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ORIGINAL RESEARCH ARTICLE



## Organo-mineral nitrogen fertilizer enhances growth, nitrogen use efficiency and protein content in red amaranth

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### ABSTRACT

Red amaranth is a popular vegetable in Bangladesh because of its high nutritional value and pleasant flavor. Efficient nitrogen (N) management is vital for sustainable crop production, but conventional urea fertilizers often cause significant N losses. In recent years, organo-mineral fertilizers (OMFs) have gained popularity for improving crop yield and soil fertility. This study examined the effect of brown Coal Urea (BCU) as an organo-mineral N fertilizer, on growth, fresh biomass yield, N use efficiency (NUE), and protein content of red amaranth (*Amaranthus tricolor* L.). A pot experiment, conducted under a completely randomized design, assessed five N application rates (0, 50, 75, 100, 150 kg N ha<sup>-1</sup>) delivered through urea, DAP, BCU applied as topdressing, and BCU applied as a basal treatment. The results showed that BCU treatment significantly ( $p < 0.05$ ) improved all parameters compared to urea. The highest plant height and fresh biomass yield were found with BCU basal application at 150 kg N ha<sup>-1</sup>, while the greatest NUE (77.29%) and FNUE (56.84%) were achieved at 50 kg N ha<sup>-1</sup>. The improved performance was attributed to slow-release and humic-rich nature of BCU, which enhances N retention and uptake efficiency. Overall, BCU effectively increased yield and N efficiency in red amaranth, highlighting its potential as a sustainable alternative to conventional fertilizers.

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### INTRODUCTION

Red amaranth (*Amaranthus tricolor*) is widely cultivated as a vegetable in tropical and subtropical regions. It can be grown year-round and reaches harvest maturity quickly, though the winter season is most suitable for both vegetable and seed production. In Bangladesh, red amaranth is highly popular for its rich nutrition, pleasant taste, and high yield potential. The cultivation area has gradually expanded in recent years, with production reaching 61,096 metric tons in 2019–2020. As a pseudo-cereal crop, it is valued for its nutritional and health-promoting properties (Managa & Nemadodzi, 2023; Islam *et al.*, 2024). The supply of mineral nutrients during critical growth stages directly influences crop yield and quality. Nitrogen (N) is an essential element for global agricultural production, and urea is the most common-

ly used N fertilizer (Cui *et al.*, 2022). However, the efficiency of Urea-N utilization is low—nearly 50% of applied N is lost through leaching, runoff, denitrification, and volatilization—causing both environmental pollution and economic loss (Liu *et al.*, 2025). Therefore, eco-friendly agricultural practices must improve productivity while ensuring environmental, human, and animal health. Enhancing N use efficiency (NUE) is crucial for reducing N losses and improving yield and quality (Mustafa *et al.*, 2022). Efforts to minimize N loss include using slow- or controlled-release N fertilizers, applying urease and nitrification inhibitors, or combining organic and inorganic fertilizers (Gil-Ortiz *et al.*, 2020; Cui *et al.*, 2022; Liu *et al.*, 2025). The use of organic fertilizers has also gained popularity for producing organic crops (Islam *et al.*, 2024; Kumari *et al.*, 2024; Zhao *et al.*, 2024). Organic farming offers a sustainable alternative that promotes safe crop pro-

duction, reduces dependence on synthetic fertilizers, and supports soil health through enhanced microbial activity. However, their low nutrient content requires higher application rates, and their variable composition makes precise nutrient management difficult. Organo-mineral fertilizers (OMFs), produced by blending organic materials with mineral N fertilizers, have proven more efficient than applying either source alone (Saha et al., 2017; Uddin et al., 2023; Yeasmin et al., 2024). For instance, Shi et al. (2020) reported that binding urea with biochar reduced N release and leaching losses compared to commercial urea. These fertilizers release N gradually to meet crop demand, minimize leaching and gaseous losses, and improve overall NUE. Studies have shown that such fertilizers outperform traditional organic and inorganic types. Humic acid promotes root development, biomass accumulation, and nutrient uptake by stimulating H<sup>+</sup>-ATPase activity (Santos et al., 2025; Zandonadi et al., 2025). Brown coal (BC) also contains functional groups such as phenolic, carboxylic, and carbonyl, which further enhance soil fertility and plant growth. Moreover, BC helps mitigate N losses by inhibiting urease activity, slowing urea hydrolysis, and reducing ammonia volatilization (Maciejewska & Kwiatkowska-Malina, 2022). It can retain hydrolyzed urea-N as ammonium on acidic exchange sites (Akimbekov et al., 2021; Lei et al., 2023). As per current evidence, although several studies have examined the combined use of brown coal and chemical fertilizers on crop yield and quality, no research has yet investigated the granulation of brown coal with urea and its impact on N use efficiency, fertilizer N use efficiency, yield and biomass production of red amaranth in Bangladesh. Therefore, this study aimed to assess the impact of BC-based organo-mineral fertilizer on the growth, fresh biomass production, N use efficiency, and fertilizer N use efficiency of red amaranth in comparison with conventional urea. It was hypothesized that combining BC with urea in granular form would improve N use efficiency, promote plant growth, and increase fresh biomass yield by ensuring a prolonged availability of N to plants relative to urea fertilizer.

## MATERIALS AND METHODS

**Table 1.** Physical and chemical properties of the experimental soil.

Soil characteristics	Analytical value
Soil color	Brownish grey
Texture	Loam
Soil pH	6.73
Organic carbon (%)	0.78
Total N (%)	0.106
Available P (ppm)	15.7
Available S (ppm)	14.9
Exchangeable K (meq 100 g <sup>-1</sup> )	0.14
Exchangeable Ca (meq 100 g <sup>-1</sup> )	6.94
Exchangeable Mg (meq 100 g <sup>-1</sup> )	2.95

**Table 2.** Treatment details.

S. No.	Treatment symbol	Rate of N (kg ha <sup>-1</sup> )	Source
1	N <sub>0</sub>	0	Urea, DAP, BCU (TD), BCU (Basal)
2	N <sub>50</sub>	50	Urea, DAP, BCU (TD), BCU (Basal)
3	N <sub>75</sub>	75	Urea, DAP, BCU (TD), BCU (Basal)
4	N <sub>100</sub>	100	Urea, DAP, BCU (TD), BCU (Basal)
5	N <sub>150</sub>	150	Urea, DAP, BCU (TD), BCU (Basal)

Total number of pots: 5 treatment × 4 replication = 20; DAP= Di-Ammonium Phosphate; CU (TD) = Brown Coal Urea (Top Dressing); BCU (Basal) = Brown Coal Urea (Basal).

## Geographical location and climatic conditions

Geographically, the experimental site was positioned at 24°75' N latitude and 90°50' E longitude, with an altitude of 18 meters above sea level. It belongs to the Old Brahmaputra Floodplain Agro-Ecological Zone (AEZ-9), which is known for its Non-calcareous Dark Grey Floodplain soil. The climate in this area is sub-tropical, featuring high humidity, significant rainfall, and moderate to high temperatures with longer daylight hours during the *Kharif* season (April-September), and lower rainfall, reduced humidity, cooler temperatures, and shorter days during the *Rabi* season (October-March). The soil used in the study was sourced from the Bangladesh Agricultural University (BAU) Farm, Mymensingh, and its physical and chemical characteristics are detailed in Table 1.

## Preparation of Brown Coal Urea (BCU) granules

The experiment utilized pre-prepared Brown Coal Urea (BCU) granules, created using the pan granulation method (Saha et al., 2017). This method involved mixing finely ground urea and brown coal in a specific ratio to achieve an optimal C: N balance, with wheat starch and molasses serving as binders. The granules were dried at temperatures between 180-200°C to maintain a moisture content of 4-5%. The BCU produced had an average size of 3.43mm, a moisture content of 3.56%, and a crush strength of 6.69 kg, containing 45.43% C, 5.28% H, and 17.31% N.

## Experimental design, treatments, and data collection

The experiment followed a Completely Randomized Design (CRD) with five treatments and four replications, using Red Amaranth (*Amaranthus tricolor* L.) as a test crop. The BARI Lalshak-1 variety, certified by the Bangladesh Agricultural Development Corporation (BADDC), served as the planting material. The crop was grown in a net house at the Department of Agricultural Chemistry, BAU, Mymensingh. Each plastic pot, measuring 28 cm in height, 27 cm in top diameter, and 20 cm in bottom diameter, was filled with 15 kg of processed soil, leaving about 3 cm of space at the top for irrigation. Treatment details are provided in Table 2. The standard N dose was calculated based on the N

content of BCU and urea to maintain the desired N levels for each treatment. Nitrogen was applied at rates of 0, 50, 75, 100, and 150 kg N ha<sup>-1</sup> from BCU, urea, and diammonium phosphate (DAP). Nitrogen fertilizers were applied in two equal portions-half during soil preparation and the rest as top dressing at 2 installments at 20 and 30 days after sowing (DAS) to provide a consistent supply of available N throughout the crop's growth. Additionally, phosphorus, potassium, and sulfur were applied as basal doses at 24, 40, and 6 kg ha<sup>-1</sup>, respectively, from triple superphosphate (TSP), muriate of potash (MoP), and gypsum, following the Fertilizer Recommendation Guide. In each pot, around 80 red amaranth seeds were evenly distributed, and after germination, thinning was done to maintain a uniform plant density. Regular intercultural practices, such as weeding, thinning, and watering, were carried out as needed to promote optimal growth and development of the crop until it was ready for harvest. The plants were harvested 50 days after sowing (DAS), and their height was measured in centimeters (cm) from the soil level to the tip of the leaf. The fresh weight at harvest was measured with an electric balance and reported as g plant<sup>-1</sup>.

### Analysis of leaf N content, uptake, and use efficiency parameters

#### Biomass protein content

The total N content in the leaf samples was analyzed using the semi-micro Kjeldahl method (Yeoh & Wee, 1994). The leaf samples were oven-dried, finely ground, and digested with concentrated H<sub>2</sub>SO<sub>4</sub> in the presence of a catalyst mixture. The N in the digest was distilled with NaOH, and the distillate was collected in an H<sub>3</sub>BO<sub>3</sub> indicator solution, followed by titration with standard H<sub>2</sub>SO<sub>4</sub>. The total N content was utilized to calculate the protein content of the plant samples using the formula given by Mariotti et al. (2008).

$$\text{Protein (\%)} = \text{Total N (\%)} \times 5.85$$

Nitrogen uptake by red amaranth was determined using the method (Yoshida et al., 1971), where the dry biomass of the plant was multiplied by the N concentration to estimate N accumulation in plant tissues. Nitrogen uptake (g pot<sup>-1</sup>) was calculated as:

$$\text{Nitrogen uptake (g pot}^{-1}\text{)} = \frac{\text{N concentration (\%)} \times \text{Dry matter weight (g)}}{100}$$

#### Nitrogen Use Efficiency (NUE)

Plant nitrogen use efficiency (NUE) was evaluated following the method of Moll et al. (1982), which measures how effectively the crop converts the supplied N into yield. It was calculated as:

$$\text{NUE (\%)} = \frac{\text{Yield (g)} \times 100}{\text{N applied (g)}}$$

#### Fertilizer Nitrogen Use Efficiency (FNUE)

Fertilizer Nitrogen Use Efficiency (FNUE) was also calculated following (Moll et al., 1982) to evaluate the proportion of applied N recovered in the plant yield. FNUE was determined as:

$$\text{FNUE (\%)} = \frac{(\text{Yield of fertilized pot} - \text{Yield of control pot (g)}) \times 100}{\text{N applied (g)}}$$

### Statistical analysis

Statistical analysis was performed using IBM SPSS software (version 20). Data normality was tested using the Kolmogorov-Smirnov goodness of fit test, and the homogeneity of variances was checked using the modified Levene's test. Treatment means were computed, and a two-way analysis of variance (ANOVA) was conducted with fertilizer type and application rate as factors. When significant differences occurred, Tukey's range test was used for multiple mean comparisons at the 5% significance level, following the methodology outlined by Gomez & Gomez (1984).

## RESULTS AND DISCUSSION

### Plant height and fresh biomass

The height of the red amaranth plant was significantly ( $P \leq 0.05$ ) affected by different forms and rates of N (Figure 1) at harvesting time. The maximum plant height was recorded 22.00 cm from the application of BCU Basal @ 150Kgha<sup>-1</sup>, followed by 18.25 cm, which was obtained by BCU basal application @ 100kgha<sup>-1</sup>. The lowest plant height was obtained from application of control BCU TD, which was 6.5 cm. A significant variation ( $P \leq 0.05$ ) was also observed in fresh biomass yield per pot of red amaranth for the interaction effect of different forms and rates of N (Figure 2). The maximum fresh biomass yield per pot was obtained for the application of BCU basal @ 150 kgh<sup>-1</sup>, which was 162.42 g. On the other hand, the minimum biomass yield per pot was recorded as 17.31 g for the control urea application. The application of different forms and rates of N significantly affected plant height and fresh biomass yield per pot. Among the different forms and rates, BCU @ 150 kgha<sup>-1</sup> produced the highest height (22.00 cm) and fresh biomass yield per pot (162.42g). These results are consistent with previous studies, which stated that the addition of BC (or humic acids) increases the growth of various crops (Karimi et al., 2020; Olaetxea et al., 2020; Ampong et al., 2022). The current study found that the height of red amaranth is proportionate to increasing N amount among different treatments. Similar results were found by Zaman et al. (2021) and Managa & Nemadodzi (2023). The improved height and fresh biomass might be due to higher N uptake and more available nutrient in soil. Jing et al. (2022) showed that the BC (or humic acid) can produce stable complex with urea and can provide more functional group and can improve the overall growth of plant. Similarly, Yeasmin et al. (2024) found that organo-mineral urea derived from poultry manure can boost growth of baby corn.

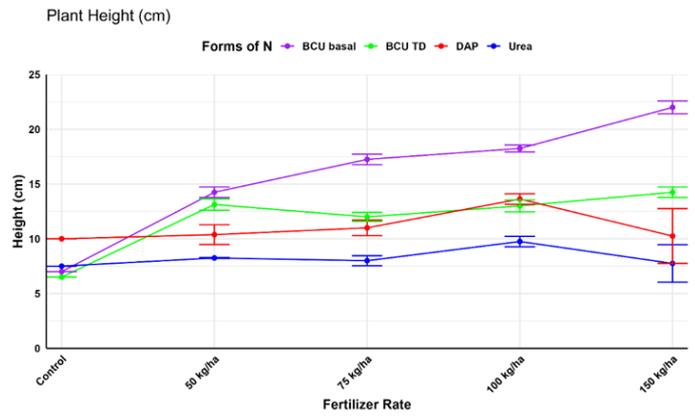
### Effect of different forms and rates of N on biomass protein content

Different forms and rates induced significant ( $P \leq 0.05$ ) variation in biomass protein content (%) (Figure 3), which ranged

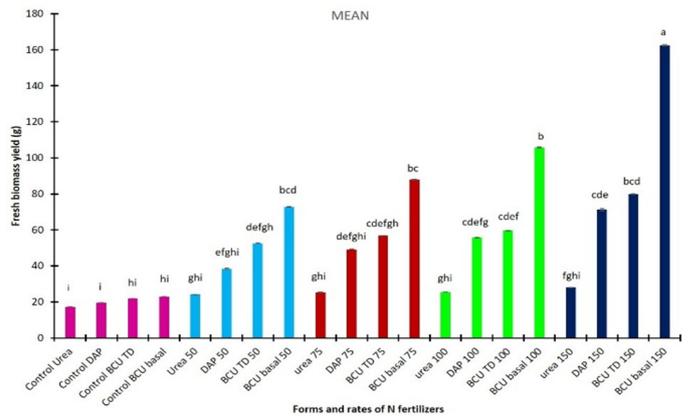
from 11.95% to 20.67%. The maximum protein content was recorded for the application of BCU basal @ 100 Kg N ha<sup>-1</sup>, while the lowest protein content was obtained from the application of control urea, DAP, BCU TD, and basal application, which were statistically indifferent. A Similar result was recorded by Efthimiadou et al. (2022) in maize. It may be due to two aspects, firstly the improvement of N concentration in plants; N is considered a vital component of the proteins and protein-carrying compounds (Beig et al., 2020). Secondly higher biomass along with available N in BCU treated plant compared to commercial urea. Zhao et al. (2022) found similar result for biochar-based fertilizer in maize and Chinese cabbage plant. Due to BCU's large surface area and great cation exchange capacity, it releases N slowly compared to Urea or DAP. On the other hand, BC (or humic acid) can also reduce the disaggregating effect cyclic wetting and drying, giving the structural stability to soil. Again, the BC is rich in phenolic and carboxylic functional group that provides reactive sites and pH buffering of soil. Resulting in greater retention of NH<sub>4</sub><sup>+</sup> and reduction in N leaching loss (Akimbekov et al., 2021; Saha et al., 2023). This may have helped to improve the synchronization between N demand of plant and the supply of N enhancing protein synthesis (Lei et al., 2023).

**Effect of different forms and rates of N on NUE and FNUE**

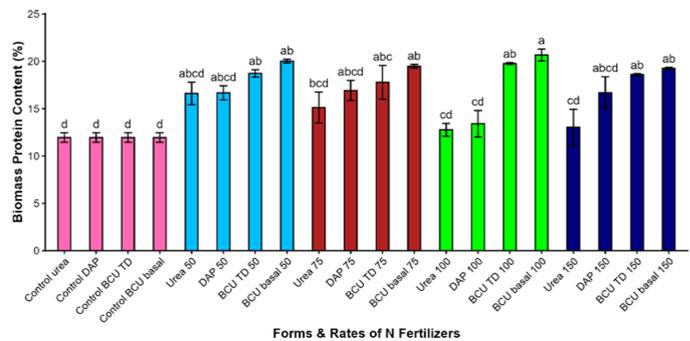
The NUE was significantly (P ≤ 0.05) affected by the application of different forms and rates of N (Figure 4). The highest NUE (77.29%) was recorded for the application of BCU basal @ 50 kg ha<sup>-1</sup>. In contrast, the lowest value (36.35%) was obtained from the urea @ 150 kg ha<sup>-1</sup> application. Again, for different forms and rates of N application, a significant (P ≤ 0.05) shift in values for fertilizer N use efficiency (FNUE) was observed (Figure 5). The maximum FNUE (56.84%) was documented for the application of BCU basal @ 50 kg ha<sup>-1</sup>; alternatively, the minimum value (31.00%) was observed for the application of urea @ 150 kg ha<sup>-1</sup>. This study showed that the BCU basal application @ 50 kg ha<sup>-1</sup> has a significant effect on both NUE and FNUE. It increased NUE and FNUE by 29.53% and 32.01% respectively, compared to urea fertilizer. This may be attributed to higher N uptake, enhanced biomass, and improved protein content. Additionally, BC might increase the retention rate and availability of N of urea compared to urea. This results in increased NUE and FNUE of red amaranth. This finding aligns with earlier research of Zhao et al. (2023) who suggested that using organo-mineral urea can improve NUE by 58.56%. This study demonstrates that approximately 60% BCU can effectively replace 100% urea without reducing yield, a finding that aligns with the earlier results reported by Saha et al. (2021). BCU (or humic-acid-coated urea) is also recognized for enhancing soil microbial activity, which in turn increases nutrient availability to plants. It also prevents nutrients from binding with metals (Yang et al., 2021). As a result, crop yield, NUE, and FNUE are improved. Similar result was found by Uddin et al. (2023), who stated that, organo-mineral fertilizer developed from peat soil increased NUE and FNUE for baby corn. Findings of Ibrahim et al. (2023) also align with the statement who suggested that MgO-modified urea has higher NUE to commercial urea.



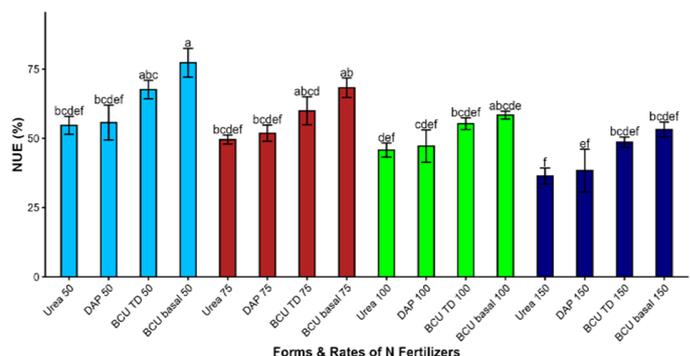
**Figure 1.** Effect of different forms and rates of N on plant height of red amaranth at harvesting. All presented values represent mean and ±standard error among the replicates (n = 4).



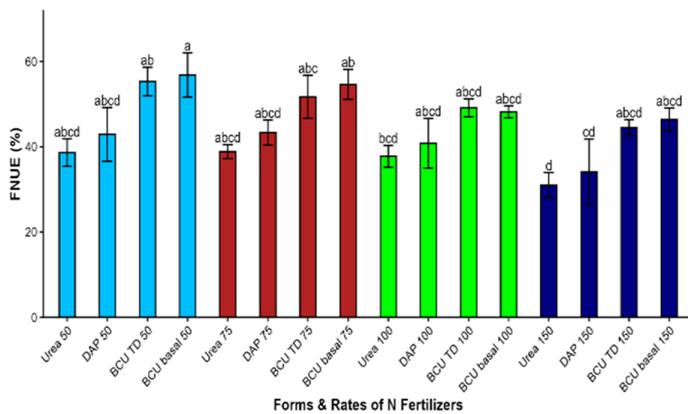
**Figure 2.** Effect of different forms and rates of N on fresh biomass yield of red amaranth. Bars with different letters differ significantly according to Tukey-test at P ≤ 0.05 and the error bars indicate the standard error among replicates (n=4).



**Figure 3.** Effect of different forms and rates of N on biomass protein content of red amaranth. Bars with different letters differ significantly according to Tukey-test at P ≤ 0.05 and the error bars indicate the standard error among replicates (n=4).



**Figure 4.** Effect of different forms and rates of N on N use efficiency (NUE) of red amaranth. Bars with different letters differ significantly according to Tukey-test at P ≤ 0.05 and the error bars indicate the standard error among replicates (n=4).



**Figure 5.** Effect of different forms and rates of N on fertilizer nitrogen use efficiency (FNUE) of red amaranth. Bars with different letters differ significantly according to Tukey-test at  $P \leq 0.05$  and the error bars indicate the standard error among replicates ( $n=4$ ).

## Conclusion

Maintaining agricultural sustainability while increasing production is absolutely crucial for modern agriculture. Organo-mineral fertilizer has the potential to be a transformative technological improvement in this regard. In this study, different forms and rates of BCU fertilizer used as OMF significantly influenced the height, fresh biomass, biomass protein content, and NUE as well as FNUE of red amaranth. Among the different form and rates of fertilizers, BCU produced the highest plant height, fresh biomass and protein content in red amaranth. Around 29.53% and 32.01% greater NUE and FNUE respectively, found in BCU compared to commercial urea fertilizer. The findings align with earlier research showing that incorporating organic substances, such as brown coal, into commercial urea through granulation substantially improves its efficiency.

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## DECLARATIONS

**Author contributions statement:** Conceptualization, T.P., S.Y.E., D.A., K.M.M., S.S.J., M.D. and B.K.S.; Methodology, T.P., S.Y.E. and B.K.S.; Formal analysis, T.P., S.Y.E., S.S.J. and M.D.; Investigation, T.P., S.Y.E. and D.A.; Resources, K.M.M. and B.K.S.; Data curation, T.P., S.Y.E., K.M.M. and B.K.S.; Writing – original draft, T.P., S.Y.E. and D.A.; Writing – review & editing, K.M.M., S.S.J., M.D. and B.K.S.; Visualization, K.M.M. and B.K.S.; Supervision, K.M.M. and B.K.S.; Project administration, K.M.M. and B.K.S.; Funding acquisition, B.K.S. and K.M.M.; Software, S.Y.E., D.A., K.M.M., S.S.J. and M.D.; Validation, K.M.M. and B.K.S. All authors have read and agreed to the published version of the manuscript.

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**Supplementary data:** No supplementary data is available for the paper.

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**Additional information:** No additional information is available for this paper.

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