Jurnal Biota Prodi Biologi Universitas Islam Negeri Raden Fatah Palembang

ACCEPTED MANUSCRIPT • OPEN ACCESS

Effects of Integrated Nutrient Management on the Growth Performance of Beetroot (Beta vulgaris L.) in Farmer's Fields

Effects of Integrated Nutrient Management on the Growth Performance of Beetroot (*Beta vulgaris* L.) under Acidic Soil Conditions in Smallholder Farmer Fields

Mohammad Samiul Ahsan Talucder[1,2], Akram Hossain[1], Rafia Islam Tisha[1], Md Abu Sayed Robi[1], Rana Roy[1], Lathuenu Marma[3], Most. Papia Sultana[4], Ahasan Ullah Khan[1*]

[1] Climate-Smart Agriculture and amp; Geospatial Lab, Department of Agroforestry and Environmental Science, Faculty of Agriculture, Sylhet Agricultural University, Sylhet, Bangladesh

[2] Interdisciplinary Research for Future Agriculture, Sylhet Agricultural University, Sylhet, Bangladesh

[3] Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh

[4] Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh

*Email: ahasanullahsau@gmail.com

Abstract

This research examines the impact of integrated nutrient management on the growth, yield, sugar content, and betalain concentration of beetroot cultivated in acidic soil (pH 4-5) within the farmer's field at Khadimnagar, Sylhet, Bangladesh. A randomized complete block design (RCBD) was used to assess six fertilizer treatments combining varying rates of Urea, MoP, TSP, and vermicompost. This study aimed to evaluate how integrated nutrient management affects the growth, yield, and quality of beetroot in acidic soil conditions. The results indicated significant effects of the treatments on the majority of parameters. Key findings showed that moderate nutrient application (T3: 300-150-300 kg/ha N-P-K + 3500 kg/ha vermicompost) produced the highest yield (26.75 t/ha), with significant improvements in root weight, length, diameter, and betalain content. In contrast, excessive fertilization (T5) led to reduced yield and quality, while no fertilization (T0) resulted in the poorest performance. The highest sugar content (Brix%) was observed in T2 at 7.775%, suggesting a positive effect of moderate nutrient application. The results indicate that a combination of N-P-K at 300-150-300 kg/ha with vermicompost at 3500 kg/ha is optimal for improving beetroot quality and productivity in slightly acidic soils. The control group (T0) exhibited the lowest performance across all measured parameters. The study highlights the importance of balanced nutrient management in acidic soils. The data suggests that higher nutrient doses (T3 and T5) lead to significant improvements in beetroot growth, quality, and yield, with T3 generally showing superior performance across key metrics. Further field trials are recommended to validate these findings across broader agroecological contexts.

Keywords: *Acidic Soil; Beetroot; Betalains; Nutrient Management; Sugar Content; and Yield.*

Introduction

Beetroot (*Beta vulgaris* L.) is a widely cultivated root vegetable and edible plant found globally [1]. It belongs to the member of the Amaranthaceae family. The plant, commonly known as beet, is widely distributed across Asia Minor, the Mediterranean region, and Europe [2]. The leaves are primarily consumed in salads, although they can also be prepared similarly to spinach. The tuberous root of beetroot is characterized by a high concentration of physiologically active substances, such as vitamins and minerals, contributing to its global popularity as a vegetable [3]. This vegetable is optimal for health-conscious individuals due to its high content of protein, carbohydrates, calcium, phosphorus, and vitamin C [4]. Beetroot functions as a dietary supplement that enhances the immune system through its antiviral, antibacterial, and antioxidant properties. Furthermore, it increases energy levels, reduces blood pressure, improves digestive health, possesses anti-inflammatory properties, and exhibits anti-cancer effects [5]. Betacyanins and betaxanthins, two types of betalains present in beetroot, contribute to the prevention and management of hypertension and cardiovascular diseases. They may also inhibit the proliferation of human tumor cells [6]. Chawla et al. [7] identify beetroot as one of the top ten vegetables in terms of phenolic compound concentration and antioxidant activity. The chemical composition and nutritional value of red beetroot are influenced by its variety, growth conditions, and anatomical part of the plant [8].

Beetroot is easy to cultivate in fields. It is considered a functional food due to its dense nutritional profile and bioactive constituents. A 100-gram serving of raw beetroot contains approximately 43 kcal of energy, 1.6 grams of protein, 0.2 grams of fat, 9.6 grams of carbohydrates, and 2.8 grams of dietary fiber [9]. It is particularly rich in folate (vitamin B9), which plays a crucial role in DNA synthesis, cell division, and prevention of neural tube defects during pregnancy [10]. Folate deficiency is prevalent in many South Asian populations, including

Bangladesh, and beetroot offers a natural dietary source to address this micronutrient gap. It exhibits high productivity, rapid growth, and is generally free from diseases and pests [11]. The optimal temperature range for beetroot cultivation is 18 to 25°C, with a preferred soil pH of 6.5 to 7.5 [12]. The growth and harvest of beetroot are affected by soils enriched with organic and inorganic fertilizers providing nitrogen (N), phosphorus (P), and potassium (K) [13]. The excessive application of nitrogen fertilizer can diminish agricultural yield and adversely affect soil ecology [14]. Proper use of nitrogen fertilizers enhances growth, thereby increasing both quality and yield. Vermicompost can influence the soil's microbial and enzyme activity, growth regulators, phosphate, potassium, total and accessible nitrogen, and micronutrients, as well as other physical, chemical, and biological properties [15].

In the context of Bangladesh, beetroot presents multiple advantages. It grows well in the Rabi season (winter), requires relatively low inputs, and can be cultivated on small plots, making it ideal for homestead gardening and smallholder farmers. Beetroot is an emerging crop that is increasingly recognized for its vibrant appearance and numerous health benefits. Most farmers (53%) cultivate it solely as a hobby. However, 32% of farmers engage in its cultivation for market purposes. The cultivation of this new crop presented several challenges for farmers, including shortages of labor and seeds, elevated labor costs, and excessive rainfall. The cultivation of beets in Bangladesh has been largely overlooked. Beetroot can be effectively cultivated in various regions of Bangladesh, and from an economic perspective, its cultivation and sale appear to be profitable.

The production of beetroot vegetables presents an opportunity for the food industry to develop foods rich in phytonutrients. Farmers in the country are likely to increase beet cultivation in the future, provided they receive adequate support during both the cultivation and marketing processes. This study aimed to investigate the impact of integrated nutrient management on the growth, yield, sugar content, and betalain concentration of beetroot cultivated in a farmer's field in Khadimnagar, Sylhet, Bangladesh, on slightly acidic soil (pH 4-5).

Materials and Methods

1. Experimental site, soil, and climate

The experiment was conducted out in a farmer’s field located in Khadimnagar, Sylhet, Bangladesh, under the Agro-Ecological Zone of Eastern Surma-Kushiyara Floodplain (AEZ 20) during the Rabi season from January to April 2023. The experimental site is positioned at a latitude of 24° 54′ 33.2″ N and a longitude of 91° 54′ 7.15″ E, with an elevation of 30 m above sea level. The soil at the site is classified under the "Khadimnagar" soil series, characterized by a sandy loam texture, and moderate levels of organic matter content (1.45%). Nutrient content includes Nitrogen (0.80%), Potassium (0.07 m mol/100 g of soil), Phosphorus (25 g/g of soil), and Sulfur (10 g/g of soil), with a soil pH of 4.5.

2. *Experimental design and treatments of the experiment*

The study was designed to evaluate the effect of four independent factors-Nitrogen (N), Phosphorus (P), Potassium (K), and Vermicompost (V) using a randomized complete block design (RCBD). A total of six treatments were tested: T0 (Control: 0-0-0-0 kg/ha), T1 (200-50-200-2500 kg/ha), T2 (250-100-250-3000 kg/ha), T3 (300-150-300-3500 kg/ha), T4 (350-200-350-4000 kg/ha), and T5 (400-250-400-4500 kg/ha) of urea, Murate of Potash (moP), Triple superphosphate (TSP), and vermicompost. The experimental layout included five treatments, each replicated four times ($4 \times 5 = 20$) with each plot measuring 1 m^2 and containing 20 plants spaced 16×20 cm apart.

3. *Land preparation*

The experimental field was prepared on 15 January 2023 by plowing with a power tiller. Four rounds of deep and cross-plowing were conducted, followed by laddering to ensure the land was leveled. The corners and bunds were shaped using a spade, and large soil clods were broken into smaller pieces with a wooden hammer. Weeds, stubbles, and crop residues were removed to prepare the field for planting. Fertilizers were applied based on precise calculations before sowing. Triple superphosphate was used as a phosphorus source, muriate of potash was applied as the potassium source during sowing, and urea was applied three times, with 15-day intervals as the nitrogen source.

4. *Sowing and Cultural Management*

Following the completion of land preparation, Redgold variety beetroot seeds were soaked overnight before sowing in the prepared plots. One week after the germination, thinning was performed to ensure optimal plant growth and density in each plot. Throughout the beetroot growing period, all necessary intercultural practices, including weeding and irrigation were conducted. The beetroot was harvested 70 days after sowing (DAS).

5. Measurement of morphological parameters

After harvest, a sample of five randomly selected plants, excluding border plants was collected from each plot for data analysis. The following parameters were recorded: number of leaves per plant, plant height (cm), leaf fresh weight (g/plant), root length (cm), root diameter (mm), root fresh weight (g/plant), sugar content (Brix % at 27°), betalain (mg/100 g), and yield (ton/ha). The mean values of the five sampled plants were calculated to represent each parameter for the beetroot plants.

6. Biochemical content Assessment

Sugar content (Brix % at 27°) was determined using a digital refractometer (NR151), while betalain content was measured following the method outlined [16].

7. Statistical Analysis

The data were analyzed using one-way analysis of variance (ANOVA) to evaluate the effects of different nutrient management treatments (T0 to T5) on the beetroot growth, yield, and quality. Statistical analysis was conducted using Statistix 10 software. Differences between treatments were considered significant at a p-value of 0.05. pairwise comparisons to identify significant differences across treatments were performed using the Least Significant Difference (LSD) tests. The mean values for each treatment, along with the standard error of the mean (SE), were presented as error bars in the graph. Microsoft Excel was used to generate the graphs. Statistical significance was indicated as follows: *$p \leq 0.05$ (significant), **$p \leq 0.01$ (highly significant), ***$p \leq 0.001$ (very highly significant), ns: Not significant.

Results and Discussion

Effect of treatment stage on various growth parameters of beetroot

There were five treatments (T0 to T5) for integrated nutrient management (INM) in farmers' fields, and Table 1 shows how the beetroot (Beta vulgaris L.) grew and how much it produced in each one. These treatments represent varying levels of nutrient management. The parameters measured include leaf number per plant, plant height, leaf fresh weight, root length, root diameter, root fresh weight, sugar content, betalain content, and yield. The analysis includes the coefficient of variation (CV %), significance level (P value), and least significant difference (LSD) at 0.05. Beetroot is widely consumed worldwide due to its high content of bioactive compounds, including essential vitamins and minerals present in the tuberous root [17]. The study showed that the best growth conditions were reached by using a moderate amount of N-P-K-V fertilizer. These included the fresh weight of the leaves, the diameter and weight of the roots, and the length of the longest root. By adding nitrogen (N), phosphorus (P), and potassium (K) to the soil with organic and inorganic fertilizers, you can change how much beet grows and how much you get [18].

Leaf Number per Plant

Leaf number per plant showed significant variation ($P < 0.001$) across treatments. Treatment T5 had the highest leaf number (11.60), followed by T4 (10.80), T3 (10.90), T2 (9.55), T1 (7.25), and T0 (6.70) (Table 1). The coefficient of variation was 13.10%, indicating moderate variability. The increase in leaf number with higher nutrient management (T5 and T4) is expected as nutrient availability is closely linked to plant growth, particularly leaf production. Treatments with the right amount of nutrients may promote vegetative growth, making it easier for the plant to make leaves. This can lead to more photosynthesis and growth overall. An earlier study [19] found similar results. It also found that the plot treated with T6 (70:180:70 kg NPK/ha) had the most leaves (7.73 kg) 60 days after planting. This adds to the evidence that using balanced inorganic fertilizers and good nutrient management greatly improves plant growth, which in turn leads to more leaves being produced.

Plant Height

Plant height did not show significant differences ($P > 0.05$) among the treatments, with the heights ranging from 32.13 cm (T5) to 35.48 cm (T0) (Table 1). The coefficient of variation was 7.93%, indicating low variability. The lack of significant differences in plant height suggests that plant height in beetroot may not be as sensitive to nutrient treatments as other parameters like leaf number or root weight. It indicates that factors like root development and leaf growth might be more responsive to nutrient management than vertical growth. However, excessive application of nitrogen fertilizers can lead to delayed maturity and create competition between the sinks (tubers) and sources (leaves). This imbalance may ultimately result in reduced yields [20]. Such findings highlight the importance of balancing fertilizer application to optimize both vegetative growth and yield.

Leaf Fresh Weight

Leaf fresh weight exhibited significant differences ($P < 0.001$). The highest fresh weight was recorded in T5 (55.80 g/plant), followed by T3 (53.40 g/plant), T4 (48.00 g/plant), T2 (39.93 g/plant), T1 (34.58 g/plant), and T0 (30.24 g/plant) (Table 1). The coefficient of variation was 5.20%, reflecting moderate variability. Managing nutrients was a key part of increasing leaf fresh weight. This was probably because it led to better photosynthesis and stronger plant growth, especially in the treatments with more nutrients (T5 and T3). Leaf fresh weight serves as an important indicator of plant health and vigor, and its increase in response to nutrient management suggests an overall improvement in plant condition [20]. However, it is important to note that excessive nitrogen fertilization can result in delayed maturity and competition between sinks (tubers) and sources (leaves), which may ultimately lead to reduced yields. This highlights the need for balanced nutrient application to optimize both growth and yield potential.

Root Length

Root length showed significant differences ($P < 0.01$) across treatments. The longest root length was observed in T3 (16.12 cm), followed by T4 (14.56 cm), T2 (14.79 cm), T1 (13.39 cm), T5 (13.84 cm), and T0 (12.66 cm) (Table 1). The coefficient of variation was 8.24%. Root length increased with higher nutrient treatments, indicating that optimal nutrient availability promotes better root development. This finding aligns with the idea that effective nutrient management enhances root growth, enabling the plant to absorb water and nutrients more efficiently. Abdelaal and Sahar [21] reported that higher nitrogen levels significantly improved both root length and diameter. In this study, the results indicated that the highest yield of roots and top fresh weight (69.8 and 19.8 tons ha^{-1}, respectively) was achieved with the addition of 20 m^3 ha^{-1} organic manure combined with 285 kg N ha^{-1}, particularly in the Salama and/or Faten cultivars. These results were consistent across both the first and second seasons, further emphasizing the importance of balanced nutrient and organic manure application for optimizing crop yield. This highlights the need for careful management of nitrogen levels to avoid negative impacts on overall plant performance.

Root Diameter

Root diameter showed significant variation (P < 0.001) across treatments. The thickest root diameter was found in T3 (59.90 mm), followed by T4 (51.35 mm), T5 (50.56 mm), T1 (50.22 mm), T2 (46.41 mm), and T0 (42.70 mm) (Table 1). The coefficient of variation was 7.19%. The increase in root diameter with higher nutrient levels indicates that nutrient management can enhance root development, both in terms of length and girth. This could be crucial for improving the overall size and quality of the roots, which are the economically valuable portion of beetroot. A study found similar results. Treatment T6 had the same height root diameter (6.27 cm) as treatments T9 (6.13 cm), T5 (6.06 cm), and T4 (5.73 cm). These treatments showed significant superiority over all other remaining treatments. The control treatment, T0, recorded the lowest root diameter, measuring 4.93 cm [20]. Another study [21] reported that higher nitrogen levels significantly improved root length and diameter. In this experiment, we observed a significant increase in root length and root weight when nitrogen fertilizer was applied at an optimal rate. However, excessive nitrogen fertilizers led to delayed maturity and competition between sinks (tubers) and sources (leaves), which could ultimately reduce yields [20].

Root Fresh Weight

Root fresh weight showed significant differences (P < 0.001). The highest root fresh weight was recorded in T3 (133.25 g/plant), followed by T4 (101.68 g/plant), T5 (83.93 g/plant), T2 (82.60 g/plant), T1 (92.57 g/plant), and T0 (55.60 g/plant) (Table 1). The coefficient of variation was 3.69%. The significant increase in root fresh weight with higher nutrient treatments, particularly in T3, is a key indicator of improved productivity. Root fresh weight is closely tied to yield, and the increase in root weight suggests that nutrient management directly contributes to better growth and productivity. The addition of 285 kg N ha^{-1} resulted in significant increases in both fresh and dry root weights, with improvements of approximately 14.4% and 16.0%, respectively. Additionally, foliage yield saw a corresponding increase of 27.9%. These increases indicate the positive impact of nitrogen application on both root and foliage development, which are crucial for the overall productivity of the crop. Foliage from sugar beet is not only beneficial for the plant itself but also serves as an excellent feed source for livestock. Furthermore, pectin, a valuable product, is derived from the pulp of sugar beet [22].

Effect of Treatment Stage on Sugar Content, Betalain Concentration, and Yield of Beetroot under Acidic Soil Conditions

1. Sugar Content (Brix %)

Sugar content in the roots (measured as Brix percentage) showed significant variation ($P < 0.001$). T2 exhibited the highest sugar content (7.78%), followed by T3 (6.45%), T1 (6.08%), T4 (4.55%), T5 (4.58%), and T0 (3.95%) (Figure 1a). The coefficient of variation was 8.40%. The fact that T2 had the most sugar suggests that the balance of nutrients in this treatment made the physiological processes that cause glucose to build up in the roots work better. Sugar content is a key quality parameter for beetroot, especially for juice and processing industries. The comparison between vertical farming (VF) and open field (OF) cultivation revealed significant differences in the biochemical composition of red beets. Notably, the sugar content in VF red beets was found to be 4.2 times higher than that in beets from open-field cultivation [23]. This study also noted that the concentration of betalains was significantly higher in VF red beets compared to those from the open field. The amount of betalain in VF red beets was 2.4–2.8 times higher than in OF beets. This shows that the VF environment helps these important antioxidants build up. Also, roots that were treated with RED light (which has a red:blue: white light ratio of 4:1) had much higher levels of betalain than roots that were treated with CON light (which has a red:blue: white light ratio of 2:1). Sitompul and Zulfati [24] found that nitrogen fertilization had a big effect on the betacyanin content of beetroots, with lower levels seen as more nitrogen was applied. In this study, it was noted that both betalain and sugar content increased with the optimal application of nitrogen fertilizer.

2. Betalain Content

Betalain content varied significantly ($P < 0.001$), with the highest levels observed in T2 (118.10 mg/100 g), followed by T3 (109.02 mg/100 g), T4 (97.48 mg/100 g), T0 (96.07 mg/100 g), T1 (107.85 mg/100 g), and T5 (79.20 mg/100 g) (Figure 1b). The coefficient of variation was 6.16%. Betalain, the pigment responsible for the color of beetroot, was highest in T2, indicating that nutrient treatments can influence the synthesis of betalain. This is important for the marketability and quality of beetroot, especially in terms of visual appeal and antioxidant content. A previous research study reported betalain concentrations in the range of 800–1300 mg/L in fresh beetroot juice, with the highest concentration of betaxanthins ranging from 75–95%, while the lowest concentration of betacyanins ranged between 5–25%, depending on the beetroot variety [25, 26].

3. Yield (t/ha)

Yield showed significant differences ($P < 0.001$), with the highest yield in T3 (26.75 T/ha), followed by T4 (20.38 T/ha), T5 (16.83 T/ha), T2 (16.53 T/ha), T1 (18.53 T/ha), and T0 (11.10 T/ha) (Figure 1c). The coefficient of variation was 3.59%. Yield was significantly higher in treatments T3 and T4, indicating that optimal nutrient management directly enhances beetroot productivity. These treatments likely provide the necessary nutrients for maximum growth and development, leading to increased root size and weight, which translates into higher yield. Mia, and Rashid, [27] noted that the Red Ball variety (V2), when combined with organic amendments such as cowdung at 5 t/ha, Mustard oil cake at 0.15 t/ha, and vermicompost at 3 t/ha (T7), along with recommended chemical fertilizers, resulted in improved yield and better quality of beetroot. This supports the notion that integrated nutrient management, combining organic and inorganic inputs, can significantly enhance both the quantity and quality of beetroot production. These findings suggest that nutrient management strategies that combine organic amendments with chemical fertilizers may be beneficial for improving beetroot quality, including sugar content. Additionally, treatments with enhanced nitrogen levels and optimized nutrient ratios, like those in VF systems, demonstrated superior performance compared to traditional open-field conditions.

Conclusion

In conclusion, the study reveals that integrated nutrient management significantly improves various growth parameters of beetroot, particularly root and leaf development, root diameter, fresh weight, sugar content, betalain levels, and overall yield. The present study showed that the application of N-P-K-V doses positively influenced different growth attributes of beetroot. The results revealed that the application of various doses of N, P, K, and V significantly altered growth-associated attributes, including plant height, root length, root diameter, and root weight in beetroot. This combination of N, P, K, and V was also highly effective in enhancing the production of root weight and Betalain content. Based on the results, Treatment T3 (300-150-300-3500) kg/ha and T4 (350-200-350-4000) kg/ha appear to be the most suitable for field conditions, as they consistently outperformed other treatments in terms of plant growth.

Conflict of interest

We declare that there is no conflict of intere.

References

[1] B. S. Punia, N. Sharma, N. Sanwal, J. M. Lorenzo, and J. Sahu, "Bioactive potential of beetroot (*Beta vulgaris*)". *Food Res. Int.*, vol. 158, pp. 111556, 2022, doi: https://doi.org/10.1016/j.foodres.2022.111556.

[2] M. Nikan, and A. Manayi, "*Beta vulgaris* L". *Nonvit. Nonmin. Nutr. Suppl.*, pp. 153-158, 2018, doi: https://doi.org/10.1016/B978-0-12-812491-8.00021-7.

[3] L. Ceclu and N. Oana-Viorela, "Red Beetroot: Composition and Health Effects - A Review". *J. Nutri. Med. Diet. Care.*, vol. 6, pp. 043, 2020, doi: doi.org/10.23937/2572-3278.1510043.

[4] C. Jagadeesh, M. Madhavi, M. Siva-Prasad, and V. V. Padmaja, "Effect of organic manures on growth and yield attributes of beetroot cv". *Crimson Globe. Intern. J. Curr. Microbiol. Appl. Sci.*, vol. 7, pp. 3538-3553, 2018.

[5] T. Clifford, G. Howatson, D. J. West, and E. J. Stevenson, "The Potential Benefits of Red Beetroot Supplementation in Health and Disease". *Nutrients*, vol. 7, no. 4, pp. 2801, 2015, doi: https://doi.org/10.3390/nu7042801.

[6] P. Neha, S. K. Jain, N. K. Jain, H. K. Jain, and H. K. Mittal, "Chemical and functional properties of beetroot (Beta vulgaris L.) for product development: A review". *Int. J. Chem. Stud.*, vol. 6, pp. 3190–3194, 2018.

[7] K. Chawla, M. Parle, K. Sharma, and M. Yadav, "Beetroot: A health promoting functional food". *Inventi Rapid Nutraceuticals*, vol. 1, pp. 0976–3872, 2016.

[8] T. Sawicki, N. Baczek, and W. Wiczkowski, "Betalain profile, content and antioxidant capacity of red beetroot dependent on the genotype and root part". *J. Funct. Foods.*, vol. 27, pp. 249–261, 2016.

[9] USDA. (2023). "Food Data Central". U.S. Department of Agriculture. https://fdc.nal.usda.gov.

[10] F. S. Tola. (2024). “The concept of folic acid supplementation and its role in prevention of neural tube defect among pregnant women: PRISMA”. *Medicine*, vol. 103, no. 19, e38154. https://doi.org/10.1097/MD.0000000000038154.

[11] S. Baião, and V. M. Paschoalin, “Beetroot, A Remarkable Vegetable: Its Nitrate and Phytochemical Contents Can be Adjusted in Novel Formulations to Benefit Health and Support Cardiovascular Disease Therapies”. *Antioxidants*, vol. 9, no. 10, pp. 960, 2020, doi: https://doi.org/10.3390/antiox9100960.

[12] B. Neelwarne, and S. B. Halagur, “Red beet: An overview. In: Red Beet Biotechnology”. *Springer US*, pp. 1–43, 2012, doi: 10.1007/978-1-4614-3458-0_1.

[13] A. Sapkota, M. D. Sharma, H. N. Giri, B. Shrestha, and D. Panday, “Effect of Organic and Inorganic Sources of Nitrogen on Growth, Yield, and Quality of Beetroot Varieties in Nepal”. *Nitrogen*, vol. 2, no. 3, pp. 378-391, 2021, doi: https://doi.org/10.3390/nitrogen2030026.

[14] B. Eickhout, A. V. Bouwman, and H. Van-Zeijts, “The role of nitrogen in world food production and environmental sustainability”. *Agric. Ecosyst. Environ.*, vol. 116, no. (1-2), pp. 4-14, 2006.

[15] S. U. Rehman, F. De Castro, A. Aprile, M. Benedetti, and F. P. Fanizzi, “Vermicompost: Enhancing Plant Growth and Combating Abiotic and Biotic Stress”. *Agronomy*, vol. 13, no. 4, pp. 1134, 2023, doi: https://doi.org/10.3390/agronomy13041134.

[16] D. C. Usha, D. P. Radhika, and E. Keshamma, 2021: “Extraction and estimation of betalain content in beetroot (*Beta vulg*aries)”. *Int. J. Innov. Res. Technol.*, vol. 8, no. 4, 186-188, 2021.

[17] M. Lock, G. J. H. Grubben, and O. A. Denton, “Plant Resources of Tropical Africa 2. Vegetables”. Kew Bull, vol. 59, p. 650, 2004.

[18] V. Deshika, and B. Karunarathna, “Effect of integrated plant nutrient management on growth and yield of radish (*Raphanus sativas* L.) in sandy regosol”. *Res. J. Agric. For. Sci.*, vol. 7, pp. 10–14, 2019.

[19] Shivani, and H. Kumar, “Effect of different levels of inorganic fertilizers on growth and yield of beetroot under poplar-based agroforestry system”. *Int. J. Environ. Clim. Change.*, vol. 13, no. 9, pp. 2227-2233, 2023, doi: https://doi.org/10.9734/ijecc/2023/v13i92456.

[20] A. A. Najm, M. H. S. Hadi, M. T. Darzi, F. Fazeli, “Influence of nitrogen fertilizer and cattle manure on the vegetative growth and tuber production of potato”. *Int. J. Agric. Crop Sci.*, vol. 5, no. 2, pp. 147-154, 2013.

[21] K. A. A. Abdelaal, and F. T. Sahar, “Response of Sugar Beet Plant (*Beta vulgaris* L.) to Mineral Nitrogen Fertilization and Bio-Fertilizers”. *Int. J. Curr. Microbiol. App. Sci*., vol. 4, no. 9, pp. 677-688, 2015.

[22] M. T. Shalaby, M. B. Doma, F. A. Abd-El-Latief and S. M. ElSadik, “Agricultural, chemical and technological studies of potassium application on yield, chemical constituents and juice quality characteristics of sugar beet”. *J. Agric. Sci. Mansoura Univ*., vol. 27, pp. 7503–7512, 2022.

[23] C. Oh, J. Park, Y. Son, C. W. Nho, N. I. Park, and G. Yoo, “Light Spectrum Effects on the Ions, and Primary and Secondary Metabolites of Red Beets (*Beta vulgaris* L.)”. *Agronomy*, vol. 12, no. 7, p. 1699, 2022, doi: https://doi.org/10.3390/agronomy12071699.

[24] S. M. Sitompul, and A. P. Zulfati, “Betacyanin and growth of beetroot (*Beta vulgaris* L.) in response to nitrogen fertilization in a tropical condition”. *J. Agric. Sci*., vol. 41, no. 1, pp. 40-47, 2019.

[25] D. Pandita, A. Pandita, R. R. Pamuru, and G. A. Nayik, “Beetroot. Ed: G. A. Nayik, A. Gul, “Antioxidants in Vegetables and Nuts—Properties and Health Benefits”. *Springer; Singapore*, pp. 45–74, 2020.

[26] J. Wruss, G. Waldenberger, S. Huemer, P. Uygun, P. Lanzerstorfer, U. Müller, O. Höglinger, and J. Weghuber, “Compositional Characteristics of Commercial Beetroot Products and Beetroot Juice Prepared from Seven Beetroot Varieties Grown in Upper Austria”. *J. Food Compos. Anal.*, vol. 42, pp. 46–55, 2015, doi: 10.1016/j.jfca.2015.03.005.

[27] M. N. Mia, and M. H. A. Rashid, “Yield and quality performance of beetroot (Beta vulgaris L.) as influenced by organic manure management”. *Fundam. Appl. Agric.*, vol. 8 no. (1 & amp 2), pp. 377–389, 2023, doi: https://doi.org/10.5455/faa.93670.

Table 1. Effect of treatment stage on various growth and yield parameters of beetroot

Parameters	T0	T1	T2	T3	T4	T5	CV (%)	P value	LSD (0.05)
Leaf No./plant	6.70c	7.25c	9.55b	10.90ab	10.80ab	11.60a	13.10	***	1.8686
Plant height (cm)	35.48a	34.19a	33.14a	33.45a	34.84a	32.13a	7.93	NS	4.0463
Leaf Fresh Weight (g/plant)	30.24c	34.58c	39.93bc	53.40a	48.00b	55.80a	05.20	***	9.9454
Root Length (cm)	12.66c	13.39bc	14.79ab	16.12a	14.56ab	13.84bc	8.24	**	1.7668
Root diameter (mm)	42.70c	50.22b	46.41bc	59.90a	51.35b	50.56b	7.19	***	5.4366
Root Fresh Weight (g/Plant)	55.60e	92.57c	82.60	133.25a	101.68b	83.93d	3.69	***	32.177

Note: *T0 (Control: 0-0-0-0) kg/ha, T1 (200-50-200-2500) kg/ha, T2 (250-100-250-3000) kg/ha, T3 (300-150-300-3500) kg/ha, T4 (350-200-350-4000) kg/ha, and T5 (400-250-400-4500) kg/ha of urea, MoP, TSP, and Vermicompost.*

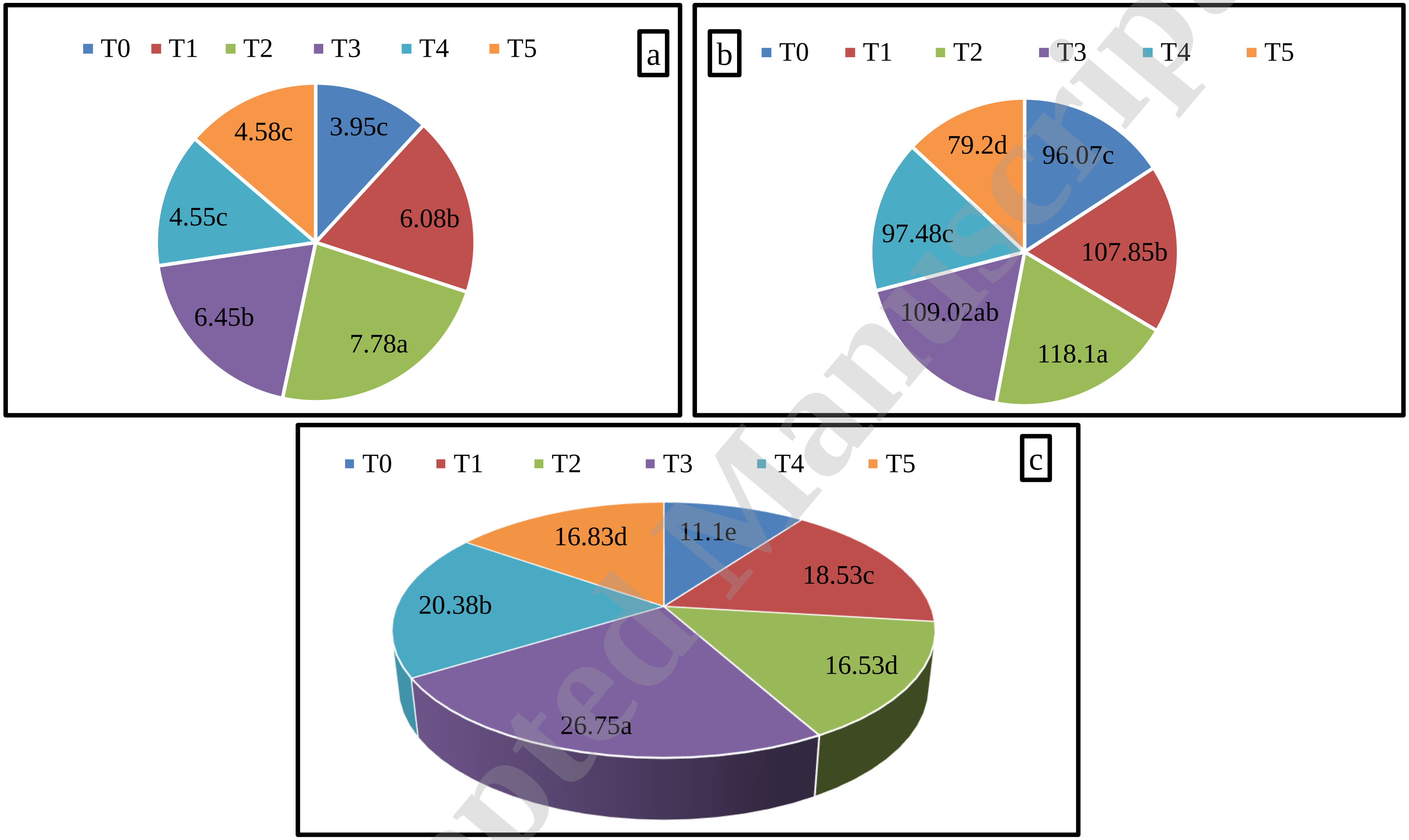

Figure 1. a) Sugar Content (Brix % at 27°C), b) Betalain Concentration (mg/100 g), and c) Yield (t/ha) of Beetroot under Different Integrated Nutrient Management Treatments. **Note:** *T0 (Control: 0-0-0-0) kg/ha, T1 (200-50-200-2500) kg/ha, T2 (250-100-250-3000) kg/ha, T3 (300-150-300-3500) kg/ha, T4 (350-200-350-4000) kg/ha, and T5 (400-250-400-4500) kg/ha of urea, MoP, TSP, and Vermicompost.*