higher side PFP-values irrespective of varieties. This is in conformity to the findings of Chandana *et al.,* 2021 and Namasharma *et al.,* 2023.

TABLE 5 Association of grain yields of rice with crop growth parameters and yield attributes.

Parameter	Correlation (r-value)	Level of significance
Dry matter production	0.980**	+ve at 1%
Effective tillers m^{-2}	0.967**	+ve at 1%
Thousand grain weight	0.985**	+ve at 1%
Filled grain per panicle	0.540	+ve NS
Plant height	-0.908**	-ve at 1%
Panicle length	-0.690*	-ve at 0.5%
Chaffs per panicle	-0.731**	-ve at 1%

TABLE 6 Available nutrients after harvesting of rice varieties as influenced by fertilizer management.

Treatment	Available nutrient status (kg ha^{-1})		
	N	P	K
Soil initial	227.12	36.45	184.61
	Post harvest		
Variety (V)			
Shatabdi	206.77	34.69	172.27
Lalswarna	198.55	32.71	168.00
Kataribhog	222.74	38.60	180.28
S Em (±)	2.29	0.40	1.87
CD (p=0.5)	6.90	1.57	7.33
Fetilizer management (F)			
N_0 +FYM+ Nano-uurea	214.02	35.03	175.97
N_{30}+Nano-urea	213.72	36.76	174.83
N_{60}+ $ZnSO_4$	202.65	33.71	170.58
N_{60}	207.03	35.84	172.67
S Em (±)	1.46	0.25	1.20
CD (p=0.5)	4.35	0.73	3.57

3.7 | Production economics

The rice production economics in terms of cost of cultivation, gross returns, net returns and benefit: cost ratio was impacted by rice varieties and foliar nutrition (Table 8). Rice high yielding cv. 'Lalswarna' had the highest gross income ₹ 104345/ and net income of ₹ 37107 ha^{-1} with the highest benefit-cost ratio of 1.55 followed by Shatabdi. Long duration aromatic rice cv. 'Kataribhog' performed less economic returns and least B:C ratio of 1.24 The direct effect of foliar management on production economics revealed that 100% RDN through prilled N_{60} + ZnSO4 (F_3) foliar application treatment was more remunerative in terms of net monetary return(₹ 37230/) and B:C ratio (1.55) than 50% RDN as prilled N_{30} + Nano-urea (F_2) and N_0 + Nano-urea (F_1) spray. Combined effects of variety and foliar fertilizer application revealed that cv. Lalswarna variety with 100% prilled N_{60} + ZnSO4 foliar treatment combination (V_2F_3) had the highest net returns of ₹ 44770/- with B:C ratio of 1.66. On the other, the lowest net return of ₹ 9013/- and B:C ratio of 1.13 recorded in aromatic rice cultivar 'Kataribhog' under N_0 + FYM + Nano-urea foliar

spray treatment combination (V_3F_1). The availability of nutrients from 100%RDN + ZnSO4 foliar two times might have helped in increasing translocation of photosynthates to sink leading to improvement in crop yields resulting enhanced income and B:C ratio in rice crop. This result is in conformity to the works of Namasharma *et al*., 2023, Nandy *et al*., 2023, Rawat *et al*., 2024.

TABLE 7 Partial factor productivity of nutrients used of rice varieties as affected by total added fertilizer in new alluvial soil during *kharif* season.

Variety	Partial factor productivity (PFP) of rice varieties (kg kg^{-1})				
	F_1: $N_0P_{30}K_{30}$+ FYM_5+2NU	F_2: $N_{30}P_{30}K_{30}$ + 2NU	F_3: $N_{60}P_{30}K_{30}$ + 2Zn	F_4: N_{60} $P_{30}K_{30}$	Mean
V_1:Shatbdi	38.42	37.53	33.25	32.45	35.41
V_2:Lal swarna	46.58	45.56	39.00	38.80	42.49
V_3:Kataribhog	22.12	21.39	19.23	17.77	20.13
Mean	35.71	34.83	30.49	29.67	

FYM_5 @25 kg N ha^{-1}; 2NU(nano-urea)@4 kg N ha^{-1}; 2Zn @ 5 kg Zn ha^{-1}

TABLE 8 Production economics of rice cultivation as influenced by varieties and foliar nutrition in new alluvial soils.

Treatment	Cost (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
Variety (V)	67216	99562	32310	1.48
Shatabdi (V_1)	67216	104345	37107	1.55
Lalswarna (V_2)	67216	83575	16286	1.24
Kataribhog (V_3)				
Foliar nutrition (F)				
N_0 +FYM+ Nano-urea(F_1)	68660	88623	19924	1.29
N_{30} + Nano-urea (F_2)	66265	91099	24797	1.37
N_{60} +ZnSO4 (F_3)	67970	105261	37230	1.55
N_{60} (F_4)	65970	98326	32318	1.49
Interaction effect				
V_1F_1	68660	91344	22603	1.33
V_1F_2	66265	94109	27825	1.42
V_1F_3	67970	109538	41549	1.61
V_1F_4	65970	103260	37262	1.57
V_2F_1	68660	96844	28156	1.41
V_2F_2	66265	99852	33569	1.51
V_2F_3	67970	112780	44770	1.66
V_2F_4	65970	107903	41933	1.64
V_3F_1	68660	77681	9013	1.13
V_3F_2	66265	79336	12998	1.20
V_3F_3	67970	93465	25372	1.38
V_3F_4	65970	83816	17761	1.27

4 | CONCLUSIONS

The study concluded that medium duration rice variety 'Lalswarna' performed superior in grain yield, straw yield, yield attributes and economic returns under New Alluvial Zone of West Bengal. Application of prilled urea @ N_{60} + ZnSO4 had the significant impact on the grain yield and yield attributes. Supplementation of 50% N by prilled urea N_{30} kg ha^{-1} + Nano-urea application achieved at par grain yield of rice with 100% N through prilled urea @ N_{60} kg ha^{-1} with full PK. Post-harvest soil NPK status was better in aromatic 'Kataribhog' than Lalswarna variety. Nano-urea foliar fertilization helped in maintaining better soil fertility, whereas, higher depletion of NPK soil reserve was observed under N_{60} + ZnSO4 application. Among the treatment combinations, 'Lalswarna' variety with N_{60} + ZnSO4 foliar had the highest net income and B:C ratio. Long-term validation of nano-urea application is needed to get clear picture of crop yield, soil health and environmental sustainability.

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CONFLICT OF INTEREST

Authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

Corresponding author is liable to make the data available on request.

AUTHOR'S CONTRIBUTION

S. B. Goswami[1] suppervised works and editing the write up. Akash Sarkar[2] carried out this experiment as M.Sc (Ag) research project work; Sarbajoya Goswami[3] prepared the write up of manuscript; Kanu Murmu[4] helped in NPK analysis and making graph.

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