



RESEARCH ARTICLE

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

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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 denitrification, 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, Chattabbar 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., Sahabhazi 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., 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 treatments were adjusted according to the recommended dose of fertilizers i.e 60:30:30 N: P₂O₅:K₂O (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).

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

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 Sahabdagidhan 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 T₈: 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

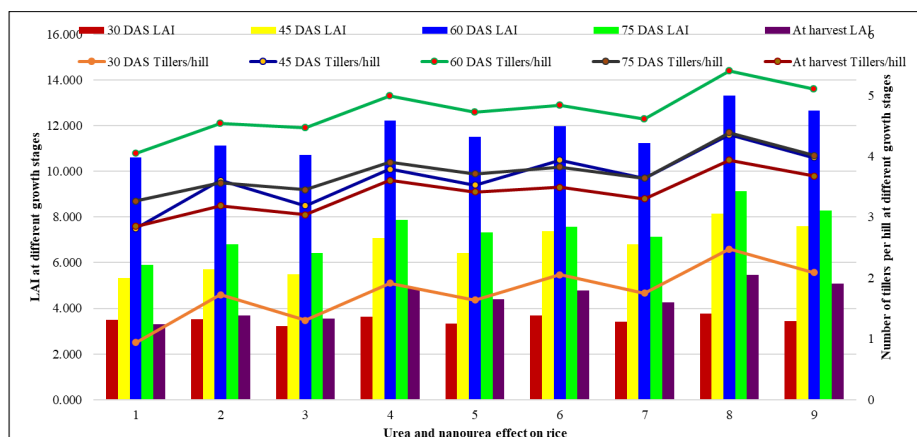


Fig. 1. Effect of urea and nano urea at different concentrations on rice growth parameters, i.e. LAI and number of tillers/hill at different growth stages.

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 T₈: 100 % Conventional N + two foliar spray of 0.4 % nano urea against T₁: 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 T₈: 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 T₆ & T₇ treatments gave numerically higher leaf area index in the initial stages but from 60 DAT T₄ & T₅ treatments gave higher leaf area index than T₆ & T₇ treatments. On an average leaf area index of rice recorded with T₈: 100 % Conventional N + two foliar

spray of 0.4 % Nano urea was 33.7 % & with T₄: 100 % Conventional N + two foliar spray of 0.2 % nano urea was 26.4 % higher than that of T₁: 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/m²) 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/m² 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 T₈: 100 % Conventional N + two foliar spray of 0.4 % nano urea at harvesting stage (1258.9 g/m²) was significantly higher than all other treatments and lowest dry matter was observed in T₁: 100 % Conventional N fertilizer through

Table 3. Effect of urea and nano urea levels on dry matter accumulation (g/m²) 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/m²). The dry matter obtained by T₈ treatment was 9.06 % higher than T₁ 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; T₄) than 0.4 % nano urea sprayed once (3794, 4896 kg/ha; T₆). 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 T₁ (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 T₈: 100 % Conventional N + two foliar spray of 0.4 % nano urea (Table 5). The additional net return obtained was ₹ 23190/ha by T₈ treated plot than T₁: 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).

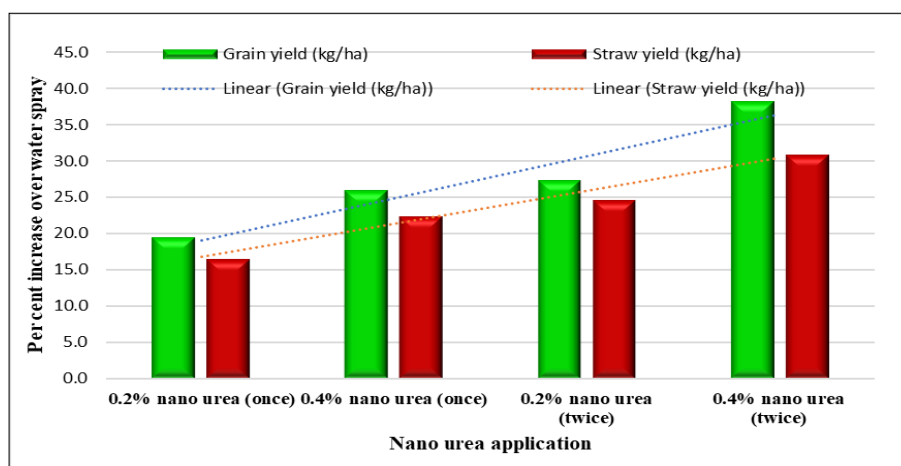


Fig. 2. Per cent increase in grain and straw yield (kg/ha) with nano urea application.

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

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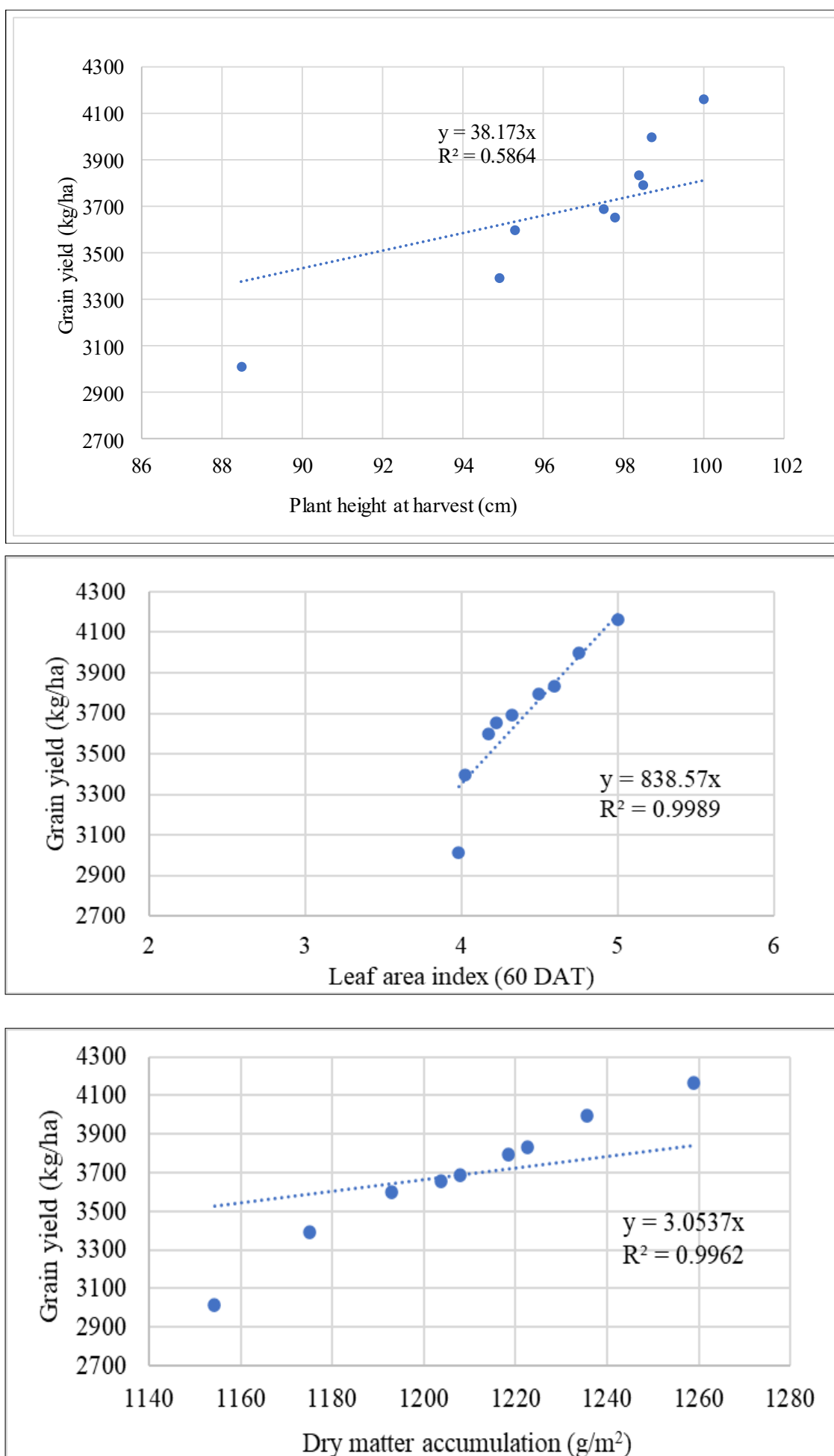


Fig. 3. Correlation regression analysis of grain yield and growth parameters of rice.

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 T₈: 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 T₁ 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 (T₈) 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 T₈: 100% Conventional N + two foliar spray of 0.4 % Nano urea. These results were in close agreement with the findings of 28 and 29. T₄ treatment shows higher potassium uptake than T₆ 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 T₈ 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.

T₈: 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 T₈ treatment than without nano urea treated plot. This was because of higher yield and uptake obtained in T₈ treatment rather than without nano urea plot. It was found that T₄ and T₆ 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 (Sahabghi 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 (Sahabghi 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.

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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.

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