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Effect of Nano-Urea Based Nitrogen Application on the Growth, Phenology and Yield of Direct Seeded Rice (*Oryza sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

As large quantum of urea is used in the rice crop, there is a need to reduce atleast some portion of prilled urea to minimize the nitrogen losses besides improving the growth and yield of rice. With this rationale, a field experiment was carried out in the *Kharif* season of 2022 at the Agronomy Research Farm in Sher-e-Kashmir University of Agricultural Sciences and Technology- Kashmir, India to study the efficiency of Nano-urea over prilled urea in direct-seeded rice. The experimental study comprised of nine treatments *viz.,* T_0 (Control), T_1 (recommended dose of prilled urea), T_2 (NU 2 sprays at 6 ml L^{-1} at AT and PI stage), T_3 (NU 2 sprays at 8 ml L^{-1} at AT and PI stage), T_4 (50 % RDPU as basal + NU 2 sprays at 2 ml L^{-1} at AT and PI stage), T_5 (50 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage), T_6 (25 % RDPU as basal + NU 2 sprays at 2 ml L^{-1} at AT and PI stage), T_7 (25 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage), T_8 (25 % RDPU as basal + NU 2 sprays at 6 ml L^{-1} at AT and PI stage) and T_9 (25 % RDPU as basal + NU 2 sprays at 8 ml L^{-1} at AT and PI stage) which were arranged in randomized complete block design and replicated three times. These treatments included the application of Nano-urea in addition to conventional nitrogen dosages of 120 kg ha^{-1} and control treatments (no application). T_5 (50 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage) was the treatment that most significantly improved growth characteristics out of all of them, with a notable achievement of a Leaf Area Index (LAI) of 4.51. In addition, T_5 performed superior to other treatments in yield-related parameters like panicle weight (2.69 g), yield (66.57 q ha^{-1}). These findings demonstrate the significant potential of Nano-urea to maximize nitrogen use and increase yield in direct-seeded rice farming systems.

Keywords: Nano-urea; direct-seeded rice; growth parameters; yield; nitrogen efficiency.

1. INTRODUCTION

A large percentage about 50% of the global population relies upon rice (*Oryza sativa* L.), therefore it is a crop of worldwide importance [1]. It is extremely important in Asian nations, where it has significant cultural and economic significance. A wide range of agricultural techniques are used in the cultivation of rice, which takes place in diverse settings such as dry upland fields and flooded paddies [2]. Rice is a major nutritional staple that is essential for ensuring global food security due to its high quantity of carbohydrates. The lack of resources and financial concerns have made traditional rice growing techniques, such transplanting seedlings into puddled soils, less economical. While puddling and transplanting can be beneficial in terms of weed reduction, improved water and nutrient management, and softening the soil for transplantation, they can ultimately eventually cause soil degradation [3]. Root development, water infiltration, and nutrient absorption are all impacted by subsurface compaction beneath the puddled soil layer. Also, anaerobic conditions that favor methanogenic bacteria in flooded rice contributes to greenhouse gas emissions, especially methane [4]. Alternative techniques including direct seeding are being investigated to lessen these issues. Direct seeding eliminates the need to transplant seedlings by placing rice seeds directly into the field. This method has advantages over transplanted rice, including better water use efficiency, lower labor requirements, and early planting that accelerates rice maturation [5]. On the other hand, direct planting often contributes to reduced yields and nitrogen use efficiency, requiring productivity-boosting alternatives [6]. Since nitrogen is required for the synthesis of chlorophyll and photosynthesis, its deficiency in Indian agricultural soils has resulted in lower yields and economic hardships. Long-term sustainability is compromised by the excessive application of traditional fertilizers, which degrade soil quality and the ecosystem even if they can increase agricultural yields. The search for more effective and environmentally friendly substitutes has also been stimulated by the increasing cost of mineral nitrogen fertilizers [7].

The utilization of nano urea presents an effective strategy, exhibiting the capacity to significantly increase rice crop productivity and improve nitrogen use efficiency (NUE). Nano urea is a modified form of urea that differs from typical urea in that it is more soluble and plant absorbable,reducing nitrogen loss through leachi ng and volatilization [8]. Its small dimensions and high surface area-to-volume ratio allow for effective nutrient encapsulation, which lowers the quantity of fertilizer needed for ideal crop growth. In addition to improving crop output, soil fertility, and quality metrics, nano urea also reduces environmental effect while optimizing economic advantages. Its primary objective is enhancing yield efficiency while reducing nutrient losses. The adverse effects of standard urea can be minimized without compromising rice's nutritional value or productivity through the introduction of nano urea into rice farming methods. Because nano urea has an amazing absorption efficiency of more than 80%, it may be applied at smaller rates to supply the nitrogen needs of plants than prilled urea or neem-coated urea [9]. The purpose of this study is to assess how effectively nano urea performs in wet Direct Seeded Rice (DSR) systems to increase production and nitrogen use efficiency. In this context, we will investigate the way nano urea differs from regular urea in terms of its impact on growth, yield, and related parameters. It is expected that the results of this study will offer important new understandings into the possibility of using nano urea as a more effective and environmentally friendly fertilizer alternative for direct-seeded rice cultivation.

2. MATERIALS AND METHODS

2.1 Location and Weather Conditions of the Experiment Site

The study was conducted at Agronomy Research Farm in SKUAST-K, India which is located at an elevation of 1590 meters above mean sea level (AMSL), positioned at geographical coordinates of 34°21'N latitude and 74°23'E longitude. The location has an average climate with 812 mm of precipitation annually. The average climatic data was recorded by the climatic Observatory of the Division of Agronomy, SKUAST Kashmir, Shalimar, during the crop growth phase of the *kharif*-2022 season. Throughout the crop-growing season, the average maximum and lowest temperatures were 34.0°C and 10.0°C, respectively, 432.40 mm of precipitation was recorded overall during this time. Additionally, the mean maximum relative humidity was recorded as 88.57%, while the mean minimum relative humidity was 37.57%.

2.2 Soil Physico-chemical Properties

The experimental site was characterized by effective drainage and a uniform topographical profile. Soil analysis conducted at the experimental location indicated that the soil has a silty clay loam texture, a pH value of 6.8 in soil and water ratio of 1:2.5, suggesting a neutral condition and medium in organic carbon (0.69%). Additionally, the soil analysis revealed moderate levels of available N (296.5 kg ha^{-1}) P (16.7 kg ha^{-1}), and K (170.5 kg ha^{-1}) estimated by Alkaline permanganate method [10], Olsen's method NaHCO3 [11] and Ammonium acetate extract method (DTPA) extractable method [12], respectively.

2.3 Experimental Setup

The field was mechanized using a disc plough (pulled by a tractor) for efficient tillage. Subsequently, three rounds of ploughing were carried out using a tiller to achieve a fine tilth, followed by manual leveling using traditional land levelers. Replication borders, plot-paths, irrigation, and drainage channels were manually constructed. The bunds, designed according to specific treatments, were built under dry conditions. Once completed, the entire field was irrigated to facilitate puddling and finalize the shape of the bunds. Before seed sowing, thorough leveling of the plots was performed. The puddling operation was conducted manually by employing labor, and the field was drained of water prior to seed sowing. Plot division was implemented, and irrigation and drainage channels were established based on the layout plan. Shalimar Rice-4 paddy seeds underwent a soaking process in water for 48 hours, followed by a 48-hour incubation period to promote sprouting. Sprouted seeds were uniformly sown

Table 1. Details of the nitrogen treatments used in rice crop

Treatment details	
T_0:	Control
T_1:	RDPU
T_2:	NU 2 sprays at 6 ml L^{-1} at AT and PI stage.
T_3:	NU 2 sprays at 8 ml L^{-1} at AT and PI stage.
T_4:	50 % RDPU as basal + NU 2 sprays at 2 ml L^{-1} at AT and PI stage.
T_5:	50 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage.
T_6:	25 % RDPU as basal + NU 2 sprays at 2 ml L^{-1} at AT and PI stage.
T_7:	25 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage.
T_8:	25 % RDPU as basal + NU 2 sprays at 6 ml L^{-1} at AT and PI stage.
T_9:	25 % RDPU as basal + NU 2 sprays at 8 ml L^{-1} at AT and PI stage.

**AT= active tillering: PI=panicle initiation; *RDPU= recommended dose of prilled urea; *NU= Nano-urea*

in rows spaced 20 cm apart. Adequate soil moisture levels were ensured before sowing to create favorable conditions for seed germination. The pre-soaked seeds were treated with Tricyclazole 75% WP (0.6 g kg^{-1}) of seeds for the protection against seed rot, pre-emergence damping off and rice blast. Manual sowing of treated seeds was carried out in rows with a spacing of 20 cm x 10 cm in the north-east direction. Hand weeding was conducted only once at 35 DAS during the crop growth period.

In this experiment, the effectiveness of Nano urea treatments was evaluated compared to a control treatment with no nitrogen application and a treatment with the recommended nitrogen dosage of 120 kg N ha^{-1} (Table 1), using the promising rice variety Shalimar Rice-4. The experiment field was laid out in RCBD design with three replications. The crop was cultivated following standard agronomic practices and principles under direct seeding rice (DSR) with net plot size 4 × 3 m (12 m^2). The rice field was not continuously submerged but moisture was maintained through a cyclic wetting and drying process. Before sowing, the recommended dosage of P (60 kg ha^{-1}) and K (30 kg ha^{-1}) was applied. N fertilizer in the form of prilled urea was applied according to the treatment details, while Nano urea @450 L ha^{-1} was sprayed at two stages of crop growth: active tillering (AT) and panicle initiation stage (PI), using a hand-held pressure sprayer.

2.4 Data Compilation

The study documented various agronomic parameters including LAI, CGR (g m^{-2} day^{-1}), RGR (g^{-1} g^{-1} day^{-1}), NAR (g cm^{-2} day^{-1}), and phenological studies such as the number of days taken to reach active tillering, panicle initiation, 50% flowering, milking, dough, and maturity stages. Yield attributes and yield parameters such as panicle weight (g), sterility percentage (%) and grain yield (q ha^{-1}) were also recorded.

The growth parameters were measured at 30-day intervals after the sowing period, while yield attributes were assessed at maturity by randomly selecting ten plants. The yield parameter (grain yield) was recorded at harvest. Furthermore, the research documented the duration in days necessary to achieve various growth stages, such as maximum tillering, panicle initiation, 50% flowering, dough stage, and maturity. The formula used to calculate the sterility % was to divide the number of unfilled grains by the total number of grains. The quotient was then multiplied by 100 to obtain the percentage.

Sterility percentage = Unfilled grains/ Total number of grains x 100

2.5 Statistical Analysis

The experimental data underwent analysis of variance following the standard method for a randomized complete block design (RCBD), using R-software (R core team, 2013). Subsequently, an LSD test at a 5% probability level was conducted to assess differences among all treatment means.

3. RESULTS

3.1 Crop Growth Analysis

All the treatments showed a gradual rise in leaf area index up to 60 days after sowing and thereafter declined sharply (Fig. 1). Treatment T_5 (50 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage) recorded highest leaf area index of 4.51 that was found at par with the treatment T_4 (50 % RDPU as basal + NU 2 sprays at 2 ml L^{-1} at AT and PI stage) with a leaf area index of 4.39. Significantly, lowest leaf area index of 0.68 was recorded in the control treatment. The crop growth rate exhibited a progressive increase as the crop aged, reaching its peak at 90 days after sowing, after which it displayed a diminishing trend. Among different treatments, CGR of 22.24 g m^{-2} day^{-1} recorded significantly highest in treatment T_2 (NU 2 sprays at 6 ml L^{-1} at AT and PI stage) which was statistically at par with treatment T_3 (NU 2 sprays at 8 ml L^{-1} at AT and PI stage). Additionally, control treatment recorded least crop growth rate at all the stages (Fig. 2). The relative growth rate demonstrated an upward trend as the crop aged, reaching its maximum at 60 days after sowing. Among the treatments, T_2 recorded highest rate of RGR of 0.108 g g^{-1} day^{-1} at 60 days after sowing of crop which was found statistically at par with the treatment T_3 with relative growth rate of 0.107 g g^{-1} day^{-1} (Fig. 3). Highest NAR of 1.45 g cm^{-2} day^{-1} was recorded in treatment T_5 closely followed by treatment T_4 with total NAR of 1.37 g cm^{-2} day^{-1} at 30 days after sowing of crop. Lowest Net assimilation rate of 0.92 g cm^{-2} day^{-1} at 30 DAS was recorded in control (Fig. 4).

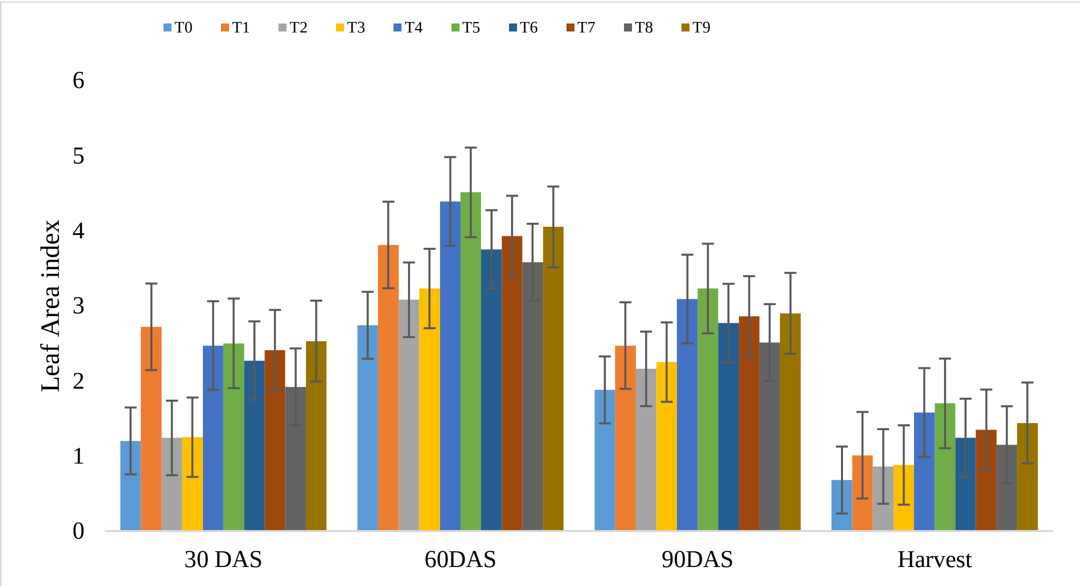

Fig. 1. Effect of nano-urea on leaf area index in direct seeded rice

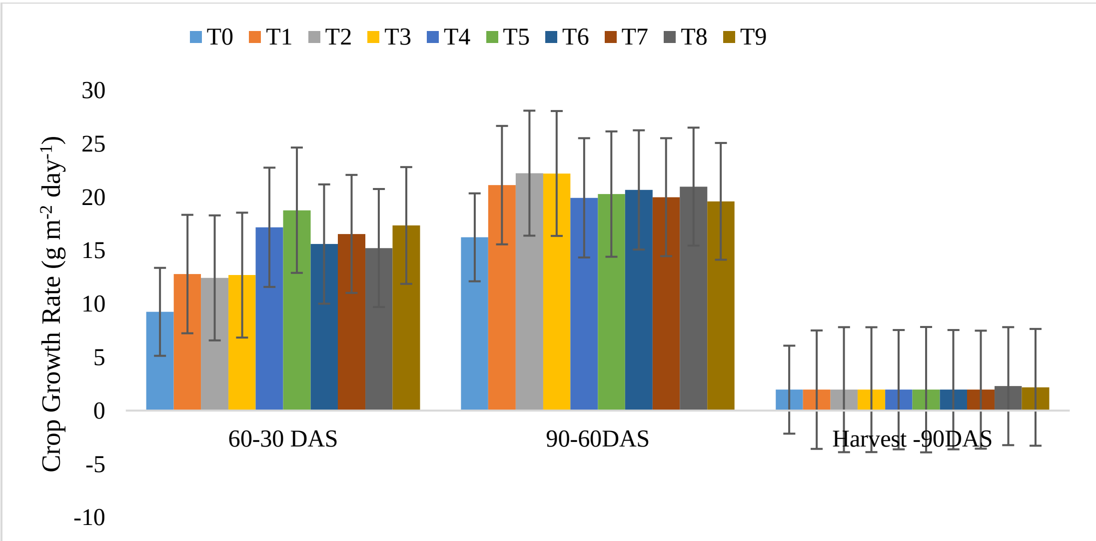

Fig. 2. Effect of nano-urea on CGR (g m^{-2} day^{-1}) in direct seeded rice

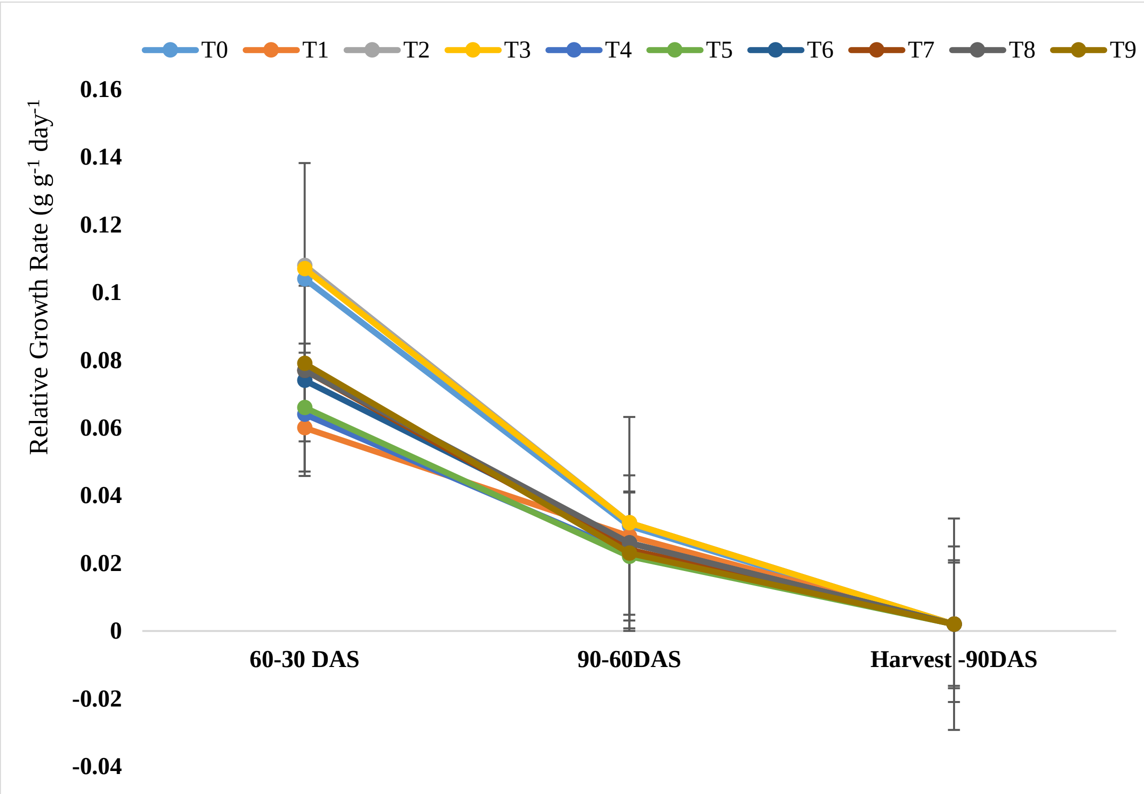

Fig. 3. Effect of nano-urea RGR (g g^{-1} day^{-1}) in direct seeded rice

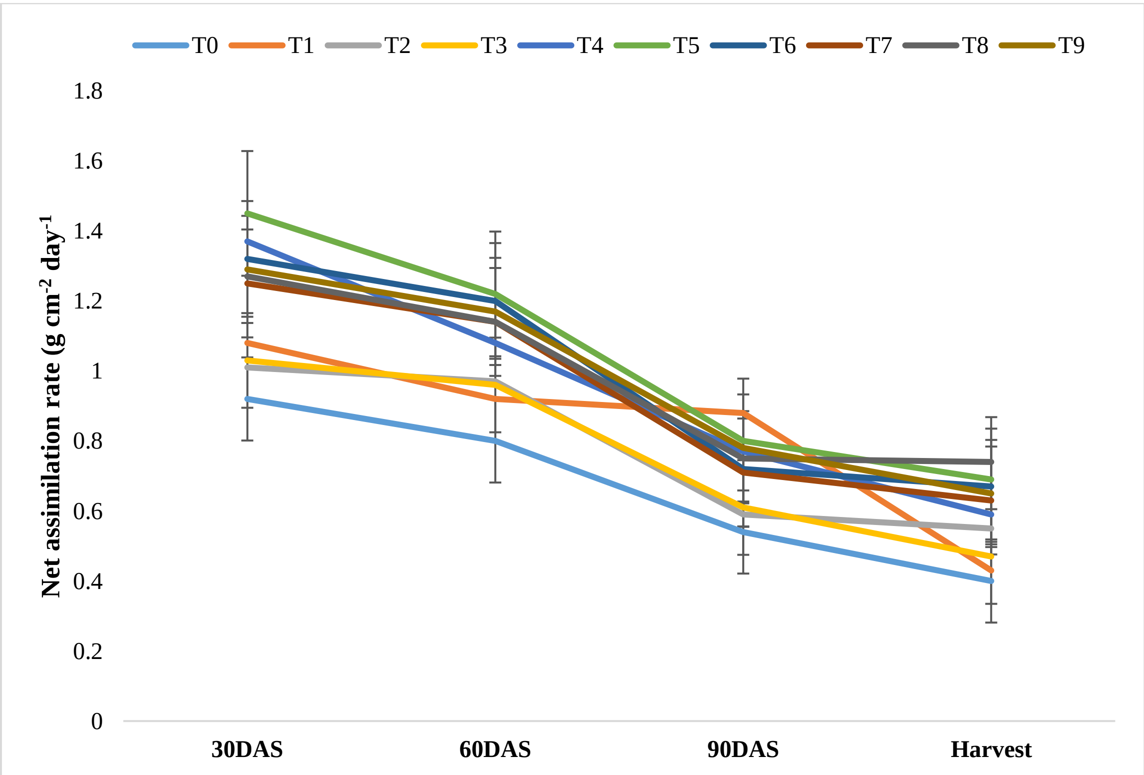

Fig. 4. Effect of nano-urea on NAR (g cm^{-2} day^{-1}) in direct seeded rice

3.2 Crop Phenology

The collected data on the phenology of crop revealed that the days taken by the crop to reach various phenological stages was markedly affected by different Nano-urea treatments throughout the crop growth season (Table 2). Treatment T_1 (recommended dose of prilled urea) took the longest time, with 130 days needed to complete the different phenophases. Among the various Nano urea treatments, Treatment T_5 (50% RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage) took a total of 127 days to reach maturity. In contrast, the control treatment required the shortest duration of 116 days to complete the different phenophases.

Table 2. Effect of nano-urea on days taken to different phenological stages in direct seeded rice

Treatments	**Active tillering**	**Panicle initiation**	**50% Flowering**	**Milking stage**	**Hard dough stage**	**Maturity stage**
T_0	39	56	74	110	94	116
T_1	46	67	85	125	108	130
T_2	41	60	79	117	100	122
T_3	41	61	80	118	101	123
T_4	44	64	82	121	104	126
T_5	45	65	83	122	106	127
T_6	42	62	79	118	102	123
T_7	42	63	80	119	102	124
T_8	45	65	81	120	104	125
T_9	45	65	82	121	105	126
SeM±	0.21	0.27	0.33	0.24	0.26	0.31

Table 3. Effect of nano-urea on yield characters in direct seeded rice

Treatments	Panicle weight (g)	Sterility (%)
T_0	1.98	23.84
T_1	2.25	13.80
T_2	2.21	15.91
T_3	2.23	15.36
T_4	2.58	9.02
T_5	2.69	7.66
T_6	2.40	12.48
T_7	2.42	11.52
T_8	2.39	12.88
T_9	2.45	10.66
Sem±	0.03	0.70
CD (p≤0.05)	0.10	2.0

Table 4. Effect of nano-urea on yield in direct seeded rice

Treatments	**Grain yield (q ha^{-1})**
T_0	39.47
T_1	53.10
T_2	51.40
T_3	50.24
T_4	61.30
T_5	66.57
T_6	57.47
T_7	58.42
T_8	56.72
T_9	59.20
Sem±	1.35
CD (p≤0.05)	4.0

3.3 Yield Attributes

Different nitrogen levels significantly influenced yield attributes in direct-seeded rice (Table 3).

The highest panicle weight of 2.69 g and lowest sterility percentage of 7.66% were recorded in T_5, being 50 % RDPU as basal + NU 2 sprays at 4 ml L-1 at AT and PI stage were found statistically at par with the treatment T_4. Significantly, lowest panicle weight of 1.98 g and highest sterility percentage of 23.84 % were found in control treatment.

3.4 Grain Yield

Application of Nano urea in rice, significantly influenced grain yield (Table 4). In comparison to control treatment and treatment T_1 (recommended dose of prilled urea), where grain yields of 39.47 and 53.10 q ha^{-1} were observed, whereas treatment T_5 (50 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage) resulted in maximum grain yield of 66.57 q ha^{-1}.

4. DISCUSSION

The analyzed data clearly demonstrates that treatment T_5 (50 % RDPU as basal + NU 2 sprays at 4 ml L-1 at AT and PI stage) outperformed both the control treatment and treatment T_1 (Recommended dose of prilled urea) in terms of major growth parameters. The leaf area index (LAI) showed an initial increase until 60 DAS (days after sowing) and then gradually declined until harvest. This pattern can be attributed to the shading effect during the crop's reproductive phase, which resulted in the senescence and eventual death of lower leaves. Notably, treatment T_5 exhibited the highest leaf area index up to 60 DAS, indicating improved canopy development. This could be attributed to the enhanced chlorophyll production stimulated by Nano-urea during critical growth periods. Increased photosynthesis was made possible by the higher chlorophyll concentration, which encouraged overall plant growth and may have led to the emergence more leaves. The mentioned outcomes accorded with those of Midde et al. [13,14 and 15].

Up to 90 days post seeding, the CGR showed an increasing tendency; thereafter, it progressively decreased. CGR at 90 Days after Sowing was greatest for Treatment T_2, indicating a significant increase in crop growth due to Nano-urea spraying. The increased dry matter accumulation in CGR can be attributed to various reasons related to Nano-urea, such as better nitrogen uptake efficiency, decreased nitrogen losses, and increased nutrient utilization efficiency. The present results are consistent with previous research conducted by Zhu et al. [16–17], which documented comparable impacts of Nano-urea on CGR and the accumulation of dry matter. Together, Nano urea and prilled urea had an impact on Relative Growth Rate (RGR). Up to 60 days after sowing, crop age showed an increasing trend in RGR; treatment T_2 had the highest RGR in comparison to treatment T_1 (recommended dosage of prilled urea) and the control. The reason for the increase in RGR is that plants are able to more efficiently use available nitrogen for growth due to greater nutrient utilization efficiency Nano-urea. According to earlier study [17], nano-urea can increase a plant's relative growth rate by up to 22% when compared to traditional urea [15–16]. These findings are consistent with that research. Net Assimilation Rate (NAR) rose with increasing crop age up to 60 (DAS), showing a similar trend to RGR. Among the treatments, T_5 recorded higher NAR whereas, the control treatment exhibited the lowest rate of net assimilation, indicating reduced efficiency in nitrogen uptake and utilization by the plants. This can be attributed to the absence of nitrogen supplementation in the treatment T_0 (control). On the other hand, the improved efficiency of nitrogen uptake and utilization in treatments utilizing nano-urea might be the main factor contributing to enhanced growth and development. Comparable results were reported by Ali et al. [18-19].

The different Nano-urea treatments had a significant impact on the days taken by the crop to reach various growth stages throughout the crop growth season. Treatment T_5 resulted in a reduction of three days in reaching 50% flowering and three days in reaching maturity compared to treatment T_1 (Recommended dose of nitrogen). Additionally, control treatment took least number of days to reach maturity. According to Schoper *et al*. (1987), providing plants with nitrogen can stimulate their vegetative growth, potentially delaying the onset of reproductive growth, including flowering and seed formation. Consequently, plants that receive higher nitrogen levels may take longer to reach maturity compared to those receiving a more balanced nitrogen supply or no nitrogen at all [20].

The yield contributing characters *viz*., panicle weight (g) and sterility percentage (%) showed significant variation due differential application of nitrogen through prilled and Nano-urea. Highest panicle weight (g) and lowest sterility percentage (%) were found in treatment T_5. The foliar application of nano urea is responsible for the observed effects on panicle weight. This is likely due to the promotion of higher assimilation of photosynthates and the facilitation of their effective transport from source to sink inside the plant. Moreover, the prompt application of nano urea, a nitrogen supplement, promoted the onset of grain production, increasing the quantity of grains per panicle. These findings align with previous studies conducted [13, 21, 22 and 23]. Their research also demonstrated similar effects of nano urea on promoting photosynthate assimilation, enhancing translocation, and improving grain formation in various crop species. Likewise, lower sterility percentage may be related to the higher starch translocation from the active site of leaves and straw to grain (sink), as well as the higher nitrogen levels provided by nano-urea throughout the growth stages, which led to a greater amount of photo-synthetically active radiation interception and increased photosynthesis. The outcomes closely aligned with the findings reported in references [13,23, 24-26].

Treatment T_5 resulted in significantly higher yield parameters, which can be attributed to the enhanced efficiency of nutrient uptake and utilization facilitated by the application of Nano urea. This improvement in nutrient utilization led to increased photosynthesis, biomass accumulation, and ultimately, higher yields. These findings align with the conclusions drawn by [17] in their investigation of different urea treatments on rice yield and yield-contributing factors.

5. CONCLUSION

The findings of this research reveal that application of Nano-urea resulted in noteworthy enhancements in growth parameters like LAI and CGR, and yield attributes including panicle weight, in comparison to the control (T_0) and the recommended dose of nitrogen (T_1). Treatment T_5 (50 % RDPU as basal + NU 2 sprays at 4 ml L^{-1} at AT and PI stage) demonstrated the highest yield of grain (66.57 q ha^{-1}), respectively, outperforming the other treatments. Therefore, it can be concluded that the application of two sprays of Nano-urea at 4 ml L^{-1} at AT and PI stage, along with 50% prilled urea as a basal dose, has the potential to enhance the productivity of direct-seeded rice.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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