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Response of spring rice (*Oryza sativa* L.) varieties to different nitrogen application methods at Nawalparasi West, Nepal

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A B S T R A C T

Rice (*Oryza sativa* L.) cultivation necessitates an adequate supply of nitrogen to achieve optimal growth and yield. This study, conducted in Nawalparasi West from February to June 2023, aimed to assess the effects of nitrogen management through a foliar spray of nano urea, compared to need-based nitrogen management using the Leaf Color Chart (LCC) and the Recommended Dose of urea Fertilizer (RDF) application. The experiment followed a Randomized Complete Block Design (RCBD) with three replications, incorporating four nitrogen management levels (Control, RDF through urea fertilizer (120 kg/ha), 25% of RDF through basal urea (30 kg/ha) + nano urea, and 25% of RDF through basal urea (30 kg/ha) + (LCC) and two rice varieties (Chaite-5 and Hardinath-1). The results indicated that the LCC-based treatment produced the highest grain yield at 5.18 mt/ha, statistically similar to the yield of the nano urea-based treatment (5.04 mt/ha). The enhanced yields were attributed to more effective tillers per m² (260.17 tillers/m² and 253.17 tillers/m², respectively), longer panicle length (28.12 cm and 25.99 cm), more filled grains per panicle (210.03 and 215.73), and lower sterility percentage (24.93% and 26.95%). Despite comparable yields, nano urea application proved to be more cost-effective [97,926.10 Nepalese Rupees (NRs)] with a higher benefit-cost ratio (1.78) and greater ease of application for farmers compared to the LCC. Varietal responses varied, with Hardinath-1 exhibiting the highest yield with LCC-based nitrogen application (5.37 mt/ha), and Chaite-5 demonstrating the highest yield (4.778 mt/ha); with nano urea-based nitrogen application (5.31 mt/ha). Chaite-5 displayed a greater effective number of tillers per m² (241.42 tillers/m²) and filled grains per panicle (224.56). Consequently, it is suggested that nano urea-based nitrogen application, particularly in conjunction with a variety of Chaite-5, holds the potential for improved productivity.

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Introduction

Rice (*Oryza sativa* L.) is a fundamental staple diet for over 60% of the global population and is cultivated across numerous nations, with the Asia-Pacific region contributing to more than 90% of the world's rice production (Nasiruddin & Roy, 2012; Papademetriou et al., 2000). In Nepal, where it covers a substantial portion of agricultural land, rice production stands at 14.73,474 ha, contributing 11.30% to the Agricultural Gross Domestic Product (AGDP) (MoALD, 2022). Nepal holds the 17th position globally in rice production and ranks 64th in rice productivity. Over the years, rice production has seen an increase, rising from 5.047 million tons in 2013/14 to 5.62 million tons in 2020/21, accompanied by a rise in productivity from 3.39 tons/ha to 3.82 mt/ha during the same period. Despite these improvements, the production area has witnessed a decline from 1,486,951 ha in 2013/14 to 1,473,474 ha in 2020/21 (MoALD, 2022). Factors such as the introduction of high-yielding varieties and technological advancements have contributed to this growth (Dawadi et al., 2023; Ghimire & Rauniyar, 2023); however, Nepal's rice production remains comparatively low when benchmarked against neighboring countries and the global average. Spring rice varieties, known for their short growth cycle, resilience to pests and diseases, and potential for high yields, are especially promising. Planting spring rice during areas' abundant irrigation capacity helps suppress weed growth, and the increased sunlight during the spring contributes to higher yields (Subedi et al., 2018). Particularly, in regions like Nawalparasi West, Nepal, where rice cultivation thrives with suitable agro-climatic conditions and fertile soil, exploring novel approaches for optimizing nitrogen management becomes imperative.

Rice requires several essential nutrients, including nitrogen, phosphorus, potassium, calcium, magnesium, silicon, boron, iron, manganese, and zinc, for proper growth and development. Nitrogen is the most limiting nutrient, followed by phosphorus and potassium, among these elements. Efficient nitrogen fertilization plays a pivotal role in enhancing rice yields and ensuring optimal crop growth (Yadvinder-Singh et al., 2007). Nitrogen is a crucial factor in crop yield, contributing to around 20% of the total yield, highlighting the importance of proper nitrogen management in rice cultivation. Providing the necessary nutrients in appropriate amounts using the correct application methods is crucial for ensuring the productivity and sustainability of the rice cropping system (Fageria et al., 2003). However, improper fertilizer application can lead to increased costs, reduced returns, and environmental pollution (Timilsina et al., 2018), and nitrogen input levels have a significant impact on yield, biomass, harvest index, and nitrogen use efficiency (Pan et al., 2017). However, the traditional application of nitrogen fertilizer has reached a plateau up to the present. Coming from 1985 to 2010 cereal yield increased by 65% while consumption of fertilizer by 512% (Chen et al., 2011). This scenario indicates a low level of efficiency in the use of fertilizers in the crop system. The loss of nitrogen through various means, such as de-nitrification, leaching, and emissions, demands the adoption of advanced tools and practices for precise nitrogen application (Gautam et al., 2024). Loss of nitrogen can occur in various forms, such as NH_4, NO_3, or NO_2 (Ghimire, Dhami, et al., 2023; Ghimire, Poudel Chhetri, et al., 2023). Under submerged conditions, leaching losses can be as high as 80-84% (Sahu & Samant, 2006). Additionally, with increased nitrogen application rates, the volatilization of ammonia also increases in rice fields (Lin et al., 2007). Various decision support tools have been introduced to enhance nitrogen use efficiency in rice and facilitate real-time N management. These tools include the Green Seeker optical sensor, Soil Plant Analysis Development (SPAD), LCC, urea briquette, Urea Super Granules (USG), and split application (Lee, 2021). In this context, the LCC emerges as an accessible and cost-effective tool for real-time nitrogen management, particularly in South Asia (Singh et al., 2016). The introduction of tools such as the LCC provides farmers with a cost-effective means to monitor the nitrogen status of rice plants, ensuring optimal fertilization practices and, consequently, higher yields (Sathiya & Ramesh, 2009). It is an inexpensive and straightforward tool used to monitor the greenness of rice leaves, which is an indicator of the plant's nitrogen status. The LCC offers a practical tool for implementing the Site-Specific Nutrient Management (SSNM) concept, allowing farmers to make informed decisions regarding top-dressing nitrogen application in rice crops. Its applicability extends to wheat and maize, providing a visual means for farmers to assess the nitrogen requirements of their crops. Implementation of LCC resulted in a significant increase in average grain yield (0.1 to 0.7 ton/ha) across various villages and seasons (Alam et al., 2005), with notable improvements in net returns (19-31%) in rice-wheat cropping systems compared to fixed-time nitrogen application (Shukla et al., 2004). Furthermore, utilizing LCC led to a reduction in nitrogen application (20.0-42.5 kg N/ha) compared to the highest level of fixed timing nitrogen application (Maiti et al., 2004), contributing to a decrease in nitrous oxide emission by 16% and methane by 11% (Bhatia et al., 2012). Farmers can effectively employ LCC as a qualitative tool to evaluate the foliar nitrogen status of crops, guiding the application of topdressing nitrogen fertilizer as needed (Balasubramanian et al., 1998). The emergence of nanotechnology offers a sustainable solution to challenges faced by modern intensive agriculture. Nanofertilizers, falling within the 1-100 nm size range, present the potential to meet plants' nutritional needs, promoting sustainable crops (Hasanuzzaman et al., 2020). Moreover, the introduction of nanotechnology, specifically nano urea, offers a promising avenue for sustainable agriculture by addressing challenges associated with conventional fertilizers (Kim et al., 2018; Sabir et al., 2014). Given the potential benefits of nano urea, evaluating its effectiveness alongside conventional practices becomes imperative for advancing agricultural sustainability.

Nawalparasi West, situated in the Lumbini Province of Nepal, has emerged as a significant hub for rice production, leveraging its favorable agro-climatic conditions. However, the existing gap in nitrogen use efficiency and the persistent issue of suboptimal fertilization practices warrant an in-depth investigation. While rice remains a staple for more than half of the global population, the national production in Nepal struggles to meet domestic demands, particularly due to inefficiencies in nitrogen use, notably in rain-fed conditions (Baral et al., 2020). The prevalent lack of site-specific nutrient management and arbitrary fertilizer application practices contribute to a substantial yield gap in the country (Shukla et al., 2004). Unchecked fertilizer application not only results in lower crop production but also imposes environmental burdens and exacerbates the high yield gap. Compounding the issue is the reported unavailability and high cost of urea fertilizer in Nepal, further hindering effective nitrogen management. These challenges necessitate a comprehensive study to evaluate and optimize nitrogen application methods, focusing on their effectiveness, economic viability, and environmental impact. The necessity for improved nitrogen management practices, coupled with the exploration of high-yielding spring rice varieties, underscores the significance of this study in Nawalparasi West, Nepal.

The study hypothesized that employing different nitrogen management practices will significantly impact the growth and yield of spring rice varieties in Nawalparasi West, Nepal. The objective of the study was to assess the effectiveness of various nitrogen application methods on the growth and yield of spring rice and evaluate the performance of Chaite-5 and Hardinath-1 rice varieties. The research findings hold practical significance for rice cultivation in the region by informing farmers about effective nitrogen management methods to enhance crop yield and resource utilization. Furthermore, the study explored the viability of innovative approaches like nano urea, offering a potentially sustainable solution to challenges in conventional urea application, thereby providing valuable guidance for farmers, policymakers, and agricultural practitioners in Nepal to improve nitrogen management practices for sustainable and efficient rice production.

Materials and methods

Experimental Site

The experimental site for the study was the Semari farmer's plot in Pratappur, Nawalparasi West, situated at coordinates 27.53° N 83.70° E, within the Lumbini province in the Terai region of Nepal. Conducted during the spring season of 2023, the site experiences a tropical monsoon climate characterized by four distinct seasons: *i)* summer, *ii)* monsoon, *iii)* autumn, and *iv)* winter. The climate provides favorable conditions for spring rice cultivation, with the crop season typically spanning from March to May, as indicated by NASA (2023).

Physiochemical Characteristics of Soil

The physiochemical characteristics of the soil were assessed by randomly collecting samples from the plot in a 'Z' pattern, utilizing a shovel for soil excavation. Subsequently, the sub-samples were amalgamated, air-dried under shade, and ground, and then submitted to the soil testing laboratory in Bhumai, Nawalparasi West. The analysis revealed a loam soil texture for the research plot, providing the following observations (Table 1).

Experimental Materials and Experimental Details

The experimental materials for the study included Chaite-5 and Hardinath-1 rice varieties which were acquired from Buddha Seeds Company, Nawalparasi West. Additionally, nitrogen management involved LCC with 25% basal urea application, along with foliar spray of nano urea at the maximum tillering stage and before panicle initiation, serving as key components for nitrogen management in spring rice. The experimental design employed a two-factorial Randomized Complete Block Design (RCBD) with nitrogen doses (4 levels) and varieties (2 types). The study comprised 8 treatments with 3 replications (Table 2). Each plot measured 3 × 2 m², resulting in a plot size of 6 m². There was a 1 m spacing between replications and treatments. The total experimental plot size covered an area of 325 m², arranged in a 25 × 13 m layout.

General cultivation practices

Nursery management, main field preparation, and fertilizer application

The nursery management involved periodic irrigation and thorough inspection for pest and disease symptoms in Chaite-5 and Hardinath-1 spring rice varieties. The main field, previously plowed, underwent additional plowing with standing water using a rotavator to create a puddled field for rice transplantation. Nitrogen (N), Phosphorus (P), and Potassium (K) were sourced from urea/nano urea, Single Super Phosphate (SSP), and Muriate of Potash (MoP), respectively. For the experimental plots, P and K were applied as a full basal dose through SSP (150 g per plot) and MoP (39.9 g per plot) with the recommended dose 60:40 PK kg/ha (AITC, 2023). A suggested approach is to apply the fertilizer in three stages: as a basal dose, a top dressing at the maximum tillering stage, and a second top dressing at the tillering stage. Nitrogen application included five different methods. Control treatment (0 kg N/ha), where no nitrogen was applied. Nutrient dose of 120 kg N/ha: 25% N as basal dose (urea: 39.13 g per plot), 50% N in tillering stage (urea: 78.26 g per plot), and 25% during panicle initiation stage (urea: 39.13 g per plot). PAU-LCC-based nitrogen management: Initially, 25% N was applied as basal dose (urea: 39.13 g per plot), and from 14 Days After Transplanting (DAT) onwards, need-based nitrogen was applied at 30 kg/ha intervals if the plant leaves' shade fell below the critical shade of LCC. Nano urea foliar spray: Initially, 25% N was applied as a basal dose (urea: 39.13 g per plot), followed by two foliar sprays of Indian Farmers Fertilizer Cooperative Limited (IFFCO) nano urea at maximum tillering and panicle initiation stages, with a concentration of 4 ml/1 liter of water.

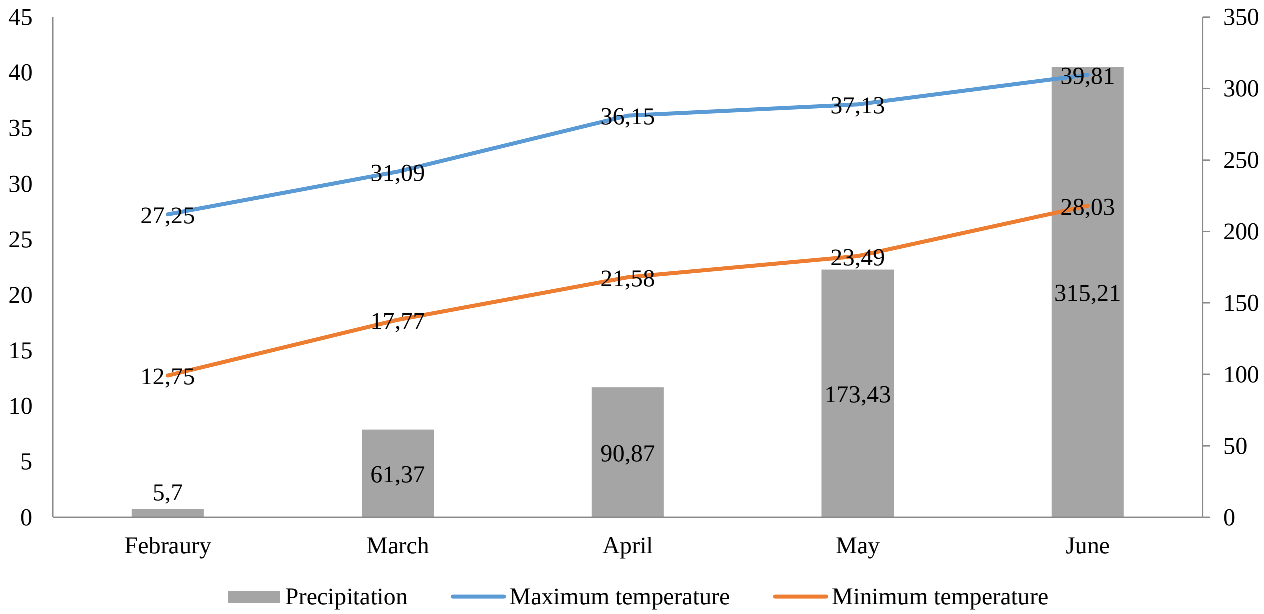

Figure 1. Maximum temperature, minimum temperature, and precipitation of Nawalparasi West from February 2023 to June 2023.

Table 1. Physiochemical properties of soil at the research site, Nawalparasi West.

S.N	Soil test	Test methods	Value
1	pH	Probe method	7.1
2	Soil organic matter (%)	Walkey and black method (Houba et al., 1989)	2.57
3	Nitrogen (%)	Kjeldahl method (Bremner & Hauck, 2015)	0.103
4	Phosphorus	Modified Olsen's method (Watanabe & Olsen, 1965)	36.23
5	Potassium	Ammonium acetate method (Pratt, 2016)	349.44
6	Soil texture	The hydrometer method (Mozaffari et al., 2024)	Loam

Table 2. Different treatment factors were used in the experiment.

Factor A: Nitrogen application methods		
1.	Control	N_1
2.	Split urea application based on RDF (120 kg/ha)	N_2
3.	Leaf color chart (PAU-LCC) based urea application with 25% basal urea application (30 kg/ha)	N_3
4.	25% RDF-based urea application (30 kg/ha) and then 2 foliar sprays of IFFCO nano urea (4 ml/l)	N_4
Factor B: Varieties		
1.	Chaite-5	V_1
2.	Hardinath-1	V_2

Transplantation of seedlings

The transplantation phase involved manual transplantation with a spacing of 20 cm x 20 cm and three seedlings per hill. Seedlings aged 30-35 days were utilized for this process. Before uprooting, the seedlings in the nursery underwent irrigation. The actual transplantation occurred promptly, within 24 hours of uprooting the seedlings, ensuring their swift and efficient relocation to the main field.

Irrigation, weed management, and plant protection measures

Rice, being a water-intensive crop, demands a substantial water supply, particularly during critical growth stages such as tillering, panicle initiation, and grain filling. To ensure an adequate water supply, tube well irrigation was diligently maintained. Weed management was addressed through hand weeding, with the initial weeding conducted at 30 DAT and the subsequent one at 45 DAT. In terms of pest and disease control, a proactive approach was adopted. Prophylactic and curative pesticide sprays were applied at appropriate doses, synchronized with the appearance of signs of diseases and pests. This strategy aimed to preemptively manage and address potential threats to the rice crop, promoting a healthy and productive cultivation environment.

Harvesting and threshing

The harvesting process involved manual cutting using traditional sickles, with special attention given to a central 3 m square area marked and harvested separately within each plot. Following harvest, the rice heads were cut, sun-dried, and manually threshed. The grains underwent a cleaning process through winnowing, and their weight was meticulously measured using an electric balance. This traditional yet meticulous approach to harvesting and threshing aimed to ensure the accurate assessment of grain yield in each experimental plot.

Data Collection

Plant height, number of tiller per square meter, and number of effective tillers per square meter

Phenological recording involved the measurement of plant height at 15-day intervals from 30 DAT for five randomly selected and tagged plants. Additionally, the quantification of tillers per square meter commenced at 30 DAT, with measurements taken at 15-day intervals throughout the crop cycle (Table 3). Effective tillers, characterized by the presence of grains, were meticulously recorded, and the count per square meter was calculated for each plot just before the crop's harvest. This systematic approach provided comprehensive data on plant height, tiller density, and effective tiller production, contributing to a detailed understanding of the experimental outcomes.

Flag leaf length and panicle length (cm)

The flag leaf length, representing the first leaf below the inflorescence in gramineous plants, was meticulously measured, specifically focusing on the first leaf beneath the panicle. Simultaneously, panicle length was assessed by randomly selecting 20 panicles from each hill, and their respective measurements were recorded as the values for panicle length. These detailed measurements provided crucial insights into the development and characteristics of the experimental rice varieties, contributing to a comprehensive evaluation of the study's outcomes.

Number of filled grains per panicle, thousand-grain weight, sterility percentage

The average number of grains was derived from 20 carefully selected samples in each plot within the experiment for the determination of the final data. These samples, representing various treatments, underwent meticulous weighing on a precision weighing machine to determine the weight of a thousand grains. Each selected panicle was scrutinized, and the number of unfilled grains per panicle was recorded to assess sterility percentage. The sterility percentage was then calculated using Equation 1. This method provided a quantitative measure of sterility, offering valuable insights into the reproductive success and overall grain quality in different treatment conditions.

$$\text{Sterility }\% = \frac{\text{Number of unfilled grains}}{\text{Total number of filled grains}} \times 100 \quad (1)$$

(Puteh et al., 2014)

Grain yield, straw yield, and harvest index

The determination of grain yield, straw yield, and harvest index involved selecting a central 1 m² plots for harvesting the crops. The harvested crops underwent sun drying, threshing, and cleaning before recording their weights. Grain moisture levels were measured using a moisture meter, and a straw sample was set aside for sun drying. The grain and straw yields obtained were then used to calculate the yields for the entire hectare area.

For grain yield, an adjustment was made to account for a moisture level of 14% using the formula proposed by Shahidullah et al. (2009), as stated in Equation 2.

$$\mathrm{GY} = \frac{(100-\mathrm{MC})*\text{plot yield (kg)}\times 1000\,\text{(ha)}}{(100-14)\times \mathrm{A}\times 1000\ \text{(mt)}} \qquad (2)$$

GY: Grain yield (mt/ha) at 14% moisture

Where, MC = Moisture content of grain (%) just before weighing the bulk, and A = Net plot area (m^2).

The straw yield of the selected sample was measured in tons/ha, and the harvest index (HI) was calculated using Equation 3.

$$\mathrm{HI}\ (\%) = \left[\frac{\text{Grain yield}}{\text{Grain yield+Straw yield}}\right] \times 100 \qquad (3)$$

(Bhatt & Ghimire, 2024)

Economic analysis

The total cost of cultivation, total return, net return, and benefit-cost ratio (BCR) were calculated. The economic analysis of the experimental cultivation involved a comprehensive assessment of various financial aspects. The total cost of cultivation comprises all incurred expenses, encompassing inputs such as seeds, fertilizers, pesticides, labor, machinery usage, and irrigation. On the other hand, the total return signifies the overall revenue generated through the sale of the harvested crops, determined by multiplying the yield with the market prices. Net return, a critical metric, represents the actual profit derived from deducting the total cost of cultivation from the total return, offering insights into the financial outcome of the agricultural endeavor. Additionally, the benefit-cost (BC) ratio serves as a key indicator, quantifying the relationship between benefits and costs. A BCR exceeding 1 indicates a profitable venture, while a ratio below 1 suggests a potential financial loss. These economic analyses contribute valuable information for farmers, researchers, and policymakers to make informed decisions regarding the economic viability and sustainability of the implemented agricultural practices.

Statistical Analysis

The recorded data subjected statistical analysis, including analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) for mean separations, utilizing R-Studio 4.3.1 software. Microsoft Word 2010 was employed for word processing, and MS Excel was used for creating tables, graphs, and basic statistical analysis. ANOVA was utilized to assess differences between the two factors, and LSD values were calculated at a 5% level of significance using R-studio.

Results and Discussion

Growth Parameters

Plant height

The examination of plant height, a pivotal indicator of crop development, unfolded notable variations influenced by both nitrogen application methods and rice varieties. The numerical data presented in Table 4 provides insights into the growth dynamics at various stages. At 30 DAT, the plant height in the control plot was 48.63 cm, significantly lower than treatments involving nitrogen application. No significant difference was observed between LCC (56.58 cm), nano urea (55.80 cm), and RDF (54.41 cm) at this early stage.

Table 3. Details of various cultural practices in an experimental plot of rice.

S.N	Cultural operations	Date
1.	Seed sowing	February 11, 2023
2.	Collection of soil samples and	February 27, 2023
3.	Main field preparation	March 16, 2023
4.	Transplanting	March 17, 2023
5.	Application of basal dose of fertilizer	March 17, 2023
6.	Top dressing	
6.1	1st top dressing	April 12, 2023
6.2	2nd top dressing	May 5, 2023
7	LCC reading	
7.1	1st LCC reading	April 1, 2023
7.2	2nd LCC reading	April 11, 2023
7.3	3rd LCC reading	April 21, 2023
7.4	4th LCC reading	May 1, 2023
7.5	5th LCC reading	May 11, 2023
8	Weeding	
8.1	1st weeding	April 18, 2023
8.2	2nd weeding	May 03, 2023
9	Harvesting	June 20, 2023 (Chaite-5) June 23, 2023 (Hardinath-1)
10	Threshing	June 21, 2023 (Chaite-5) June 24, 2023 (Hardinath-1)

Table 4. Plant height as influenced by nitrogen application methods and spring rice varieties.

Treatments	Plant height (cm)				
	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Nitrogen application methods					
Control (0 kg N/ha)	48.63^{b}	63.67^{c}	78.53^{c}	80.67^{c}	87.33^{c}
RDF (120 kg N/ha)	54.41^{a}	68.50^{b}	83.33^{bc}	88.00^{b}	95.67^{b}
30 kg N/ha + LCC	56.58^{a}	71.67^{ab}	87.83^{ab}	96.50^{a}	102.00^{ab}
30 kg N/ha + Nano urea	55.80^{a}	73.67^{a}	91.50^{a}	95.33^{a}	103.10^{a}
SEm (±)	1.78	1.14	1.76	1.87	2.25
$LSD_{0.05}$	5.39	3.46	5.35	5.67	6.83
F-test	*	***	***	***	***
Varieties					
Chaite-5	53.89^{a}	69.19^{a}	83.10^{b}	87.67^{b}	94.25^{b}
Hardinath-1	53.82^{a}	69.58^{a}	87.50^{a}	92.59^{a}	99.80^{a}
SEm (±)	1.26	0.81	1.25	1.32	1.59
$LSD_{0.05}$	3.81	2.49	3.79	4.01	4.83
CV (%)	8.08	4.03	5.07	5.08	5.69
F-test	NS	NS	*	*	*
Grand mean	53.86	69.35	85.30	93.99	97.02

Treatment means separated by DMRT and columns represented with the same letter(s) are non-significant at 5% level of significance, DAT = Days after transplanting, NS = non-significant, LSD = Least Significance Difference, SEm = Standard Error of mean, CV = Coefficient of Variance, RDF = Recommended Dose of Fertilizer, ***= significant at 0.001 level of significance, *= significant at 0.05 level of significance.

From 45 DAT onwards, the superiority of nano urea became evident, consistently exhibiting the highest plant height: 73.67 cm at 45 DAT, 91.50 cm at 60 DAT, 95.33 cm at 75 DAT, and 103.10 cm at 90 DAT. LCC showed comparable growth, while RDF followed, and the control consistently displayed the lowest plant height. At 30 and 45 DAT, Chaite-5 and Hardinath-1 showed similar plant heights. However, from 60 DAT onward, Hardinath-1 exhibited significantly greater plant height: 87.50 cm at 60 DAT, 92.59 cm at 75 DAT, and 99.80 cm at 90 DAT, compared to Chaite-5.

The early-stage uniformity in plant height across nitrogen application methods suggests that initial growth responses were comparable. Nano urea emerges as a promising option for farmers, demonstrating consistent growth benefits throughout the crop cycle. The observed increase in plant height in the nano urea and LCC treatments can be elucidated by the distinctive mechanisms associated with these nitrogen management approaches. Nano urea, characterized by the encapsulation of urea in nanocarriers, facilitates efficient nutrient release, ensuring a sustained and controlled nitrogen supply to the plants (Iqbal et al., 2019). This leads to continuous and robust vegetative growth, contributing to elevated plant height. Additionally, nano urea's targeted nutrient delivery system enhances nutrient uptake efficiency, further promoting optimal growth conditions (Midde et al., 2022). Reduced nitrogen loss from the soil due to minimized leaching and volatilization in nano urea formulations also contributes to increased plant height (Dimkpa et al., 2020). Similarly, the leaf color chart enables precision in nitrogen application by visually indicating the crop's nitrogen status. The enhanced plant height associated with LCC aligns with its positive impact on meristematic development, cell division, and cell elongation, as reported in previous studies (Bhavana et al., 2020). This allows farmers to adjust nitrogen application timely and accurately, ensuring that the plants receive an optimal amount of nitrogen for healthy and vigorous growth, including the observed higher plant height. The combination of these factors highlights the effectiveness of nano urea and LCC in promoting enhanced plant height through improved nutrient management strategies. Varietal differences became more pronounced in later stages, with Hardinath-1 showcasing taller plants, emphasizing the impact of specific rice varieties on growth dynamics.

Number of tillers per square meter

The number of tillers per square meter in spring rice crops, recorded from 30 to 90 DAT at 15-day intervals, exhibited significant variations based on nitrogen management methods and rice varieties. The data revealed a continuous increase in tiller numbers up to 60 DAT, followed by a decline thereafter. At 30 DAT, no significant difference was observed among nitrogen management methods (Nano urea, LCC, and RDF), but by 45 DAT, LCC exhibited the highest number of tillers per square meter (300.50), statistically comparable to nano urea (293.67) and RDF (291.50). Nano urea consistently demonstrated the maximum number of tillers per square meter at 60 (509.13), 75 (379.50), and 90 DAT (287.00), surpassing other treatments (Table 5). The control group exhibited the lowest tiller count at all observed time points (212.83 to 217.17). This outcome suggests that both nano urea and LCC are effective in enhancing the number of tillers, aligning with findings from Adhikari et al. (2022). Furthermore, the influence of rice varieties on tiller numbers was evident, with Hardinath-1 initially exhibiting higher tiller counts at 30 DAT (281.42). However, from 45 DAT onward, Chaite-5 consistently displayed significantly higher tiller numbers (374.41 to 268.33) compared to Hardinath-1. This observation aligns with results reported by Shrestha et al. (2022), indicating a varietal difference in tillering patterns. Overall, the enhanced tiller numbers associated with nano urea and LCC can be attributed to their precise and effective nitrogen management, promoting optimal vegetative growth (Midde et al., 2022). The results underscore the significance of these nitrogen management strategies in influencing tillering dynamics in spring rice cultivation.

The higher tillering observed in the LCC and nano urea foliar application treatments can be attributed to the efficient and site-specific nitrogen management strategies employed by these methods. LCC is a visual tool that enables farmers to assess the nitrogen status of crops and make informed decisions about nitrogen application (Ali et al., 2017). It allows for real-time adjustments based on the visual indicators of nitrogen deficiency or sufficiency in plant leaves. In the case of nano urea foliar application, the use of nanotechnology in delivering nitrogen to plants offers several advantages. Nano urea provides a more controlled and targeted release of nitrogen, ensuring that the nutrient is efficiently taken up by the plants when needed (Vejan et al., 2021). This precision in nutrient delivery can lead to optimal conditions for tillering, promoting robust vegetative growth. Both LCC and nano urea foliar application methods contribute to a more tailored and responsive approach to nitrogen management, which likely results in an environment conducive to higher tillering. These approaches align with the concept of Site-Specific Nutrient Management (SSNM), where nutrient application is customized based on the specific needs of the crop at different growth stages. The ability to fine-tune nitrogen application in response to the crop's requirements may lead to the observed higher tillering in the LCC and nano urea treatments compared to conventional methods.

Yield Attributing Parameters

The study delved into various yield attributes influenced by different nitrogen application methods and rice varieties, shedding light on their intricate impact on rice growth and productivity.

Table 5. Number of tillers/m^2 as influenced by nitrogen application methods and spring rice varieties.

Treatments	Number of tillers m^{-2}				
	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Nitrogen application methods					
Control (0 kg N/ha)	212.83^b	328.50^c	423.17^c	317.83^c	217.17^c
RDF (120 kg N/ha)	291.50^a	365.00^b	487.50^b	355.00^b	258.83^b
30 kg N/ha + LCC	300.50^a	388.33^a	506.17^a	377.00^a	273.50^{ab}
30 kg N/ha + Nano urea	293.67^a	377.67^{ab}	509.13^a	379.50^a	287.00^a
SEm (±)	4.86	7.051	6.11	6.61	8.60
$LSD_{0.05}$	14.76	21.39	18.53	20.06	26.10
F-test	***	***	***	***	***
Varieties					
Chaite-5	267.83^b	374.41^a	488.58^a	366.25^a	268.33^a
Hardinath-1	281.42^a	355.33^b	474.50^b	348.42^b	249.42^b
SEm (±)	3.44	4.98	4.32	4.67	6.08
$LSD_{0.05}$	10.43	15.12	13.10	14.19	18.46
CV (%)	4.34	4.73	3.11	4.53	8.14
F-test	*	*	*	*	*
Grand mean	274.63	364.87	481.54	357.33	258.87

Treatment means separated by DMRT and columns represented with the same letter(s) are non-significant at a 5% level of significance, DAT = Days after transplanting, LSD = Least Significance Difference, SEm = Standard Error of mean, CV = Coefficient of Variance, RDF = Recommended Dose of Fertilizer, ***= significant at 0.001 level of significance, *= significant at 0.05 level of significance.

Table 6. Yield attributing characters as influenced by nitrogen application methods and spring rice varieties.

Treatments	Yield attributes					
	ET/m^2	Flag leaf length (cm)	Panicle length (cm)	FGPP	TGW (g)	Sterility (%)
Nitrogen application methods						
Control (0 kg N/ha)	191.33^c	25.33^c	21.75^c	159.77^c	23.17^a	30.22^a
RDF (120 kg N/ha)	223.00^b	28.00^{bc}	22.82^c	189.93^b	24.10^a	23.45^b
30 kg N/ha + LCC	260.17^a	30.90^{ab}	28.12^a	210.03^a	24.27^a	24.93^b
30 kg N/ha + Nano urea	253.17^a	33.67^a	25.99^b	215.73^a	24.12^a	26.95^{ab}
SEm (±)	9.33	1.12	0.54	4.15	0.79	1.40
$LSD_{0.05}$	28.31	3.41	1.64	12.58	2.38	4.27
F-test	***	***	***	***	NS	*
Varieties						
Chaite-5	241.42^a	28.87^b	21.58^b	224.56^a	20.14^b	28.37^a
Hardinath-1	222.42^a	30.87^a	27.76^a	163.17^b	27.68^a	24.39^b
SEm (±)	6.60	0.80	0.38	2.93	0.55	0.99
$LSD_{0.05}$	20.01	2.41	1.16	8.89	1.68	3.02
CV (%)	9.86	9.34	5.37	5.24	8.04	13.08
F-test	NS	*	***	***	***	*
Grand mean	231.92	29.47	24.67	193.87	23.91	26.39

Treatment means separated by DMRT and columns represented with the same letter(s) are non-significant at a 5% level of significance, NS = non-significant, LSD = Least Significance Difference, SEm = Standard Error of mean, CV = Coefficient of Variance, RDF = Recommended Dose of Fertilizer, *** = significant at 0.001 level of significance, * = significant at 0.05 level of significance.

Table 7. Interaction effect of nitrogen application methods and rice varieties on panicle length.

Treatment combinations	Panicle length (cm)	
	Varieties	
Nitrogen application methods	Chaite-5	Hardinath-1
Control (0 kg N/ha)	18.50[d]	24.99[c]
RDF (120 kg N/ha)	20.43[d]	25.21[c]
30 kg N/ha + LCC	23.24[c]	33.00[a]
30 kg N/ha + Nano urea	24.15[c]	27.84[b]
SEm (±)	0.77	
$LSD_{0.05}$	2.32	
CV (%)	5.64	
F-test	**	
Grand Mean	24.67	

Treatment means separated by DMRT and columns represented with the same letter(s) are non-significant at 5% level of significance, LSD = Least Significance Difference, SEm = standard Error of mean, CV = Coefficient of Variance, ** = significant difference at 0.01 level of significance, RDF = Recommended Dose of Fertilizer.

In terms of effective tillers per square meter (ET/m^2), the treatment with 30 kg N/ha + LCC emerged as the most effective, showcasing the importance of innovative nitrogen management methods in promoting tiller development. Conversely, the control treatment exhibited the lowest ET/m2, emphasizing the necessity of proper nitrogen utilization for optimal tillering (Table 6). The results of a higher number of effective tillers per m^2 in LCC-based nitrogen management were in harmony with Adhikari et al. (2022). Moving to flag leaf length, the treatment with 30 kg N/ha + Nano urea stood out with the longest flag leaf (33.67 cm), indicating the positive influence of nano urea on leaf development. In contrast, the control treatment showed the shortest flag leaf (25.33 cm), emphasizing the pivotal role of nitrogen in supporting healthy plant growth (Table 6).

When considering panicle length, 30 kg N/ha + LCC exhibited the longest panicle (28.12 cm), highlighting the positive impact of LCC-based nitrogen management on panicle elongation (Table 6). Both 30 kg N/ha + Nano urea and RDF treatments also demonstrated competitive panicle lengths, underscoring the effectiveness of these nitrogen sources. The interaction between nitrogen application methods and rice varieties significantly influenced panicle length, revealing distinct patterns in panicle development across different treatment combinations (Table 7). The treatment combination of 30 kg N/ha + LCC and Hardinath-1 demonstrated the longest panicle length at 33.00 cm, indicating a synergistic effect between LCC-based nitrogen management and the specific rice variety. Conversely, the other treatment combinations, including Control (0 kg N/ha), RDF (120 kg N/ha), and 30 kg N/ha + Nano urea, produced significantly shorter panicles. This result underscores the importance of considering both nitrogen management practices and rice varieties for optimizing panicle development. The observed longer panicle length in the treatment combining LCC and Hardinath-1 suggests potential compatibility or positive interaction between the unique characteristics of Hardinath-1 and the benefits derived from LCC-based nitrogen application. The contribution and variation in crops are primarily led by their genotypes. Genotypes represent the genetic makeup of a crop, and the variation in traits such as growth and yield arises from different combinations of these genotypic factors (Ghimire, Neupane, et al., 2023). The diverse genotypic combinations contribute to the overall variability observed in crop characteristics, influencing their performance and adaptability to various environmental conditions.

In terms of filled grains per panicle (FGPP) and thousand-grain weight (TGW), 30 kg N/ha + Nano urea (215.73 FGPP and 24.12 g, respectively) consistently outperformed other treatments, indicating enhanced grain development and maturation. This observed enhancement in grain filling can be attributed to the unique properties of nano urea. The nano-sized particles facilitated a more efficient translocation of starch from the actively photosynthesizing areas of the leaves and straw toward the developing grains (Basavegowda & Baek, 2021). This increased translocation efficiency is associated with the smaller particle size of nano urea, allowing for better mobility within the plant's vascular system. Furthermore, the application of nano urea contributed to an elevated and sustained nitrogen supply during critical growth stages (Upadhyay et al., 2023). This sustained nitrogen availability facilitated an extended period of enhanced photosynthetic activity. According to findings by Sahu et al. (2022), nano urea has been reported to provide a continuous and controlled release of nitrogen, ensuring a steady nutrient supply to the plants. This prolonged availability of nitrogen played a crucial role in optimizing the interception of sunlight for photosynthesis, thereby promoting greater overall photosynthetic efficiency. In essence, the combined effects of improved starch translocation and sustained nitrogen availability induced by nano urea application synergistically contributed to the observed increase in the number of filled grains per panicle. This underscores the potential of nano urea not only in inefficient nutrient delivery but also in positively influencing the physiological processes crucial for achieving optimal crop yield.

The lower sterility percentage in treatments with 30 kg N/ha + LCC (24.93%) and 30 kg N/ha + Nano urea (26.95%) further attested to the positive impact of these innovative nitrogen management methods on grain quality. Moreover, varietal differences were evident, with Chaite-5 consistently outperforming Hardinath-1 in most yield attributes, emphasizing the importance of selecting suitable rice varieties for optimal yields. The distinctive trends observed in various agronomic parameters, including effective tillers per square meter, flag leaf length, panicle length, FGPP, TGW, and sterility, can be ascribed to the nuanced and specific mechanisms associated with each nitrogen management method and nano urea. Beginning with the effective tillers per square meter, the LCC-based nitrogen management likely played a pivotal role in optimizing nutrient availability during critical growth stages. By offering real-time assessments and facilitating precise nitrogen applications, LCC ensured an optimal balance for tiller development, thereby resulting in a higher number of effective tillers. On the other hand, the nano-sized urea particles in nano urea might have contributed to controlled and sustained nitrogen release, fostering effective tiller development through enhanced nutrient uptake efficiency. The nano urea application might have demonstrated its efficacy by promoting efficient nutrient absorption, which translated into robust vegetative growth, including longer flag leaves (Javed et al., 2022). Simultaneously, the continuous monitoring and responsive nitrogen management offered by LCC may have maintained an optimal nutrient balance, influencing the elongation of flag leaves (Bijay-Singh & Singh, 2017). In terms of panicle length, both nitrogen management methods showed their impact. The precision in nitrogen application guided by LCC likely supported sustained panicle elongation, resulting in longer panicles. Similarly, the nano-sized urea particles in nano urea contributed to a consistent nitrogen supply during crucial growth stages, leading to increased panicle length. Moving on to the grain-related parameters, namely FGPP, TGW, and sterility percentage, both nano urea and LCC demonstrated positive effects. The controlled release of nitrogen from nano urea and the dynamic monitoring offered by LCC-optimized grain-filling processes resulted in higher FGPP and TGW. Moreover, the efficient nitrogen supply may have reduced stress conditions, contributing to lower sterility rates in both nano urea and LCC treatments.

Measurement of Yields

The grain yield, a critical parameter in determining the success of rice cultivation, exhibited significant variations under different nitrogen management methods and across rice varieties. Notably, LCC-based nitrogen management emerged as the most effective, yielding the highest grain production at 5.18 mt/ha. Nano urea application also demonstrated promising results, closely trailing behind LCC with a grain yield of 5.04 mt/ha, surpassing the conventional RDF treatment (4.45 mt/ha). This result aligns with previous findings by Krishnakumar and Haefele (2013) and Duttarganvi et al. (2014), indicating the potential of LCC in enhancing nitrogen use efficiency and consequently boosting grain yield. Varietal differences played a significant role in influencing grain yield, with Chaite-5 showcasing superior performance at 4.778 mt/ha compared to Hardinath-1 at 4.368 mt/ha (Table 8). The higher yield in Chaite-5 could be attributed to its significantly higher number of effective tillers per square meter and filled grains per panicle (Table 7). Further dissecting the interaction between nitrogen management methods and rice varieties on grain yield, LCC-based nitrogen application on Hardinath-1 rice displayed the highest yield. Intriguingly, this was statistically comparable to nano urea on Chaite-5, LCC on Chaite-5, and RDF urea on Chaite-5, suggesting nuanced varietal responses to specific nitrogen management approaches.

The interaction effect of nitrogen (N) application methods and spring rice varieties on grain yield unveils nuanced responses within specific treatment combinations. Table 9 outlines the grain yield (mt/ha) for various nitrogen application methods (Control, RDF, LCC, and Nano urea) under two rice varieties, Chaite-5 and Hardinath-1. In the control group, both varieties, Chaite-5 and Hardinath-1, exhibited relatively lower grain yields, marked as 3.997 mt/ha and 3.200 mt/ha, respectively. The RDF treatment, representing the conventional recommended dose of fertilizer, showcased an improvement in grain yield for both varieties.

Chaite-5 recorded 4.773 mt/ha, while Hardinath-1 exhibited 4.133 mt/ha. The introduction of innovative nitrogen management methods, such as Leaf Color Chart (LCC) and Nano urea, further elevated grain yields. Chaite-5, under LCC, demonstrated a notable increase to 5.020 mt/ha, while Hardinath-1 reached 5.357 mt/ha. Nano urea application resulted in even higher yields, with Chaite-5 at 5.313 mt/ha and Hardinath-1 at 4.780 mt/ha.

Table 8. Effect of different nitrogen application methods and spring rice varieties of rice on yield parameters.

Treatments	Yield parameters		
	Grain yield (mt/ha)	Straw yield (mt/ha)	Harvest index (%)
Nitrogen application methods			
Control (0 kg N/ha)	3.59[c]	5.27[c]	0.41[a]
RDF (120 kg N/ha)	4.45[b]	6.46[b]	0.41[a]
30 kg N/ha + LCC	5.19[a]	7.28[a]	0.41[a]
30 kg N/ha + Nano urea	5.05[a]	7.29[a]	0.42[a]
SEm (±)	0.14	0.12	0.01
$LSD_{0.05}$	0.418	0.37	0.25
F-test	***	***	NS
Varieties			
Chaite-5	4.778[a]	6.961[a]	0.408[a]
Hardinath-1	4.368[b]	6.194[b]	0.411[a]
SEm (±)	0.0975	0.0862	0.006
$LSD_{0.05}$	0.296	0.261	0.018
CV (%)	7.391	4.538	5.046
F-test	*	***	NS
Grand mean	4.572	6.578	0.409

Treatment means separated by DMRT and columns represented with the same letter(s) are non-significant at a 5% level of significance, NS = non-significant, LSD = Least Significance Difference, SEm = Standard Error of mean, CV = Coefficient of Variance, RDF = Recommended Dose of Fertilizer, *** = significant at 0.001 level of significance, * = significant at 0.05 level of significance.

Table 9. Interaction effect of N application methods and spring rice varieties on grain yield.

Treatment combinations	Grain yield (mt/ha)	
	Varieties	
Nitrogen application methods	Chaite-5	Hardinath-1
Control	3.997[c]	3.200[c]
RDF	4.773[a]	4.133[b]
LCC	5.020[a]	5.357[a]
Nano urea	5.313[a]	4.780[a]
SEm (±)	0.195	
$LSD_{0.05}$	0.592*	
CV (%)	7.390	
Grand Mean	4.572	

Treatment means separated by DMRT and columns represented with the same letter(s) are non-significant at 5% level of significance, NS= non-significant, LSD=Least Significance Difference, SEm= Standard Error of mean, CV= Coefficient of Variance, *= significant difference at 0.05 level of significance, RDF= Recommended Dose of Fertilizer.

Table 10. Cost of cultivation, total return, net return, and BCR as influenced by nitrogen application methods and spring rice varieties.

Treatments	Economic analysis			
	Total cost of production (NRs)	Total return (NRs)	Net return (NRs)	BCR
Nitrogen application methods				
Control (0 kg N/ha)	95066.10[d]	120976.00[a]	25909.87[c]	1.27[c]
RDF (120 kg N/ha)	101566.10[a]	149721.10[b]	48154.97[b]	1.47[b]
30 kg N/ha + LCC	99191.10[b]	169668.90[a]	70477.83[a]	1.71[a]
30 kg N/ha + Nano urea	97926.10[c]	174431.80[a]	76505.67[a]	1.78[a]
SEm (±)	62.50	4637.49	4615.32	0.05
$LSD_{0.05}$	189.58	14066.40	13999.13	0.14
F-test	***	***	***	***
Varieties				
Chaite-5	98499.85[a]	160563.50[a]	62063.67[a]	1.63[a]
Hardinath-1	98374.85[a]	146835.50[b]	48460.59[b]	1.49[b]
SEm (±)	44.19	3279.21	3263.52	0.03
$LSD_{0.05}$	134.05	9946.45	9898.87	0.10
CV (%)	0.15	7.39	20.46	7.35
F-test	NS	*	*	*
Grand mean	98437.35	153699.40	55262.08	1.56

Treatment means separated by DMRT and columns represented with the same letter(s) are non-significant at a 5% level of significance, ns = non-significant, LSD = Least Significance Difference, SEm = Standard Error of mean, CV = Coefficient of Variance, LCC = Leaf Color Chart, RDF = Recommended Dose of Fertilizer, *** = significant at 0.001 level of significance, * = significant at 0.05 level of significance, 1 USD = 132.37 NRs.

Moving to straw yield, it demonstrated sensitivity to both nitrogen management and rice varieties. Nano urea application resulted in the highest straw yield at 7.295 mt/ha, closely followed by LCC at 7.282 mt/ha (Table 8). These outcomes underline the importance of optimal nitrogen use in promoting vegetative growth and dry matter production. Harvest index, a critical indicator of the allocation of resources between grain and straw, did not exhibit significant differences across nitrogen management methods or rice varieties. However, the nano urea application method resulted in the highest HI (0.42). This implies that the distribution of assimilates to grain and straw components remained relatively consistent under the diverse conditions tested. The higher yield observed in nano urea and LCC treatments can be attributed to several scientific factors related to nitrogen management and physiological responses in rice plants. Both nano urea and LCC treatments involve more precise and efficient nitrogen management compared to the control and conventional RDF methods. Nano urea, being in nanoparticle form, likely provides a more controlled and sustained release of nitrogen, ensuring a consistent nutrient supply during critical growth stages. The higher yield in nano urea may be linked to improved photosynthetic efficiency (Upadhyay et al., 2023). Nano urea, as previously mentioned, likely contributes to increased interception of sunlight for photosynthesis due to sustained nitrogen availability (Astaneh et al., 2021). Similarly, LCC-guided nitrogen application ensures that the plants receive the necessary nutrients when they are most needed, optimizing the photosynthetic process and ultimately leading to higher grain yields (Yadav et al., 2017). The results indicate that nano urea foliar application treatments led to an increase in the number of filled grains per panicle (Table 7). This could be attributed to more efficient starch translocation from the leaves and straw to the developing grains. Nano urea, with its smaller particle size, may facilitate better mobility within the plant's vascular system, aiding in the translocation of starch (Seleiman et al., 2020). LCC-guided nitrogen application ensures that the plants receive sufficient nutrients, which is crucial for proper grain filling. The observed increase in yield in nano urea and LCC treatments may be indicative of optimized nitrogen use efficiency. Efficient nitrogen use is crucial for maximizing crop yield, and both nano urea and LCC are associated with improved nitrogen utilization. Nano urea's controlled release and LCC's real-time monitoring likely contribute to a more judicious and effective use of nitrogen by the rice plants. The higher yield in nano urea and LCC treatments can be attributed to their ability to provide a more controlled and sustained nitrogen supply, enhance photosynthetic efficiency, improve starch translocation, and optimize nitrogen use efficiency.

Economic Analysis

The economic analysis of rice cultivation, as presented in Table 10, sheds light on the impact of nitrogen application methods and rice varieties on various financial parameters. Notably, treatments involving innovative nitrogen application methods, such as LCC and nano urea, showcased superior economic performance compared to conventional practices. The treatment combining 30 kg N/ha with LCC exhibited the highest total return (169,668.90 NRs; 1 USD = 132.37 NRs) and net return (70,477.80 NRs), resulting in a favorable BCR of 1.71. Similarly, the 30 kg N/ha with Nano urea treatment demonstrated significant economic gains with a BCR of 1.78. Conversely, the control group incurred lower costs but yielded a substantially reduced return and net profit. The influence of rice varieties on economic outcomes was evident, with Chaite-5 exhibiting higher returns and net profits compared to Hardinath-1.

Conclusion

The study revealed significant variations in growth parameters such as plant height and the number of tillers per m^2, as well as yield attributing characters, including effective tillers per m^2, flag leaf length, panicle length, filled grains per panicle, thousand-grain weight, and sterility percentage. These differences were observed under varying nitrogen management strategies and spring rice varieties. Notably, nano urea-based nitrogen management demonstrated superior effectiveness compared to both the recommended dose of urea application and LCC-based urea application, taking into account both yield and cost efficiency. The findings underscore the potential of nano urea as a promising alternative for improved nitrogen management practices, emphasizing the need for further research to validate and optimize its application in diverse agricultural settings. The results also revealed the commendable performance of both Hardinath-1 and Chaite-5 varieties in terms of growth and yield. Notably, Chaite-5 exhibited a higher grain yield compared to Hardinath-1. Continued investigations into nano urea's potential and its integration into agricultural systems are warranted to refine and promote its adoption as a superior nitrogen management strategy.

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Conflict of interest

The authors declare no conflict of interest.

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Data will be made available on request.

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