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# Optimizing integrated nutrient management strategies for maximizing yield and quality of table beet (*Beta vulgaris* L.) under subtropical conditions

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## ABSTRACT

The experiment, conducted at the Agronomy Field Laboratory, BAU, Mymensingh (Nov 2023 – Feb 2024), aimed to assess integrated nutrient management effects on table beet growth, yield, and quality. This experiment comprised fifteen nutrient management strategies, including inorganic fertilizers, organic sources (cow dung, poultry manure, and vermicompost), and their combinations with three replications, followed by a randomized complete block design (RCBD). The highest beet yield (25.02 t/ha) was recorded in recommended doses of fertilizer (RDF), which was statistically identical with $T_3$ (50% RDF + cow dung @ 5 t/ha: $CD_5$) treatment (24.73 t/ha). The highest total soluble solid (15.78%) and ascorbic acid (24.20 mg/100g) was recorded in $T_7$ (25% RDF + poultry manure @ 2.5 t/ha: $PM_{2.5}$) and $T_{10}$ (25% RDF + vermicompost @ 2.5 t/ha: $VC_{2.5}$), respectively where maximum total antioxidant (45.53%) was observed in using 50% RDF + $CD_5$. The highest benefit-cost ratio (7.57) was achieved when the plots were treated with 50% RDF + $CD_5$. Considering the yield, quality and economic aspects, it can be concluded that 50% RDF + $CD_5$ emerges as the most promising treatment for table beet cultivation.

**Keywords:** beetroot, fertilizer application, productivity, antioxidant

## INTRODUCTION

Table beet (*Beta vulgaris* L.), belonging to the family *Chenopodiaceae*, is a widely cultivated dicotyledonous thickened hypocotyl vegetable crop known as red beet or salad beet with a moderate caloric value (Kondal et al., 2024). It is cultivated globally, with Germany and France as the leading producers (Jasmitha et al., 2018). Nowadays beets are widely cultivated in home gardens and on a commercial scale for their fleshy, thickened hypocotyl, which offers numerous health benefits such as improving liver function, aiding digestion, lowering blood pressure, strengthening blood vessel walls, and regulating cholesterol levels (Delgado-Vargas et al., 2000). The phenolics observed in the soluble fraction and cell wall of table beet exhibit bioactive properties (Kugler et al., 2007; Pradhan et al., 2010). An immune-boosting food, beet functions as an antiviral, antibacterial, and antioxidant due to being enriched with nutrients like magnesium, sodium, potassium, vitamin C, and betaine (Neha et al., 2018). In particular, beetroot's betalains, which include betacyanins and betaxanthins, have the potential to prevent and cure cardiovascular and hypertension-related diseases, as well as prevent the development of human tumor cells. Moreover, humans primarily obtain their dietary nitrates from vegetables, and fresh food is of particular importance due to nitrate buildup (Chen et al., 2021). Mineral fertilizers are widely used due to their quick nutrient-releasing capacity, which helps to boost crop yields. However, the excessive use of these fertilizers poses toxicity risks to living beings and contributes to depleting nutrients, contaminating groundwater, and reducing the effectiveness of microbial communities (Chen, 2006). Conversely, the organic manure enhances the physical and chemical properties of the soil, providing favorable conditions for crop growth minimizing the environmental impact (Suthamathy and Seran, 2013).

Moreover, organic fertilizer application, especially animal excreta appear to be an eminent alternative, due to its significant benefits for the beet crop, which possesses delicate and demanding roots in terms of soil's physical characteristics (Curvêlo et al., 2018).

To meet the demand for environmentally friendly and sustainable agriculture, integrated nutrient management (INM) serves as a key strategy which involves the combined application of organic and mineral fertilizers, is recognized as an effective approach for enhancing agricultural productivity (Wu and Ma, 2015). Incorporating organic manures, including compost, vermicompost, goat manure, and farmyard manure (FYM), enhances soil water retention and provides essential macro and micronutrients, thereby improving crop yields (Biondo et al., 2014). Additionally, the synergistic blend of organic and mineral fertilizers has profoundly revolutionized the agricultural landscape, showcasing substantial and transformative impacts on both the yield and exquisite quality of vegetable crops (Sundharaiya et al., 2003; Baniuniene and Zekaite, 2008; Biondo et al., 2014; Yadav et al., 2023). In previous studies, Hussain and Kerketta (2023) found that 75% recommended dose fertilizer + 12.5% chicken manure + 12.5% vermicompost boosted the growth and yield of table beet. Paul et al. (2018b) and Sarker et al. (2023) observed a considerable improvement in beet yield and quality when manure and mineral fertilizers were applied together. The primary objectives of integrated nutrient management are to increase agricultural yields efficiently and sustainably while preserving soil fertility for future generations.

Despite the increasing popularity of table beet in Bangladesh, research on its optimal production practices, particularly nutrient management strategies, remains limited. Proper nutrient management is crucial for enhancing both yield and nutritional quality. In this context, the present study aims to evaluate the influence of integrated nutrient management on the growth, yield, and quality of table beet, providing insights into effective fertilization strategies for its sustainable cultivation.

## MATERIALS AND METHODS

### *Experimental site*

The research was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University (BAU), geographically positioned at a latitude of 24°25'N and a longitude of 90°50'E, with an altitude of 18 meters. The test site is located within the Old Brahmaputra Floodplain (AEZ-9) (UNDP and FAO, 1988) and is characterized by a subtropical monsoon climate with high humidity. Prior to the experiment, composite topsoil samples (0–20 cm depth) were collected from the field for laboratory analysis. The physicochemical properties of the soil analyzed are presented in Table 1.

**Table 1.** Physiochemical properties of the soil in the field before the experiment

| Properties of soil | Values |
|---|---|
| Soil texture | Silty clay loam |
| Soil pH | 7.1 |
| Organic Carbon (%) | 1.27 |
| Organic matter (%) | 2.15 |
| Total nitrogen (%) | 0.11 |
| Exchangeable K (meq. 100 /g soil) | 0.20 |
| Available Phosphorus (P) (ppm) | 12.05 |
| Available Sulphur (S) (ppm) | 18.10 |
| Available Zinc (Zn) (ppm) | 1.5 |

From November 2023 to February 2024, the meteorological data (Figure 1) showed temperatures, rainfall, and relative humidity.

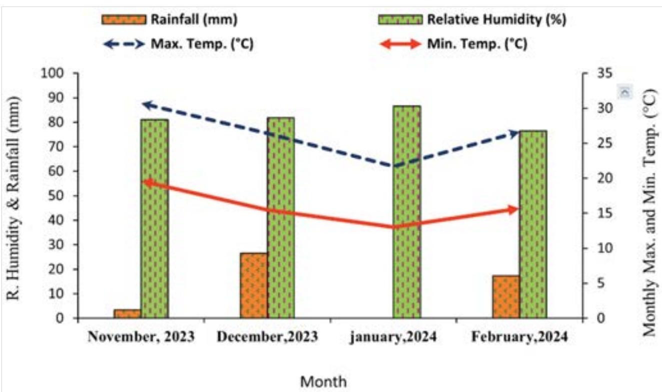



**Figure 1.** Meteorological data for November 2023 to February 2024 of the experimental site

### *Experimental design*

The experiment was conducted using a randomized complete block design with three replications and fifteen integrated nutrient management treatments (Table 2). Cow dung and vermicompost were collected from the Agronomy Field Laboratory, BAU. Poultry manure was obtained from the Poultry Farm, BAU. All organic amendments were screened to remove non-decomposable materials, air-dried to reduce moisture content, and properly stored prior to field application, with representative samples taken for laboratory analysis. The cow dung, poultry manure and vermicompost contained 1.2, 1.9 and 1.58% N; 1.0, 0.56 and 1.51% P; and 1.6, 0.75 and 0.9% K, respectively. The unit plot measured 4.0 $m^2$ (2.0 m × 2.0 m), with 1.0 m between blocks, 0.5 m between adjacent plots, and 0.2 m between plants. A total of 45 plots (15 × 3) were arranged, with each replication containing 15-unit plots.

### *Land preparation and intercultural operation*

The field was thoroughly ploughed using a tractor, including deep and cross-directional plowing, followed by laddering to optimize soil tilth. Two days before seeding, the soil was spaded, clods broken with a wooden hammer, weeds and residues removed, and plots arranged as per design specifications. Application of fertilizer for each plot followed by the prescribed treatment guidelines, which involved the incorporation of recommended fertilizers, cow dung, poultry manure and vermicompost. To supply the N-P-K-S-Zn-B nutrients, fertilizers such as urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate, and boric acid @ 130, 208, 100, 50, 6, and 12 kg/ha, respectively, were applied. Except for urea, all the fertilizers were entirely incorporated during the final land preparation phase. Urea was applied in three segments: the initial application occurred during land preparation, followed by subsequent applications at 20 and 40 DAS (days after sowing).

**Table 2.** Treatment combinations of integrated nutrient management

| Treatment code | Treatment combinations |
|---|---|
| $T_1$ | Recommended doses of fertilizer (RDF) N-P-K-S-Zn-B @ 60-44-50-9-2-2 kg/ha |
| $T_2$ | Cow dung @ 10 t/ha ($CD_{10}$) |
| $T_3$ | 50% RDF + cow dung @ 5 t/ha ($CD_5$) |
| $T_4$ | 25% RDF + $CD_5$ |
| $T_5$ | Poultry manure @ 5 t/ha ($PM_5$) |
| $T_6$ | 50% RDF + PM @ 2.5 t/ha ($PM_{2.5}$) |
| $T_7$ | 25% RDF + $PM_{2.5}$ |
| $T_8$ | Vermicompost @ 5 t/ha ($VC_5$) |
| $T_9$ | 50% RDF + VC @ 2.5 t/ha ($VC_{2.5}$) |
| $T_{10}$ | 25% RDF + $VC_{2.5}$ |
| $T_{11}$ | 25% RDF + $CD_5$+ $PM_{2.5}$ |
| $T_{12}$ | 25% RDF + $CD_5$+ $VC_{2.5}$ |
| $T_{13}$ | 25% RDF + $PM_{2.5}$ + $VC_{2.5}$ |
| $T_{14}$ | 25% RDF + $CD_5$ + $PM_{2.5}$ + $VC_{2.5}$ |
| $T_{15}$ | $CD_{10}$ + $PM_5$ + $VC_5$ |

Seeds were sown in rows 40 cm apart and seeds 20 cm apart. Additional seeds were sown separately beside the experimental field to be used for gap filling as needed. Table beet faces intense weed competition, managed through manual weeding at 15, 30, 45, and 60 DAS using "*Niri*". Additionally, gap filling at 30 DAS with extra seedlings and irrigation was performed to improve yield.

### *Data Collection and Harvesting*

The total number of leaves and plant height (cm) were documented from four randomly selected plants per plot at 20-day intervals up to 60 days after sowing. At harvest, twenty table beets were randomly selected from each plot, bundled, labelled, and taken to the threshing floor for data collection on plant height, leaf number, beet length, beet girth, individual beet weight, beet yield, individual shoot weight, shoot weight, total soluble solids (%), ascorbic acid and antioxidant activity. Beet length and girth were recorded in centimeters and individual beet and shoot weights were determined by dividing the total weight of beets and shoots by the number of beets. Beet weight was converted into tons per hectare (t/ha) to obtain the final beet yield. Moreover, fresh samples were taken from each plot to the laboratory for chemical analysis.

### *Measurement of quality components*

*Total soluble solids*, *ascorbic acid* and *antioxidant determination*. Brix (%) or total soluble solids (TSS%) was measured in juice of fresh roots by using a Hand Refractometer (ATAGO, Japan) or Brix meter. Moreover, ascorbic acid was estimated using the dye method, an oxidation-reduction titration technique. The sample was titrated in a reactive mixture of acetic acid and metaphosphate with 2,6-dichlorophenol indophenol. The endpoint was indicated by a transition in color from clear to pink, and the concentration was ascertained through comparison with a standard solution (Raman et al., 2023). In case of determining antioxidant activity, a test was employed named DPPH (2,2-diphenyl-1-picrylhydrazyl) test, which is an extensively utilized, rapid, efficient, and economic approach that employs free radicals to evaluate antioxidant properties, specifically to evaluate the capacity of substances to function as hydrogen donors or free-radical scavengers (FRS). The DPPH assay method involves the elimination of the stable free radical DPPH, which interacts with an unpaired electron, resulting in notable absorbance at 517 nm (Baliyan et al., 2022).

$$\%\ Inhibition\ of\ DPPH\ radical\ activity = \frac{A\ Control - A\ Sample}{A\ Control} \times 100$$

### *Statistical analysis*

The dataset underwent analysis utilizing a one-way ANOVA (analysis of variance); prior to this, the homogeneity of variances was confirmed using R-studio software (Version 4.2.2). Descriptive statistics were used to obtain the mean, and differences between variables were tested for significance at $P \le 0.05$ using the least significant difference (LSD) test (Gomez & Gomez, 1984).

## RESULTS

### *Growth parameters*

The impact of integrated nutrient management on the plant height and leaf number of table beet exhibits substantial significance (Table 3). At 20 DAS, 40 DAS and 60 DAS the maximum plant height and leaf number was observed with the application of recommended dose fertilizer (RDF) ($T_1$), which was statistically similar with application of 50% RDF + 5 t/ha cow dung ($T_3$), where the shortest plant height and leaf number was recorded in sole application of cow dung at 10 t/ha ($T_2$).

### *Yield attributes*

Integrated nutrient management strategies had a significant impact on beet length, beet girth, and beet yield. Statistically, the maximum beet length (8.50 cm) and girth (21.03 cm) were achieved with the recommended fertilizer dose ($T_1$), with a comparable result under 50% RDF + 5 t/ha cow dung ($T_3$). Conversely, the shortest beet length and girth were recorded in the 10 t/ha cow dung treatment ($T_2$) (Figure 2A, 2B). The recommended dose of fertilizers (RDF) exhibited the highest beet yield (25.02 t/ha), which was statistically identical with 50% RDF + $CD_5$ ($T_3$), (24.73 t/ha).

**Table 3.** Impact of integrated nutrient management on plant height and leaf number/plant of table beet

| Treatments | Plant height (cm) | | | Leaf number/plant | | |
|---|---|---|---|---|---|---|
| | 20 DAS | 40 DAS | 60 DAS | 20 DAS | 40 DAS | 60 DAS |
| $T_1$ | 18.25$^{a}$ | 33.5$^{a}$ | 40.22$^{a}$ | 5.75$^{a}$ | 8.33$^{a}$ | 11.33$^{a}$ |
| $T_2$ | 12.67$^{d}$ | 21.42$^{c}$ | 28.22$^{cd}$ | 4.58$^{c}$ | 6.33$^{d}$ | 9.00$^{e}$ |
| $T_3$ | 17.17$^{ab}$ | 31.5$^{ab}$ | 35.44$^{ab}$ | 5.58$^{ab}$ | 8.00$^{ab}$ | 10.89$^{ab}$ |
| $T_4$ | 14.67$^{b-d}$ | 28.67$^{a-c}$ | 33.33$^{bc}$ | 5.33$^{ab}$ | 7.25$^{a-d}$ | 9.55$^{b-e}$ |
| $T_5$ | 14.17$^{cd}$ | 23.83$^{bc}$ | 26.44$^{d}$ | 5.42$^{ab}$ | 6.67$^{cd}$ | 9.11$^{de}$ |
| $T_6$ | 15.92$^{a-c}$ | 24.58$^{bc}$ | 35.08$^{ab}$ | 4.91$^{bc}$ | 7.42$^{a-d}$ | 9.22$^{c-e}$ |
| $T_7$ | 15.42$^{bc}$ | 30.00$^{ab}$ | 33.33$^{bc}$ | 4.59$^{c}$ | 7.50$^{a-c}$ | 10.11$^{a-e}$ |
| $T_8$ | 14.92$^{b-d}$ | 26.08$^{a-c}$ | 30.55$^{b-d}$ | 5.25$^{a-c}$ | 6.92$^{b-d}$ | 9.33$^{b-e}$ |
| $T_9$ | 13.92$^{cd}$ | 29.17$^{a-c}$ | 34.21$^{a-c}$ | 5.00$^{bc}$ | 7.58$^{a-c}$ | 10.67$^{a-d}$ |
| $T_{10}$ | 16.08$^{a-c}$ | 30.50$^{ab}$ | 35.56$^{ab}$ | 5.17$^{a-c}$ | 7.25$^{a-d}$ | 11.22$^{a}$ |
| $T_{11}$ | 14.25$^{cd}$ | 26.17$^{a-c}$ | 30.67$^{b-d}$ | 5.25$^{a-c}$ | 7.00$^{b-d}$ | 10.00$^{a-e}$ |
| $T_{12}$ | 15.75$^{a-c}$ | 29.33$^{a-c}$ | 33.11$^{bc}$ | 5.17$^{a-c}$ | 7.50$^{a-c}$ | 10.11$^{a-e}$ |
| $T_{13}$ | 15.92$^{a-c}$ | 29.33$^{a-c}$ | 34.67$^{ab}$ | 5.50$^{ab}$ | 7.50$^{a-c}$ | 10.78$^{a-c}$ |
| $T_{14}$ | 14.92$^{b-d}$ | 28.42$^{a-c}$ | 33.56$^{bc}$ | 5.42$^{ab}$ | 7.83$^{ab}$ | 10.67$^{a-d}$ |
| $T_{15}$ | 14.83$^{b-d}$ | 28.83$^{a-c}$ | 33.56$^{bc}$ | 5.50$^{ab}$ | 7.83$^{ab}$ | 11.33$^{a}$ |
| *Level of sig.* | * | * | ** | * | * | * |
| CV (%) | 10.50 | 6.98 | 11.08 | 8.15 | 8.95 | 9.67 |

Means with identical letters in a column are not significantly different.
** = Statistically significant at the 1% probability level, * = Statistically significant at the 5% probability level.
All treatment variants are fully described in Table 2.

The lowest yield (10.86 t/ha) was observed in the 10 t/ha cow dung treatment ($T_2$) (Figure 2C). Nutrient management also affected fresh beet weight. The heaviest individual beet and shoot (top) weights were recorded with the recommended fertilizer dose ($T_1$), showing no significant difference from 50% RDF + 5 t/ha cow dung ($T_3$) (Table 4). Meanwhile, the highest top weight was achieved with 50% RDF + 5 t/ha cow dung ($T_3$) (Table 4).

### *Beet quality*

Integrated nutrient management significantly influenced the total soluble solids (TSS), ascorbic acid concentration, and antioxidant activity of table beet. The highest TSS (15.78%) was recorded in the 25% RDF + 2.5 t/ha poultry manure ($T_7$) treatment, which was statistically similar to 50% RDF + 5 t/ha cow dung ($T_3$). In contrast, the lowest TSS (13.44%) was observed under the recommended fertilizer dose ($T_1$) (Figure 2D).

Ascorbic acid concentration varied significantly across treatments, reaching a maximum of 24.20 mg/100g in 25% RDF + 2.5 t/ha vermicompost ($T_{10}$), while the lowest concentration (14.79 mg/100g) was recorded in 50% RDF + 5 t/ha cow dung ($T_3$), highlighting the substantial differences among treatments (Figure 3A).

**Table 4.** Effect of integrated nutrient management on individual beet weight, individual shoot weight and top weight of table beet

| Treatments | Individual Beet weight (g) | Individual shoot weight (g) | Top weight (t/ha) |
|---|---|---|---|
| $T_1$ | 200.13[a] | 96.57[a] | 11.87[a] |
| $T_2$ | 86.87[d] | 53.33[cd] | 6.33[de] |
| $T_3$ | 197.83[a] | 86.17[ab] | 12.06[a] |
| $T_4$ | 102.87[cd] | 52.40[cd] | 6.55[c-e] |
| $T_5$ | 85.00[d] | 48.57[d] | 6.07[e] |
| $T_6$ | 164.73[ab] | 74.50[a-d] | 10.31[a-c] |
| $T_7$ | 160.33[ab] | 83.32[a-c] | 10.41[ab] |
| $T_8$ | 100.73[cd] | 55.33[b-d] | 6.92[b-e] |
| $T_9$ | 160.10[ab] | 63.13[b-d] | 9.56[a-e] |
| $T_{10}$ | 166.40[ab] | 78.78[a-d] | 10.18[a-c] |
| $T_{11}$ | 136.13[bc] | 80.00[a-d] | 10.00[a-d] |
| $T_{12}$ | 134.97[bc] | 63.60[b-d] | 8.62[a-e] |
| $T_{13}$ | 161.35[ab] | 72.80[a-d] | 9.77[a-e] |
| $T_{14}$ | 171.05[ab] | 81.67[a-c] | 10.54[ab] |
| $T_{15}$ | 141.17[bc] | 64.37[b-d] | 8.71[a-e] |
| Level of sig. | ** | * | * |
| CV (%) | 8.63 | 6.74 | 5.51 |

Means with identical letters in a column are not significantly different.

** = Statistically significant at the 1% probability level, * = Statistically significant at the 5% probability level.

All treatment variants are fully described in Table 2.

Similarly, antioxidant activity exhibited notable variation, with the highest value (45.53%) observed in 50% RDF + 5 t/ha cow dung ($T_3$). In contrast, the lowest antioxidant activity (25.19%) was recorded in 25% RDF + 2.5 t/ha poultry manure + 2.5 t/ha vermicompost ($T_{13}$) (Figure 3B).

### *Economic returns*

Expenses, including material, non-material, and overhead, were documented for each treatment of unit plots and computed on a per-hectare basis, focusing on marketable yield. The treatment 50% RDF + $CD_5$ was the most profitable treatments having the benefit-to-cost ratio of 7.57. $VC_5$ is the least cost-effective treatment, having benefit cost ratio of 3.03. Based on the experimental outcomes, it can be inferred that when taking into account quality, yield attributes, and economics, 50% RDF + $CD_5$ ($T_3$) is the preferred treatment for farming as we are heading towards sustainable agriculture (Table 5).

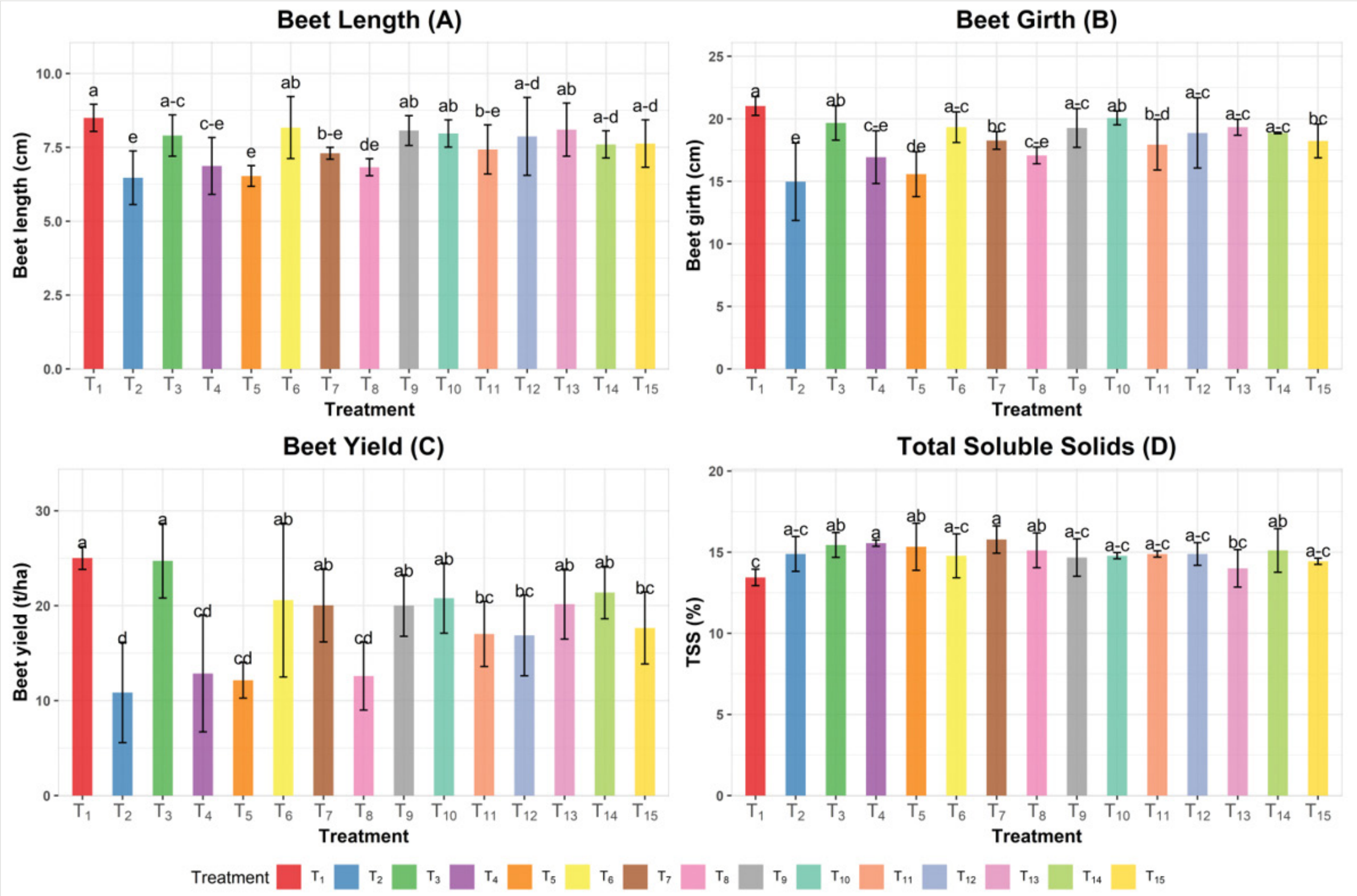
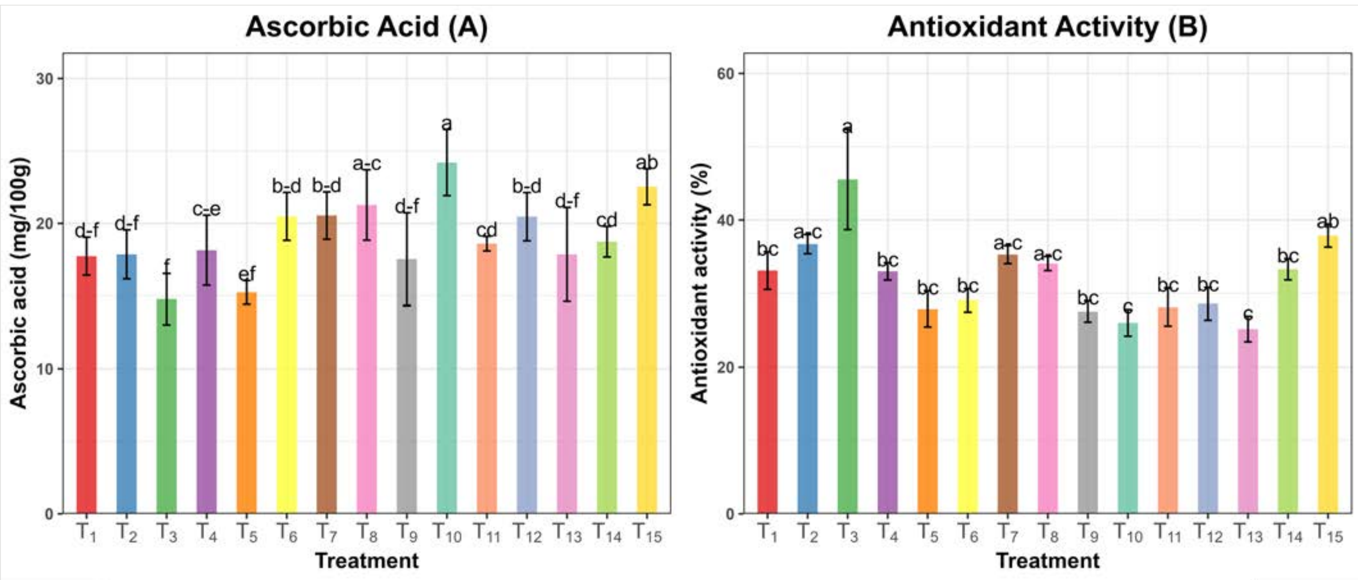



**Figure 2.** Effect of integrated nutrient management on beet length (A), beet girth (B), beet yield (C), and TSS (D) of table beet




Means with identical letters in the bar are not significantly different. All treatment variants are fully described in Table 2.

**Figure 3.** Effect of integrated nutrient management on ascorbic acid (A) and antioxidant activity(B) of table beet

**Table 5.** Effect of integrated nutrient management on total cost of production, gross income and benefit-cost ratio of table beet

| Treatments | Total Cost of Production (Taka) | Yields (t/ha) | Gross Income | Benefit Cost Ratio |
|---|---|---|---|---|
| $T_1$ | 249,480 | 25.02 | 1,876,500 | 7.52 |
| $T_2$ | 251,190 | 10.86 | 814,500 | 3.24 |
| $T_3$ | 244,860 | 24.73 | 1,854,750 | 7.57 |
| $T_4$ | 239,813 | 12.86 | 964,500 | 4.02 |
| $T_5$ | 234,765 | 12.15 | 911,250 | 3.88 |
| $T_6$ | 242,123 | 20.59 | 1,544,250 | 6.37 |
| $T_7$ | 237,075 | 20.04 | 1,503,000 | 6.34 |
| $T_8$ | 311,415 | 12.59 | 944,250 | 3.03 |
| $T_9$ | 280,448 | 20.01 | 1,500,750 | 5.35 |
| $T_{10}$ | 275,400 | 20.8 | 1,560,000 | 5.66 |
| $T_{11}$ | 242,550 | 17.02 | 1,276,500 | 5.26 |
| $T_{12}$ | 280,875 | 16.87 | 1,265,250 | 4.50 |
| $T_{13}$ | 278,138 | 20.17 | 1,512,750 | 5.43 |
| $T_{14}$ | 283,613 | 21.38 | 1,603,500 | 5.65 |
| $T_{15}$ | 338,790 | 17.65 | 1,323,750 | 3.91 |

All treatment variants are fully described in Table 2

## DISCUSSION

The application of mineral fertilizers at recommended doses significantly enhances the growth, yield, and overall quality of beet (Kandil et al., 2002; Ramadan et al., 2003; Bairagi et al., 2013; Kashem et al., 2015; Paul et al., 2018b). Conversely, organic manure serves as a valuable source of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca), which are gradually released into the soil through mineralization. This slow nutrient release ensures sustained availability, particularly in the later growth stages, leading to improved plant growth and yield attributes, including increased plant height, leaf number, beet length, beet girth, and overall beet productivity (Bairagi et al., 2013; Paul et al., 2018a). In our study, the highest growth, yield, and overall yield components were recorded with the application of the recommended dose of fertilizers (RDF). However, the treatment combining 50% RDF with cow dung @ 5 t/ha ($CD_5$) produced statistically comparable results to RDF. This study reveals that combine application of organic and mineral fertilizer produces almost similar growth and yield parameters as recommended mineral fertilizer doses. This trend is also observed in root crops, which were reported previously (Paul et al., 2018a, 2018b). Kumar et al. (2023) and Kondal et al. (2024) mentioned that the combined application of organic amendments and mineral fertilizer increases root yield where sole application of manure decreases yield attributes.

The quality characteristics of table beets are significantly degraded by the application of mineral fertilizers in this study. Conversely, the utilization of organic fertilizers individually or in integration with mineral fertilizers significantly improves the quality parameters of table beet, such as TSS (%), ascorbic acid and antioxidants. The result from the experiment showed that the highest TSS

(%), ascorbic acid and antioxidant were obtained with the application of 25% RDF + $PM_{2.5}$ ($T_7$), 25% RDF + $VC_{2.5}$ ($T_{10}$) and 50% RDF + $CD_5$ ($T_3$), respectively. This is attributed to the synergistic effect of organic manure and mineral fertilizers which improves soil health and microbial activity (Kondal et al., 2024). Moreover, Mounika et al. (2020) observed that the combination of vermicompost and mineral fertilizers boosts antioxidant enzymes, like ascorbate peroxidase, which are crucial for ascorbic acid biosynthesis and recycling, enhancing antioxidant capacity and reducing oxidative stress for higher ascorbic acid levels. In the $T_3$ treatment (50% RDF + $CD_5$), a decrease in ascorbic acid content was observed alongside a significant increase in total antioxidant activity. This suggests that ascorbic acid was actively utilized and oxidized as part of the plant's antioxidant defense mechanisms. At the same time, the enhanced accumulation of phenolics, flavonoids, and other secondary antioxidants, stimulated by the integrated nutrient management approach, contributed to the overall increase in antioxidant activity (Ibrahim et al., 2013).

In the case of economic returns, the integrated nutrient management approach not only enhances crop yield but also minimizes the dependence on mineral fertilizers, thereby reducing input costs and increasing overall profitability. Therefore, the highest benefit-cost ratio was observed in the plot treated with 50% RDF + $CD_5$ ($T_3$), which exceeded that of the RDF treatment despite its comparatively lower yield. These findings are in line with the reports of Mounika et al. (2020), who observed that the integrated use of organic and mineral fertilizers improved yield and economic returns in beet root (*Beta vulgaris* L.).

By taking into account soil health, microbial activity, soil physical and chemical properties, as well as sustainable agriculture and economic returns, optimizing yield outcomes can be achieved through the integration of mineral and organic fertilizers. In this context, the application of 50% RDF + $CD_5$ ($T_3$) emerges as the most effective strategy for maximizing yield while minimizing reliance on mineral fertilizers. This finding is consistent with the results of Antil and Singh (2007), who reported that the application of organic manures, such as cow or poultry manure, in conjunction with mineral fertilizers, is highly effective in sustaining crop productivity. Moreover, the integrated use of organic and inorganic fertilizers offers environmental benefits, as it reduces the need for mineral fertilizers, and promotes sustainable crop production.

## CONCLUSION

Based on the experimental results, it can be concluded that when evaluating the yield and quality attributes, 50% recommended dose fertilizer + cow dung @ 5 t/ha seems the most promising treatment for table beet cultivation. The findings suggest that the integration of organic and mineral fertilizers can be effectively utilized for the cultivation of table beet within a sustainable agricultural framework. Additionally, the implementation of organic fertilizers contributes to the mitigation of high costs associated with mineral fertilizers. The application of organic fertilizers allows for a reduction in reliance on expensive chemical inputs, thereby facilitating sustainable and environmentally sound vegetable farming practices. Furthermore, it is imperative to conduct field trials under specific conditions to assess the efficacy of these fertilizers and achieve optimal yield outcomes.

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