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on

RATE OF VERMICOMPOST FERTILIZER ON YIELD AND YIELD COMPONENTS OF CARROT (*Daucus carota* L.), AT GERADO, SOUTH WOLLO, ETHIOPIA

BY

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ABSTRACT

Carrot (Daucus carota L.) is an economically important root crop that can be produced from the lowlands to the highlands of Ethiopia. It has plentiful advantages, such as being a good source of carotenoids, vitamins, and dietary fiber, and is also rich in minerals and antioxidants. However, its yield and yield components are highly affected by agronomic factors, such as poor soil fertility. Yield response is directly related to the application of essential nutrients. The use of chemical fertilizers alone is associated with several human health and environmental problems and is unaffordable to small scale farmers. Therefore, it is crucial to look for other alternative approaches and avoid overdependence on the sole application of chemical fertilizer. Thus, the aim of this research was to evaluate the effect of vermicompost fertilizer on carrot yield and yield components at Gerado, South Wollo, Ethiopia. To do so, mature, viable, and healthy carrot seed, variety Nantes, was bought from a commercial center. Besides, ready-to-use vermicompost was bought from the farmers' association in Haik. The experiment consisted of vermicompost (0, 3, 6, and 9 tons/ha). Arranged in a randomized complete block design with three replications. Data were collected on phenological, growth and yield parameters; and analyzed using R-software. The application of vermicompost significantly ($P<0.05$) affected the phenological, growth, yield and yield related components. The maximum values for mean plant height (50.5cm), leaf number (18.67), root length (18.53 cm), root diameter (4.5cm), total yield (44.67 t/ha), marketable yield (43.09 t/ha) and the minimum unmarketable yield (1.61 t/ha) were recorded from the treatment receiving 9 t ha^{-1} vermicompost. The correlation (r) analysis showed that most of yield and yield contributing factors were positively and highly significantly ($p < 0.01$) correlated to each other. In general, the increasing rate of vermicompost up to 9 t ha^{-1} was found best for carrot production. It is, therefore, using organic fertilizer like vermicompost is better for ecological organic agriculture

1. INTRODUCTION

Carrot (*Daucus carota L.*) belongs to the Apiaceae family. Based on historical documents and experimental results, central Asia was thought to be one origin of cultivated carrot (Iorizzo et al., 2013). Eastern carrots are thought to originate from Afghanistan, while the origin of western carrots is still uncertain (Rong et al., 2014). The carrot is a biennial herbaceous species. The flower of the carrot is a flattened umbrella-shaped umbel. The umbel is a characteristic for distinguishing carrots from related taxa. The colors of the cultivated carrot flowers are usually white (Essing, 2013), and the carrot leaves are compound leaves (Stolarczyk and Janick, 2011). The fleshy taproot of the carrot develops from the hypocotyls, and the shape of the carrot root is always conical. The color of the root is varied and includes orange, yellow, purple, red, and white (Simon et al, 2008).

Among the vegetables whose edible parts are the root, carrot storage root is a good source of carotenoids, vitamins, and dietary fiber and is also rich in minerals and antioxidants (Arscott et al., 2010). Several medicinal qualities are also attributed to this vegetable crop such as cooling effect on the body strengthening effect on the heart and brain, prevention of constipation and possession of diuretic properties. This root vegetable contains valuable phytochemicals. The presence of phytochemicals, in addition to vitamins and pro vitamins has been recently considered of crucial nutritional importance in the prevention of chronic diseases, such as cancer, cardiovascular disease, and diabetes (Nambia et al., 2010; Jamuna et al., 2011). It is also produced by subsistence farmers because being easy to grow and do not need a larger amount of fertilizers (Allemann and Young, 2002).

Carrot is among the top-ten most economically important vegetable crops in the world, in terms of both area of production and market value. With European countries in lead, carrot is produced throughout the world. While carrot is a mostly winter consumed vegetable, it is consumed in every season in many countries (Ahmad et al., 2012). The world production in 2012 was 36.9 million Mg, cropped in an area of 1.19 million hectares, with average yield of 31.0 Mg ha^{-1} (FAO, 2014). Similarly, FAO (2017) reported that world carrot plantation area was 1,147,155 ha and production was 42,831,958 tones.

Although the exact time of introduction of carrots to Ethiopia is not known, the crop has been known since the early 1960s in the research system. Carrot production has been expanding since then and the total production reached 12,345.8 tons on 2,215 hectares of land (CSA, 2011). Carrots are produced in a wide range of agro-ecologies from the lowlands to the highlands of Ethiopia. They are frost tolerant and have become one of a few alternative crops that can be grown in the frost prone highlands around 3,000 m.a.s.l. It grows in well drained alluvial and sandy loam soils but not in heavy clay and water-logged soils (Kifle Zerga and BirhanuTsegaye, 2019).

General Objective

- The main objective of this research was to evaluate the effect of vermicomposting fertilizer on carrot yield and yield components at Gerado, South Wollo, Ethiopia.

Specific Objectives

The specific objectives of this study were;

- ✓ To evaluate the response of carrot yield to different rate of vermicompost in the study area
- ✓ To determine the economically feasible rates of vermicompost

2. MATERAL AND METHODS

2.1. Description of the Study Area

The study was conducted at Gerado Farmers Training Center (FTC), Dessie, Ethiopia in 2022 cropping seasonusing supplementary irrigation. Dessie is located in the northeast of Amhara Regional State, 401 km from the capital city, Addis Ababa, and Gerado is about 5 km from Dessie towards the west. Geographically, Gerado is located between 10^0 10' N and 38^0 28' E with an altitude range of 2,200 to 2,800 meters above sea level (m.a.s.l.). The climatic condition is generally 4% Dega (high land) and 96% Woyna-Dega (temperate). The average annual temperature ranges between 15-20°C. Theaverage annual rainfall is 900 mm-1000 mm. The rainfall at this location is characterized by a bimodal distribution, with the major rainy season being from June to August and the "Belg" from March to April. The topography comprises hills and slightly deep gorges (Gebre-Egziabher Fentahun *et al.*, 2018). The soil of study area was dominantly *Vertisol* (63%) while the remaining 25% and 12% dominated by *Leptosol and Regosol*, respectively (SWZDCA, 2013).

The farming system of the area is characterized by mixed crop-livestock system carried on a subsistence scale. The major cereal crops grown in the area are sorghum, teff, barely, and maize. Vegetable crops such as carrots, cabbage, potatoes, and tomatoes are produced as cash crops (Gebre Egziabher Fentahun *et al*., 2018).

2.2. Description of Experimental Materials

For this study, mature, viable, and healthy carrot (*variety Nantes*) seed was bought from commercial centers. According to Getachew Tabor and Mohammed Yesuf (2012), Nantes has an orange color, cylindrical roots with a blunt end, and strong leaves. Farmers are highly needed for its good adaptation to highlands, its high market demand, and for its good color, thick and long roots, and sweet taste. Nantes grows well at altitudes ranging from 1600–2400 m a.s.l. with an annual precipitation of 760-1010 mm. It can be grown all year under both rain and irrigation conditions (Wassue et al., 2014).Ready-to-use vermicompost was also bought from Haik farmers association.

2.3. Treatments and Experimental Design

Two different factors were considered in this study. Four different levels of vermicompost (0, 3, 6, and 9 tons/ha) were used as experimental treatments. The experiment was arranged in a randomized complete block design (RCBD) with three replications. All of the treatments were randomly assigned in each plot. There were nine rows per plot and 40 plants per row, making a total of 360 plants per plot. In each row and plant, 20 cm and 5 cm of spacing were left, respectively. Thus, the plot size was 2.0 m x 1.8 m (3.6 m2), and there were 1 m and 0.5 m distances between replications and plots, respectively. However, data were collected from the middle six rows to avoid border effect.

2.4. Experimental Procedures and Field Management

2.4.1. Land Preparation:

The land was ploughed three times using oxen. The first ploughing was done on March 28, 2014 E.C; the second ploughing was done on April 12, 2014 E.C and the third ploughing for further softening of the land was also done on April 20, 2014 E.C. All crop residues and other debris were carefully cleared, levelled by hand, and 1.8-by-2-meter beds were constructed.

2.4.2. Pre-planting Physico-chemical Soil Analysis

Soil samples were collected with a shovel from 10 different randomly selected points at a depth of 0-30 cm, using a W-pattern. The collected soils were mixed together, air dried, and crushed to pass them through a 2 to 0.5 mm sieve to determine soil texture, soil PH, organic matter, total N, organic C, available P, and CEC through standard methods and procedures at the Dessie soil testing laboratory center.

Soil pH was determined using a glass electrode attached to a digital pH meter from a filtered suspension of a 1:2.5 soil to water ratio (Peck, 1983). The methods of Walkley and Black (1934) and Kjeldhal (Jackson, 1962) were used to determine organic carbon and total N respectively. Available P was determined by extraction with 0.5 M NaHCO3, according to the methods of Olsen et al. (1965). CEC was measured after saturating the soil with 1 N ammonium acetate and then displaying it with 1 N sodium acetate (Toth and Prince, 1949).

2.4.3. Chemical analysis of experimental vermicompost

In this study, fully decomposed vermicompost was bought at Haik farmers association. According to the farmer's oral description, the vermicompost was produced from organic wastes such as crop residues, weeds, and cattle manure by decomposing with earthworms for three months. The chemical properties of vermicompost were analysed using standard methods and procedures: total N (Kjeldhal methods (Jackson, 1962)), organic C (Walkley and Black, 1934), pH (Peck, 1983), available P (Olsen et al., 1965), and CEC (Toth and Prince, 1949).

2.4.4. Fertilization

According to the treatment, the predetermined rates of vermicompost were applied to well-prepared experimental plots about a week before seed sowing using broadcast methods.

2.4.5. Sowing and Crop Management

Carrot seeds were drilled on experimental plots with 20-cm row spacing. After seed sowing, all the necessary management practices like watering, weeding, and earthing up were done manually whenever required to keep the plants in healthy growth. Thinning was performed after seedling emergence to maintain 5 cm of spacing between plants.

2.5. Data Collection

Ten plants per plot were sampled in the middle rows and marked by bamboo sticks for collection of plant data while the crop of the whole plot was harvested to record plot data. The plants in the outer rows and the extreme end of the middle rows were excluded from the random sampling to avoid the border effect.

3.1.1. Phenological Parameters

Days to 50% Emergence: It was measured by counting the number of days from days of sowing to days of 50% seed emergence.

Days to 90 % Maturity: It was measured by counting the number of days elapsing from the date of sowing to the date when 90% of the plants in each plot attained physiological maturity and were used for further analysis. According to Scheme (1998), carrot plants are physiologically mature when the roots are harvestable and the crown has a diameter ranging from 2-3.8 cm.

3.5.2 Growth Parameters

Plant height (cm): Plant height was recorded by measuring the height of ten randomly selected plants taken from the middle rows using a ruler, starting from the base of the plant to the most pointed part.

Number of Leaves: The number of leaves of ten randomly selected plants was counted at 60 and 90 DAS. All the leaves of the plants were counted separately. Only the smallest young leaves at the growing point were excluded from the counting.

3.5.3. Yield and Yield Related Parameters

Root Length (cm): It was recorded by measuring the root length from the shoulder to the root tip of ten randomly selected carrot roots harvested from the net plot using a ruler, and the mean value was computed and used for further analysis.

Root Diameter (cm): It was recorded by measuring the root diameter about two centimeters below the root collar of ten randomly selected carrot roots harvested from the net plot using a ruler, and the mean value was computed and used for further analysis.

Average Fresh Root weight (g/plant): It was recorded by weighing ten randomly selected carrot roots harvested from the net plot using a sensitive balance, and the mean value was computed and used for further analysis.

Total Yield of Roots per Hectare (t/ha): The yield of roots per hectare was computed from the per-plot yield and recorded in tones per hectare.

Marketable yield of roots per hectare (t/ha):

Carrot roots with small sizes (>50 g) and free of mechanical damage, disease, and insect pest attack were deemed marketable. The weight of such carrots harvested from the net-plot area was weighed using a scale and expressed as tons per hectare.

Unmarketable Yield (ton/ha): Carrot roots that are diseased, insect pest-damaged, cracked, split, or undersized (<50 g) were considered unmarketable. The weight of such carrots harvested from the net-plot area was weighed using a scale and expressed as tons per hectare.

3.6 Data Analysis

The collected data (phenological, growth, and yield parameters) were subjected to analysis of variance (ANOVA) procedures using R- software. All pairs of treatment means were compared using Least Significant Difference (LSD) test at 5% level of significance. Pearson correlation analysis was done between major growth and yield component of carrot.

3. RESULT AND DISCUSSION

3.1. Introduction

This section discussed the physical and chemical status of the soil before planting, the nutrient composition status of the experimental vermicompost, on phenological parameters *(*days to 50% emergency and days to 90% maturity*)*, growth parameters *(*plant height and number of leaves*),* various yields, and related parameters such as root length, root diameter, root fresh weight, root yield, and marketable and unmarketable root yield. The relationship between parameters (correlation and regression) was discussed. In addition to presenting the current results, this research outcome was compared and contrasted with other related works.

3.2. Physico-chemical Characterstics of Soil and Vermicompost

3.2.1. Pre-planting physical and chemical properties of the soil

The pre-planting soil texture analysis result for the study area showed that the clay content of the soil was 43.0%, while the silt and sand contents were 12.0% and 46.0%, respectively (Table 1). As a result, the overall textural class of soil in the study area was sandy clay. The field capacity of soil by volume was 40%. As indicated on Table 2, the soil pH in the study site was 7.03, which is in the category of neutral soil.

The total nitrogen content of the soil was 0.17%, which was in the low range according to Murphy's (1968) classification rate. Available phosphorus in the soil at the experimental site (5.72 ppm) was rated very low according to Zebarth et al (2007) report. Manoj (2013) described that the availability of P in most soils is declining due to the impacts of fixation due to higher pH. The organic carbon (OC) and organic matter (OM) contents were 2.38% and 4.10%, respectively, which were in the moderately low category as suggested by Murphy (1968). Low OC and OM contents imply that the soil has poor water storage and nutrient retention capacity (Zelalem Addis et al., 2021). This low organic matter content in the soil might be associated with factors like intensive tillage with reduced organic matter input and the removal of crop residues from cultivated fields for human and animal needs. The finding of Taiwo and Adekiya (2011) revealed that the low organic matter content of cultivated soil can increase with increased organic matter application. The CEC of the soil in the study area was 24.43 cmol (+)/kg, which was moderate according to Metson's (1961) rating.

In general, the soil fertility of the study area indicated a deficiency of all major plant nutrients, particularly total nitrogen, available phosphorus, and organic carbon. This study revealed poor soil fertility status, which indicates that the experimental soil in the study area has limitations with regards to its use for crop production. Hence, it requires external application of nutrients in organic and inorganic forms to improve the nutrient as well as the structural properties.

Table 1: Selected physico-chemical properties of soil in the study site before planting

Physicochemical properties of the soil

Soil properties	Parameters	Values	Rating	References
Physical properties	Clay	43.0%	High	(Hazelton and Murphy, 2007
	Silt	12.0%	Low	
	Sand	46.0%	High	
	Field capacity (Vol)	40.0%		
Chemical properties	pH	7.03	Neutral	
	TN	0.17%	low	
	Av. P	5.72 ppm	Low	
	OC	2.38%	Low	
	OM	4.10%	Low	
	CEC	24.43 cmol (+)/kg	Low	

Where: *TN = total nitrogen, Av. P = Available phosphorus, organic carbon, OM = organic matter, CEC = Cation exchange capacity*

3.2.2. Chemical property of experimental vermicompost

The analysis of vermicompost used in the current study, presented in Table 3, showed that it was in the slightly acidic classification category (pH = 6.93), as per Bruce and Rayment's (1982) rating. Likewise, Jouqut et al (2013) stated that the pH of vermicompost should in the range of 6.8 -8.41 to be suitable for the survival of earthworm and crop production. On the other hand, the decline in pH during vermicomposting indicated the mineralization of nitrogen and phosphorus compounds and the production of humic and fulvic acids (Bhat et al., 2015). The total organic carbon and nitrogen contents of vermicompost were 10.48% and 0.85% (a very high rate), respectively. The C: N ratio (12.3:1), which is medium as per Allison (1973) interpretation, indicated a higher mineralization and decomposition rate.

The total phosphorus content of vermicompost was 13.75 ppm (moderate rate), which was twofold higher than the respective values in the soil (5.72 ppm). As a result, adding vermicompost to cultivated soil can increase its phosphorus content. Similarly, the amount of total carbon and nitrogen in vermicompost was higher than their respective values in the soil (2.38% and 0.17%, respectively). According to Tadele Geremu et al (2020) report, vermicompost made from all materials could correct the plant nutrient imbalance and enhancing soil fertility. The cation exchange capacity (CEC) of vermicompost was 57.5 cmol (+)/kg, which was higher than the CEC value (24.43 cmol (+)/kg) in the soil (Table 2).

Table 2: Selected chemical properties of experimental vermicompost

Parameters	pH	TN%	OC%	C: N	Av. P (ppm)	CEC
Values	6.93	0.85	10.48	12.3:1	13.75	57.5 cmol (+)/kg

***Where**: pH = power of hydrogen, TN = total nitrogen, OC = organic carbon, Av. P = available phosphorus, CEC = cation exchange capacity*

3.3. Effect of Vermi-compost Fertilizer on Phenological Parameters of Carrot

3.3.1. Days to 50% Emergence

The analysis of variance showed the effect of vermicompost ferrtilizer had a significant ($p < 0.05$) effect on the days of 50% seedling emergence (Table 3). The minim number of days (8 days) for seedling emergence was recorded with 3 t ha^{-1} vermicompost fertilizer applications. However, the maximum numbers of days (20.3 days) required to realize a 50% emergence of carrot seedlings were recorded in the control. Increasing rates of application of vermicompost fertilizer significantly reduced the time required to attain 50% seedling emergence in carrot. In addition, vermicompost may have hormonal impact for seedling emergence (Muhie et al., 2020). Studies of Hopkins et al. (2014) and Alemu et al. (2016), also summarized that application of vermicompost reduce soil bulk density and increase soil porosity which in turn make sustainable conditions for plant growth.

3.3.2. Days to 90% Maturity

Maturity stage in crops is influenced by the availability nutrients in the soil, as some nutrients such as N may delay stage of maturity (Nadeem et al., 2019). Prolonged duration (99 days) for 90% physiological maturity was recorded with 9 t ha^{-1} vermicompost. Increasing rate of sole vermicompost delayed 90% physiological maturity. This might be associated with easily uptake of nutrients that enhanced early maturity of carrot roots and the capacity of vermicompost to hold soil moisture, and it increases the amount and availability of nutrients in soil, which in turn increase carrot growth.

Table 3: Effect of Vermicompost Fertilizer rate on Phenology of Carrot

VC (t ha $^{-1}$)	**Trt**	**D 50% E** (day)	**D 90% M** (day)
0	T1	20.33^{a}	94.67^{de}
	T2	16.67^{b}	94.33^{e}
	T3	14^{d}	94.33^{e}
	T4	8^{e}	91^{f}
3	T5	16.67^{b}	96^{bc}
	T6	17^{b}	95.67^{bcd}
	T7	14^{d}	95.33^{bcde}
	T8	8^{e}	95^{cde}
6	T9	17^{b}	95.67^{bcd}
	T10	17^{b}	95.33^{bcde}
	T11	13.67^{d}	95.67^{bcd}
	T12	8^{e}	94.67^{de}
9	T13	17^{b}	99^{a}
	T14	15.67^{c}	96^{bc}
	T15	14^{d}	95.33^{bcde}
	T16	8^{e}	96.33^{b}
Mean		14.06	95.27
LSD(5%)		0.69	1.22
CV (%)		2.96	0.77

Means followed by the same letter(s) in columns are not significant different at 5% level of significance. VC = vermicompost, Trt= treatment, D 50% E = days to 50% emergency, D 90% M = days to 90% maturity.

3.4. Effect of Vermicompost fertilizer rate on Growth Parameters of Carrot

3.4.1. Leaf number

About 18.67 numbers of leaves per plant were recorded with the sole application of vermicompost (9 t ha^{-1}) on 90 DAS (Table 4, Fig 1). These differences can be explained by the plant phenology of carrots, which increases growth, and the nutrient-releasing status of fertilizers, in which vermicompost releases more nutrients slowly with an increase from time to time. The observed increment in leaf number in vermicompost at later stage might be associated with better availability of nutrients, organic matter, cation exchange capacity, and moisture holding capacity, all of which lead for better root establishment and leaf number. According to Przemieniecki et al. (2021) and Abbey et al. (2018), vermicompost is rich with plant growth compounds such as humic substances, amino acids, enzymes, and NPK nutrients, which have a positive effect largely on leaf production. Likewise, Baba and Simon (2015) reported that regular moisture content increased the leaf number of carrot plants. Moreover, vermicompost has high microbial activity due to the presence of fungi, bacteria, and actinomycetes. They can produce plant growth regulators (PGRs) such as auxins, gibberellins, and cytokinins (Frankenberger and Arshad, 1995), which then affect positively the plant's growth.

On the contrary, the minimum leaf numbers (4.87) per plant was recorded with plant receiving not VC both at 60 and 90 DAS (Fig 1). According to this result, a moderate rate of fertilization supported more leaf production, and this is in accordance with a recent study by Ye et al. (2022).

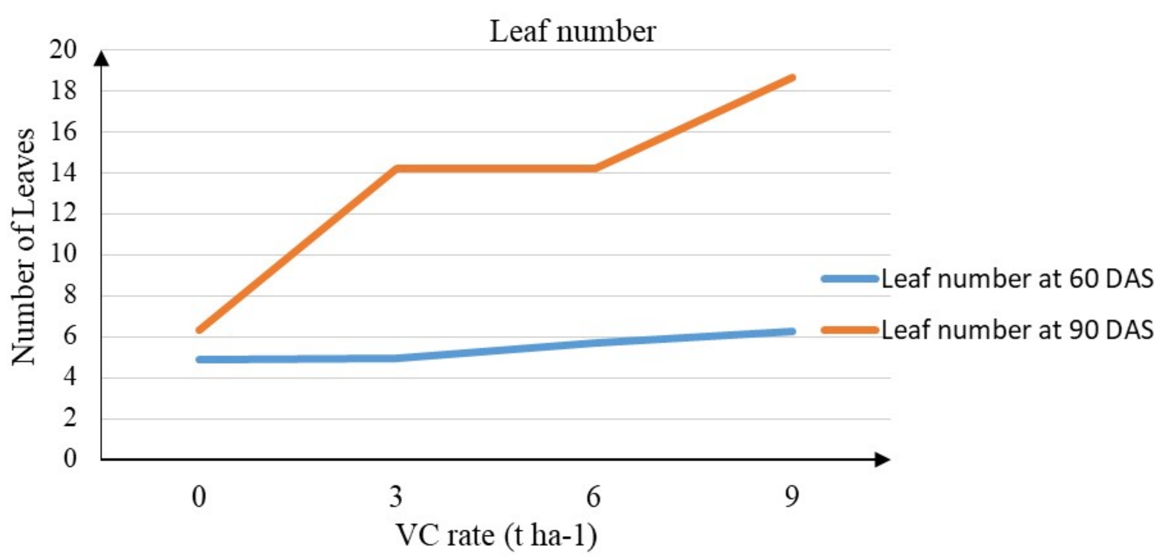

Fig. 1: Effect of vermicompost (VC) on leaf number of carrot

3.4.2. Plant Height

The analysis of variance indicated that various application rates of vermicompost fertilizer significantly ($P< 0.05$) influenced the height of carrot plants both at 60 and 90 DAS (Table 4; Fig 2). The longest plant height (33.9 cm) was recorded with a combined application of 6 t ha^{-1} VC and 100 kg ha^{-1} NPSB at 60 DAS. However, it did not differ significantly with the increased rates (100 and 150 kg ha^{-1}) of the sole NPSB and VC (6 and 9 t ha^{-1}). Numerically, the shortest plant height was found at the control. In addition, the physical appearance of plants in the control treatment looked stunted and yellowish green in leaf color.

At 90 DAS, the maximum plant height (50.5 cm) was recorded from the sole application VC (9 t ha^{-1}) , which is two-fold as compared with that of the control. On this day, the carrot plant was found to be significantly longer with the sole application of VC than with NPSB. The increasing plant height might be due to the improved chemical properties of the soil which might be because of the enhanced physico-chemical properties of the soil as a result of VC decomposition and incorporation (Table 3). This is agreed with Yourtchi et al. (2013), who reported that the increment in plant height was due to the large amount of nitrogen in vermicompost, which had a positive effect on plant height. The applied VC must have supplied important nutrients such as N, P, and K, which are vital for plant growth and optimization of the use of water, which leads to vigorous growth of plants (Laird, 2010; Alemu et al., 2016; Hajare and Akole, 2022). When vermicompost provided maximum P and K and a reasonable concentration of nitrogen and supplied the elements throughout the growth phases of the plant, that might have fulfilled the demand of the crop and encouraged better plant growth (Rekha et al., 2018).

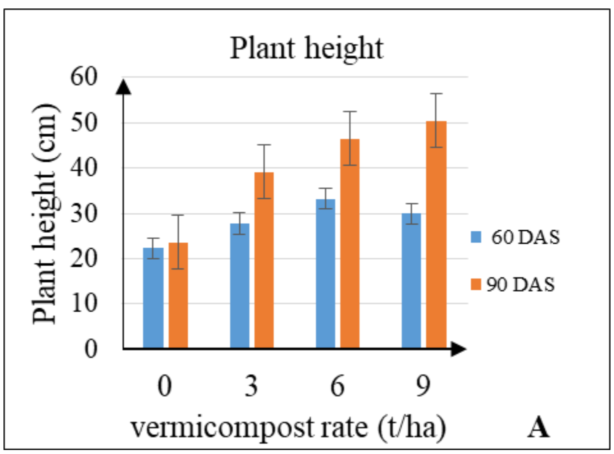

Fig. 2: Effect of vermicompost on plant height

Table 4: Effect of vermicompost fertilizer rate on growth of Carrot

VC (t ha^{-1})	**Trt**	**LN**		**PH**	
		LN 60 DAS	**LN 90 DAS**	**PH 60 DAS** (cm)	**PH 90 DAS**

					(cm)
0	T1	4.87^{e}	6.33^{l}	22.3^{d}	23.67^{f}
	T2	$5.3d^{e}$	7.67^{ijk}	25.6^{cd}	26.67^{ef}
	T3	5.53^{de}	$7.27j^{kl}$	29.93^{abc}	31.02^{de}
	T4	12.5^{a}	12.67^{c}	29.97^{abc}	31.67^{cd}
3	T5	4.97^{e}	14.17^{b}	27.8^{c}	39.17^{b}
	T6	$5.3d^{e}$	6.8^{kl}	26.67^{cd}	36.4^{bc}
	T7	6.17^{d}	8.5^{hi}	30.07^{abc}	34.3^{bcd}
	T8	9.87^{b}	11.33^{de}	29.13^{bc}	32.23^{cd}
6	T9	5.67^{de}	14.17^{b}	33.27^{ab}	46.57^{a}
	T10	5.43^{de}	7.83^{ij}	28.47^{c}	36.4^{bc}
	T11	7.87^{c}	9.77^{fg}	33.9^{a}	39.13^{b}
	T12	11^{b}	11.67^{d}	33.77^{ab}	35.13^{bcd}
9	T13	6.27^{d}	18.67^{a}	30^{abc}	50.5^{a}
	T14	5.77^{de}	9.33^{gh}	29.2^{bc}	31.2^{de}
	T15	8.67^{c}	10.5^{ef}	26.67^{cd}	34.9^{bcd}
	T16	7.67^{c}	10.67^{ef}	28.27^{c}	31.1^{de}
Mean		7.05	10.46	29.06	35.00
LSD(5%)		1.17	0.98	4.66	4.93
CV (%)		9.97	5.63	9.61	8.44

Means followed by the same letter(s) in columns are not significant different at 5% level of significance. VC = vermicompost, Trt= treatment, LN= leaf number, LN 60 DAS = leaf number 60 days after sowing, LN 90 DAS = leaf number 90 days after sowing, PH= plant height, PH 60 DAS= plant height 60 days after sowing, PH 90 DAS= plant height 90 days after sowing.

3.5. Effect of Vermicompost fertilizer rate on Yield and Yield Component of Carrot

3.5.1. Root length

Root length per plant is one of the most important parameters for measuring the yield performance of carrots. In the present study, the analysis of variance indicated that the root length per plant was significantly ($P<0.05$) influenced by the application of VC (Table 5). The maximum root length (18.53 cm) was recorded with the application of VC (9 t ha^{-1}) followed by 18.1 cm from treatment receving 6 t ha^{-1}. However, the shortest mean root length per plant (15.57 cm) was recorded with the sole application of VC (3 t ha^{-1}). Likewise, the control treatment showed the shortest mean root length per plant (12.5 cm). In this regard, the addition of vermicompost increased carrot root length by 32% over the control treatment. Murphy (2014) confirmed that the addition of organic matter (vermicompost) to the growth medium improves soil functioning, which in turn positively affects plant growth.

The root length was observed to increase with the increasing dose of VC application (Table 5). This is due to the fact that vermicompost stimulates the increase of oxygen availability, maintains normal soil temperature, increases soil porosity and infiltration of water, and improves nutrient content (Arora *et al*. 2011), all of which may contribute to the longer root length. In addition to this, the application of organics helps the soil microorganisms produce polysaccharides and thus leads to better soil structure useful for root growth (Kumar and Venkatasubbaiah, 2017). The mean root length per plant with the application of VC was significantly higher.

3.5.2. Root diameter

Root diameter per plant is also another parameter for measuring carrot yield performance. In this study, root diameter per plant was significantly influenced ($p < 0.05$) by various application rates of VC, (Table 5). Different treatments viewed different root diameters per plant at the time of harvesting. The mean root diameter per plant ranged from 3.11 to 4.25 cm. It was seen that the highest mean diameter of root per plant (4.25 cm) was obtained with the sole application of VC (9 t ha^{-1}) and the lowest (3.11 cm) was recorded with control.

The increased application rates of VC showed an increase in the root diameter of carrots. In this point of view, the carrot plant that got sufficient nutrients, which might have enhanced photosynthesis and produced the highest number of carrot leaves per plant (Table 5), resulted in higher photosynthetic production and translocation to the storage organ (root), which ultimately increased the root diameter of the carrot plant. This was in close conformity with Yadev et al. (2022). Benjamin and Wren (1978) reported that the growth of the storage organ is dependent on the current photosynthesis. Also, the better availability of macro- and micronutrients in vermicompost might be attributed to enhanced cell division and rapid cell multiplication.

3.5.3. Root fresh and dry weight

In this study, root fresh and dry weight of carrots, an important parameter for comparing carrot yield, significantly ($p < 0.05$) varied with various application rates of VC (Table 5). The highest mean root fresh weight (110.33 gram) and dry weight (19 gram) per plant were obtained with the sole application of VC (9 t ha-1), while the smallest root fresh weight (41.67 gram) and root dry weight (4.2 gram) were measured at plants receiving neither VC nor NPSB fertilizer. This was because vermicompost is a good source of nutrients, which are vital to improving soil fertility, and this may be greatly helped by the synergetic positive effect on root growth. For instance, a report by FAO (2006) indicated that phosphorus is known to stimulate the growth and development of the root more than the shoot. Besides, Rabindra and Srivastava (2006) suggested that the increase in weight might be due to the accelerated mobility of photosynthates from source to sink as influenced by growth hormone, released or synthesized due to organic sources of fertilizers. As evidenced by the present study, the increasing rate of sole application of VC showed a significant increment in fresh and dry root weight and was higher as compared to the sole application of NPSB. This could be due to the prolonged availability of nutrients in the soil and the uptake of nutrients, both of which have a positive effect on carrot fresh and dry weight yield.

3.5.4. Leaf Fresh and Dry Weight

Leaf freshness and dry weight are important indicators of carrot yield quality. It was evident that the statistical analysis of the data revealed that all application rates of VC, significantly ($p < 0.05$) affected both the fresh and dry weight of carrot plants (Table 5). The maximum leaf fresh weight per plant (39.33 gram) and leaf dry weight (9.97 gram) were recorded with sole VC application (9 t ha^{-1}) whereas the minimum leaf fresh weight (12.2 gram) and dry weight (3.3 gram) were obtained at plants in the control. Both leaf fresh and dry weight were increased significantly in response to increasing rate of sole application of vermicompost. Kibnesh Adimasu and Anteneh Aragaw (2022) indicated that the increased availability of nitrogen and other macro- and micronutrients in vermicompost possibly increased leaf expansion and leaf number, which lead to increased concentration of chlorophyll in the leaves, hastened photosynthesis, and high rates and dry matter accumulation in the aboveground biomass. Moreover, the maximum fresh and dry weight might be associated with plant growth attributions such as leaf number and plant growth, which were superior with the sole application of VC as compared to other treatments.

Table 5: Effect of vermicompost fertilizer rate on yield and yield component of Carrot

VC (t ha-1)	**Trt**	**RL** (cm)	**RD** (cm)	**RFW** (g)	**RDW** (g)	**LFW** (g)	**LDW** (g)
0	T1	12.15^{e}	3.11^{d}	41.67^{j}	4.2^{f}	12.2^{h}	3.3^{f}
	T2	14^{cd}	3.69^{bc}	45.67^{i}	4.4^{f}	12.97^{defgh}	3.43^{ef}
	T3	13.45^{d}	3.77^{abc}	46.33^{i}	4.5^{f}	12.8^{efgh}	3.53^{ef}
	T4	13.9^{cd}	3.73^{bc}	71.33^{g}	7.83^{de}	13.4^{cdefg}	3.97^{de}
3	T5	15.57^{b}	3.78^{abc}	91^{c}	8.87^{bc}	14.33^{c}	4.6^{c}
	T6	14.23^{cd}	3.61^{bcd}	56.67^{h}	7.2^{e}	12.63^{fgh}	4.33^{cd}
	T7	14.15^{cd}	3.53^{bcd}	84^{d}	7.81^{de}	13.77^{cde}	4.37^{cd}
	T8	14.17^{cd}	3.75^{abc}	77.67^{e}	7.2^{e}	13.63^{cde}	4.53^{cd}
6	T9	18.1^{a}	3.73^{abc}	96.33^{b}	9.1^{b}	30^{b}	9.14^{b}
	T10	14.83^{bc}	3.43^{cd}	84.33^{d}	7.97^{cde}	12.57^{gh}	4.0^{cde}
	T11	14.33^{cd}	3.7^{bc}	84.33^{d}	7.53^{e}	13.77^{cde}	4.53^{cd}
	T12	14.88^{bc}	4.05^{ab}	84.67^{d}	7.37^{e}	13.6^{cdef}	4.27^{cd}
9	T13	18.53^{a}	4.25^{a}	110.33^{a}	19^{a}	39.33^{a}	9.97^{a}
	T14	15.57^{b}	3.7^{bc}	71^{g}	7.23^{e}	13.83^{cd}	4.57^{cd}
	T15	14.68^{bc}	3.63^{bc}	75^{f}	7.57^{e}	13.63^{cde}	4.37^{cd}
	T16	14.23^{cd}	3.63^{bcd}	76.67^{ef}	8.7^{bcd}	13.43^{cdefg}	4.23^{cd}
Mean		14.80	3.69	74.81	7.90	15.99	4.82
LSD (5%)		1.17	0.52	1.87	0.93	0.97	0.61
CV (%)		1.50	8.47	1.50	7.05	3.64	7.54

Means followed by the same letter(s) in columns are not significant different at 5% level of significance. VC = vermicompost, Trt= treatment, RL= root length, RD= root diameter, RFW= root fresh weight, RDW= root dry weight, LFW= leaf fresh weight, LDW= leaf dry weight.

3.5.5. Total Carrot Root Yield per Hectare

The analysis of variance revealed that different application rates of VC, significantly ($P < 0.05$) influenced carrot root yield (Table 6). The mean carrot yields per hectare increased with the increased rate of sole VC application. The highest mean yield per hectare (44.67 t/ha) was recorded with the sole application of VC (9 t ha^{-1}) whereas the lowest mean yield per hectare (20.71 t/ha) was obtained with control.

The increment of carrot root yield with sole application of vermicompost might be associated with, firstly, the increased yield parameters at this treatment combination, including root length, root diameter, and root fresh and dry weight; secondly, the slow release of nutrients from vermicompost and their better utilization by carrots during the growing period might have resulted in higher root yields of carrot; thirdly, better availability of nutrients and the balanced C/N ratio might have increased synthesis of carbohydrates, which encouraged greater yield and better carbon assimilation and better accumulation of carbohydrates in the plants. Similar findings by Singh (2000) were recorded in the tuber yield of potatoes with the application of organic fertilizer. Various studies ensured that the increasing rate of vermicompost led to an increasing trend in the yield of red amaranth (Alam et al., 2007) and wheat (Patil and Bhilare, 2000; Gowda et al., 2008). This is due to vermicompost's slow release of nutrients and slow mineralization, which helps plants access nutrients throughout the growth period. Inconsistent results were reported by Singh et al. (2020), who stated that maximum yield (38.9 t/ha^{-1}) and superior quality carrots were produced with the combined application of organic and inorganic fertilizer.

3.5.6. Marketable carrot root yield per hectare

The marketable carrot root yield per hectare was found statistically significant ($p < 0.05$) because of the variation in application rates of VC (Table 6). The plants that received 9 t ha^{-1} VC produced the maximum marketable root yield per hectare (43.09 t/ha), while the lowest marketable yield per hectare (18.65 t/ha) was obtained with carrot plants in non-fertilized plots (control). Like the total carrot root yield, the marketable carrot root yield increased along with the increasing rate of sole VC application. Comparatively, marketable root yield with sole VC application was 46% higher than the marketable root yield with sole NPSB and 56.7% higher than the control (Fig.3. There was no significant variation in marketable yield per hectare among the sole applications of NPSB.

The reason for the higher marketable yield per hectare as compared to control and sub-optimal treatments might be due to uniform seedling growth, a well-developed root system, and efficient consequent growth with lesser competition for nutrients, which all might lead to desired marketable size and quality. On the other hand, a lower marketable yield per hectare under control could be allied with a lower total yield, widely spread seedlings, uniform growth, and a higher struggle for resources.

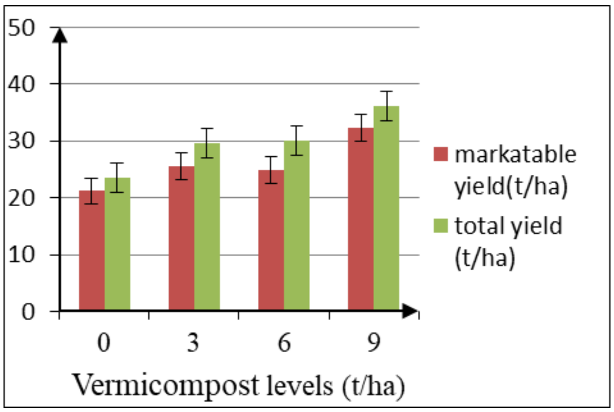

Fig. 3: Effect of vermicompost levels on the total yield and marketable yield of carrot

3.5.7. Unmarketable root yield per hectare

According to the analysis of variance, the application of various rates of VC significantly ($P < 0.05$) affected the size and quality of carrot roots. Some of the carrots were small in size (below 50 grams), while others were cracked and forked. The highest unmarketable yield (6.96 t/ha) was observed on the combination treatment of VC (3 t ha^{-1}) and NPSB (150 kg ha^{-1}). Balvoll (1995) reported that Nitrogen application above 110 kg $ha^{-}1$ decreases the yield and quality due to root cracking. And his finding confirmed that increasing the amount of fertilizer did not necessarily increase yield but increased unmarketable yield due to root cracking.

On the other hand, the sole application of VC (3 t ha^{-1}) gave the lowest unmarketable yield (1.61 t/ha) followed by 1.76 t/ha with 9 tha^{-1} VC. In this regard, the combination of chemical fertilizer (NPSB), especially at its higher rate, increased the unmarketable yield of carrots. Bender et al. (2020) found a higher marketable and a lower discarded yield of carrot in organic fertilizer when they studied organic carrot production recently.

Table 6: Effect of vermicompost and blended NPSB fertilizer rate on total yield, marketable and unmarketable yield of carrot

VC ($t\ ha^{-1}$)	**Trt**	**TYPH** (t/ha)	**MYPH** (t/ha)	**UMYPH** (t/ha)
0	T1	20.71^{g}	18.65^{e}	2.24^{gh}
	T2	23.96^{f}	21.39^{d}	2.65^{fgh}
	T3	24.97^{f}	22.42^{d}	2.54^{fgh}
	T4	24.57^{f}	22.17^{d}	3.17^{efgh}
3	T5	32.43^{c}	30.82^{b}	1.61^{h}
	T6	29.39d	25.73^{c}	3.65^{defgh}
	T7	28.68^{de}	22.5^{d}	6.17^{ab}
	T8	27.5^{e}	23.27^{d}	4.56^{bcdef}
6	T9	35.33^{b}	31.93^{b}	3.52^{defgh}
	T10	27.93^{de}	22.77^{d}	5.53^{abcd}
	T11	28.49^{de}	22.74^{d}	5.79^{abc}
	T12	28.53^{de}	21.92^{d}	6.96^{a}
9	T13	44.67^{a}	43.09^{a}	1.76^{h}
	T14	32.49^{c}	27.45^{c}	5.03^{abcde}
	T15	31.61^{c}	27.78^{c}	3.83^{cdefg}
	T16	36^{b}	30.82^{b}	5.18^{abcde}
Mean		29.83	25.97	4.01
LSD (0.05)		1.75	2.10	2.06
CV (%)		3.51	4.85	30.80

Means followed by the same letter(s) in columns are not significant different at 5% level of significance. VC = vermicompost, Trt= treatment, TYPH= total yield per hectare, MYPH= marketable yield per hectare, UMYPH= unmarketable yield per hectare.

4.6. Relationships of Yield and Yield Contributing Factors of Carrot as Influenced by Vermicompost

The correlation analysis was performed to determine the extent and direction of relationships among yield and yield-contributing factors (Table 7). In the present study, the correlation coefficient values (r) indicated that the total carrot root yield per hectare was positively and highly significantly ($P < 0.01$) correlated with most of the yield contributing factors, except days to 50% emergence ($r = -0.02^{ns}$), leaf number at 60 days after sowing ($r = -09^{ns}$), plant height at 60 days after sowing (r = 0.25ns), and unmarketable yield per hectare ($r = -0.03^{ns}$). Total root yield was also positively and significantly ($P < 0.05$) correlated with root diameter (r = 0.36). The positive correlation of total root yield with other phenological, growth, yield, and yield-related components of carrots might be due to the direct provenance of growth and yield-related parameters for total root yield.

Up on the result of correlation analysis, marketable carrot yield was positively and highly significantly ($P < 0.01$) related with days to 90% maturity ($r = 0.69^{***}$), leaf number at 90 days after sowing ($r = 0.78^{***}$), plant height at 90 days after sowing ($r = 0.69^{***}$), root length ($r = 0.76^{***}$), root fresh weight ($r = 0.67^{***}$), root dry weight ($r = 0.86^{***}$), leaf fresh weight ($r = 0.82^{***}$), leaf dry weight (0.81^{***}), and it had a positive and significant ($P < 0.05$) correlation with root diameter ($r = 0.36^{*}$) and a positive and significant (P None of the yield-causative factors showed a negative, significant relationship with marketable yield.

Among all examined yield-related factors, leaf number at 60 days after sowing had a negative and highly significant ($p < 0.01$) relation with days to 50% emergence ($r = -0.84^{**}$) and days to 90% maturity ($r = -0.42^{**}$). Additionally, plant height at 60 days after sowing also had a negative significant relationship with days to 50% emergence ($r = -0.34^{*}$). Likewise, unmarketable yield was negatively correlated with almost all yield parameters. The negative correlation indicated that one of the factors increases while the other decreases, and vice versa.

Table 7: Simple correlation coefficient (r) among stud yield and yield contributing factors ied traits as influenced by vermicompost and NPSB rates in carrot

Traits	EP	DM	LN60 DAS	LN90 DAS	PH60 DAS	PH90 DAS	RL	RFW	RDW	LFW	LDW	RD	MYPH	UMYPH	TYPH
EP	1														
DM	0.33^{*}	1													
LN60 DAS	-0.83^{***}	-0.42^{**}	1												
LN90-DAS	-0.18^{ns}	0.33^{*}	0.28^{ns}	1											
PH60-DAS	-0.34^{*}	-0.01^{ns}	0.30^{*}	0.36^{*}	1										
PH90-DAS	0.14^{ns}	0.49^{***}	-0.05^{ns}	0.71^{***}	0.58^{***}	1									
RL	0.17^{ns}	0.50^{***}	-0.09^{ns}	0.75^{***}	0.38^{**}	0.81^{***}	1								
RFW	-0.15^{ns}	0.47^{***}	0.18^{ns}	0.81^{***}	0.49^{***}	0.80^{***}	0.74^{***}	1							
RDW	0.03^{ns}	0.62^{***}	0.04^{ns}	0.82^{***}	0.25^{ns}	0.77^{***}	0.73^{***}	0.79^{***}	1						
LFW	0.25^{ns}	0.56^{***}	-0.14^{ns}	0.77^{***}	0.24^{ns}	0.76^{***}	0.81^{***}	0.64^{***}	0.84^{***}	1					
LDW	0.21^{ns}	0.57^{***}	-0.11^{ns}	0.78^{***}	0.33^{*}	0.81^{***}	0.84^{***}	0.71^{***}	0.80^{***}	0.97***	1				
RD	-0.20^{ns}	0.18^{ns}	0.21^{ns}	0.46^{***}	0.22^{ns}	0.41^{**}	0.41^{**}	0.36^{*}	0.37^{**}	0.36*	0.34*	1			
MYPH	0.14^{ns}	0.69^{***}	-0.16^{ns}	0.78^{***}	0.13^{ns}	0.69^{***}	0.76^{***}	0.67^{***}	0.86^{***}	0.82***	0.81***	0.36*	1		
UMYPH	-0.42^{***}	-0.05^{ns}	0.31^{*}	-0.22^{ns}	0.33^{*}	-0.07^{ns}	-0.12^{ns}	0.19^{ns}	-0.12^{ns}	-0.29*	-0.22^{ns}	-0.01^{ns}	-0.33*	1	
TYPH	0.02^{ns}	0.74^{***}	-0.09^{ns}	0.74^{***}	0.25^{ns}	0.71^{***}	0.76^{***}	0.76^{***}	0.87^{***}	0.76***	0.79***	0.36*	0.95***	-0.03^{ns}	1

Where EP= emergence percentage, DM= days to maturity, LN60DAS= Number of leaves at 60 days after sowing, LN90DAS= Number of leaves at 90 days after sowing, PH60DAS= plant height at 60 days after sowing, PH90DAS= plant height at 90 days after sowing, RL= root length, RD= root diameter, LFW= leaf fresh weight, LDW= leaf dry weight, RFW = root fresh weight, RDW= root dry weight, UMYPH= unmarketable yield per hectare, MYPH= marketable yield per hectare, TYPH= total yield per hectare, Ns= non- significant, *= significant at ($p<0.05$), **= highly significant (p<0.

4. CONCLUSION

An experiment was conducted to measure the effect of vermicompost fertilizer rates on carrot yield and yield-related components at Gerado, South Wollo, Ethiopia. The results of the present study showed that most of the examined phenological, growth, yield, and yield-related parameters of the carrot plant were significantly influenced by vermicompost. At 90 days after sowing, the highest mean number of leaves per plant (18.67) and the tallest plant (50.5 cm) were found on plants that were treated with 9 t ha^{-1} vermicompost. At harvest, the greatest root length (18.52 cm), root diameter (4.25 cm), fresh root weight per plant (110.33 g), dry root weight (19 g), total yield (44.67 t/ha), and marketable yield (43.09 t/ha) were observed with the application of vermicompost (9 t ha^{-1}). The lowest unmarketable yield (1.61 t/ha) was recorded on plants that received 3 t/ha of vermicompost. Considering the correlation analysis, the yield and other yield contributory factors like root length, root diameter, root fresh and dry weight, total yield, and marketable yield had a positive and highly significant relationship, i.e., one increase will increase the other component.

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