PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.7114

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Enhancing production, profitability and soil health with nano urea fertilization in late transplanted rice (*Oryza sativa* L.)

S Das, B Patra*, J K Nayak, K Sur, S R Swain, S Mallick & T Audhya

Department of Agronomy, Faculty of Agricultural Sciences, Sikhsha 'O' Anusandhan deemed to be University, Bhubaneswar 751 003, India

*Email - bishnupriyapatra@soa.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 07 January 2025
Accepted: 28 March 2025
Available online
Version 1.0 : 23 May 2025

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Das S, Patra B, Nayak JK, Sur K, Swain SR, Mallick S, Audhya T. Enhancing production, profitability and soil health with nano urea fertilization in late transplanted rice (*Oryza sativa* L.). Plant Science Today (Early Access). https:/doi.org/10.14719/pst.7114

Abstract

India is one of the largest producers and consumers of rice in the world. In India, besides climatic factors, deterioration of soil fertility has been widely reported to be the major cause for stagnating rice productivity. Nano fertilizers possess a high surface area, excellent activity, improved catalytic surface, faster chemical reaction, rapid dispersibility and stronger water adsorption efficiency, which can be used for enhancing rice yield. An experiment was conducted to find the effect of urea and nano urea levels in rice at Binjhagiri, Chhatabar of Faculty of Agricultural Sciences, SOADU, Bhubaneswar (Odisha) during *kharif,* 2022, which was replicated thrice with Randomized Block Design. The soil of the experimental site was sandy loam in texture, neutral in reaction, high in organic carbon and available nitrogen and medium in available phosphorus and potassium. The experimental results revealed that 100 % conventional N through urea + two foliar sprays of 0.4 % nano urea resulted in significantly higher growth parameters, namely plant height (100.1 cm) at maturity, tillers/hill (14.4 no.) and LAI (5.00) at 60 days after transplanting (DAT) than other treatments. Similarly, the treatment with 100 % conventional N through urea + two foliar spray of 0.4 % nano urea gives significantly higher yield attributes resulting in maximum grain yield of 4164 kg/ha which was 38.25 % higher over 100 % conventional N through urea + water spray treatment and highest nutrient uptake (80.9, 18.6, 97.7 kg/ha N, P, K) as well as net return of ₹ 42018/ha.

Keywords

dry matter production; nano urea; net return; plant height; yield

Introduction

Rice is one of the world's most important staple crops, providing a vital source of nutrition for millions of people globally. It is a staple food for more than half of the global population in about 40 countries and more than 65 % of the population in India. Globally, it is grown on acreage of 166 million hectares with a total production of 504 million tons and a productivity of 4.8 tons per hectare (1). In Odisha, 69 % cultivated area is under rice and occupies 63% of the total area under food grain production (1). The late sowing of rice in the *Kharif* season is a critical agricultural practice that can significantly impact crop yield and food security. Late sowing/planting occurs due to various reasons like the late onset of the monsoon, or no irrigation availability and sometimes flood conditions due to more rainfall. Delayed planting leads to drought during critical stages in the rice growth cycle, reduces available moisture for crop growth and ultimately, there is a drastic reduction in yield.

In India, besides climatic factors, deterioration of soil fertility has been widely reported to be the major cause for stagnating rice productivity (2). Nitrogen is an essential primary nutrient which promotes growth and development and also influences the availability of other nutrients. It is the most critical input that limits rice productivity in the irrigated ecosystem (3). Managing nitrogen fertilization in rice fields is a challenging task for farmers because of various kinds of losses due to de nitrification, deep percolation and run-off in flooded soils resulting in low nitrogen use efficiency (4). In lowland rice cultivation, the application of conventional urea fertilizer provides low N to rice plants and exhibits low N use efficiency (~ 30 %) due to greater loss of N. In this context nanotechnology can play a greater role in crop production with a strong promise to affect the current status of fertilizer use with environmental safety, ecological sustainability and economic stability (2, 5, 6). Nano-fertilizers are an effective means of increasing the quantity and quality of the yield in conditions unsuitable for expansion in the reclamation of agricultural land, especially in the absence of water resources (7). More importantly, the nano formulated nutrient elements hold great promise for application in plant nourishment because of the size-dependent qualities, high surface-volume ratio and unique optical properties. Because of a high surface area to volume ratio, the effectiveness of nano-fertilizers may surpass the most innovative polymer-coated conventional fertilizers, which have seen little improvement in the past ten years (8). Hence, the present study hypothesized that nano-urea spray could fulfil N requirement of rice plants and thereby produce high yields So, here we evaluate the level and combination of nano urea with urea fertilizers on growth and yield components of the rice crop.

Materials and Methods

Study site description

A field experiment was carried out in the late *kharif* season (September) 2022 in sandy loam soil at Binjhagiri, Chattabar of Faculty of Agricultural Sciences, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar (Odisha) using Randomized block design and distribute the parameters randomly in three replicates. The soil of the experimental site was sandy loam in texture, neutral in reaction (7.1), high in OC (0.44 %) and available N (183 kg/ha) and medium in available phosphorus (12.43 kg/ha) and potassium (158 kg/ha).

Experimental details and management

The experiment was undertaken on rice variety *viz.,* Sahabhagi Dhan (105-110 days) which is a conventionally bred, drought-tolerant rice variety at 30 kg/ha transplanted on 27/08 with 20 cm × 15 cm spacing, using 9 treatment combinations *i.e.,* T_1: 100 % Conventional N fertilizer through urea + water spray, T_2: 100 % Conventional N fertilizer through urea + 0.2 % nano urea spray, T_3: 75% Conventional N fertilizer through urea + 0.2% nano urea spray, T_4: 100% Conventional N fertilizer through urea + two foliar spray of 0.2 % nano urea, T_5: 75 % Conventional N fertilizer through urea + two foliar spray of 0.2 % nano urea, T_6: 100% Conventional N fertilizer through urea + 0.4% Nano urea spray, T_7: 75 % Conventional N fertilizer through urea + 0.4 % nano urea spray, T_8: 100 % Conventional N fertilizer through urea + two foliar spray of 0.4% Nano urea, T_9: 75 % Conventional N fertilizer through urea + two foliar spray of 0.4 % nano urea. The treatments were adjusted according to the recommended dose of fertilizers *i.e* 60:30:30 N: P_2O_5:K_2O (kg/ha), where, Phosphorus (Basal) and potassium were applied whole and nitrogen as basal 50 %, topdressing (50 %). Different levels of nano urea were applied at the tillering and panicle initiation stage based on the treatment condition. In this study, we have used IFFCO nano urea (liquid) which is included in the Fertilizer Control Order (FCO) issued by the Government of India. Nano nitrogen particle size varies from 20-50 nm and contains 4.0 % total nitrogen (w/v) evenly dispersed in water (IFFCO). Crop service operations and removal of weeds were carried out as needed (2).

Plant sampling and analysis

Phenological stages were observed visually and the days taken to reach the phenological stages were calculated. The plant height of tagged plants was measured from the ground surface to the tip of a new emerging leaf and after anthesis up to the tip of the panicle. The height of five randomly tagged plants representing the whole plot was recorded at 30, 45, 60, 75 DAT and maturity. Plants from one hill (rice) from each plot, representing the entire plot, were uprooted from the ground at 30, 45, 60, 75 DAT and at maturity to record LAI. The leaf blades were separated from the shoot and the total area was measured manually. Average leaf area per unit area was used for the computation of LAI which is the ratio between the area of the surface of green leaves and the ground area covered.

Effective tillers were considered those tillers which produced panicles filled with grains out of the total tillers recorded with in a hill. Five representative hills from which effective tillers and panicle length were measured. The harvest was done on 27/11. A composite sample of grains was taken from the produce of each net plot and 1000 grains were counted at random, weighed and expressed in grams. After threshing with the help of mini plot thresher, the grain yield was measured for each net plot area. Then it was converted into (kg/ha). The harvest index for each plot was calculated by dividing the total grain yield (economical yield) by the total biological yield (grain + straw) and multiplying by 100 as given below (9).

$$\text{Harvest index} = \frac{\text{Economical yield}}{\text{Biological yield}} \text{ X } 100$$

Statistical analysis of experimental data for various growth, yield attributing characters, yield, quality parameters and nutrient uptake were performed and the critical difference was worked out as described by (10).

Results and Discussion

Phenological parameters

Phenological information is useful in predicting crop development under field conditions. The duration of different phenophases is dependent upon crop cultivar response to environmental factors.

In the present study, phenological observations were recorded at four stages of growth *viz.,* primordial initiation, 50 % flowering, milking and maturity stage (Table 1). It takes 40-41 days to reach tillering stage, 49-51 days to reach panicle initiation, 63-65 days to reach 50 % flowering and milking stage was observed at 70-71 days in most of the treatments. The transplanted Sahabhagidhan takes a period of 90-91 days after transplanting for its maturity. The effect of various urea and nano urea levels on days to reach various phenological stages is found to be non-significant. This might be due to similar growth pattern in all the treatments to reach a particular stage (11).

Growth parameters

Plant height: The data on plant height at various stages of growth are presented in Table 2. In general plant height was increased with the advancement of crop growth up to maturity. The increment of plant height was significantly higher under 100 % conventional N fertilizer through urea + two foliar sprays of 0.4 % of nano urea (46.7 cm, 57.8 cm, 85.2 cm, 96.4 cm and 100.0 cm) as compared to all other treatments.

In the initial stages 0.4 % nano urea spray gives better plant height of rice (46.7 cm, 57.8 cm) while from 60 DAT two spray of nano urea with 0.4 % concentration showed significantly higher plant height (85.2 cm, 96.4 cm, 100.0 cm) as well as two spray of 0.2 % nano urea (84.8 cm, 93.8 cm, 98.4 cm). However, 25 % reduction in conventional N fertilizer does not give better results with respect to plant height at all the stages of crop growth.

Significant increase in plant height might be due to the fact that basal application of conventional fertilizers along with foliar spray of nano fertilizers increased the activity of enzymes and auxin metabolism in the plant, which in turn enlarges the cell and cell elongation might result in taller plants (12-16).

Tillers/hill: The number of tillers/hill of rice differed significantly among various treatments (Fig. 1). The tillers were found to be more at 60 DAT then decreased till harvest, as the plant shifts resources towards reproductive development, some tillers may die or degenerate due to competition for resources like sunlight, nutrients and water. Highest number of tillers/hill (6.6, 11.6, 14.4, 11.7, 10.5) of rice was observed in case of T_8: 100 % Conventional N + two foliar spray of 0.4 % nano urea at all

Table 1. Effect of urea and nano urea on phenological parameter (days after transplanting) of rice

Treatment	Active tillering	Panicle initiation	50% flowering	Milking	Maturity
T_1	40.7	50.7	65.0	70.3	90.0
T_2	40.3	49.3	64.0	69.7	90.3
T_3	40.0	50.0	63.7	70.0	90.0
T_4	41.0	49.3	63.3	69.7	90.3
T_5	40.3	49.0	63.7	68.0	90.0
T_6	40.0	49.0	63.0	69.3	90.7
T_7	40.3	49.3	62.7	69.0	90.3
T_8	41.7	48.7	62.7	68.7	90.7
T_9	41.3	49.3	63.3	69.7	90.3
SEm (±)	0.80	0.53	0.48	0.52	0.23
CD (5%)	NS	NS	NS	NS	NS

NS: Non significant; T1: 100% Conventional N fertilizer through urea + water spray; T2: 100% Conventional N fertilizer through urea + 0.2% nano urea spray; T3: 75% Conventional N fertilizer through urea + 0.2% nano urea spray; T4: 100% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T5: 75% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T6: 100% Conventional N fertilizer through urea + 0.4% nano urea spray; T7: 75% Conventional N fertilizer through urea + 0.4% nano urea spray; T8: 100% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea; T9: 75% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea

SEm (±): Standard error of mean

CD (5%): Critical difference at 5 % level of significance

Table 2. Effect of urea and nano urea levels on plant height (cm) of rice

Treatment	30 DAT	45 DAT	60 DAT	75 DAT	At Harvest
T_1	41.5	48.2	76.2	85.9	88.5
T_2	43.4	50.9	79.2	91.3	95.3
T_3	43.1	49.5	78.9	90.4	94.9
T_4	44.9	54.6	84.8	93.8	98.4
T_5	44.5	52.2	82.0	92.5	97.5
T_6	45.1	55.1	82.3	94.5	98.5
T_7	44.3	53.0	81.1	92.6	97.8
T_8	46.7	57.8	85.2	96.4	100.0
T_9	45.2	55.5	84.9	95.1	98.7
SEm (±)	0.46	0.39	0.72	0.44	0.51
CD (5%)	1.4	1.1	2.1	1.3	1.5

NS: non significant; T1: 100% Conventional N fertilizer through urea + water spray; T2: 100% Conventional N fertilizer through urea + 0.2% nano urea spray; T3: 75% Conventional N fertilizer through urea + 0.2% nano urea spray; T4: 100% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T5: 75% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T6: 100% Conventional N fertilizer through urea + 0.4% nano urea spray; T7: 75% Conventional N fertilizer through urea + 0.4% nano urea spray; T8: 100% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea; T9: 75% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea

SEm (±): Standard error of mean

CD (5%): Critical difference at 5 % level of significance

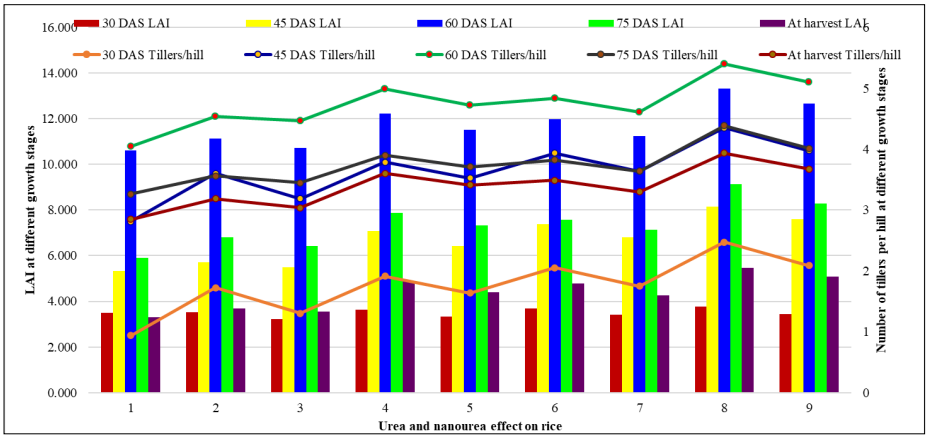

Fig. 1. Effect of urea and nano urea at different concentrations on rice growth parameters, i.e. LAI and number of tillers/hill at different growth stages.

X axis: 1-9 indicates treatment T1 to T9. T1: 100% Conventional N fertilizer through urea + water spray; T2: 100% Conventional N fertilizer through urea + 0.2% Nano urea spray; T3: 75% Conventional N fertilizer through urea + 0.2% nano urea spray; T4: 100% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T5: 75% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T6: 100% Conventional N fertilizer through urea + 0.4% nano urea spray; T7: 75% Conventional N fertilizer through urea + 0.4% nano urea spray; T8: 100% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea; T9: 75% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea.

the growth stages.

The average rate of increase in numbers of tillers/ hill of rice at 60 DAT was 33.33 % due to T_8: 100 % Conventional N + two foliar spray of 0.4 % nano urea against T_1: 100 % Conventional N fertilizer through urea + water spray (control). These findings were in accordance with the previous findings which stated that a higher number of tillers in rice were obtained with the application of nano fertilizers because of better nutrient absorption by plant; better nutrition, better growth (12). Similar results were found by other researchers (15-18).

Leaf area index: Leaf area index increased from initial stage till 60 DAT and declined thereafter. Differences in leaf area index of rice due to various treatments using nano urea in rice were significant from each other at all the growth stages (Fig. 1).

Maximum leaf area index was recorded with T_8: 100% Conventional N + two foliar spray of 0.4 % Nano urea (1.41, 3.06, 4.92, 3.42, 2.05) followed by all other treatments it has been found that T_6 & T_7 treatments gave numerically higher leaf area index in the initial stages but from 60 DAT T_4 & T_5 treatments gave higher leaf area index than T_6 & T_7 treatments. On an average leaf area index of rice recorded with T_8: 100 % Conventional N + two foliar spray of 0.4 % Nano urea was 33.7 % & with T_4: 100 % Conventional N + two foliar spray of 0.2 % nano urea was 26.4 % higher than that of T_1: 100 % Conventional N fertilizer through urea + water spray (control) treated plot. Nano-urea fertiliser exhibits greater activity because of its larger surface area. This increased activity may have improved the plants' ability to absorb nutrients, which in turn caused a cumulative increase in plant height, leaf area and number of tillers per plant. Greater utilisation of solar radiation and available nutrients, which are necessary for greater photosynthetic surface area, are facilitated by larger leaf areas (16, 17).

Dry matter accumulation (g/m²): Dry matter accumulation (g/m^2) increased progressively with age till maturity of crop (Table 3). Average dry matter production was 203.9, 402.6, 882.2, 1169.3, 1207.7 g/m^2 at 30, 45, 60, 75 DAT and at maturity stage respectively. Difference in dry matter of rice due to different urea and nano urea levels was significant at all 5 stages of plant growth.

The dry matter obtained under T_8: 100 % Conventional N + two foliar spray of 0.4 % nano urea at harvesting stage (1258.9 g/m^2) was significantly higher than all other treatments and lowest dry matter was observed in T_1: 100 % Conventional N fertilizer through

Table 3. Effect of urea and nano urea levels on dry matter accumulation (g/m^2) of rice

Treatment	30 DAT	45 DAT	60 DAT	75 DAT	At Harvest
T_1	202.8	381.8	848.5	1126.6	1154.3
T_2	207.5	404.8	876.5	1158.8	1192.9
T_3	195.9	392.7	861.3	1142.7	1175.1
T_4	209.0	406.5	891.8	1181.6	1222.6
T_5	196.5	393.6	879.7	1168.0	1207.9
T_6	209.6	414.1	887.1	1176.5	1218.4
T_7	198.9	402.7	878.8	1162.1	1203.6
T_8	212.2	419.9	914.8	1213.5	1258.9
T_9	202.9	407.2	901.0	1194.1	1235.5
SEm (±)	1.64	2.72	3.12	3.45	3.69
CD (5%)	4.9	8.1	9.3	10.3	10.9

NS: non significant; T1: 100% Conventional N fertilizer through urea + water spray; T2: 100% Conventional N fertilizer through urea + 0.2% nano urea spray; T3: 75% Conventional N fertilizer through urea + 0.2% nano urea spray; T4: 100% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T5: 75% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T6: 100% Conventional N fertilizer through urea + 0.4% nano urea spray; T7: 75% Conventional N fertilizer through urea + 0.4% nano urea spray; T8: 100% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea; T9: 75% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea

SEm (±): Standard error of mean

CD (5%): Critical difference at 5 % level of significance

urea + water spray (1154.3 g/m^2). The dry matter obtained by T_8 treatment was 9.06 % higher than T_1 treatment. Tiny size of nano fertilizers results in better absorption of nano nutrients, which affects plant growth mechanisms. Plant metabolic activities such as chlorophyll synthesis and photosynthetic activity both of which enhance vegetative growth increased due to proper supply of nutrients and accumulation of dry matter in leaves helped, the photosynthetic area to remain active for, longer period and was responsible for overall growth of plant in terms of dry matter production (11, 18-20).

Yield

Grain and Straw yield of rice as influenced by urea and nano urea levels are given in Table 4. The data revealed that there was a significant increase in yield of rice with nano urea applications.

100 % Conventional N + two foliar spray of 0.4 % Nano urea (4164 kg/ha, 5234 kg/ha) resulted in significantly higher grain and straw yield than all other treatments. Application of 0.2 % Nano urea sprayed twice gives higher yield (3835, 4987 kg/ha; T_4) than 0.4 % nano urea sprayed once (3794, 4896 kg/ha; T_6). However, both treatments were statistically at par. There was an increase of 38.25 %, 30.8 % in grain and straw yield by T8 treated rice crop over T_1 (Fig. 2). It is mainly because of increasing growth of plant parts and metabolic processes, such as photosynthesis leads to higher photosynthates accumulation and translocation to the economic parts of the plant (21, 22).

Also, it might be due to nano fertilizer's quick absorption by the plant and ease of translocation, which aided in better rates of photosynthesis and more dry matter accumulation, resulting in higher straw yield (22, 23). The harvest index (Table 4) in the present study varies between 42.9 % to 44.3 %. The harvest index was not influenced significantly by increase in urea and nano urea levels (22, 24). Grain yield had positive and strong correlation with growth parameters like plant height, dry matter accumulation at maturity and LAI at the active growth (60 DAT) stage (Fig. 3). The determination factor was 0.99 for every growth parameter.

Economics

Critical examination of the data revealed that net return (Rs. 42018/ha) and return per rupee investment (1.70) were significantly higher in T_8: 100 % Conventional N + two foliar spray of 0.4 % nano urea (Table 5). The additional net return obtained was ₹ 23190/ha by T_8 treated plot than T_1: 100 % Conventional N fertilizer through urea + water spray treatment (Table 4). It was due to the cumulative result of higher grain, stover and biological yield, leading to more gross return and net return (26). Similar results were also obtained by (12, 27).

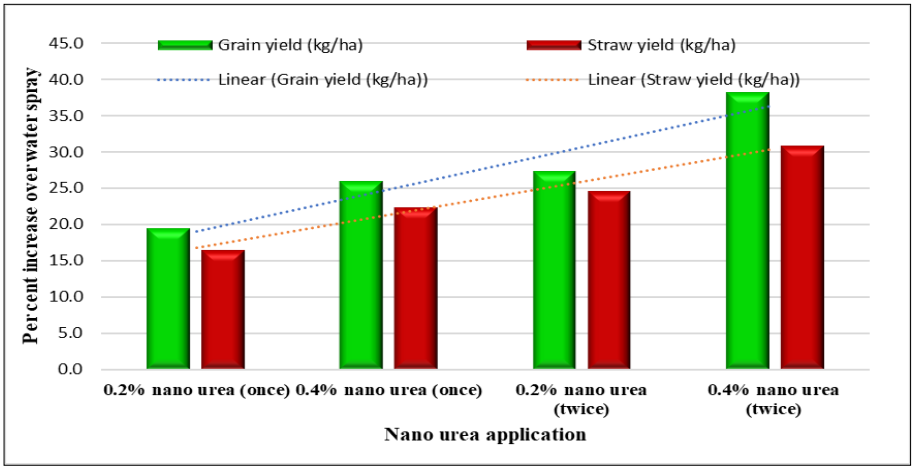

Fig. 2. Per cent increase in grain and straw yield (kg/ha) with nano urea application.

Table 4. Effect of urea and nano urea levels on yield and economics of rice

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest Index (%)	Net return (₹/ha)	Return per rupee investment
T_1	3012	4001	42.9	18828	1.36
T_2	3598	4660	43.6	31499	1.58
T_3	3395	4451	43.3	27094	1.51
T_4	3835	4987	43.5	36046	1.65
T_5	3690	4709	43.9	33115	1.61
T_6	3794	4896	43.7	35350	1.64
T_7	3656	4677	43.9	32668	1.60
T_8	4164	5234	44.3	42018	1.74
T_9	3998	5037	44.2	38426	1.68
SEm (±)	54.4	65.6	0.39	1231.84	0.022
CD (5%)	162	195	NS	3659	0.07

NS: non significant; T1: 100% Conventional N fertilizer through urea + water spray; T2: 100% Conventional N fertilizer through urea + 0.2% nano urea spray; T3: 75% Conventional N fertilizer through urea + 0.2% nano urea spray; T4: 100% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T5: 75% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T6: 100% Conventional N fertilizer through urea + 0.4% nano urea spray; T7: 75% Conventional N fertilizer through urea + 0.4% nano urea spray; T8: 100% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea; T9: 75% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea

SEm (±): Standard error of mean

CD (5%): Critical difference at 5 % level of significance

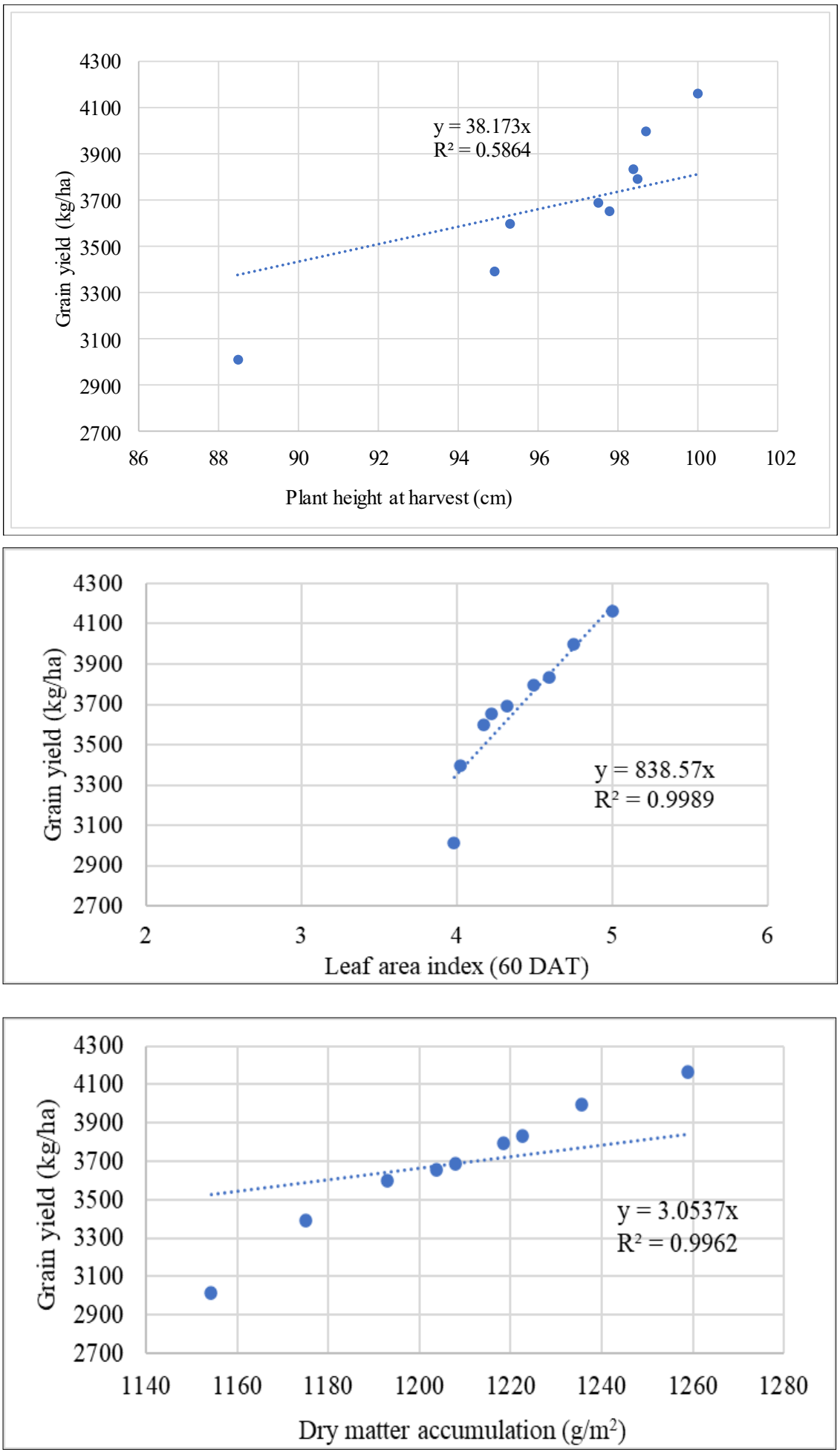

Fig. 3. Correlation regression analysis of grain yield and growth parameters of rice.

Table 5. Effect of urea and nano urea levels on nutrient uptake and post-harvest properties of soil

Treatment	Nutrient uptake by plant (kg/ha)			Nutrient in soil (kg/ha)		
	N	P	K	N	P	K
T_1	48.25	14.346	75.138	156.78	10.53	287.34
T_2	64.41	16.682	87.500	174.41	9.36	276.45
T_3	58.70	15.976	83.544	167.23	10.02	282.21
T_4	70.26	17.429	93.167	183.00	8.66	257.34
T_5	65.24	16.857	88.373	171.76	8.97	266.74
T_6	72.25	17.273	91.610	186.72	8.93	262.09
T_7	65.45	16.830	87.911	179.79	9.20	272.04
T_8	80.90	18.561	97.656	194.96	8.18	242.29
T_9	73.54	17.913	94.335	189.57	8.50	253.55
SEm (±)	0.955	0.358	1.215	1.820	0.359	1.102
CD (5%)	2.837	1.064	3.610	5.40	1.06	3.27

NS: non significant; T1: 100% Conventional N fertilizer through urea + water spray; T2: 100% Conventional N fertilizer through urea + 0.2% nano urea spray; T3: 75% Conventional N fertilizer through urea + 0.2% nano urea spray; T4: 100% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T5: 75% Conventional N fertilizer through urea + two foliar spray of 0.2% nano urea; T6: 100% Conventional N fertilizer through urea + 0.4% nano urea spray; T7: 75% Conventional N fertilizer through urea + 0.4% nano urea spray; T8: 100% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea; T9: 75% Conventional N fertilizer through urea + two foliar spray of 0.4% nano urea

SEm (±): Standard error of mean

CD (5%): Critical difference at 5 % level of significance

Nutrient uptake by plant

Application of T_8: 100 % Conventional N + two foliar spray of 0.4 % Nano urea recorded higher N uptake of 80.90 kg/ ha showing 56.9 % higher nitrogen uptake than T_1 treatment. The nutrient uptake of rice was found to be increased with the foliar application of nano urea which might be due to nano fertilizer have large surface area and particle size is less than the pore size of root and leaves of the plant which can increase their penetration into the plant from applied surface and improve nutrient uptake. These results were in close agreement with the previous research (28, 29).

Rice treated with 100 % Conventional N + two foliar sprays of 0.4 % Nano urea (T_8) recorded significantly higher phosphorus uptake, 18.56 kg/ha, while 100 % conventional and 75 % conventional nitrogen were statistically at par in respect of phosphorus uptake. This is due to smaller size and larger effective surface area of nanoparticles, which can easily penetrate into the plant and lead to better uptake of nitrogen and phosphorus. The higher uptake 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 seeds. Similar results were reported by 30 and 31.

Potassium uptake by rice (97.66 kg/ha) was significantly higher by T_8: 100% Conventional N + two foliar spray of 0.4 % Nano urea. These results were in close agreement with the findings of 28 and 29. T_4 treatment shows higher potassium uptake than T_6 treatment however, both remained at par with respect to uptake in grain straw as well as total uptake. This happens because of higher yield obtained under T_8 treatment.

Soil health status

Perusal of results present in Table 5 revealed that there was a significant variation among different treatments; nano urea treated plot shows higher nitrogen content compared to water spray treated control plot.

T_8: 100 % Conventional N + two foliar spray of 0.4 % Nano urea shows significantly higher nitrogen content (194.96 kg/ha in soil) than all other treatments. This happens because of addition of nano urea helps in better root growth, which in turn increases higher rhizospheric microorganisms that help in solubilizing the nutrients present in the soil and make them available. The application of nano fertilizers enhances some biogeochemical processes such as nitrification, which increases the available nitrogen in soil. The nano fertilizers release some humic acid and root exudates during slow release of nutrients, which increases the content of carbon and nitrogen that serves as food for soil microorganisms (32). Slow-release pattern of nano fertilizers showed better growth and productivity of crop thus nutrient uptake from soil is less as nutrient required obtained from foliar application and also plant root releases some humic acid and exudates which reduces environmental footprint by reducing Nutrient losses from the applied fertiliser thus higher available nitrogen observed in post-harvest soil than conventional fertilizers applied plot (33). Application of nano fertilizers increases the available micronutrients (Zn, Fe, Mn and Cu) content in the soil after the harvest of the rice crop (7, 34-36).

However, phosphorus and potassium content were found to be significantly lower in T_8 treatment than without nano urea treated plot. This was because of higher yield and uptake obtained in T_8 treatment rather than without nano urea plot. It was found that T_4 and T_6 treatments were statistically at par in influencing nitrogen, potassium and phosphorus in soil. The slow-release mechanism of nano fertilizers is able to enhance the nutrient status of soil by reducing leaching loss, fixation,

atmospheric losses and microbial conversion (37). The application of nano nitrogen fertilizers (Nano urea) increased the phosphorus and potassium content by 26% and 6 % than conventional urea (38). Similar results were also observed by 39-41.

Conclusion

On the basis of this study, it can be concluded that late transplanted rice (Sahabhagi dhan) shows better improvement with Nano urea application. 100% Conventional N + two foliar spray of 0.4 % Nano urea gave significantly better growth parameters and yield attributes results than all other treatments, including without nano urea treated plot. The late transplanted rice (Sahabhagi dhan) treated with 100 % Conventional N + two foliar sprays of 0.4 % Nano urea produced significantly higher yield (4164 kg/ha) and economic net returns (Rs. 42018/ha) than water sprayed plot. So, it is suggested to apply nano urea (0.4 %) with 500 litre of water for one hectare during maximum tillering and panicle initiation or booting stage along with conventional N, P, K for improving productivity of rice in case of late transplanted condition.

Acknowledgements

We are thankful to the Department of Agronomy, Faculty of Agricultural Science (IAS), SOADU, Bhubaneswar, Odisha, for technical help and encouraging us to conduct this research work at the Agronomy Research Farm of the SOADU, Chhatabar, Binjhagiri, Bhubaneswar.

Authors' contributions

BP and SD conceptualized and designed the study. SD participated in the methodology and investigation. BP, SD and KS contributed to data analysis. SD wrote the original draft. All authors reviewed and edited the manuscript. BP contributed to resources. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. FAO. Food Outlook - Biannual report on global food markets. Rome: FAO; 2023. p. 1–160.
2. Velmurugan A, Subramani T, Bommayasamy N, Ramakrishna, Kumar M, Swarnam TP. The effect of foliar application of nano urea (liquid) on rice (*Oryza sativa* L). J Andaman Sci Assoc. 2021;26 (2):76–81.
3. Spiertz JHJ. Nitrogen, sustainable agriculture and food security. A review. Agron Sustain Dev. 2010;30:43–55. https://doi.org/10.1051/agro:2008064
4. Mahmud K, Panday D, Mergoum A, Missaoui A. Nitrogen losses and potential mitigation strategies for a sustainable agroecosystem. Sustainability. 2021;13(4):2400(2–23). https://doi.org/10.3390/su13042400
5. Anjuman AR, Shurovi Z, Shah M, Imamul H. Preparation characterization and evaluation of efficacy of phosphorus and potassium incorporated nano fertilizer. Adv Nanoparticles. 2017;6:62–74. https://doi.org/10.4236/anp.2017.62006
6. Davarpanah S, Tehranifar A, Davarynejad G. Effects of foliar Nano-nitrogen and urea fertilizers on the physical and chemical properties of pomegranate (*Punica granatum cv.* Ardestani) Fruits. Hortscience. 2017;52(2):288–94. https://doi.org/10.21273/HORTSCI11248-16
7. Jassim RAH, Kadhem HN, Nooni GB. Impact of levels and times of foliar application of nano fertilizer (Super Micro Plus) on some components of growth and yield of rice (*Oryza sativa* L.). Plant Arch. 2019;19(Suppl 1):1279–83.
8. Naderi MR, Danesh-Shahraki A. Nanofertilizers and their roles in sustainable agriculture. Int J Agric Crop Sci. 2013;5(19):2229–32.
9. Watson DJ. Comparative physiological studies on the growth of field crops I. Variation in net assimilation rate and leaf area between species and varieties and within and between years. Ann Bot. 1956;2:41–46.
10. Gomez KA, Gomez AA. Statistical procedures for agricultural research, a willey inter science publication, New York; 1984. p. 76–83.
11. Sun Y, Xing M, He Z, Sun Y, Deng Y, Luo Y, et al. Effects of urea topdressing time on yield, nitrogen utilization and quality of mechanical direct-seeding hybrid indica rice under slow-mixed fertilizer base application. Front Plant Sci. 2024;15:1400146. https://doi.org/10.3389/fpls.2024.1400146
12. Chinnappa SA, Krishnamurthy D, Ajayakumar MY, Ramesha YM, Ravi S. Response of nano fertilizers on growth, yield and economics of kharif sorghum. Pharma Innov J. 2023;12(9):761–65.
13. Rathnayaka RMNN, Iqbal YB, Rifnas LM. Influence of urea and nano-nitrogen fertilizers on the growth and yield of rice (*Oryza sativa L.*) cultivar 'Bg 250'. Int J Res Publ. 2018;5(2):7.
14. Gupta SP, Mohapatra S, Mishra J, Yadav SK, Verma S, Singh S. Effect of nano nutrient on growth attributes, yield, Zn content and uptake in wheat (*Triticum aestivum* L.). Int J Environ Clim Change. 2022;12(11):2028–36. https://doi.org/10.9734/ijecc/2022/v12i1131193
15. Yasser E, El-Ghobashy, Elmehy AA, El-Douby KA. Influence of intercropping cowpea with some maize hybrids and N nano mineral fertilization on productivity in salinity soil. Egypt J Agron. 2020;42(1):63–78. https://doi.org/10.21608/agro.2020.19752.1194
16. Dhamankar C, Mankar D, Pusdekar V, Mane S, Nakat S, Dodewar P. The effect of nano urea on growth of drilled paddy. Pharma Innov J. 2023;12(8):441–43.
17. Dhawne MN, Shamkuwar GR, Shamkuwar SG, Landge NH, Sable AD, Tinpayale AD. Influence of foliar application of nano-urea on morpho-physiological and yield parameters in rice (*Oryza sativa* L.). Biol Forum. 2023;15(11):548–53.
18. Saud M, Joseph M, Hemalatha M, Rajakumar D, Jothimani S, Srinivasan S. Effect of bio-organic fertilizers (BoF) with nano urea spray on nitrogen economy of rice. Pharma Innov J. 2022;11(7): 4475–80.
19. Yomso J, Menon S. Impact of nano fertilizers on growth and yield parameters of rice crop; A Review. Pharma Innov J. 2021;10(6):249–53.
20. Rawate D, Patel JR, Agrawal AP, Agrawal HP, Pandey D, Patel CR, et al. Effect of nano urea on productivity of wheat (*Triticum aestivum L.*) under irrigated condition. Pharma Innov J. 2022;11 (9):1279–82.
21. Sharma SK, Sharma PK, Mandeewal RL, Sharma V, Chaudhary, R, Pandey R, et al. Effect of foliar application of Nano-Urea under different nitrogen levels on growth and nutrient content of

Pearlmillet (*Pennisetum glaucum L.).* Int J Plant Soil Sci. 2022;34 (20):149–55. https://doi.org/10.9734/ijpss/2022/v34i2031138

22. Kumar Y, Tiwari KN, Singh T, Sain NK, Laxmi S, Verma R, et al. Nano fertilizers for enhancing nutrient use efficiency, crop productivity and economics returns in winter season crops of Rajasthan. Ann Plant Soil Res. 2020;22(4):324–35. https://doi.org/10.47815/apsr.2020.10001
23. Sahu TK, Kumar M, Kumar N, Chandrakar T, Singh DP. Effect of Nano-Urea application on growth and productivity of rice (*Oryza sativa L.*) under midland situation of Bastar region. Pharma Innov J. 2022;11(6):185–87.
24. Khalil MH, Abou AAF, Abdrabou RTH, Abdalhalim SH, Abdel maaboud MSH. Response of two maize cultivars (*Zea mays* L.) to organic manure and mineral nano nitrogen fertilizer under siwa oasis conditions. Arab Univ J Agric Sci. 2019;27(1):299–312. https://doi.org/10.21608/ajs.2019.43527
25. Mehta S, Bharat R. Effect of integrated use of nano and non-nano fertilizers on yield and yield attributes of wheat (*Triticum aestivum L.*). Int J Curr Microbiol Appl Sci. 2019;8(12):598–606. https://doi.org/10.20546/ijcmas.2019.812.078
26. Ranjan P, Kumar B, Mala A, Priyadarshi S, Shri A, Babu L, et al. Effect of foliar spray of Nano urea on yield and economics of rice. Pharma Innov J. 2023;12(1):3030–33. https://doi.org/10.22271/tpi.2023.v12.i1ai.19419
27. Sankar LR, Mishra GC, Maitra S, Barman S. Effect of nano NPK and straight fertilizers on yield, economics and agronomic indices in baby corn (*Zea mays* L.). Int J Chem Stud. 2020;8(2):614–18. https://doi.org/10.22271/chemi.2020.v8.i2j.8836
28. Lahari S, Hussain SA, Parameswari YS, Sharma SHK. Grain yield and nutrient uptake of rice as influenced by the nano forms of nitrogen and zinc. Int J Env Clim Change. 2021;11(7):1–6. https://doi.org/10.9734/ijecc/2021/v11i730434
29. Sahu TK, Kumar M, Kumar N, Chandrakar T, Singh DP. Effect of nano-urea application on growth and productivity of rice (*Oryza sativa L.*) under midland situation of Bastar region. Pharma Innov J. 2022;11(6):185–87.
30. Bhargavi G, Sundari A. Effect of nano urea on the growth and yield of rice (*Oryza sativa* L.) under SRI in the Cauvery delta zone of Tamil Nadu, Annamalai University, Chidambaram (Tamil Nadu), India. Crop Res. 2023;58 (1 and 4):12–17. https://doi.org/10.31830/2454-1761.2023.CR-885
31. Kumar MRA, Fathima PS, Yogananda SB, Sowmyalatha BS. Comparative evaluation of nano urea and urea foliar sprays on nutrient uptake and soil fertility in fodder maize (*Zea mays* L.) production. J Sci Res Rep. 2024;30(5):939–46. https://doi.org/10.9734/jsrr/2024/v30i52011
32. Yoon HY, Lee JG, Esposti LD, Iafisco M, Kim PJ, Shin SG, et al. Synergistic release of crop nutrients and stimulants from hydroxyapatite nanoparticles functionalized with humic substances: toward a multifunctional nanofertilizer. ACS Omega. 2020;5:6598–610. https://doi.org/10.1021/acsomega.9b04354
33. Rajonee AA, Nigar F, Ahmed S, Huq SI. Synthesis of nitrogen nano fertilizer and its efficacy. Canadian J Pure Appl Sci. 2016;10 (2):3913–19.
34. Namasharma S, Pahari A, Banik A, Pal S, Sana M, Pal S, et al. Impact of foliar applied nano-urea on growth, productivity and profitability of hybrid rice (*Oryza sativa* L.). Oryza. 2023;60(3):464–72. https://doi.org/10.35709/ory.2023.60.3.10
35. Rathore R, Hasan A, David AA, Thomas T, Reddy IS. Effect of different levels of nano urea and conventional fertilizer on soil health of maize (*Zea mays* L.) Var, P3544 in an Inceptisols of Prayagraj, (UP) India. Pharma Innov. 2022;11(8):560–63.
36. Udgata J, Barik M, Phonglosa A, Joshi SK, Mishra PJ, Rahman FH, et al. Assessment of Balance Nutrition (N, P, K, Zn and B) and green manuring on yield, nutrient uptake, economics and soil fertility of rainfed rice (*Oryza sativa* L.) in drought prone areas of Odisha. Curr J Appl Sci Technol. 2020;39(27):10–19. https://doi.org/10.9734/cjast/2020/v39i2730915
37. Subramanian KS, Thirunavukkarasu M. Nano-fertilizers and nutrient transformations in soil. In: Ghorbanpour M, Manika K, Varma A, editors. Nanoscience and Plant–Soil Systems. Soil Biology, vol 48. Springer, Cham; 2017. p. 305–19. https://doi.org/10.1007/978-3-319-46835-8_11
38. Astaneh N, Bazrafshan F, Zare M, Amiri B, Bahrani A. Nano-fertilizer prevents environmental pollution and improves physiological traits of wheat grown under drought stress conditions. Sci Agropecu. 2021;12(1):41–47. https://doi.org/10.17268/sci.agropecu.2021.005
39. Rani B, Nirali B, Bahu D. Effect of chemical and nano nitrogenous fertilizers on availability of major nutrients (N, P, K) in soil after harvest of the sorghum crop. Int J Chem Stud. 2019;7(4):2940–42.
40. Meena RH, Jat G, Jain D. Impact of foliar application of different nano-fertilizers on soil microbial properties and yield of wheat. J Environ Biol. 2021;42(2):302–08. https://doi.org/10.22438/jeb/42/2/MRN-1465
41. Udapudi P, Pushpa K, Sukanya TS, Krishnamurthy R. Alterations in the nutrient status of soil and enzymatic activity of finger millet cultivated soil accompanying to nano urea application. Environ Ecol. 2024;42(2A):716–25. https://doi.org/10.60151/envec/VGQA5833