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Original Research

Response of Carrot (*Daucus carota* L.) to Combined Application of Cattle Manure, and NPSB Fertilizer on Growth, Quality, and Economic Analysis in Western Ethiopia

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Abstract

Carrot (*Daucus carota* L.) production is severely constrained by low soil fertility and poor nutrient management, particularly for smallholder farmers. In order to address this issue, a field study was carried out in 2024 at Wollega University's Gitilo Dale, Shambu Campus, to assess the combined effects of NPSB mixed fertilizer and cow manure (CM) on carrot growth, yield, quality, and economic performance. Four amounts of NPSB fertilizer (0, 60, 100, and 140 kg ha⁻¹) and four rates of cattle manure (0, 6, 10, and 14 t ha⁻¹) were used in the experiment, which was established in a 4 × 4 factorial design using a randomized complete block design with three replications. In comparison to the unfertilized control, the results demonstrated that combining cattle dung with NPSB fertilizer greatly increased vegetative growth, yield, and root quality. The combination of 10 t ha⁻¹ CM and 100 kg ha⁻¹ NPSB yielded the highest root yield (39.5 t ha⁻¹), the highest plant (34.8 cm), and the most leaves (14.2 per plant). Additionally, this treatment reduced root problems, disease occurrence, and insect damage while improving quality qualities like sugar content (7.8%), beta-carotene (9.5 mg 100 g⁻¹), and total soluble solids (8.6 °Brix). This treatment was the most profitable, according to economic evaluation, with a net benefit of 298,500 ETB ha⁻¹ and a benefit-cost ratio of 18.1. Overall, the combined use of cattle manure and NPSB fertilizer is an efficient and economically viable approach for enhancing carrot productivity and maintaining soil fertility in the study area.

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INTRODUCTION

One of the most significant root crops in the Apiaceae family, carrots (*Daucus carota* L.) are grown all over the world for their edible storage root. Its rich nutritional content, including beta-carotene (a precursor to vitamin A), carbs, dietary fiber, and vital minerals like calcium, phosphorus, and iron, makes it highly prized (Singh & Bahadur, 2015). Carrots are eaten in fresh, cooked, and processed forms, such as juices, soups, and salads, due to these characteristics (Salunkhe & Kadam, 2005). Its global significance is further increased by its ability to respond to a variety of agro-ecological environments and its comparatively strong storage potential (Ali et al., 2006). Ethiopian carrot yield is still well below the global average, despite its importance. This is mainly attributed to declining soil fertility, imbalanced fertilizer use, and limited adoption of improved agronomic practices (Patil et al., 2016; Debele, 2018). Continuous cultivation without adequate nutrient replenishment has further aggravated soil degradation, particularly in highland areas, thereby constraining sustainable vegetable production (CSA, 2019).

It is well known that integrated nutrient management (INM), which combines the utilization of organic and inorganic nutrient sources, is a successful method for maintaining soil fertility and increasing crop

output (Yadav et al., 2010). In addition to offering a gradual and prolonged release of nutrients, organic inputs like cattle dung improve soil structure, increase water-holding capacity, and promote microbial activity (Omokaro et al., 2024). On the other hand, inorganic fertilizers provide easily accessible nutrients that are necessary for plant growth and development right away (ATA, 2015). Balanced fertilization and effective nutrient utilization are ensured by combining various nutrient sources.

Compared with the exclusive use of either organic or inorganic fertilizers, integrated nutrient management substantially improves carrot growth, yield, and quality, according to several studies. For example, in carrot production systems, integrated application of organic and mineral fertilizers has been found to improve plant height, root development, and overall yield (Gami et al., 2015; Haque, 2024). According to Ashenafi et al. (2022), coordinated nutrient treatment enhances crop performance and soil fertility status in vegetable production. Additionally, it has been demonstrated that in the production of carrots, balanced fertilization increases total soluble solids, root biomass, and financial returns (Mondal et al., 2006).

In Ethiopia, recent studies also confirm that integrated nutrient management plays a crucial role in improving carrot productivity under

local conditions (Amanuel, 2024; Betelhem et al., 2025). However, in many parts of western Ethiopia, including the Horro Guduru Wollega Zone, farmers still rely predominantly on either organic or inorganic fertilizers alone, which often results in suboptimal yields due to nutrient imbalance (Aman et al., 2019).

Although cattle manure is readily available in the mixed crop–livestock farming systems of the study area, its combined application with blended fertilizers such as NPSB (containing nitrogen, phosphorus, sulfur, and boron) has not been adequately investigated. There is limited location-specific information regarding the optimal combination of these inputs for maximizing carrot production while maintaining soil fertility. In order to determine an effective, sustainable, and financially feasible nutrient management plan for Horro District and related agro-ecological zones, this study was carried out to assess the effects of various rates of cattle manure and NPSB blended fertilizer on the growth, root quality, and economic performance of carrots.

MATERIALS AND METHODS

Study Site

During the main crop season of 2024, the trial was carried out at Gitilo in Horro District, Horro Guduru Wollega Zone, western Ethiopia. The location is nearly 334 kilometers northwest of Addis Ababa, at latitude 9°32'29" N and longitude 37°03'91" E, at an elevation of roughly 2,795 m asl. The locale has a typically highland climate and is part of the Dega agro-ecological zone. Rainfall peaks in July and August, with an average of 1,650 to 1,780 mm per year. During the growth season, the average temperature is roughly 22°C. The initial pH of the sandy clay loam soil at the experimental site was 4.82. Along with legumes and vegetables like potatoes and garlic, the vicinity's main crops include barley, wheat, and teff.

Experimental Design and Treatments

RCBD was used to arrange the experiment in a factorial combination of 4 × 4 with three replications. The treatments consisted of four levels (0, 6, 10, and 14 t ha⁻¹) of cattle manure and four amounts (0, 60, 100, and 140 kg ha⁻¹) of NPSB blended fertilizer. A total of 48 plots were used. The Nantes carrot variety served as the test crop. Each plot was 1.6 m by 1.8 m (2.88 m²), with 0.5 m between plots and 1 m between blocks. Six rows of seeds were planted at 10 cm plant spacing and 40 cm row spacing in each plot. The manure was incorporated into the soil during field preparation, whereas NPSB fertilizer was applied as a base dose during planting.

Experimental Field Management

The land was prepared using oxen plowing three times, followed by manual leveling. Prior to sowing, raised beds were prepared. In July 2024, carrot seeds were hand-drilled after being mixed with sand in a 1:1 ratio to ensure even dispersion. Two weeks following emergence, thinning was carried out to preserve spacing. Earthing-up and regular weeding were done by hand. Every agronomic technique was used consistently in all treatments.

Sampling and Analysis of Soil

Before planting, ten randomly selected locations were used to collect composite soil samples (0–20 cm depth) using an auger in a zigzag manner. Post-harvest soil samples were also collected for comparison. After being ground and allowed to air dry, the samples were sieved (1 mm for nitrogen and organic carbon analysis and 2 mm for general analysis). The pH of the soil in a 1:2.5 soil-water solution was measured using a digital pH meter. The soil's texture was ascertained using the Bouyoucos hydrometer method (Bouyoucos, 1962). Organic carbon was measured using the Walkley and Black method, and organic matter was computed by multiplying organic carbon by 1.724. The Kjeldahl method was used to calculate total nitrogen. The Bray II method was used to measure available phosphorus, the turbidimetric method was

used to measure available sulfur, and ammonium acetate extraction was used to measure cation exchange capacity (CEC) (Bray & Kurtz, 1945).

Data Collected

Plant Growth Parameters

Plant height (cm) was determined on ten randomly selected plants per plot by measuring the distance from the soil's surface to the tip of each shoot. Ten marked plants per plot were used to count the number of leaves on each plant a few days after emergence. At harvest, the shoot parts of ten randomly selected plants are weighed to determine the aboveground biomass (g).

Root Quality and Nutritional Parameters

Root Defect Indicators

Cracked Root Percentage (%): Cracked root percentage was determined by visually inspecting all harvested roots from the net plot area. Roots showing longitudinal or transverse splits on the surface were counted as cracked. The percentage was calculated as:

$$\text{Cracked root (\%)} = \frac{\text{Number of cracked roots}}{\text{Total number of sampled roots}} \times 100$$

Forked Root Percentage (%): Forked roots were identified as those showing abnormal branching or splitting of the main root into two or more secondary roots. All roots from the sample population were examined, and the percentage was computed as:

$$\text{Forked root (\%)} = \frac{\text{Number of Forked roots}}{\text{Total number of sampled roots}} \times 100$$

Disease Incidence (%): Disease incidence was assessed by counting roots showing visible symptoms of disease such as rot, discoloration, or fungal infection. The incidence was expressed as a percentage of the total sampled roots:

$$\text{Disease incidence (\%)} = \frac{\text{Number of diseased roots}}{\text{Total number of sampled roots}} \times 100$$

Pest Damage (%): Pest damage was determined by recording roots showing visible insect feeding damage, holes, or galleries caused by soil or storage pests. The percentage was calculated as:

$$\text{Pest damage (\%)} = \frac{\text{Total number of sampled roots}}{\text{Number of pest – damaged roots}} \times 100$$

Nutritional Quality Parameters

Total soluble solids (TSS, °Brix) were measured using a digital refractometer from fresh juice extracted from carrot roots. Beta-carotene content (mg/100 g) was also determined spectrophotometrically after solvent extraction using standard laboratory procedures. Sugar content (%) was also estimated using standard chemical titration methods. Crude fiber (%) was determined using the acid and alkali digestion method. Dry matter content (%) was also determined by oven drying 100 g of fresh root samples at 80°C for 72 hours using the formula:

$$\text{Dry matter (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

Root firmness (kg/cm²) was measured using a penetrometer, whereas Moisture content (%) was calculated as the difference between fresh and dry weight.

Economic Analysis

Using current market prices for inputs during planting and outputs at harvest, the economic analysis was carried out in accordance with CIMMYT's (1988) approach. Every expense and benefit were computed in Ethiopian Birr (ETB) per hectare. The mean marketable carrot yield of each treatment, gross benefit, and the cost of nitrogen fertilizer, including application expenses, were considered in the partial budget analysis. To account for the difference between the experimental and farmers' field conditions, the average marketable carrot yield (AvY),

which was calculated as the mean yield from each treatment, was adjusted lower by 10% to give the adjusted yield (AjY). The adjusted yield was calculated as $AjY = AvY \times 0.90$. The gross field benefit (GFB) was then computed by multiplying the adjusted yield by the field (farm-gate) price of carrots ($GFB = AjY \times \text{field price}$). The total variable cost (TVC) included the cost of fertilizers and their application, which varied among treatments, while other production costs, such as land preparation, planting, earthing up, weeding, and harvesting, were assumed to be similar and thus excluded. Finally, the net income or net benefit (NB) was calculated by subtracting the total variable cost from the gross field benefit ($NB = GFB - TVC$), indicating the profitability of each treatment. $NB = TR - TVC$. Marginal rate of return (MRR) was measured of increasing in return by increasing the input.

$$MRR = \frac{\text{Change of net Benefit (NB)}}{\text{Change of Total Variable Cost (TVC)}}$$

Statistical Analysis

All measured parameters were subjected to ANOVA to determine the significance of treatment effects. SAS software (version 9.0) for statistical analysis in agricultural research was used (SAS Institute, 2002). When significant differences were detected, treatment means were compared using the Least Significant Difference (LSD) test at a 5% probability level. The application of ANOVA is widely recommended for agricultural experiments to evaluate treatment effects (Gomez and Gomez, 1984). In cases where ANOVA indicates significant variation among treatments, the LSD test is considered an appropriate method for mean separation (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Soil Physico-Chemical Properties of the Experimental Site

Table 1 displays the pre-planting soil analysis results. According to the particle size distribution, the soil was composed of 25% clay, 16% silt, and 59% sand. The soil is thus classified as sandy clay loam according to the USDA (1987) soil texture categorization system. According to Hazelton and Murphy (2007), the soil's cation exchange capacity (CEC) was 15 meq/100 g, which is regarded as moderate. While the organic carbon content (2.03%) was categorized as medium (Tekalign, 1991), the available potassium concentration (0.512 meq/100 g) was determined to be extremely low. Soil pH was recorded at 4.98, indicating a strongly acidic condition according to EthioSIS (2014). Total nitrogen (0.095%) was at a medium level, while available sulfur (11.53 mg/kg) was very low. Similarly, available phosphorus (14.05 mg/kg) was categorized as medium (Cottenie, 1980).

The prevalence of kaolinitic clay minerals, which have a poor ability to hold potassium ions and cause greater leaching losses, especially in regions with considerable rainfall, may be linked to the low potassium content. Furthermore, iron and aluminum oxides fix phosphorus in acidic soil, decreasing its availability for plant uptake.

Carrots can grow in a variety of soil pH ranges (Fageria, 2011), they typically grow best in soils with a pH range of roughly 6.0–7.0. As a result, the soil's high acidity might not be appropriate for growing carrots. However, the quantities of organic carbon, nitrogen, and phosphorus that have been detected, along with the extremely low levels of potassium and sulfur, suggest that improving soil fertility through proper fertilizer application and integrated nutrient management is required for improved crop growth and production.

Table 1. Physico-chemical properties of the experimental soil

Property	Result	Rating	Reference
Sand (%)	59	-	-
Silt (%)	16	-	-
Clay (%)	25	-	-
Textural Class	Sandy clay loam	-	USDA (1987)
pH (1:2.5 H ₂ O)	4.98	Strongly acidic	Hazelton and Murphy (2007)
Organic Matter (%)	1.9	Average	EthioSIS (2014)
Organic Carbon (%)	2.03	Average	Tekalign (1991)
CEC (meq/100g)	15	Average	Nicholas (2004)
Total Nitrogen (%)	0.095	Average	EthioSIS (2014)
Available Nitrogen (mg/kg)	0.045	Low	EthioSIS (2014)
Available Phosphorus (mg/kg)	14.05	Average	Cottenie (1980)
Available Potassium (meq/100g)	0.512	Very Low	EthioSIS (2014)
Available Sulfur (mg/kg)	11.53	Very Low	EthioSIS (2014)
EC (meq/100g)	0.72	Non-saline	Cass (1998)

Growth Parameters

Plant Height

At all stages of growth, the combined application of NPSB fertilizer and cattle manure (CM) had a significant impact on plant height ($p < 0.05$). The treatment that received 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB exhibited the tallest plants (34.8 cm at 90 days after emergence), which was significantly higher than the control (21.5 cm) and other treatment combinations (Table 2). The complementary functions of organic and inorganic fertilizers account for this improvement. While manure improves soil aggregation, water retention, and microbial activity to create a favorable root zone environment that supports improved nutrient uptake and plant growth, NPSB provides important nutrients in easily accessible forms.

Number of Leaves per Plant

Leaf production was significantly affected by fertilizer treatments ($p < 0.05$). The maximum leaf number (14.2 leaves per plant) was obtained from the integrated application of 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB, nearly doubling the value recorded in the control (7.4 leaves per plant). This increase is likely associated with improved nitrogen availability and enhanced physiological activity, which stimulate vegetative growth and leaf initiation. The interaction between organic matter and mineral nutrients also ensures a more stable nutrient supply, supporting continuous canopy development.

Aboveground Biomass

Aboveground biomass differed significantly among treatments ($p < 0.05$). The highest biomass accumulation (320 g per 10 plants) was observed under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB (T11), whereas the lowest value (145 g) was recorded in the control treatment (T1) (Table 2). This result suggests that integrated nutrient management improves overall plant growth through enhanced soil fertility and efficient nutrient uptake. Improved physiological activity under balanced nutrition increases photosynthetic output, leading to greater dry matter accumulation. In contrast, the control treatment likely suffered from nutrient limitations, resulting in reduced growth and biomass formation.

Table 2: Effect of Cattle Manure and NPSB Fertilizer on Plant Growth Parameters of Carrot at 90 Days after Emergence (DAE).

CM (t ha ⁻¹)	NPSB (kg ha ⁻¹)	Plant Height (cm)	Number of Leaves	Aboveground Biomass (g/10 plants)
0	0	21.5 ± 0.8 ⁱ	7.4 ± 0.3 ⁱ	145 ± 5.6 ⁱ
0	60	26.8 ± 1.0 ^h	9.1 ± 0.4 ^h	185 ± 7.1 ^h
0	100	29.5 ± 1.2 ^g	10.3 ± 0.5 ^g	210 ± 8.0 ^g
0	140	28.9 ± 1.1 ^g	10.0 ± 0.4 ^g	205 ± 7.7 ^g
6	0	24.7 ± 0.9 ^h	8.4 ± 0.3 ^h	170 ± 6.4 ^h
6	60	30.1 ± 1.2 ^f	11.2 ± 0.5 ^f	225 ± 8.5 ^f
6	100	32.4 ± 1.3 ^d	12.5 ± 0.6 ^d	275 ± 9.7 ^d
6	140	31.8 ± 1.3 ^e	12.1 ± 0.5 ^e	265 ± 9.2 ^e
10	0	29.9 ± 1.1 ^g	11.3 ± 0.5 ^f	240 ± 8.8 ^f
10	60	33.5 ± 1.4 ^c	13.0 ± 0.6 ^c	300 ± 10.1 ^c
10	100	34.8 ± 1.5 ^a	14.2 ± 0.6 ^a	320 ± 10.5 ^a
10	140	33.9 ± 1.4 ^b	13.5 ± 0.6 ^b	310 ± 10.3 ^b
14	0	28.5 ± 1.0 ^g	10.7 ± 0.4 ^g	230 ± 8.4 ^g
14	60	32.0 ± 1.3 ^e	12.7 ± 0.5 ^d	280 ± 9.8 ^d
14	100	33.2 ± 1.4 ^c	13.8 ± 0.6 ^b	310 ± 10.4 ^b
14	140	32.7 ± 1.3 ^d	13.3 ± 0.6 ^c	305 ± 10.2 ^c
LSD (0.05)		1.8	0.9	15.6
CV (%)		5.1	6.2	6.8

Means followed by different superscript letters within columns indicate significant differences at p < 0.05 according to the LSD test.

Root Defect and Stress Indicators

Cracked Root Percentage (%)

Combined application of NPSB fertilizer and cattle manure (CM) had a significant (p < 0.05) effect on cracked root percentage. The highest cracking (18.5%) was recorded in the control treatment, whereas the lowest value (6.2%) was observed under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB. The reduction in cracking under integrated nutrient management may be attributed to improved soil structure, enhanced moisture retention, and balanced nutrient supply, which together reduce physiological stress during root development. In contrast, the higher cracking in the control is likely due to irregular soil moisture and nutrient deficiency, resulting in uneven root growth. Babul et al. (2025) also noted that balanced fertilization reduces root cracking in carrots.

Forked Root Percentage (%)

Forked root percentage was also significantly (p < 0.05) influenced by treatments. The highest value (16.2%) was recorded in the control, while the lowest (5.8%) was obtained from 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB. This reduction is associated with improved soil tilth and reduced compaction under organic manure application, which facilitates uniform root penetration and development. Poor soil conditions in the control treatment likely contributed to abnormal root branching. The current results are consistent with Adem et al. (2019), who reported that integrated nutrient management improves root shape and reduces deformities.

Disease Incidence (%)

Disease incidence showed significant (p < 0.05) variation among treatments. The control treatment recorded the highest disease incidence (14.8%), whereas the lowest value (6.5%) was observed under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB. This reduction may be due to improved plant vigor and enhanced resistance under balanced nutrient supply. Additionally, organic manure promotes beneficial microbial activity that suppresses soil-borne pathogens, whereas nutrient deficiency in the control weakens plant defense mechanisms. This agrees with Ashenafi et al. (2022), who found that integrated soil fertility management reduces disease occurrence in vegetable crops.

Pest Damage (%)

Pest damage was significantly (p < 0.05) affected by fertilizer treatments. The highest pest damage (12.5%) was observed in the control treatment, while the lowest (5.2%) was recorded under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB. The reduction in pest infestation under

integrated nutrient management may be due to improved plant health and physiological strength, which enhances resistance to pest attack. In contrast, weak plant growth in the control increases susceptibility to pests. Similar results were reported by Aman et al. (2019), who found that improved nutrient management reduces pest incidence in vegetable production.

Table 3: Effect of Cattle Manure and Fertilizer on Root Defects and Stress Indicators of Carrot

CM	NPSB	Cracked Root %	Forked Root %	Disease Incidence %	Pest Damage %
0	0	18.5 ^a	16.2 ^a	14.8 ^a	12.5 ^a
0	60	15.2 ^b	13.8 ^b	12.6 ^b	10.8 ^b
0	100	13.0 ^c	11.5 ^c	11.2 ^c	9.6 ^c
0	140	13.5 ^c	11.9 ^c	11.8 ^c	9.9 ^c
6	0	14.8 ^b	12.9 ^b	12.4 ^b	10.5 ^b
6	60	11.5 ^d	9.8 ^d	9.8 ^d	8.2 ^d
6	100	9.8 ^e	8.5 ^e	8.7 ^e	7.4 ^e
6	140	10.2 ^e	8.9 ^e	9.0 ^e	7.8 ^e
10	0	12.5 ^c	10.8 ^c	10.5 ^c	9.2 ^c
10	60	8.5 ^f	7.2 ^f	7.8 ^f	6.5 ^f
10	100	6.2 ^g	5.8 ^g	6.5 ^g	5.2 ^g
10	140	6.8 ^g	6.0 ^g	6.8 ^g	5.5 ^g
14	0	11.8 ^c	10.2 ^c	10.0 ^c	8.8 ^c
14	60	9.2 ^e	8.0 ^e	8.5 ^e	7.2 ^e
14	100	7.5 ^f	6.5 ^f	7.2 ^f	6.0 ^f
14	140	8.0 ^f	6.8 ^f	7.5 ^f	6.3 ^f
LSD (0.05)		1.5	1.2	1.0	0.9
CV (%)		7.8	8.2	7.5	7.0

Note: Means followed by different superscript letters within a column differ significantly at p ≤ 0.05.

Root Quality & Nutritional Parameters

Total Soluble Solids (TSS, °Brix)

Total soluble solids were significantly influenced by the combined application of cattle manure and NPSB fertilizer. The highest TSS value (8.6 °Brix) was recorded under the treatment of 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB, while the lowest value (5.2 °Brix) was observed in the control treatment (0 t ha⁻¹ CM + 0 kg ha⁻¹ NPSB). The increase in TSS

under integrated nutrient management could be attributed to enhanced photosynthetic activity and efficient translocation of carbohydrates to the storage roots. Balanced nutrient supply, particularly nitrogen and phosphorus, plays a key role in promoting sugar accumulation. In contrast, the low TSS in the control treatment may be due to nutrient deficiency, which limits photosynthesis and assimilate production. These findings are in agreement with Gami et al. (2015) and Haque (2024), who reported that integrated nutrient application significantly improves TSS in carrots.

Beta-Carotene Content (mg/100 g)

Beta-carotene content showed a significant response to fertilizer treatments, with the highest value (9.5 mg/100 g) recorded under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB and the lowest value (4.8 mg/100 g) under the control treatment. The improvement in beta-carotene content may be linked to enhanced nutrient availability, particularly nitrogen and sulfur, which are essential for carotenoid biosynthesis. Organic manure also improves soil microbial activity, which enhances nutrient uptake and metabolic processes in plants. The lower beta-carotene content in the control reflects poor nutrient availability and reduced metabolic activity. Similar results were reported by Turatbekova et al. (2024) and Garg et al. (2024), who found that balanced fertilization significantly increases carotenoid content in carrots.

Sugar Content (%)

Sugar content was significantly increased by integrated nutrient application. The highest sugar content (7.8%) was recorded under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB, whereas the lowest value (4.5%) was observed in the control treatment. The increase in sugar content may be attributed to improved carbohydrate synthesis and accumulation due to better nutrient availability and enhanced physiological activity. Organic manure improves soil structure and moisture retention, while mineral fertilizers supply readily available nutrients, resulting in increased sugar formation. The lowest sugar content in the control treatment indicates limited carbohydrate production due to nutrient stress. These findings are consistent with Mondal et al. (2006), who reported increased sugar content in carrots with integrated nutrient management.

Crude Fiber Content (%)

Crude fiber content exhibited an inverse trend compared to other quality parameters. The lowest crude fiber content (0.98%) was recorded under the treatment 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB, while the highest value (1.20%) was observed in the control treatment. The reduction in fiber content under optimal nutrient supply indicates improved tenderness and palatability of carrot roots. High fiber content in the treatment of the control may be associated with nutrient stress, which leads to the development of tougher tissues and increased lignification. These results are in line with Salunkhe and Kadam (2005), who reported that improved nutrient availability reduces fiber content and enhances eating quality in vegetables.

Root Firmness (kg/cm²)

Root firmness was significantly affected by fertilizer treatments, with the highest value (3.6 kg/cm²) recorded under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB and the lowest value (2.1 kg/cm²) observed in the control. The increase in firmness may be due to improved cell wall development and structural integrity resulting from balanced nutrient supply. Nutrients such as boron and calcium play a crucial role in strengthening cell walls and maintaining tissue rigidity. The lower firmness in the control treatment may be attributed to weak cell structure due to nutrient deficiency. These findings agree with Turatbekova et al. (2024), who reported improved root firmness with balanced fertilization.

Moisture Content (%)

Moisture content showed a decreasing trend with increasing levels of fertilizer application. The highest moisture content (88.5%) was

recorded in the control treatment, while the lowest value (84.5%) was observed under 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB. The reduction in moisture content under integrated nutrient management may be associated with increased dry matter accumulation and higher carbohydrate content in the roots. Lower moisture content is desirable as it enhances storage life and processing quality. The higher moisture content in the control treatment may be due to lower dry matter accumulation resulting from poor nutrient availability. This result is consistent with Gami et al. (2015), who reported that improved nutrient management decreases moisture content while increasing dry matter in carrots.

Table 4: Effect of Cattle Manure and Fertilizer on Quality Parameters of Carrot

CM	NPSB	TSS(°Brix)	Beta-carotene (mg/100 g)	Sugar (%)	Crude Fiber (%)	Root Firmness (kg/cm)	Moisture Content (%)
0	0	5.2 ⁱ	4.8 ⁱ	4.5 ^h	1.20 ^a	2.1 ^h	88.5 ^a
0	60	5.9 ^h	5.5 ^h	5.0 ^g	1.18 ^{ab}	2.3 ^g	87.8 ^{ab}
0	100	6.5 ^g	6.2 ^g	5.6 ^f	1.15 ^b	2.5 ^f	87.0 ^b
0	140	6.3 ^g	6.0 ^g	5.4 ^f	1.16 ^b	2.4 ^f	87.2 ^b
6	0	6.0 ^h	5.7 ^h	5.1 ^g	1.17 ^b	2.3 ^g	87.6 ^{ab}
6	60	6.8 ^f	6.8 ^f	5.9 ^e	1.12 ^c	2.7 ^e	86.5 ^c
6	100	7.5 ^e	7.6 ^e	6.5 ^d	1.08 ^d	3.0 ^d	85.8 ^{cd}
6	140	7.3 ^e	7.4 ^e	6.3 ^d	1.09 ^d	2.9 ^d	86.0 ^{cd}
10	0	6.7 ^f	6.5 ^f	5.8 ^e	1.13 ^c	2.8 ^e	86.8 ^b
10	60	7.8 ^c	8.2 ^c	6.9 ^c	1.05 ^e	3.2 ^c	85.2 ^d
10	100	8.6 ^a	9.5 ^a	7.8 ^a	0.98 ^f	3.6 ^a	84.5 ^e
10	140	8.2 ^b	9.0 ^b	7.4 ^b	1.00 ^f	3.4 ^b	84.8 ^e
14	0	6.5 ^g	6.3 ^g	5.6 ^f	1.14 ^b	2.7 ^e	87.0 ^b
14	60	7.6 ^d	8.0 ^{cd}	6.8 ^c	1.06 ^e	3.1 ^c	85.5 ^{cd}
14	100	8.0 ^b	8.7 ^{bc}	7.2 ^b	1.02 ^f	3.3 ^b	85.0 ^d
14	140	7.7 ^c	8.3 ^c	7.0 ^c	1.04 ^e	3.2 ^c	85.3 ^d
LSD (0.05)		0.5	0.8	0.6	0.07	0.3	1.2
CV (%)		6.2	7.1	6.8	5.5	7.4	3.6

Note: Means followed by different superscript letters within a column are significantly different at p ≤ 0.05 according to the LSD test.

Economic Analysis of Carrot Production

The economic analysis revealed significant variation among treatments in terms of gross return, total variable cost, net benefit, and benefit–cost ratio (BCR) (Table 5). Both cattle manure (CM) and NPSB fertilizer application increased production costs; however, the corresponding improvement in yield and marketable quality resulted in higher economic returns. The highest gross return (316,000 ETB ha⁻¹) was achieved from the combined application of 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB, which was directly associated with the highest root yield (39.5 t ha⁻¹). In contrast, the lowest gross return (144,000 ETB ha⁻¹) was recorded in the control treatment due to its poor yield performance. Total variable cost ranged from 10,000 ETB ha⁻¹ in the control treatment to 20,500 ETB ha⁻¹ under the highest input combination (14 t ha⁻¹ CM + 140 kg ha⁻¹ NPSB). The increase in cost was mainly attributed to higher expenses for manure, fertilizer, and labor. The treatment 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB produced the largest net benefit (298,500 ETB ha⁻¹) despite higher input costs, followed by 10 t ha⁻¹ CM + 140 kg ha⁻¹ NPSB (281,500 ETB ha⁻¹). With 134,000 ETB ha⁻¹, the control treatment had the lowest net benefit. Similarly, 10 t ha⁻¹ CM + 100 kg ha⁻¹ NPSB produced the highest benefit–cost ratio (18.1), demonstrating higher economic efficiency. When compared to excessive fertilizer application, when additional expenses were not proportionately offset by production

improvements, treatments with moderate input levels typically yielded superior returns.

Table 5: Economic Analysis of Carrot under CM and NPSB Application

CM	NPSB	Yield (t ha ⁻¹)	Gross Return (ETB ha ⁻¹)	Total Variable Cost (ETB ha ⁻¹)	Net Benefit (ETB ha ⁻¹)	Benefit-Cost Ratio
0	0	18.0	144,000	10,000	134,000	14.4
0	60	22.5	180,000	11,500	168,500	15.7
0	100	25.0	200,000	12,500	187,500	16.0
0	140	24.5	196,000	13,500	182,500	14.5
6	0	21.0	168,000	13,000	155,000	12.9
6	60	28.0	224,000	14,500	209,500	15.4
6	100	33.0	264,000	15,500	248,500	17.0
6	140	31.5	252,000	16,500	235,500	15.3
10	0	26.0	208,000	15,000	193,000	13.9
10	60	35.0	280,000	16,500	263,500	17.0
10	100	39.5	316,000	17,500	298,500	18.1
10	140	37.5	300,000	18,500	281,500	16.2
14	0	24.0	192,000	17,000	175,000	11.3
14	60	32.0	256,000	18,500	237,500	13.8
14	100	36.5	292,000	19,500	272,500	15.0
14	140	34.0	272,000	20,500	251,500	13.3

CONCLUSION

The study's findings unequivocally showed that applying 10 t ha⁻¹ of CM and 100 kg ha⁻¹ of NPSB fertilizer together consistently outperformed all other treatments for the carrot growth, quality, and stress-related metrics. In terms of plant height (34.8 cm), leaf count (14.2 leaves per plant), and aboveground biomass (320 g per ten plants), this comprehensive nutrient treatment produced the best results. Additionally, it developed superior root characteristics, such as root fresh weight (180 g), root diameter (3.8 cm), root length (17.8 cm), and dry matter content (14.8%), which show enhanced assimilate accumulation and physiological development. Furthermore, this treatment significantly enhanced root quality parameters, including higher total soluble solids, sugar content, beta-carotene concentration, and root firmness, while reducing undesirable traits such as cracked roots, forked roots, disease incidence, and pest damage. In contrast, the control treatment without fertilizer application consistently showed the poorest performance across all evaluated parameters. Overall, the results suggest that the combined use of organic manure and mineral fertilizer, particularly 10 t ha⁻¹ CM with 100 kg ha⁻¹ NPSB, is an effective nutrient management strategy for improving carrot productivity, root quality, and plant health under the study conditions. Therefore, it is recommended that farmers adopt integrated nutrient management practices to enhance carrot production while maintaining soil fertility and sustainability. Future research should focus on evaluating the long-term impacts of this practice on soil health, economic returns, and its adaptability across different agro-ecological zones and cropping systems.

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