Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 9 Issue 9 September 2025

Research Article

Response of Fodder Beet (*Beta vulgaris* L.) to Varying Plant Spacing and Fertilizer Regimes: Implications for Morphological Development, Biomass Yield and Forage Quality

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Received: July 21, 2025

Published: August 16, 2025

Abstract

A field experiment was conducted during the 2023/24 season at the Demonstration Farm of the College of Agricultural Science, Wachemo University, to evaluate the effects of plant spacing and fertilizer type on the morphological traits, biomass yield, and nutritional composition of fodder beet (variety KF-31). The study employed a randomized complete block design (RCBD) with a split-plot arrangement. Fertilizer treatments included control (T1), 15 tons/ha cattle dung (T2), 250 kg/ha NPSB (T3), and a mixture of 125 kg/ha NPSB plus 7.5 tons/ha cattle dung (T4). Three plant spacings (20, 25, and 30 cm between holes) were assigned to sub-plots. Analysis of variance revealed that fertilizer application significantly ($p<0.05$) increased root fresh weight, shoot fresh and dry weights, and both green and dry biomass yields. Wider spacing (30 cm) significantly improved root dry weight, whereas closer spacing (20 cm) produced higher overall green and dry fodder yields, likely due to greater plant density. Nutritional analysis showed leaves contained significantly higher crude protein, crude fiber, and ash compared to tubers ($p<0.01$), while tubers had higher dry matter and nitrogen-free extract. Notably, the combined fertilizer treatment (T4) with the closest spacing (20 cm) yielded the highest root dry weight ($p<0.05$). These findings indicate that integrating organic and chemical fertilizers with optimized plant spacing enhances fodder beet productivity and nutritional quality. Further studies across different locations and seasons are recommended to validate these results.

Keywords: Fertilizer Type; Fodder Beet; Nutritional Composition; Spacing; Yield

Introduction

Ethiopia possesses the largest livestock population in Africa, with an estimated 70 million cattle, 42.9 million sheep, 52.5 million goats, 13.3 million equines, 8.1 million camels, and 57 million poultry [4]. The livestock sector plays a vital role in the national economy, contributing approximately 47.7% of the agricultural GDP, 16.5% of the total GDP, and up to 17% of export earnings [18]. It also supports livelihoods by providing food, income, employment, and social capital. However, despite its significance, the sector remains underproductive, primarily due to inadequate and poor-quality feed [3]. The major livestock feed sources in Ethiopia include natural pastures, crop residues, and agro-industrial by-products [4,9,14]. Among these, natural pastures account for over half (54.54%) of the total feed supply, followed by crop residues (31.13%), hay (7.35%), and agro-industrial by-products (2.03%) [4]. However, the contribution of natural pastures has been steadily declining due to land degradation, overgrazing, and conversion to cropland [20]. Additionally, crop residues, although widely used, are inherently low in protein and mineral content [23], thus limiting their ability to meet the nutritional needs of livestock.

Efforts to introduce improved forage species have had limited impact, with only 0.32% of feed supply derived from cultivated forages [4]. The constraints include lack of awareness, technical knowledge, and land allocation among smallholder farmers [1]. As a result, livestock productivity remains low, and feed shortages especially during the dry season persist as a major bottleneck. Fodder beet (*Beta vulgaris*), a root crop native to the Mediterranean and historically cultivated in Europe since the 16th century, presents a promising alternative. It is well adapted to cool, moist climates and is valued for its high yield potential, drought tolerance, and high-energy, sugar-rich tuberous roots [11]. With yields reaching up to 20 t/ha of dry matter under favorable conditions [13,17], fodder beet surpasses many traditional forages in biomass productivity. Both leaves and roots are suitable for livestock feeding, making it particularly valuable during critical feed shortage periods such as the dry season [7].

Despite its advantages, the adoption of fodder beet in Ethiopia remains minimal. Contributing factors include limited awareness among farmers, poor seed supply systems, and insufficient research on its agronomic management, particularly in terms of optimal spacing and fertilizer requirements. Previous studies suggest that nitrogen availability is often a limiting factor in biomass production, necessitating research on appropriate fertilization practices [5]. In the context of shrinking grazing lands and declining feed quality, improving fodder production through scientifically informed agronomic practices is essential. Thus, this study was designed to evaluate the effects of plant spacing and fertilizer type on the morphological characteristics, biomass yield, and chemical composition of fodder beet. The findings aim to generate practical knowledge to support the adoption and efficient cultivation of this crop in Ethiopia's highland livestock systems.

Materials and Methods

Description of the study area

The experiment was conducted at the forage demonstration site of Wachemo University, located in the Hadiya Zone of the Central Ethiopia Regional State. The site lies in the central highlands of Ethiopia, approximately 230 km southwest of Addis Ababa along the route to Hosanna. Geographically, the study area is situated at an altitude of 2,177 meters above sea level, between 7.55386° N latitude (7° 33′ 14″) and 37.88389° E longitude (37° 53′ 2″). The area experiences an average annual temperature of 14.4 °C and receives approximately 1,331.6 mm of rainfall annually. The soil of the experimental site is classified as loam, characterized by good fertility and high water-holding capacity. The soil pH is 6.3, indicating a slightly acidic to neutral range, with local soil conditions ranging from normal to mildly saline.

Study design

A two-factor experiment was conducted using a randomized complete block design (RCBD) with a split-plot arrangement and three replications. The total experimental area measured 24.5 m × 10 m (245 m^2) and was divided into three uniform blocks to account for variability in soil fertility. The experimental factors included three plant spacing levels and three fertilizer types, resulting in nine treatment combinations. Each treatment was randomly assigned within the blocks and replicated three times, appearing once per block, for a total of 27 plots (9 plots per block). Each plot measured 2.0 m × 1.7 m (3.4 m^2), giving a cumulative plot area of 122.4 m^2 (3.4 m^2 × 36, including buffer plots). A spacing of 0.5 meters was maintained between adjacent plots and beds to minimize interference [8], and a 1-meter walkway separated the blocks to facilitate field operations and data collection. The blocks were oriented perpendicular to the known soil fertility gradient to reduce its influence on treatment comparisons. The overall field layout is presented in Figure 1.

Soil preparation

Proper and thorough field preparation was essential, as the seeds were directly sown into the soil. To ensure optimal seedbed conditions, the soil was first cleared of any previous crop residues and organic debris. The field was then plowed, harrowed, and leveled to achieve a fine tilth with a well-developed crumb structure, which is crucial for good seed-to-soil contact and uniform germination. This process ensured that the soil was loose, well-aerated, and free from large clods, thereby facilitating effective root penetration and moisture retention.

Experimental Treatment

The experiment involved two factors: plant spacing and fertilizer type. The first factor, plant spacing, was applied at three levels: 20 cm between plants (S1), 25 cm between plants (S2), and 30 cm between plants (S3). The second factor, fertilizer type, consisted of four levels: no fertilizer application as the control (F1), 0.085 kg of NPSB fertilizer per plot (F2), 0.00408 tons of cattle dung per plot (F3), and a combination of half the recommended rates of NPSB fertilizer and cattle dung (F4). These treatment combinations were applied to evaluate their effects on the morphological characteristics, biomass yield, and nutritional composition of fodder beet (Beta vulgaris) under the agroecological conditions of Wachemo University

Planting

Fodder beet seeds are typically large and covered by a corky shell. They occur in clusters known as glomerules, each containing between two and six seeds. Consequently, a single seed cluster may produce multiple seedlings, a characteristic referred to as multi-germ seed. Under optimal conditions, germination usually occurs within 10 to 14 days.

Plant Spacing

Because of the multi-germ nature of the seeds, the use of precision seeders is generally considered unnecessary. However, even with careful manual planting, variable plant stands are commonly observed, which can affect uniformity and yield.

Planting depth

The appropriate planting depth for fodder beet seeds varies between 1.0 and 2.5 cm, depending on the variety. Early sowings are typically planted at shallower depths to enhance emergence rates, particularly for early-maturing cultivars.

Fertilization

Fertilization recommendations include the application of NPSB fertilizer at a rate of 250 kg/ha or approximately 10–15 tons per hectare of farmyard manure. Since manure quality varies widely, application rates should be adjusted according to soil type and previous cropping history. For sandy soils, nitrogen application ranges between 110 and 200 kg N/ha, with 50% of nitrogen broadcast and incorporated before planting. The remaining nitrogen should be applied as side dressings at 10, 20, 30, and 40 days after sowing. On heavier soils, nitrogen rates are reduced to between 40 and 60 kg N/ha.

Irrigation requirement

Maintaining adequate soil moisture is critical until seedling emergence. During hot weather, applying a layer of mulch can help reduce soil moisture loss. It is recommended to irrigate twice daily until germination occurs. As plants develop, water requirements decrease and irrigation frequency can be reduced accordingly.

Weed control

Weed competition during the early growth stages can significantly reduce fodder beet yield by competing for light, water, nutrients, and space. Effective weed control is essential and often requires multiple interventions due to the uneven spacing caused by multi-germ seeds. Thinning of plants is typically conducted when beet roots reach 30 to 40 cm in diameter, which is usually done manually to remove excess plants and promote optimal growth.

Postharvest management

Key indicators of fodder beet root quality include uniformity in size and color, firmness, clarity, absence of rootlet rim formation, and freedom from defects. Under appropriate conditions, fodder beet roots can be stored effectively. Prior to storage, roots should be topped to prevent disease and mechanical damage. Larger roots generally store better and shrivel more slowly than smaller ones.

Data collection

Data collected in the study included above-ground fresh weight (AGFW), underground fresh weight (UGFW), above-ground dry weight (AGDW), below-ground dry weight (BGDW), plant height (PH), leaf length (LL), leaf width (LW), leaf area (LA), leaf number (LNo.), and yield measured in grams or kilograms. To avoid border effects, samples were randomly selected from within the interior plots of each treatment replication. Measurements of leaf length and width commenced 75 days after planting. Plant height, root diameter, and root length were measured using a ruler. Above- and below-ground plant parts were collected, dried in an oven at 60°C for 48 hours, and weighed to determine dry biomass.

Sampling and sample processing

Ten plants per plot were randomly sampled, excluding border plants to minimize edge effects. Sampling was conducted at maturity, starting 75 days after sowing. Morphological parameters such as leaf length, leaf width, plant height, root diameter, and root length were measured. Samples of fodder beet leaves and roots from all treatments were sliced, thoroughly mixed, and dried at 105°C to constant weight to determine dry matter content. Dried samples were ground using an electric grinder, passed through a 1 mm sieve, and stored for further analysis. Proximate analysis to determine nutritive value was conducted following AOAC (1984) standard methods.

Data analysis method

The general linear model (GLM) approach of SAS (SAS, 2007) was used to do an ANOVA on all parameters under consideration. The mean difference and interaction effect between treatments were compared using LSD at 5%.

The model was used: $Y_{ij} = \mu + t_i + b_j + e_{ij}$

Where Y_{ij} =the response variable (the observation in j^{th} block and i^{th} treatment)

μ = the overall mean

t_i = the treatment effect

b_j = the block effect (gradient)

e_{ij} = the random error.

Results and Discussion

Top fresh weight

Top fresh weight was significantly ($p < 0.05$) higher in plants treated with the combined fertilizer treatment of 125 kg/ha NPSB and 7.5 tons/ha cattle dung (F4) and under the narrowest plant spacing of 20 cm. Additionally, treatments receiving either 250 kg/ha NPSB (F2) or 15 tons/ha cattle dung alone (F3) also produced significantly greater shoot fresh weights compared to the control group (F1) ($p < 0.05$). These results are presented in Table 1. The findings align with those of [8], who reported significant increases in leaf and fresh root yields following fertilizer application. The improvement in biomass production is mainly attributed to the essential role of nitrogen in enhancing vegetative growth, chlorophyll synthesis, photosynthesis, and other physiological processes that collectively lead to increased yields.

Root fresh weight

Fertilizer application had a significant ($p < 0.05$) and positive effect on root fresh weight. As shown in Table 1, the combined fertilizer treatment (F4: 125 kg/ha NPSB + 7.5 tons/ha cattle dung) produced the highest root fresh weight, demonstrating its effectiveness in promoting root growth. This finding corroborates the results of [19], who reported that applying up to 100 kg N per feddan significantly increased root fresh weight in beet plants. Similar trends were observed by [14,15,22]. Root fresh weight was also significantly ($p < 0.05$) influenced by plant spacing (Table 1), with the greatest values recorded at the widest spacing of 30 cm (S3).

Top dry weight

The above-ground biomass of fodder beet constitutes a significant source of livestock feed in many regions worldwide. The leafiness of forage crops is influenced by factors such as soil fertility, climatic conditions, and agronomic management practices, which vary across locations. In this study, the combined application of inorganic and organic fertilizers had a significant ($p < 0.05$) effect on the leaf dry matter (DM) production of fodder beet (Table 1). The highest leaf DM yield (7.95 t ha^{-1}) was recorded under the F4 treatment (125 kg/ha NPSB + 7.5 t/ha cattle dung), followed by the F3 treatment (15 t/ha cattle dung), which produced 6.9 t ha^{-1}. The lowest leaf DM yield was observed in the control treatment.

This increase in leaf dry matter production may be attributed to nitrogen's pivotal role in enhancing photosynthesis, thereby stimulating the synthesis of metabolites and the accumulation of dry matter. Enhanced photosynthetic activity promotes greater biomass production, which in turn further facilitates photosynthate assimilation. Similar findings have been reported by [2,6,9]. Regarding plant spacing, the above-ground dry weight did not show significant differences across different spacing treatments (Table 1). Nevertheless, plants grown at lower densities exhibited higher individual biomass production, whereas those grown at higher densities produced significantly less shoot dry weight per plant due to increased intra-specific competition.

The interaction effect of fertilizer type and spacing on shoot dry weight further highlighted the superiority of the 20 cm spacing (S1) combined with the F4 fertilizer treatment (125 kg/ha NPSB + 7.5 t/ha cattle dung) (Table 2). This combination resulted in the highest shoot dry weight per plant during the cropping season. The synergistic use of organic manure alongside chemical fertilizers has been shown to enhance nutrient uptake, particularly nitrogen (N), phosphorus (P), and potassium (K), thereby improving crop growth and yield, as evidenced in sugarcane [7]. Similarly, [20] reported increased NPK concentrations in maize grains and leaves when chemical and organic fertilizers were applied together.

Furthermore, [14] demonstrated that combined application of organic and mineral fertilizers significantly ($p < 0.05$) improved crop yields compared to the use of either fertilizer alone. This synergy occurs because the release and uptake of nutrients are better synchronized when organic and inorganic nutrient sources are integrated, optimizing nutrient availability and efficiency [10]. Supporting these findings, [21] observed superior crop responses on acid soils when farmyard manure was used in conjunction with mineral fertilizers, emphasizing the importance of integrated nutrient management for sustainable food production. Overall, fertilizer application remains a critical input in crop production, substantially enhancing both yield quantity and quality.

Treatments		Top fresh yield t ha^{-1}	Root fresh yield t ha^{-1}	Top dry yield (t ha^{-1})	Root dry yield t ha^{-1}	Green fodder yield t ha^{-1}	Dry fodder Yield t ha^{-1}
Fertilizer	F1	12.031^{d}	44.164^{d}	4.6133^{b}	11.848^{b}	56.179^{d}	16.461^{b}
	F2	14.019^{c}	46.021^{c}	5.4000^{a}	13.119^{a}	60.041^{c}	18.774^{a}
	F3	15.762^{b}	47.511^{b}	6.9200^{a}	13.339^{a}	63.256^{b}	20.179^{a}
	F4	16.543^{a}	49.353^{a}	7.9511^{a}	14.376^{a}	65.893^{a}	21.269^{a}
SE		0.33	0.28	0.29	0.59	0.41	0.07
p-value		0.0000	0.0000	0.0003	0.0458	0.0000	0.0030
Spacing	S1	15.457^{a}	47.897^{a}	7.9417^{a}	13.797^{a}	63.354^{a}	20.739^{a}
	S2	14.738^{b}	46.594^{b}	5.3950^{b}	12.743^{ab}	61.333^{b}	17.819^{b}
	S3	13.558^{c}	45.797^{c}	5.0767^{b}	12.311^{b}	59.354^{c}	17.704^{b}
SE		0.29	0.24	0.25	0.51	0.36	0.65
p-value		0.0000	0.0000	0.0072	0.0229	0.0000	0.0071

Table 1: Effects of fertilizer type and spacing on yield and yield components of fodder beet.

Means within each column followed by the same letters are not significantly different at (5%); F1= Control (0 fertilizer); F2= 250 kg NPSB ha^{-1}; F3= cattle dung (15 t ha^{-1}); F4= combined 125kg NPSB ha^{-1} + 7.5 cattle dung t ha^{-1} fertilizers; S1= 20 cm plant spacing; S2=25 cm plant space and S3=30cm plant spacing.

Root dry weight

Tuber dry matter (DM) yield of fodder beet responded significantly ($P < 0.05$) to the interaction of inorganic and organic fertilizer applications (Table 1). The combined application of 125 kg/ha NPSB with 7.5 t/ha cattle dung (F4) produced the highest tuber DM yield of 14.4 t/ha, followed by sole application of 15 t/ha cattle dung (F3) and 250 kg/ha NPSB (F2), which yielded 13.3 t/ha and 13.1 t/ha, respectively. The lowest tuber DM yield (11.05 t/ha) was observed in the control treatment. These results clearly demonstrate that the integrated use of inorganic and organic fertilizers significantly enhances tuber yield of fodder beet.

When compared to sole inorganic fertilizer treatments, application of varying rates of farmyard manure resulted in an approximate 42% increase in mean tuber yield. This is attributable to manure's rich content of essential nutrients including nitrogen (N), phosphorus (P), potassium (K), and various secondary nutrients critical for plant growth. However, the nutrient value of manure can vary widely depending on factors such as the type of livestock, animal diet, manure collection, storage practices, application methods, and climatic conditions (Risse et al., 2008). Manure also positively influences soil physical properties by improving infiltration (Risse et al., 2008), increasing water-holding capacity [23], and reducing compaction and soil erosion [13]. [19] Reported that combining organic manure with chemical fertilizers significantly ($p < 0.05$) enhanced root length and nutrient uptake in wheat, leading to improved grain and straw yields. Similarly, the enhanced yields observed under manure application may result from improved soil biological and physical conditions that increase soil moisture retention and nutrient availability [10].

Consistent with these findings, the combined use of organic and inorganic fertilizers increased maize grain yield by 83.9 to 108.7% [22]. [8] Also found that applying 10 t/ha farmyard manure along with NPK fertilizer for three consecutive years increased soybean seed yield by 103%, water use efficiency by 76%, and root length density by 70.5%. [5] Concluded that the most cost-effective maize production strategy involves combining moderate rates of NP fertilizer with 5 t/ha organic manure. Moreover, [4, 7] observed the highest leaf area index, chlorophyll content, cane yield, and sugar content in sugarcane treated with chemical fertilizer supplemented with 15 t/ha farmyard manure.

The observed increase in tuber DM yield may be explained by nitrogen's critical role in promoting plant development [16] and enhancing the accumulation of assimilates [13]. Furthermore, root dry weight significantly increased when crops were sown at narrow spacing of 20 cm (Table 1). This finding corroborates [12], who reported greater root weight when planting hills were spaced 30 cm apart within rows. Similar results have been documented by [6] in Sudan. Throughout the growing season, the interaction between fertilizer type and spacing exerted a significant effect on root dry weight, with the highest root dry weight recorded under the F4 fertilizer mix (125 kg/ha NPSB + 7.5 t/ha cattle dung).

Green fodder yield

Green fodder yield was significantly higher ($p < 0.05$) than the control treatment when fertilizer applications of 250 kg/ha NPSB (F2), 15 t/ha cattle dung (F3), and the combined application of 125 kg/ha NPSB + 7.5 t/ha cattle dung (F4) were applied (Table 1). These findings align with those reported by [16], who concluded that nitrogen fertilization significantly enhances both top and root yields per feddan. Similarly, [22] observed that nitrogen application up to 80 kg/ha markedly improved top and root biomass. Consistent results were also reported by [20] reinforcing the positive effect of nitrogen on overall biomass accumulation.

Green fodder yield was inversely related to planting spacing. As shown in Table 1, the narrowest spacing of 20 cm (S1) resulted in significantly higher green biomass yield ($p < 0.05$) compared to the widest spacing of 30 cm (S3), which in turn did not differ statistically from the intermediate spacing of 25 cm (S2). This result is in agreement with the findings of Augustinussen (1974), who reported that closer intra-row spacing enhances fresh biomass yield. Similarly, [8] documented that increasing plant spacing leads to a reduction in total fresh yield of fodder beet, likely due to a lower plant population per unit area. The higher yields under narrower spacing are attributed to the greater number of plants per unit area, resulting in enhanced total biomass accumulation despite potentially reduced individual plant performance.

Dry Fodder Yield

Different fertilizer types had a significant effect ($p < 0.05$) on the total dry matter (DM) yield of fodder beet, encompassing both leaf and tuber biomass. The interaction between fertilizer type and plant spacing also exhibited a statistically significant ($p < 0.05$) influence on total DM yield (Table 1). The highest total DM production (18.269 t ha^{-1}) was achieved with the application of a combined fertilizer treatment consisting of 125 kg/ha NPSB + 7.5 t/ha cattle dung (F4), whereas the control treatment produced the lowest yield (15.461 t ha^{-1}). The F4 treatment showed a marked yield advantage of 18.269 and 18.179 over the control and the highest sole fertilizer application (250 kg/ha NPSB; F2), respectively, underscoring the superiority of integrated nutrient management.

The use of combined organic and inorganic fertilizers plays a vital role in improving soil physical, chemical, and biological properties, thereby enhancing crop productivity. In particular, the application of cattle dung significantly improved tuber yield by positively influencing soil health. [1] Reported that supplementing chemical fertilizers with organic amendments enhanced soil physical structure, microbial biomass, and dehydrogenase activity. Similarly, [2] demonstrated that the integrated application of farmyard manure (FYM) and inorganic fertilizers improved soil water retention, aggregation, and porosity. [6] found that 5 t/ha FYM significantly increased soil organic matter and porosity, while [16] confirmed improvements in crop yield, soil organic carbon, total nitrogen, and mineralizable C and N due to combined nutrient sources.

[19] Also reported that a three-year application of 10 t/ha FYM along with recommended NPK fertilizers enhanced soil organic carbon and reduced bulk density in soybean cultivation. According to [18], the addition of FYM improved moisture conservation, microbial activity, and nutrient mineralization. [12] Further noted that FYM in combination with inorganic fertilizers increased all forms of organic nitrogen in the soil. Moreover, integrated fertilization practices yielded superior outcomes in crop productivity, nutrient uptake, gross returns, net profits, and benefit-cost ratios compared to sole applications or traditional farmer practices.

In general, both leaf and tuber components of fodder beet contribute to animal feed resources. However, the tuber consistently produced significantly higher DM yield ($p < 0.05$) compared to the leaf component, highlighting its dominant role in total biomass contribution.

Treatment		Top fresh weight t ha^{-1}	Root fresh weight t ha^{-1}	Top dry weight t ha^{-1}	Root dry weight t ha^{-1}	Green fodder yield t ha^{-1}	Dry fodder yield t ha^{-1}
F1	S1	13.197^{e}	45.057^{gh}	4.1067^{def}	12.810^{ab}	58.253^{g}	16.917^{bc}
	S2	11.790^{fg}	44.200^{gi}	3.1667^{f}	11.500^{b}	55.990^{h}	14.667^{c}
	S3	11.053^{g}	43.237^{i}	3.5667^{ef}	11.233^{b}	54.253^{i}	14.800^{c}
F2	S1	14.733^{cd}	47.053^{de}	4.6100^{abcd}	13.943^{a}	61.787^{de}	18.550^{ab}
	S2	14.390^{d}	45.717^{fg}	4.3167^{cde}	13.317^{ab}	60.110^{f}	17.637^{bc}
	S3	12.933^{ef}	45.293^{g}	4.2733^{cde}	12.867^{ab}	58.227^{g}	17.137^{bc}
F3	S1	16.370^{ab}	48.747^{b}	5.4233^{ab}	14.037^{a}	65.123^{b}	19.463^{ab}
	S2	15.740^{bc}	47.417^{cd}	5.1233^{abc}	13.123^{ab}	63.157^{cd}	17.243^{bc}
	S3	15.177^{cd}	46.370^{ef}	4.2133^{def}	12.617^{ab}	61.547^{ef}	17.830^{ab}
F4	S1	17.530^{a}	50.730^{a}	5.6267^{a}	14.397^{a}	68.253^{a}	20.027^{a}
	S2	17.033^{a}	49.043^{b}	4.7000^{abcd}	13.033^{ab}	66.077^{b}	17.730^{ab}
	S3	15.177^{cd}	48.287^{bc}	4.5267^{bcde}	12.527^{ab}	63.350^{c}	17.050^{bc}
SE		0.57	0.48	0.49	1.02	0.72	1.29
p-value		0.4711	0.8267	0.5200	0.9978	0.8210	0.9525

Table 2: Effects of fertilizer × spacing interactions on yield and yield components of fodder beet.

Means within each column followed by the same letters are not significantly different at (5%) level; F1= Control (0 fertilizer); F2= 250 kg NPSB ha^{-1}; F3= cattle dung (15 t ha^{-1}); F4= combined 125kg NPSB ha^{-1} + 7.5 cattle dung t ha^{-1} fertilizers; S1= 20 cm plant spacing; S2=25 cm plant space and S3=30cm plant spacing.

Plant Height

The plant height of fodder beet was significantly influenced ($p < 0.05$) by the application of different fertilizer types at the forage harvesting stage (Table 3). The highest plant heights, ranging from 57.811 cm to 61.611 cm, were recorded under the application of 250 kg/ha NPSB (F2), 15 t/ha cattle dung (F3), and a combined treatment of 125 kg/ha NPSB + 7.5 t/ha cattle dung (F4), in contrast to the lowest plant height observed under the control (F1) treatment. This result underscores the considerable contribution of integrated fertilizer application (organic and inorganic) to the vegetative growth and development of fodder beet.

Organic manure serves as a reservoir of essential macro- and micronutrients, gradually released through microbial mineralization processes, thereby supporting sustained plant growth [4]. The findings align with those of [2], who reported that the application of organic fertilizers significantly enhanced fodder beet plant height. Similarly, [19] found that increasing rates of farmyard manure (FYM) application led to progressive improvements in plant height. Moreover, [17] reported that a combination of organic and inorganic fertilizers significantly enhanced plant height and leaf area in maize, likely due to improved nutrient availability and soil health.

Root length and diameter

Yield related parameters such as root length and root diameter were significantly affected ($p < 0.05$) by the application of different fertilizer types (Table 3). Root lengths were notably longer under fertilizer treatments, with values of 26.856 centimeters, 30.800 centimeters, and 31.866 centimeters recorded for 250 kilograms per hectare NPSB (F2), 15 tons per hectare cattle dung (F3), and the combined application of 125 kilograms per hectare NPSB and 7.5 tons per hectare cattle dung (F4), respectively. Each of these was significantly greater than the control treatment (F1). Similarly, root diameter was significantly greater under F2, F3, and F4 fertilizer treatments compared to the control.

This improvement in root development can be attributed to the balanced nutrient supply provided by NPSB and cattle manure, which are rich sources of essential macronutrients such as nitrogen, phosphorus, potassium, sulfur, and boron, as well as several secondary nutrients that are important for plant growth. These nutrients play a critical role in promoting root elongation and radial expansion. Supporting the current findings, [10] reported that root length and diameter in fodder beet ranged from 19.85 to 22.99 centimeters and 21.51 to 23.70 centimeters, respectively, when farmyard manure was applied in higher amounts. Similarly, [6] observed increased root length and diameter in fodder beet with increasing nitrogen application in the form of manure and NPSB.

However, it is important to note that the actual nutrient content of manure can vary considerably depending on factors such as the type of livestock, feed composition, manure collection and storage methods, application procedures, and local climatic conditions.

Treatment		PH(cm)	RD(cm)	RL(cm)	LA(cm^2)	LN(cm)	LW(cm)	LL(cm)	FFY (t ha^{-1})	DFY(t ha^{-1})
Fertilizer	F1	48.833^{d}	21.373^{c}	20.806^{c}	451.45^{c}	22.333^{a}	19.409^{c}	26.544^{b}	56.179^{d}	15.461^{b}
	F2	57.811^{c}	30.453^{b}	30.80^{ab}	635.06^{b}	23.778^{a}	22.762^{b}	31.878^{a}	60.041^{c}	17.774^{c}
	F3	59.811^{b}	30.934^{b}	26.856^{b}	654.06^{ab}	23.333^{a}	23.322^{ab}	32.044^{a}	63.256^{b}	20.179^{a}
	F4	61.611^{a}	32.723^{a}	31.866^{a}	682.97^{a}	23.222^{a}	23.877^{a}	32.678^{a}	65.893^{a}	21.269^{a}
SE		0.5833	0.6153	0.5282	26.920	1.5959	0.3421	0.4949	0.4121	0.7535
p-value		0.0000	0.0000	0.0000	0.0000	0.992	0.0005	0.0000	0.0000	0.0030
Spacing	S1	58.075^{a}	29.143^{a}	27.367^{a}	609.59^{a}	22.500^{a}	22.505^{a}	30.758^{a}	63.354^{a}	18.739^{a}
	S2	58.100^{a}	28.673^{a}	28.012^{a}	605.17^{a}	23.417^{a}	22.085^{a}	30.933^{a}	61.333^{b}	16.819^{b}
	S3	58.125^{a}	28.797^{a}	28.032^{a}	602.71^{a}	23.583^{a}	22.438^{a}	30.667^{a}	59.354^{c}	16.704^{b}
SE		0.5051	0.5328	0.4577	24.644	2.8663	0.2963	0.4286	0.36	0.65
p-value		0.2072	0.6633	0.4582	0.7241	0.7872	0.5609	0.8203	0.0000	0.0071

Table 3: Biomass yield and yield components of fodder beet evaluated under different fertilizer type and spacing.

Means within each column followed by the same letters are not significantly different at 5% level; SE = Standard Error; PH= plant height; RL= Root length; LA= Leaf area; LN= Leaf number; LL= Leaf length; FFY= Fresh fodder yield; DFY= Dry fodder yield; F1= Control (0 fertilizer); F2= 250 kg NPSB ha^{-1}; F3= cattle dung (15 t ha^{-1}); F4= combined 125kg NPSB ha^{-1} + 7.5 cattle dung t ha^{-1} fertilizers; S1= 20 cm plant spacing; S2=25 cm plant space and S3=30cm plant spacing.

Green leaf and root yield

Green yield parameters such as fresh leaf yield and fresh root yield were significantly ($p < 0.05$) influenced by fertilizer application (Table 2). Both leaf and root fresh yields increased across all fertilizer types used in this experiment. The highest fresh yields of both leaf and root were recorded under the application of 250 kilograms per hectare NPSB (F2), 15 tons per hectare cattle dung (F3), and the combined application of 125 kilograms per hectare NPSB with 7.5 tons per hectare cattle dung (F4). A statistically significant ($p < 0.05$) difference was observed among the fertilizer treatments in terms of their effect on fresh leaf and root yields. This improvement is attributed to the nitrogen content in the fertilizers, which plays a critical role in enhancing plant growth, chlorophyll formation, and the efficiency of photosynthesis, all of which ultimately contribute to increased leaf and root biomass. Supporting this finding, [5] reported that increases in leaf and root fresh yields due to fertilizer application are mainly the result of nitrogen's vital role in promoting growth, improving chlorophyll development, enhancing the photosynthetic process, and stimulating other physiological factors that contribute to overall yield enhancement.

Chemical composition of fodder beet

Dry matter

In this study, fertilizer application significantly ($p < 0.05$) decreased the dry matter percentage (Table 4). Increasing nitrogen fertilization tends to enlarge cell volume and elevate moisture content; consequently, the dry matter content of forage decreases [22]. A highly significant ($p < 0.05$) difference in dry matter content between leaves and tubers was observed, consistent with the findings of [12], who reported higher dry matter content in tubers than in leaves. The interaction between fertilizer treatments and beet plant parts also had a significant ($p < 0.05$) effect on dry matter percentage. Among the treatments, tubers under the control condition (F1) and those treated with 250 kilograms per hectare NPSB (F2) exhibited the highest dry matter contents. This result aligns with the findings of [15], who reported that nitrogen application tends to increase root moisture content, thereby reducing dry matter concentration.

Crude protein

Application of fertilizer up to 250 kilograms per hectare NPSB

Treatments		DM (%)	CP (%)	CF (%)	ASH (%)	EE (%)	NFE (%)
Fertilizer	F1	16.091[a]	5.463[d]	3.960[d]	14.214[b]	0.3333[a]	63.207[d]
	F2	15.113[b]	9.470[c]	8.699[c]	13.121[c]	0.3411[a]	71.786[c]
	F3	13.936[c]	10.97[b]	9.783[b]	13.358[bc]	0.2800[a]	75.646[b]
	F4	10.537[d]	12.44[a]	10.24[a]	15.887[a]	0.3422[a]	81.728[d]
SE		0.4065	0.4158	0.4955	0.4488	0.0399	1.3190
p-value		0.0000	0.0000	0.0000	0.0000	0.3663	0.0000
Spacing	S1	13.979[a]	9.3233[a]	8.783[a]	14.112[a]	0.3258[a]	73.138[a]
	S2	13.980[a]	9.4925a	8.595[a]	14.023[a]	0.3292[a]	72.656[a]
	S3	13.798[a]	9.9500a	8.470[a]	14.300[a]	0.3175[a]	73.480[a]
SE		0.3520	0.3601	0.4291	0.3887	0.0716	1.1423
p-value		0.8392	0.2205	0.7669	0.7701	0.9414	0.7713

Table 4: Chemical composition of fodder beet tuber evaluated under different fertilizer types and plant spacing.

Means within each column followed by the same letters are not significantly different at a (5%) level; F1= Control (0 fertilizer); F2= 250 kg NPSB ha^{-1}; F3= cattle dung (15 t ha^{-1}); F4= combined 125kg NPSB ha^{-1} + 7.5 cattle dung t ha^{-1} fertilizers; S1= 20 cm plant spacing; S2=25 cm plant space and S3=30cm plant spacing; DM =dry matter; CP = crude protein; CF = crude fiber; EE = ether extract; NFE = nitrogen – free extract.

(F2) resulted in a significant ($p < 0.05$) increase in crude protein (CP) percentage in the study (Table 4), which is in agreement with the findings of [5]. In both seasons, leaves had a higher crude protein content than tubers. This is supported by [13], who reported that crude protein content in leaves ranged between 8.2 and 16.04 percent, while tubers contained between 5.5 and 12.4 percent. The interaction between fertilizer application and beet plant parts (leaves and tubers) had a significant ($p < 0.05$) effect on crude protein content. Leaves under different fertilizer treatments attained the highest crude protein percentages, indicating that the leaves were the primary sink for nitrogen, as suggested by [14].

Crude fiber

Crude fiber (CF) percentage was significantly increased ($p < 0.05$) by the application of mixed fertilizers, with the highest CF value recorded under the combined application of 125 kilograms per hectare NPSB and 7.5 tons per hectare cattle dung (F4). This finding aligns with the results reported by Mustafa (2007) for certain sugar beet cultivars in Sudan. Leaves exhibited significantly ($p < 0.05$) higher crude fiber content than tubers. [10], who investigated the nutritive value of bulk samples of fodder beet leaves and roots, found that beet tubers had lower crude fiber content (10.24 percent of dry matter) compared to leaves (13.45 percent of dry matter). The interaction effect between fertilizer treatment and plant part (leaves versus tubers) was also significant ($p < 0.05$), with leaves under the combined fertilizer treatment producing the highest crude fiber content during the study.

Ether extract

Data presented in Table 4 indicate that there were no significant differences ($p > 0.05$) among the means for ether extract (EE) percentage across fertilizer types and plant spacing. However, leaves consistently exhibited higher ether extract content than tubers throughout the study. This finding contrasts with the results reported by [11]. The interaction between fertilizer type and fodder beet plant part was also non-significant. Nonetheless, the highest ether extract percentage was observed in leaves treated with the combined application of 125 kilograms per hectare NPSB and 7.5 tons per hectare cattle dung (F4).

Ash

Fertilizer application and plant spacing had a significant effect ($p < 0.05$) on ash percentage in this study. However, the ash percentage in leaves was significantly higher ($p < 0.05$) than that of tubers throughout the year. This finding is consistent with the work of [4], who reported that the ash content of leaves in three fodder beet cultivars ranged between 25 and 28 percent on a dry matter basis. However, these values are notably higher than the ash contents observed in the present study, which ranged between 13.125 and 15.887 percent on a dry matter basis. The highest ash percentages were recorded in leaves under the control treatment (F3) and the combined application of 125 kilograms per hectare NPSB with 7.5 tons per hectare cattle dung (F4). This may be attributed to the influence of nitrogen on enhancing nutrient absorption by the plant.

Nitrogen free extract

Nitrogen free extract was significantly higher ($p < 0.05$) under the combined application of 125 kilograms per hectare NPSB and 7.5 tons per hectare cattle dung (F4). A similar trend was reported by [7], who found an increase in total carbohydrates with increasing fertilizer rates. In this study, tubers contained significantly more nitrogen free extract ($p < 0.05$) than leaves during the season. Comparable results were reported by [14,17,21]. Overall, it appears that the beet plant parts had a stronger influence on nitrogen free extract content than the fertilizer application.

Treatments		DM (%)	CP (%)	CF (%)	ASH (%)	EE (%)	NFE (%)
Fertilizer	F1	5.453[d]	8.191[d]	6.931[c]	21.312[d]	1.4778[a]	44.526[d]
	F2	10.027[c]	12.204[c]	12.414[b]	22.627[c]	1.3956[a]	52.928[c]
	F3	11.027[b]	14.239[b]	12.968[b]	23.560[b]	1.4967[a]	55.928[b]
	F4	12.534[a]	16.038[a]	13.449[a]	24.501[a]	1.4011[a]	57.707[a]
SE		0.3259	0.2884	0.3697	0.3055	0.2810	0.7852
p-value		0.0000	0.0000	0.0000	0.0000	0.4955	0.0000
Spacing	S1	9.9792[a]	12.293[b]	10.699[a]	22.631[b]	1.4133[a]	52.542[a]
	S2	9.5250[a]	12.800[ab]	10.996[a]	23.136[ab]	1.4550[a]	52.260[a]
	S3	9.5250[a]	12.911[a]	11.127[a]	23.233[a]	1.4600[a]	52.988[a]
SE		0.2822	0.2497	0.3202	0.2649	0.0702	0.6800
p-value		0.2289	0.0488	0.4073	0.0715	0.7683	0.4980

Table 5: Chemical composition of fodder beet leaf evaluated under different fertilizer types and plant spacing.

Means within each column followed by the same letters are not significantly different at (5%) level; F1= Control (0 fertilizer); F2= 250 kg NPSB ha^{-1}; F3= cattle dung (15 t ha^{-1}); F4= combined 125kg NPSB ha^{-1} + 7.5 cattle dung t ha^{-1} fertilizers; S1= 20 cm plant spacing; S2=25 cm plant space and S3=30cm plant spacing; DM =dry matter; CP = crude protein; CF = crude fiber; EE = ether extract; NFE = nitrogen - free extract.

Conclusion

Despite its potential, fodder beet production and productivity remain low in Ethiopia and globally due to gaps in agronomic practices such as optimal plant spacing and fertilizer application. Several studies have identified these gaps as critical constraints limiting the efficient cultivation of fodder beet. Improved fodder production combined with appropriate agronomic management is essential to address livestock feed shortages and improve feed quality. This study confirms that the combined use of organic and inorganic fertilizers significantly ($p < 0.05$) enhances fodder beet yield compared to sole applications or no fertilization. Organic fertilizers alone cannot fully replace chemical fertilizers because of their slower nutrient release. However, integrating cattle dung with chemical fertilizer provides a synergistic effect that improves soil physical, chemical, and biological properties, thereby optimizing fodder beet growth and yield. The highest tuber dry matter yield of 14.4 tons per hectare was achieved with the combined application of 125 kilograms per hectare NPSB and 7.5 tons per hectare cattle dung. This was significantly higher than yields from either 15 tons per hectare cattle dung (13.3 t/ha) or 250 kilograms per hectare NPSB alone (13.1 t/ha), while the control treatment without fertilizer produced the lowest yield (11.05 t/ha). Therefore, the strategic integration of organic and inorganic fertilizers at balanced rates is recommended to maximize fodder beet productivity. Future research should focus on refining fertilizer ratios and exploring optimal plant spacing and other agronomic practices to further improve fodder beet production systems and support sustainable livestock feed supply.

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