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Growth and growth indices of rice (*Oryza sativa* L.) as influenced by different sources of nano urea and mulches

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Abstract
Enhancing nutrient use efficiency and optimizing plant growth through nano-based inputs and eco-friendly mulching strategies is a promising approach for sustainable rice production. A field experiment was conducted during the *kharif* 2024 at the Instructional Farm, Department of Agronomy, DBSKKV, College of Agriculture, Dapoli to study the influence of different sources of nano urea and mulches on growth indices of *kharif* dibbled rice (*Oryza sativa* L.). The experiment was laid out in a split-plot design with three main plot treatments: Nano urea (market product) @ 40 ppm (N_1), Nano urea synthesized @ 40 ppm (N_2), and Nano urea conjugate @ 40 ppm (N_3) and five subplot treatments: 100% wool mulch (M_1), 100% wool mulch with micronutrients (M_2), polythene mulch (silver-black, 30 microns) (M_3), drip HDPE mulch (M_4), and no mulch (control) (M_5)**.** The results indicated that, nano urea conjugate (N_3) significantly improved plant height, dry matter accumulation and showed higher values for growth indices such as absolute growth rate (AGR) for plant height and dry matter accumulation and crop growth rate (CGR), similarly for treatment M_2 (100% wool mulch with micronutrient, 200GSM) and treatment N_1- nano urea (market product) @40ppm and M_5 showed higher values for relative growth rate (RGR) and net assimilation ratio (NAR) across all growth stages.

Keywords: Nano urea, wool mulch, relative growth rate, net assimilation ratio, absolute growth rate, crop growth rate

Introduction
Rice (*Oryza sativa* L.) is a vital staple crop for over half of the global population and plays a central role in food security, especially in Asia (Chaudhary *et al.*, 2023) [5]. In India, rice occupies nearly 51.4 million hectares with a production of around 149.07 million metric tonnes (Anonymous, 2025a) [2]. Despite advances in production technologies, achieving high rice productivity remains a challenge due to declining resource use efficiency, especially of nitrogen fertilizers. Nitrogen is essential for vegetative growth and biomass accumulation, influencing key physiological processes such as chlorophyll synthesis, cell division, and protein formation, which are critical for improved plant growth indices like leaf area index (LAI), crop growth rate (CGR), and net assimilation rate (NAR) (Manikandan *et al.*, 2022) [11].
Recent advancements in nanotechnology have introduced nano-fertilizers as a viable alternative to conventional nutrient delivery systems. Nano urea, with particle sizes ranging from 20-50 nm, offers improved nitrogen use efficiency (NUE) by minimizing losses through leaching and volatilization and enhancing synchronized nutrient release (Mansingh & Nanda, 2023) [12]. The application of nano-fertilizers has been shown to positively influence rice growth attributes such as plant height, tiller production, leaf expansion, and dry matter accumulation, ultimately improving crop performance (Chaitra *et al.*, 2021) [4]. Notably, the conjugation of nano urea with chitosan- a biodegradable, nitrogen-rich polymer, further enhances nutrient availability and stress resistance in rice by stimulating enzymatic activities related to nitrogen metabolism, like nitrate reductase and glutamine synthetase (Abd Elgadir *et al.*, 2015) [1].
Growth indices serve as powerful tools for quantifying the physiological efficiency of plants under varying nutrient and environmental conditions.

Enhanced LAI, CGR, and NAR reflect the crop's capacity to utilize resources efficiently and produce biomass, especially during the critical stages of vegetative and reproductive development (Liu & Lal, 2015) [10]. Studies have shown that foliar application of nano urea and its conjugates can lead to significant improvements in these indices compared to conventional urea, likely due to better translocation, foliar absorption, and reduced nitrogen loss (Baboo, 2021) [3].

In this context, the present investigation was undertaken to assess the combined effect of different sources of nano urea and mulching materials-especially biodegradable options like wool mulch on the growth and growth indices of *kharif* dibbled rice. The study focuses on exploring how nano-urea conjugates and organic mulches influence early crop vigour, resource use efficiency, and physiological attributes under coastal lateritic soil conditions. This approach aims not only to improve the understanding of nano-formulated nutrient uptake and utilization in rice but also to offer sustainable solutions aligned with environmentally safe and resource-efficient agriculture.

Materials and Methods

A field experiment entitled "Effect of different sources of nano urea and mulches on performance of *kharif* dibbled rice (*Oryza sativa* L.)" was conducted during the *kharif* season of 2024 at the Instructional Farm, Department of Agronomy, College of Agriculture, Dapoli, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, Maharashtra. The site is geographically located at 17°45′24″ N latitude and 73°17′47″ E longitude, with an elevation of approximately 157.8 meters above sea level. The experimental field exhibited a well-drained sandy clay loam soil, categorized under Alfisols, with initial soil properties indicating low nitrogen (178.5 kg ha^{-1}), low phosphorus (12.5 kg ha^{-1}), medium potassium (282.5 kg ha^{-1}), high organic carbon (11.1 g kg^{-1}), acidic pH (5.55), and low EC (0.130 dSm^{-1}).

The experiment was laid out in a split-plot design with three replications. The main plot consisted of three nano urea treatments: N_1: Market available nano urea (40 ppm), N_2: Synthesized nano urea (40 ppm), N_3: Nano urea conjugate (40 ppm). The sub-plots comprised five mulch treatments: M_1: 100% wool mulch (200 GSM), M_2: Wool mulch enriched with micronutrients (200 GSM), M_3: Silver-black polythene mulch (30 microns), M_4: Drip HDPE mulch and M_5: No mulch (control).In total, 15 treatment combinations were evaluated over 45 plots (5.2 m × 3.0 m gross; 4.7 m × 2.5 m net).

The rice variety Ratnagiri-24 was used, characterized by semi-dwarf stature, high tillering ability, and tolerance to stem borer and blast. Dibbling was done manually at 25 cm × 25 cm spacing using a seed rate of 15-20 kg ha^{-1}. Fertilizer was applied as per RDF (100:50:50 kg N: P_2O_5: K_2O ha^{-1}), with nitrogen given in two equal splits (basal and at tillering), while P and K were applied entirely at sowing. Nano urea treatments were foliar-applied at 45 and 60 DAS. Five plants from each plot were randomly selected from the net plot and tagged. These plants were used for recording the observations on growth attributes Further, growth indices were calculated using following formulas as given by Ramachandrappa and Jayadeva. (2021) [15].

$$\text{Absolute growth rate (g plant}^{-1}\text{ day}^{-1}) = \frac{W_2 - W_1}{t_2 - t_1}$$

W_1 and W_2 are dry weights at times t_1 and t_2, respectively.

$$\text{Crop growth rate (g m}^{-2}\text{ day}^{-1}) = \frac{1}{p} \times \frac{W_2 - W_1}{t_2 - t_1}$$

p- land area (m^2)

$$\text{Relative growth rate (g g}^{-1}\text{ day}^{-1}) = \frac{\text{Loge } W_2 - \text{Loge } W_1}{t_2 - t_1}$$

Net assimilation rate (g day^{-1} m^{-2}) = (W_2 - W_1) (Loge L_2 - Loge L_1)/ (t_2 - t_1) (L_2 - L_1)

L_1 and L_2 - leaf area at t_1 and t_2, respectively

The data recorded on various parameters were subjected to Fisher's method of analysis of variance and interpretation of the data was made as given by Gomez and Gomez (1984) [7].

Results and Discussion

Growth attributes

Plant height and dry matter accumulation

The data related to plant height and dry matter accumulation is represented in table 1 and the mean plant height recorded at various stages was 30.79 cm (30 DAS), 61.06 cm (60 DAS), 83.04 cm (90 DAS) and 84.14 cm at harvest and the mean dry matter accumulation $hill^{-1}$ (g) recorded at different stages was 2.00, 12.29, 33.01 and 38.91 g at 30, 60, 90 DAS and at harvest, respectively, were significantly influenced by both nano urea sources and mulch treatments.

Among nano urea sources, N_3 (nano urea conjugate @ 40 ppm) recorded the highest plant height (87.38 cm) and dry matter accumulation (39.86 g $hill^{-1}$) at harvest. This superiority can be attributed to improved nitrogen availability and efficient uptake due to the conjugated nano urea's-controlled release of nano urea conjugate and foliar absorption characteristics. These results are consistent with those reported by El-Badri *et al.* (2021) [6], who found that nanofertilizers enhanced plant height, biomass production, and chlorophyll content in cereals due to better nutrient synchronization and minimized losses. Similarly, Rehman *et al.* (2019) [16] observed that nano urea foliar sprays significantly improved plant height and biomass in rice by enhancing nitrogen uptake and delaying senescence through sustained nutrient release. The slow-release nature of the nano urea conjugate likely contributed to extended vegetative growth, resulting in greater biomass accumulation.

With respect to mulch treatments, M_2 (wool mulch enriched with micronutrients) showed the highest plant height (88.59 cm) and dry matter accumulation (46.20 g $hill^{-1}$), followed closely by M_1 (100% wool mulch). The superior performance of wool mulch treatments is in agreement with Turnwald *et al.* (2023) [18], who found that wool mulch significantly improved aboveground biomass and moisture conservation in organic farming systems. Their results demonstrated that wool mulch moderated soil temperature and retained moisture, supporting microbial activity and root development contributing directly to higher plant height and dry matter production. Further, Singh *et al.* (2022) [17] also reported similar improvements in growth and yield attributes of upland rice under wool mulch. They observed that wool mulch increased tillering, plant height, and total biomass by enhancing soil physical conditions and conserving moisture during critical growth stages.

Growth indices

Absolute Growth Rate (AGR)

The data related to absolute growth rate for plant height and dry matter accumulation is presented in Table 2. The mean AGR for plant height observed to be 1.063 cm day^{-1} (0-30DAS), 0.972 cm day^{-1} (30-60DAS) and 0.694 cm day^{-1} (60-90DAS) and for dry matter accumulation 0.067 g day^{-1} (0-30DAS), 0.342 g day^{-1} (30-60DAS) and 0.691 g day^{-1} (60-90DAS).

The N_3 treatment recorded the highest AGR values for both plant height [1.134 cm day^{-1} (0-30 DAS), 1.048 cm day^{-1} (30-60DAS) and 0.764 cm day^{-1} (60-90DAS)] and dry matter (0.070 g day^{-1} (0-30DAS), 0.351 g day^{-1} (30-60DAS) and 0.714 g day^{-1} (60-90 DAS)], confirming its ability to sustain active vegetative growth. These findings align with those of Rehman *et al*. (2019) [16], who demonstrated enhanced AGR in nano-urea-treated rice, attributing the results to better nutrient availability and delayed senescence and similar results were also found by Patil *et al.* (2025) [14] in sweet corn.

Among mulches, M_2 exhibited the highest AGR values for both plant height [1.307 cm day^{-1} (0-30 DAS), 1.073 cm day^{-1} (30-60DAS) and 0.793 cm day^{-1} (60-90DAS)] and dry matter [0.103 g day^{-1} (0-30DAS)], 0.423 g day^{-1} (30-60DAS) and 0.940 g day^{-1} (60-90 DAS)], which is consistent with the findings of Kasirajan and Ngouajio (2012) [9]. Their study emphasized that biodegradable mulches, including organic wool mulches, support crop vigour by regulating root-zone temperature and improving soil structure, ultimately increasing growth rates.

Crop Growth Rate (CGR) (g m^{-2} day^{-1})

The data related to CGR is presented in Table 3. The mean CGR values are 1.067 g m^{-2} day^{-1} (0-30DAS), 5.459 g m^{-2} day^{-1} (30-60DAS) and 11.051 g m^{-2} day^{-1} (60-90DAS). The CGR was significantly improved by both nano urea and mulch treatments. N_3 recorded the highest CGR (11.39 g m^{-2} day^{-1} at 60-90 DAS), indicating superior resource conversion into biomass. This outcome corroborates the work of El-Badri *et al*. (2021) [6], who reported that nano-fertilizers improved CGR by increasing enzymatic activity and nitrogen metabolism in rice and similar results were found by Nagangoudar *et al.* (2023) [13]. Mulch treatment M_2 achieved the highest CGR (15.03 g m^{-2} day^{-1}) followed by M_1, while control M_5 had the lowest. These results are similar to those of Singh *et al*. (2022) [17], who documented enhanced CGR in rice under wool mulch due to improved soil moisture and enhanced microbial activity in the root zone.

Relative Growth Rate (RGR) (g g^{-1} day^{-1})

The data related to RGR (g g^{-1} day^{-1}) is presented in Table 3, it showed an inverse pattern, with higher values under control (M_5) in mulches. For nano urea, N_1 showed a marginally higher RGR (0.0767 g g^{-1} day^{-1}) at 30-60 DAS. These higher relative rates can occur under lower biomass accumulation where initial plant weight is low, resulting in proportionally higher growth. This observation is supported by Hunt. (1982) [8], who noted that RGR tends to be higher in early growth stages or under limited biomass due to reduced self-shading and higher nutrient concentration per unit tissue.

Net Assimilation Rate (NAR) (g day^{-1} m^{-2})

The data related to Net assimilation rate (NAR) (g day^{-1} m^{-2}) was found to be highest under M_5 (control) treatment. This may reflect higher leaf photosynthetic efficiency per unit area under reduced canopy conditions. However, NAR was not directly related to total growth or biomass, as these treatments had lower overall productivity. These findings are consistent with the growth analysis by Manikandan *et al.* (2022) [11], who emphasized that higher NAR alone does not guarantee higher biomass accumulation if leaf area index and duration are low. Among nano urea sources, N_1 again showed slightly higher NAR during 30-60 DAS, while N_3, despite having the highest biomass, showed lower NAR- likely due to a dilution effect, as total biomass increases faster than leaf-level assimilation.

Table 1: Plant height (cm) and dry matter accumulation hill^{-1} (g) as influenced by different treatments

Treatments	Plant height (cm)				Dry matter accumulation hill^{-1} (g)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Main plot: Nano urea sources (N)								
N_1: Nano urea (market product) @40ppm	29.75	60.23	80.44	81.24	1.91	11.89	32.21	38.05
N_2: Nano urea synthesised @40ppm	31.03	60.60	82.18	83.80	1.97	12.28	32.77	38.81
N_3: Nano urea conjugate @40ppm	31.58	62.34	86.50	87.38	2.13	12.71	34.07	39.86
S.E.m.±	0.42	0.41	1.03	0.51	0.05	0.07	0.04	0.11
C.D. at 5%	NS	1.59	4.04	1.99	NS	0.28	0.15	0.45
Sub plot: Mulches (M)								
M_1: 100% Wool mulch (200GSM)	36.45	64.02	86.01	87.57	2.94	15.67	43.34	45.83
M_2: 100% Wool mulch with micronutrients (200GSM)	37.87	66.53	87.66	88.59	3.08	15.76	43.94	46.20
M_3: Polythene mulch (silver black) (30 microns)	29.72	59.46	82.51	83.38	1.73	11.37	34.80	39.66
M_4: Drip HDPE (High density polyethylene)	25.79	58.09	79.56	80.79	1.22	9.76	22.54	34.89
M_5: Without mulch (control)	24.10	57.19	79.47	80.36	1.03	8.90	20.45	27.96
S.E.m.±	0.91	1.62	1.76	1.35	0.07	0.12	0.25	0.20
C.D. at 5%	2.67	4.72	5.12	3.95	0.21	0.35	0.73	0.60
Interaction effect (N X M)								
S.E.m.±	1.58	2.80	3.04	2.34	0.12	0.21	0.43	0.35
C.D. at 5%	NS	NS	NS	NS	NS	NS	1.26	1.03
General mean	30.79	61.06	83.04	84.14	2.00	12.29	33.01	38.91

Table 2: Effect of nano urea sources and mulches on absolute growth rate for plant height (cm day^{-1}) and dry matter accumulation (g day^{-1})

Treatments	AGR for plant height (cm day^{-1})			AGR for dry matter accumulation (g day^{-1})		
	0-30 DAS	30-60 DAS	60-90 DAS	0-30 DAS	30-60 DAS	60-90 DAS
Main plot: Nano urea sources (N)						
N_1: Nano urea (market product) @40ppm	0.992	0.908	0.626	0.063	0.331	0.678
N_2: Nano urea synthesised @40ppm	1.062	0.960	0.692	0.067	0.345	0.682
N_3: Nano urea conjugate @40ppm	1.134	1.048	0.764	0.070	0.351	0.714
Sub plot: Mulches (M)						
M_1: 100% Wool mulch (200GSM)	1.217	1.020	0.750	0.097	0.418	0.923
M_2: 100% Wool mulch with micronutrients (200GSM)	1.307	1.073	0.793	0.103	0.423	0.940
M_3: Polythene mulch (silver black) (30 microns)	1.037	0.947	0.677	0.060	0.323	0.783
M_4: Drip HDPE (High density polyethylene)	0.927	0.923	0.647	0.040	0.287	0.423
M_5: Without mulch (control)	0.827	0.897	0.603	0.033	0.260	0.387
General mean	1.063	0.972	0.694	0.067	0.342	0.691

Table 3: Effect of nano urea sources and mulches on crop growth rate, relative growth rate and net assimilation ratio of rice

Treatments	CGR (g m^{-2} day^{-1})			RGR (g g^{-1} day^{-1})			NAR (g day^{-1} m^{-2})		
	0-30 DAS	30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS	90- At harvest	0-30 DAS	30-60 DAS	60-90 DAS
Main plot: Nano urea sources (N)									
N_1: Nano urea (market product) @40ppm	1.018	5.294	10.836	0.0767	0.0462	0.0139	0.0213	0.0357	0.0124
N_2: Nano urea synthesised @40ppm	1.050	5.466	10.928	0.0754	0.0454	0.0125	0.0204	0.0345	0.0109
N_3: Nano urea conjugate @40ppm	1.134	5.616	11.390	0.0746	0.0451	0.0119	0.0189	0.0310	0.0090
Sub plot: Mulches (M)									
M_1: 100% Wool mulch (200GSM)	1.570	6.637	14.759	0.0675	0.0404	0.0091	0.0191	0.0307	0.0041
M_2: 100% Wool mulch with micronutrients (200GSM)	1.643	6.763	15.026	0.0656	0.0407	0.0068	0.0180	0.0306	0.0036
M_3: Polythene mulch (silver black) (30 microns)	0.924	5.141	12.493	0.0759	0.0447	0.0108	0.0202	0.0321	0.0101
M_4: Drip HDPE (High density polyethylene)	0.650	4.555	6.815	0.0836	0.0509	0.0215	0.0215	0.0374	0.0173
M_5: Without mulch (control)	0.548	4.198	6.162	0.0853	0.0512	0.0155	0.0222	0.0380	0.0188
General mean	1.067	5.459	11.051	0.0756	0.0456	0.0127	0.0202	0.0338	0.0108

Conclusion

The foliar application of nano urea conjugate (N_3) at 40 ppm significantly improved plant height, dry matter accumulation, and all growth indices compared to other nano urea sources. Among mulches, wool mulch enriched with micronutrients (M_2) showed superior performance by enhancing moisture conservation and nutrient availability, leading to maximum values for absolute and crop growth rates. The integration of nano-formulated nutrients with biodegradable wool-based mulching offers a sustainable approach to improving rice growth and physiological efficiency under coastal lateritic soil conditions.

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