ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-5051 (Print)
ISSN: 2521-506X (Online)
CODEN: ASMCCQ

Acta Scientifica Malaysia (ASM)

DOI: http://doi.org/10.26480/asm.01.2025.45.51

CrossMark

RESEARCH ARTICLE

SWITCHING FROM CONVENTIONAL UREA TO LIQUID NANO-UREA FEEDING FOR SUSTAINING RICE CULTIVATION

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ARTICLE DETAILS

Article History:

Received 10 July 2025
Revised 15 August 2025
Accepted 19 September 2025
Available online 06 October 2025

ABSTRACT

Prilled urea is mostly used as a nitrogen source having low efficiency (~35%) causing serious environmental concerns like eutrophication, greenhouse gas emissions and soil pollution and economic harm due to high production cost. Considering these issues, a study was carried out to investigate into the effect of integrated application liquid nano-urea fertilizer with conventional prilled urea on the productivity and profitability of monsoon rice. The experiment was a single factor comprising 13 different combinations of prilled urea and liquid nano-urea fertilizer treatments arranged in a randomized complete block design with three replications. The maximum number of total tillers hill-1 (20.03), effective tillers hill-1 (16.50) and grains panicle-1 (116.33) were observed from the application of recommended prilled urea + 0.5 % nano-urea combination. The highest grain yield (4.28 t ha-1) and straw yield (5.20 t ha-1) were found from the application of 75 % recommended prilled urea + 0.5 % nano-urea combination which provided maximum net return (62,959 BDT ha-1) and gross return (1,91,400 BDT ha-1). In contrast, the minimum gross return (1,39,180 BDT ha-1) was demonstrated from applying 50 % recommended prilled urea + 0.2 % nano-urea combination. Based on the findings, it may be concluded that applying 0.2–0.5% nano-urea allows a 25% reduction in prilled urea without yield reduction. However, using only 50% prilled urea with nano-urea reduces yield. The most cost-effective option was 75% prilled urea with 0.5% nano-urea which will make this combination a promising strategy for sustainable rice production

.KEYWORDS

Prilled urea, Nano-nitrogen, Nitrogen use efficiency, Productivity, Cost effectiveness, Paddy

1. INTRODUCTION

Rice (Oryza sativa L.) plays a vital role as it is the staple food for more than 3.5 billion people (Fukagawa and Ziska, 2019). This places rice fourth in the list of crops by production, after sugarcane, maize, and wheat. Major part of world rice production is from Asia (FAO, 2022). Rice is a dominant crop in Bangladesh serves as main source of calories and becomes world's third largest rice producing country (Mamun et al., 2021). For these reasons, rice-based food production is a key factor in Bangladesh's economy, social stability, and overall food security (Jamal et al., 2023). Over the time, the demand of rice is increasing where total cultivable land is decreasing. To meet the projected food demands, farmers are adopting high yielding exotic rice varieties (Sarkar et al., 2022; Islam et al., 2024). But high yielding rice varieties require more nitrogenous fertilizers compared to local varieties as nitrogen promotes rapid plant growth and improves grain yield and quality through higher tillering, leaf area development, grain formation, grain filling, and protein synthesis.

The use of chemical fertilizers including urea enhance grain production that contributes 40 to 60% of the total agricultural output (Stewart and Roberts, 2012). Most of the farmers are using large amount of prilled urea as a source of nitrogen though nitrogen use efficiency is very low nearly 33% (Cai et al., 2002; Li et al., 2017). Excessive and uncontrolled use of nitrogenous fertilizers may arise environmental problems for instance eutrophication, ammonia volatilization, greenhouse gas emission especially nitrous oxide (Kottegoda et al., 2011; Liang et al., 2007). Besides, leaching losses of nitrate or surface run-off nitrogen in different forms pose a threat to pollution of groundwater and surface waters, respectively.

Nano-urea is a nitrogenous fertilizer produced by using nano technology in liquid form invented by Indian Farmers Fertilizers Cooperative Limited (IFFCO). Average size of nano formulated fertilizers is between the range of 1 to 100 nanometers (Yadav et al., 2023). According to IFFCO, nano-urea contains nano nitrogen particles of the size range (20- 50 nm) dispersed in water which surface area is 10,000 times higher than conventional urea and around 55,000 nano-sized nitrogen particles are equivalent to a single 1 mm prilled urea. Nanoscale urea has greater adsorption capacity because of its large surface area, less volume and more reactive with other compounds (Sharma et al., 2023). This attribute enhances nitrogen utilization and promotes less environmental footprint. Its minute size enhances higher retention on the surface area of the leaf surface at the same time rapidly enter into plant system reducing volatilization and leaching loss (Madlala et al., 2024). Nano-urea is a controlled release fertilizer that precisely delivers nitrogen with plant requirements and becomes available throughout the life cycle (Tarafdar, 2020).

Integrated use of prilled urea and liquid nano-urea is considered as a smart fertilizer application system. Generally, nano-urea is applied to the crops by foliar spray at different concentrations. Foliar spray facilitates easy entry through leaf stomata and finally assimilated by plant cell as its bioavailability rate is higher (Sahoo et al., 2024). It is freely distributed

Quick Response Code	Access this article online	
	Website: www.actascientificamalaysia.com	**DOI:** 10.26480/asm.01.2025.45.51

Cite The Article: Md. Parvez Anwar, Md. Sazzad Hossain Shemul, Mst. Jannatun Fiza, Anjon Mallick, Md. Taibur Rahman, Ahmed Khairul Hasan, Sabina Yeasmin and A K M Mominul Islam(2025). Switching From Conventional Urea To Liquid Nano-Urea Feeding For Sustaining Rice Cultivation. Acta Scientifica Malaysia, 9(1): 45-51.

through phloem inside the plant, translocated and metabolically absorbed as proteins, amino acids and so on as per the plants need. Unused nitrogen is stored in plant vacuole and slowly released. Therefore, nano-urea demonstrates greater efficiency and advantages compared to conventional urea (Namasharma et al., 2023; Chudasama et al., 2024).

This study aims to evaluate the impact of nano-urea fertilizers on the growth and yield of monsoon rice, comparing them with conventional urea fertilizers to assess their potential advantages. The major objectives of this study were to reduce the amount of conventional urea application through the application of liquid nano-urea fertilizer and to determine the most suitable concentration of nano-urea for achieving higher productivity and economic returns from monsoon rice.

2. Materials And Methods

2.1 Experimental Site And Soil Characteristics

The research was conducted at the Agronomy Field Laboratory (24°72′ N, 90°42′ E, at an elevation of 18 m), Bangladesh Agricultural University, Mymensingh during June- November 2023. The experimental soil belongs to the Sonatala soil series under the Old Brahmaputra Floodplain (AEZ-9) (UNDP and FAO, 1988). The land was medium-high with moderate drainage. The soil was silty loam, nearly neutral in pH (6.45), and low in organic matter content (0.85%). The experimental soil had a total nitrogen (N) content of 0.68%, available phosphorus (P) of 16.67 ppm, exchangeable potassium (K) of 0.20 meq/100 g soil, and available sulfur (S) of 12.75 ppm. During the growth period, the highest air temperature (33.4 °C) was recorded in August, while the lowest temperature (18.3 °C) was observed in November. The total rainfall during the experimental period was 934.56 mm, the average relative humidity was 83.80%, and the average monthly sunshine duration was 187.63 hours.

2.2 Experimental Treatments and Design

The experiment was a single factor one comprising 13 different combinations of prilled urea and liquid nano-urea fertilizer treatments such as i) Only recommended dose of nitrogen (RDN) using prilled urea (control) (T1), ii) RDN + 0.2 % nano-urea (T2), iii) RDN + 0.3 % nano-urea (T3), iv) RDN + 0.4% nano-urea (T4), v) RDN + 0.5% nano-urea (T5), vi) 75% RDN + 0.2% nano-urea (T6), vii) 75% RDN + 0.3% nano-urea (T7), viii) 75% RDN + 0.4% nano-urea (T8), ix) 75% RDN + 0.5% nano-urea (T9), x) 50% RDN + 0.2% nano-urea (T10), xi) 50% RDN + 0.3% nano-urea (T11), xii) 50% RDN + 0.4% nano-urea (T12) and xiii) 50% RDN + 0.5% nano-urea (T13). Prilled urea was applied at the rate of 300 kg ha-1 as the recommended dose of nitrogen (RDN). The experiment followed an RCBD design with three replications. There was total 39 plots, each measuring 10 m^2 (4.0 m × 2.5 m).

2.3 Crop Husbandry

A monsoon rice variety BRRI dhan49 developed by the Bangladesh Rice Research Institute, Gazipur (BRRI) was used as plant materials. The seeds were collected from the Agronomy Field Laboratory of BAU, Mymensingh for conducting this experiment. Healthy seeds were selected by a specific gravity method. Seeds were dipped in water in a bucket for 24 hours. These were then taken out from the water and kept thickly in gunny bags. The seeds started sprouting after 48 hours. A small sized high land was selected for raising seedlings. Sprouted seeds were sown on 28 June 2023 after puddling well the nursery bed with spades followed by cleaning and leveling with a ladder. A power tiller was used for plowing and cross ploughing the land. The weeds, stubbles, and crop residues were removed from the plots followed by laddering. To avoid mechanical injury to the seedling's roots, on the previous day of uprooting nursery beds were made wet by the application of water. After thirty days, seedlings were uprooted carefully by hand and similar-sized healthy seedlings were transplanted in the well-prepared puddled field on 25th July 2023 at the rate of two seedlings hill-1, maintaining line-to-line and plant- to-plant distances of 25 cm and 15 cm respectively. Chemical Fertilizers were applied to the plots at the rate of 100, 165, and 110 kg ha-1 of triple super phosphate, muriate of potash, and gypsum respectively, as per the recommendation of BRRI during land preparation, while prilled urea was top dressed in three equal splits at 15, 30, and 45 days after transplanting (DAT). Nano-urea application was done according to treatments by foliar spray at 30 and 60 days after transplanting. The experimental plots were regularly observed to ensure normal growth of the plants. A pre-emergence herbicide Pendimethalin (Trade name: Panida 33 EC) @ 5 mL L-1 A of water was applied at 3 days after transplanting for weed control. Weeding was done twice by hand pulling at 30 and 45 days after transplanting. Spinosad 45% SC was applied twice to control yellow stem borer. Tilt 250EC was used to protect rice from brown spot disease. Flood irrigation was given in the experimental field to maintain a constant level of standing water up to 5 cm during transplantation. Since monsoon rice grows on rainfed condition, no additional irrigation was needed later on. The field was drained out before 15 days of harvest. Other intercultural operations were carried out following the standard practices of rice cultivation. Harvesting was done on 13 November 2023 when 90% rice grain become yellowish.

2.4 Data Collection

Five randomly selected rice hills per unit plot (excluding boundary hills) were sampled before harvest to collect growth and yield parameters. The data of plant height (cm) and number of total tiller per plot were collected at 45 DAT, 60 DAT and at the time of harvesting. Other yield contributing characteristics, such as no. of effective tiller per hill, grains per panicle, sterile spikelets per panicle and 1000 grains weight (at 14% moisture content) were measured. After harvesting, rice grain (at 14% moisture content) and straw (sundried) were recorded and expressed in tons/ha.

2.5 Economic Analysis

Economic analysis was done to determine the gross return, net return and benefit: cost ratio (BCR) of different treatments. Labor wages and prices of different inputs and products were calculated based on local market price.

2.6 Statistical Analysis

The collected data for various characters were statistically analyzed using the MSTAT computer package program. The means were calculated and the analysis of variance for each of the characters was performed by the F (variance ratio) test. The differences between the treatment means were evaluated by LSD test at 1 % or 5 % probability level wherever applicable (Gomez and Gomez, 1984).

3. Results

3.1 Growth

Plant height was significantly influenced by different combinations of prilled urea and nano-urea fertilizer treatments (Figure 1). Findings showed that at harvest, the tallest plant (112.33 cm) was observed with the application of RDN + 0.5 % nano-urea (T5), and the shortest plants (95.13 cm) was obtained from applying 50 % RDN + 0.2 % nano-urea (T10). Same amount of prilled urea (recommended dose) was applied for treatment T2 (107.20 cm), T3 (109.87 cm), T4 (112.10 cm) and T5 (112.33 cm) but 0.2%, 0.3%, 0.4%, and 0.5% of nano-urea was used for those treatments respectively. Similar type of variation was observed for T6, T7, T8, T9 where 75% RDN prilled urea was applied and for T10, T11, T12, T13 where 50% RDN prilled urea was applied (Figure 1).

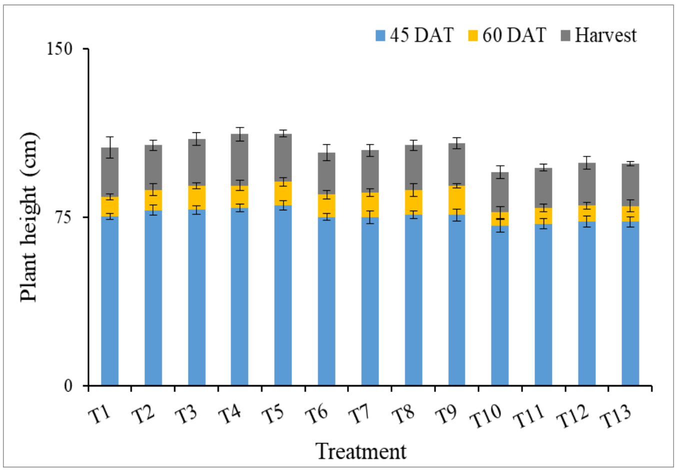

Figure 1: Plant height of monsoon rice variety BRRI dhan49 as influenced by different combinations of prilled urea and nano-urea fertilizer treatments

(Here, T1: Recommended dose of nitrogen (RDN) using prilled urea (control), T2: RDN + 0.2% nano-urea, T3: RDN + 0.3% nano-urea, T4: RDN + 0.4% nano-urea, T5: RDN + 0.5% nano-urea, T6: 75% RDN + 0.2% nano-urea, T7: 75% RDN + 0.3% nano-urea, T8: 75% RDN + 0.4% nano-urea, T9: 75% RDN + 0.5% nano-urea, T10: 50% RDN + 0.2% nano-urea, T11: 50% RDN + 0.3% nano-urea, T12: 50% RDN + 0.4% nano-urea, T13: 50% RDN + 0.5% nano-urea)

Tillering ability was significantly influenced by different applications of nano-urea doses at 45 DAT, 60 DAT, and harvest. Table 1 shows that at 45 DAT, the maximum number of tillers hill-1 (18.03) was observed with the application of RDN + 0.5 % nano-urea (T5), and the minimum number of tillers hill-1 at 45 DAT (11.10) was found when 50 % RDN + 0.2 % nano-urea (T10) was applied. Findings showed that at 60 DAT, the maximum number of tiller hill-1 (22.03) was recorded with the application of RDN + 0.5 % nano-urea (T5), and the minimum number of tillers hill-1 at 60 DAT (15.03) was found with the application of 50 % RDN + 0.2 % nano-urea (T10) showed significant result. Results showed that at harvest, the maximum number of tillers (20.03) was obtained from the application of RDN + 0.5% nano-urea (T5), and the minimum number of tillers hill-1 at harvest (12.03) was found from the application of 50 % RDN + 0.2 % nano-urea (T10) showed significant result (Table 1).

Table 1: Effect of different combinations of prilled urea and nano-urea fertilizer treatments on tillering ability of monsoon rice variety BRRI dhan49

Treatments	Total tillers hill^{-1} at different days after transplanting (DAT)		
	45 DAT	60 DAT	At harvest
T_1	15.03a-d	19.03a-d	15.96 b-e
T_2	15.96a-c	20.36a-c	17.90abc
T_3	17.06ab	21.16ab	19.03ab
T_4	17.10ab	21.10ab	19.96a
T_5	18.03a	22.03a	20.03a
T_6	12.10cd	16.03cd	15.03c-f
T_7	13.26a-d	16.96b-d	15.10c-f
T_8	14.03a-d	17.03b-d	15.66c-e
T_9	14.10a-d	19.10a-d	17.06a-d
T_{10}	11.10d	15.03d	12.03f
T_{11}	11.03d	15.96cd	12.96ef
T_{12}	12.06cd	17.03b-d	14.50d-f
T_{13}	13.03b-d	17.06b-d	15.13c-f
Sx	1.31	1.20	0.90
Level of Sig.	**	**	**
CV (%)	11.39	8.06	6.86

In the column, means followed by different letters are significantly different; ** means Significant at 1 % level of probability, NS = non-significant. T1: Recommended dose of nitrogen (RDN) using prilled urea (control), T2: RDN + 0.2% nano-urea, T3: RDN + 0.3% nano-urea, T4: RDN + 0.4% nano-urea, T5: RDN + 0.5% nano-urea, T6: 75% RDN + 0.2% nano-urea, T7: 75% RDN + 0.3% nano-urea, T8: 75% RDN + 0.4% nano-urea, T9: 75% RDN + 0.5% nano-urea, T10: 50% RDN + 0.2% nano-urea, T11: 50% RDN + 0.3% nano-urea, T12: 50% RDN + 0.4% nano-urea, T13: 50% RDN + 0.5% nano-urea

3.2 Yield Attributes

The number of effective tillers hill-1 at harvest was significantly influenced by different combinations of prilled urea and nano-urea fertilizer treatments. It was found that the highest number of effective tillers hill-1 at harvest (16.50) was obtained from the treatment T4, which showed no significant difference from T1, T2, T3, T5, T7, T8 and T9 (Table2). The minimum number of effective tillers hill-1 at harvest (9.20) was found from treatment T10 (Table 2), which was 44.56% lower than T4.

The number of grains panicle-1 was significantly influenced by different combinations of prilled urea and nano-urea fertilizer treatments. The maximum number of grains panicle-1 (116.33) was observed from treatment T5 (116.33) followed by T4 (115.33), T3 (113.33), and T2 (112.33) and a minimum number of grains panicle-1 (96.67) was found T13 showed significant result (Table 2). Sterile spikelets panicle was significantly influenced by different combinations of prilled urea and nano-urea fertilizer treatments. The maximum number of sterile spikelets panicles (18.76) was observed with the application of (T10) and the minimum number of sterile spikelets panicle (10.50) was found by applying (T5) showed significant result (Table2). The weight of 1000-grain (g) was significantly influenced by different combinations of prilled urea and nano-urea fertilizer treatments. The highest 1000 grain-weight (18.13 g) was found from the application of RDN+ 0.4 % nano-urea (T4) and the lowest 1000-grain weight (16.53 g) was found by applying 50 % RDN +0.2 % nano-urea (T10) was (Table 2).

Table 2: Effect of different combinations of prilled urea and nano-urea fertilizer treatments on yield contributing characters of monsoon rice variety BRRI dhan49

Treatments	Effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	1000-grain weight (g)
T_1	14.06abc	110.00ab	12.23 cde	17.53
T_2	15.70ab	112.33a	11.36 de	17.66
T_3	16.16ab	113.33a	11.06 de	17.80
T_4	16.60a	115.33a	10.76 de	18.13
T_5	16.50ab	116.33a	10.50 e	17.96
T_6	12.73 bcd	106.67abc	15.40 b	17.13
T_7	12.96abcd	107.67abc	14.40 bc	17.30
T_8	13.16abc	110.33a	13.63 bcd	17.50
T_9	13.96abc	109.67ab	13.63 bcd	17.53
T_{10}	9.200 d	97.00 c	18.76a	16.53
T_{11}	10.36 cd	97.33 c	16.23ab	16.53
T_{12}	11.53 cd	98.33 bc	16.06ab	16.76

Table 2(CONT) : Effect of different combinations of prilled urea and nano-urea fertilizer treatments on yield contributing characters of monsoon rice variety BRRI dhan49

T_{13}	11.46 cd	96.67 c	15.73 b	16.73
Sx	1.03	3.25	0.78	0.50
Level of sig.	**	**	**	NS
CV (%)	9.45	3.73	6.97	3.58

In the column, means followed by different letters are significantly different; ** means Significant at 1 % level of probability, NS = non-significant.

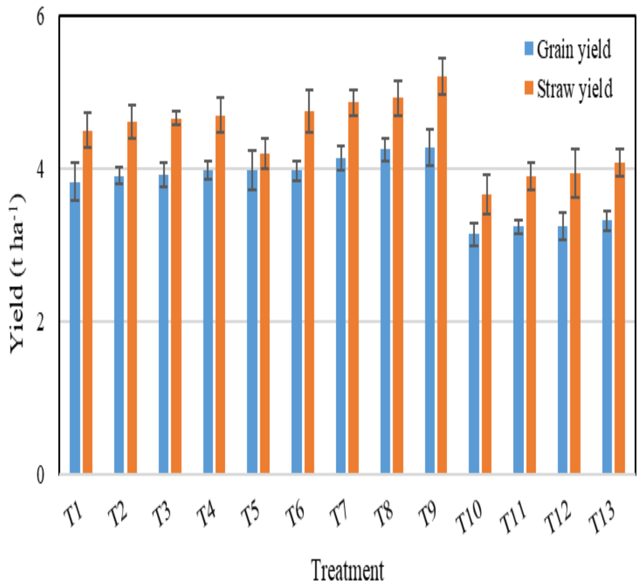

Figure 2: Grain and straw yields of monsoon rice variety BRRI dhan49 as influenced by treatments

(Here, T1: Recommended doses of nitrogen (RDN) using prilled urea (control), T2: RDN + 0.2% nano-urea, T3: RDN + 0.3% nano-urea, T4: RDN + 0.4% nano-urea, T5: RDN + 0.5% nano-urea, T6: 75% RDN + 0.2% nano-urea, T7: 75% RDN + 0.3% nano-urea, T8: 75% RDN + 0.4% nano-urea, T9: 75% RDN + 0.5% nano-urea, T10: 50% RDN + 0.2% nano-urea, T11: 50% RDN + 0.3% nano-urea, T12: 50% RDN + 0.4% nano-urea, T13: 50% RDN + 0.5% nano-urea).

3.3 Yield Performance

Different combinations of prilled urea and nano-urea fertilizer treatments significantly influenced grain yield. The highest grain yield (4.28 t ha-1) and the highest straw yield (5.20 t ha-1) were found from the application of 75 % RDN + 0.5 % nano-urea (T9) and the lowest grain yield (3.14 t ha-1) as well as the lowest straw yield (3.66 t ha-1) were found from applying 50 % RDN + 0.2 % nano-urea (T10). Rice yields remain statistically unchanged or even improve when 75% of the nitrogen is applied as prilled urea and supplemented with two nano-urea foliar sprays, compared to with the sole application of 100% prilled urea (Figure 2).

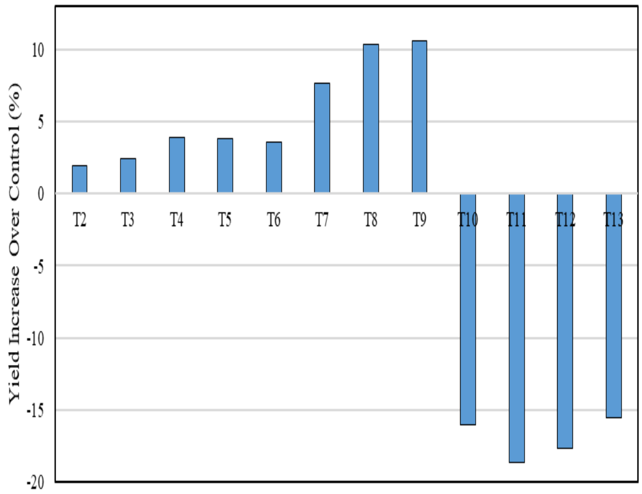

Figure 3: Percent yield of monsoon rice variety BRRI dhan49 increased/decreased (%YOC) over control due to different treatments

(Here, T1: Recommended dose of nitrogen (RDN) using prilled urea (control), T2: RDN + 0.2% nano-urea, T3: RDN + 0.3% nano-urea, T4: RDN + 0.4% nano-urea, T5: RDN + 0.5% nano-urea, T6: 75% RDN + 0.2% nano-urea, T7: 75% RDN + 0.3% nano-urea, T8: 75% RDN + 0.4% nano-urea, T9: 75% RDN + 0.5% nano-urea, T10: 50% RDN + 0.2% nano-urea, T11: 50% RDN + 0.3% nano-urea, T12: 50% RDN + 0.4% nano-urea, T13: 50% RDN + 0.5% nano-urea).

The yield increase/decrease over control (YOC%) values represent the different yield performances of combined application of prilled urea and nano-urea compared with the recommended prilled urea application alone. Treatments T2 to T6 showed a slight positive increase over the control, ranging from about 1.95% to 3.83%. A remarkable improvement was observed under treatments T7, T8, and T9, where yield increased substantially over the control. In the case to T9, he maximum yield was recorded, indicating this treatment was the most effective in enhancing crop performance and may provide practical benefits for yield improvement. On the other hand, treatments T10, T11, T12, and T13 showed negative YOC values, ranging from −16.04% to −18.66%, which means these treatments actually lowered the yield compared to the control and could therefore be harmful if used in the field (Figure 3).

3.4 Economics

The economics of rice production was affected by varying doses of foliar-applied nano-urea. The maximum gross return, net return and B:C ratio was observed in T9 (Table3). A similar amount of prilled urea (75% RDN) were applied in T6, T7, T8 and T9, while nano-urea doses were different. This means even a 0.3% increase in nano-urea could enhance the gross return (14450 BDT), net return (13046 BDT) and B:C ratio (0.097) (Table 3).

Table 3: Cost-benefit analysis of different combinations of prilled urea and nano-urea application of monsoon rice variety BRRI dhan49

Treatment	Variable cost except urea and nano-urea cost	Variable cost (BDT ha^{-1})			Total cost	Gross return	Net return	B:C ratio
		Urea cost	Nano-urea cost	Labor cost				
T_1	120000	4468	0	0	124468	170050	45582	1.366
T_2	120000	4468	936	2750	128154	173460	45306	1.354
T_3	120000	4468	1404	2750	128622	174400	45778	1.356
T_4	120000	4468	1872	2750	129090	176900	47810	1.370
T_5	120000	4468	2340	2750	129558	172820	43262	1.334
T_6	120000	3351	936	2750	127037	176950	49913	1.393

Table 3 (CONT): Cost-benefit analysis of different combinations of prilled urea and nano-urea application of monsoon rice variety BRRI dhan49

T_7	120000	3351	1404	2750	127505	183510	56005	1.439
T_8	120000	3351	1872	2750	127973	188110	60137	1.470
T_9	120000	3351	2340	2750	128441	191400	62959	1.490
T_{10}	120000	2234	936	2750	125920	139180	13260	1.105
T_{11}	120000	2234	1404	2750	126388	144600	18212	1.144
T_{12}	120000	2234	1872	2750	126856	145270	18414	1.145
T_{13}	120000	2234	2340	2750	127324	148840	21516	1.169

Urea = 27 BDT Kg^{-1}, Nano-urea = 900 BDT L^{-1}, Rice = 35 BDT kg^{-1}, Straw = 8 BDT kg^{-1}, Labor = 550 BDT day^{-1}. 1US$= 120 BDT

4. Discussion

Nano-fertilizer represents an innovative strategy for fertilizer management, as it enables the gradual release of nutrients, thereby enhancing nutrient use efficiency and minimizing nutrient losses through leaching into groundwater compared to traditional fertilizers (Upadhyay et al., 2023; Verma et al., 2023). Conventional fertilizers have been widely used in agriculture for many years, while nano-fertilizers represent a recent innovation with significant potential. Integrating both forms within a nutrient management strategy can enhance productivity while reducing costs (Wu and Ma, 2015). In rice cultivation, nitrogen is a key macronutrient but is highly susceptible to rapid leaching when applied as conventional urea (Li et al., 2018; Wu et al., 2023). Our study demonstrated that the different combination of recommended dose of nitrogen (RDN) using prilled urea and liquid nano-urea considerably influenced rice growth and yield potentials. Combined uses not only improved rice yield but also substantially reduced the need for excessive use of conventional prilled urea. In case of the growth attributes of rice (Plant height and Tillers per hill), higher values were observed in 100% RDN applied as prilled urea and combined with nano urea. It could be attributed to the readily available nitrogen supplied by nano-urea. As a key component of foliar application, nano-urea provides nitrogen in nano-sized particles that enhance nutrient availability compared to conventional fertilizers. This improved form promotes better absorption and translocation within the plant, which stimulates cell division and boosts cellular protein content. Consequently, the enhanced nutrient accessibility contributes to increased plant height and a higher number of tillers per plant (Hasan et al., 2024; Upadhyay et al., 2023). Our finding is supported by some previous research findings (Midde et al., 2022; Namasharma et al., 2023; Chudasama et al., 2024). As a study where it was evident that nano-urea application enhanced plant stature, growth rate, tillering ability, and leaf area index, highlighting the crucial role of nitrogen in promoting cell division and internode elongation (Gewaily et al., 2019).

Rice yield attributes, including effective tillers per hill and grains per panicle, increased markedly with the combined application of nano-fertilizer (0.2–0.5%) and RDN using prilled urea (75–100%). This combination also enhanced both grain and straw yields. In contrast, reducing RDN (prilled urea) to 50% led to a rise in sterile spikelets per panicle and a substantial decline in overall yield performance. The enhanced grain yield can be attributed to the continuous nitrogen supply provided by conventional urea along with nano-urea sprays at the active tillering and panicle initiation stages. This sustained nitrogen availability likely promoted higher photosynthetic efficiency, better translocation and accumulation of assimilates in the reproductive organs, and stimulated cell division and elongation. Collectively, these physiological improvements contributed to the increased grain yield of rice (Bhardwaj et al., 2022; Verma et al., 2023). These findings are closely aligned with (Gewaily et al., 2019; Namasharma et al., 2023; Chudasama et al., 2024; Sunil et al., 2023). This Research who stated that nano-fertilizers enhance rice yield by promoting vigorous plant growth and vital metabolic processes such as photosynthesis, which increase the accumulation and translocation of assimilates to grains; moreover, their combined use with conventional fertilizers ensures a steady and slow nitrogen release, improving stress tolerance and ultimately leading to higher productivity (Attri et al., 2022). he reduction in yield observed with 50% RDN applied as prilled urea, supplemented with varying amounts of nano-urea, may be attributed to insufficient nitrogen supply. This deficiency can cause degradation of photosynthetic pigments, leaf chlorosis, and ultimately inhibit crop growth and yield. Similar results were reported who observed that the application of nano-urea in combination with only 50% of the recommended urea dose neither improved nitrogen use efficiency nor enhanced rice yield by (Sikka et al., 2025; Upadhyay et al., 2023).

The economic analysis clearly indicated that the combination of 75% RDN (prilled urea) with 0.5% nano-urea was more profitable than other treatments. This was primarily due to the increase in grain yield, the reduction in costs from minimizing excessive use of prilled urea, and the precise application of nano-urea. The results of the analysis also confirmed that application of granular urea in conjunction with nano-urea had a positive impact on gross return, net return, and the benefit–cost (B:C) ratio in hybrid rice cultivation (Namasharma et al., 2023).

5. Conclusion

The application of 0.5% nano-urea may replace 25% of the recommended doses of prilled urea in rice cultivation. Not only that, this practice may significantly reduce production costs, increase rice productivity, and improve the benefit–cost ratio. Additionally, this small change in rice production may decrease rice-based pollution and make our environment safer for healthy living.

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