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Investigations on the Effects of Different Types of Organic Manures and Mulching Materials on the Growth, Yield and Quality of Carrot (*Daucus carota* L.)

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Research Article

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ABSTARCT

Carrot is a root vegetable crop belonging to the Umbelliferea family. The management of agronomic practices is an important factor that strongly affects the growth, yield and quality of carrots. A field experiment was conducted to evaluate the effects of different types of organic manure and mulching materials on the growth, yield and quality of carrots. The study consisted of four organic manures (control, 20 t PM ha^{-1}, 20 t FYM ha^{-1} and 20 t mixed manure (10 t PM+10 t FYM) ha^{-1}) and three types of mulching (no mulching, sawdust mulching and grass mulching) laid in the Randomized Complete Block Design (RCBD), with four replications in a factorial arrangement. Analysis was performed *via* the SAS software package. The root diameter, fresh weight, dry weight, yield and total yield were significantly ($P \leq 0.05$) affected by the interaction effect of organic manure and mulching materials. Among the different combinations, 20 t of mixed manure (10 t PM+10 t FYM) with grass mulch ha^{-1} surpassed all the other combinations in terms of maximum root length (22.45 cm), root diameter (6.60 cm), fresh weight (179.25 g), dry weight (26.16 g), marketable root yield (27.90 t ha^{-1}) and total root yield (33.92 t ha^{-1}) during the experimental year. Similarly, PM with grass mulching also produced better results pertaining to carrot growth and yield.

Keywords: Cracking; Mulch quality; Sawdust; Yield; Umbelliferea

Abbreviations: FYM: Farmyard Manure; PM: Poultry Manure; RCBD: Randomized Complete Block Design; FAO: Food and Agriculture Organization; GFB: Gross Field Benefit; TVC: Total Variable Costs; NB: Net Benefit; SAS: Statistical Analysis Software; LSD: Least Significant Difference; CEC: Cation Exchange Capacity; MRR: Marginal Rate of Return; ANOVA: Analysis of Variance; TSSs: Total Soluble Solids; ETB: Ethiopian Birr.

INTRODUCTION

Carrot (*Daucus carota* L.) is one of the most widely consumed, economically important, nutritious and delicious root vegetables and belongs to the Umbelliferea family [1]. Domestic carrots originate from wild plants growing in Afghanistan [2]. Carrots with purple roots were domesticated in Afghanistan and spread to the Eastern Mediterranean area under Arab influence in the 10th to 12th centuries and to Western Europe in the 14th century [3]. Carrots were first introduced to China by the 13th century, and their cultivation spread from the Middle East to Italy, Spain and throughout Europe in the fourteenth century [4]. The exact timing of the introduction of carrots to Ethiopia is unknown, and the crop has been known since the early 1960's in the research system [5].

Worldwide, production has approached 44,762,859 tons of carrot and turnips on 1,137,738 hectares on a yearly basis, with an average yield of 37 t ha^{-1} [6]. The development of cultivars adapted for cultivation in both the summer and winter seasons on all continents has allowed for the year-round availability of carrot products with relatively stable prices to consumers [7]. The top three carrot-producing countries in terms of production are China, Uzbekistan and the United States of America, with total productions of 21,482,971, 2,769,613 and 2,259,000 tons, respectively [8]. The three main carrot-producing countries in Africa are Algeria, Morocco and Kenya, with total production levels of 419,534, 412,219 and 329,025 tons, respectively [4]. In Ethiopia, the total area under carrot production was approximately 4,135 ha, 16590.56 tons of which were produced in 2021, for an average yield of 6.5 t ha^{-1} [9]. This finding showed that the production of carrots in Ethiopia is significantly under the global average (37 t ha^{-1}) [9,10].

Ethiopia has diverse agro-climatic conditions that provide favorable environments for carrot cultivation [11]. However, traditional agricultural practices in the country rely heavily on synthetic fertilizers, pesticides and herbicides, leading to soil degradation, water pollution and negative impacts on human health [12]. Consequently, there is a pressing need to transition toward more sustainable and eco-friendly farming methods [13]. In recent years, several studies have explored the potential of organic farming as an alternative approach to improve agricultural sustainability [9]. Organic fertilizers, such as compost, manure and green manures, are considered essential components of organic agriculture because they increase soil fertility, increase nutrient availability, promote beneficial soil microorganisms and increase yield [10]. Demonstrated the positive effects of organic fertilizers on crop growth and yield in different regions of Ethiopia [5].

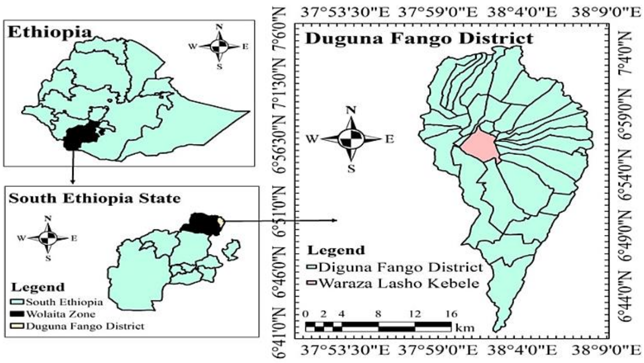
However, specific research on organic carrot production in Diguna Fango district is limited and there is a knowledge gap regarding the comparative performance of different organic manures on carrot crops in this region [4]. Understanding the effectiveness of various organic manure types with mulching on carrot growth under the specific agro-climatic conditions of Diguna Fango district is essential for farmers to adopt sustainable agricultural practices and improve their livelihoods [6]. The primary research problem addressed in this study was the lack of comprehensive data on the performance of carrot cultivation using organic manure with mulching in Diguna Fango district. Consequently, farmers may be hesitant to shift from using inorganic fertilizer to using organic fertilizer because of uncertainty about its efficacy and economic viability. This study focused on data on carrot yield under organic manure with mulching; however, further studies that include information on the soil before and after the application of mulching, nutrient status before use, and weather conditions during the experiment are important and a lack of such information is considered a limitation of the study. Several studies have been conducted to determine the effects of organic manures on the growth and yield of carrots, but studies on the effects of organic mulching practices with organic nutrient supplementation on the growth and yield of carrots are rare. Therefore, the present study was undertaken to evaluate the effects of organic manure on the mulched and unmulched conditions of carrots. Therefore, the present study is an attempt to investigate the yield and quality response of carrots to different organic manures and mulching materials in Diguna Fango district, Southern Ethiopia [8].

MATERIALS AND METHODS

Description of the study site

The experiment was conducted at Waraza Lasho Kebele of Diguna Fango district, Wolaita, Ethiopia, during the 2022/2023 main cropping season from February, 2022 to May, 2023. The experimental site is located 431 km south of Addis Ababa at 6059'0" N latitude and 37059'0" E longitude with an elevation of 1800 m above sea level. The area receives annual rainfall of 1500 mm, and the average minimum and maximum temperatures are 16°C and 25°C, respectively. The soil is sandy clay loam in texture and slightly acidic, with a pH of 6.1 (Figure 1).

Figure 1. Study area map.



Experimental materials

The Nantes orange-colored carrot variety imported from the Netherlands and certified by the Ethiopian Institute of Agricultural Research (EIRA) was used as the planting material. Poultry manure, farmyard manure and mixed poultry and farmyard manures were used as mineral sources. Grass and sawdust were used as mulching materials for the study.

Experimental design and treatment combinations

The treatments consisted of four levels of organic manure (0, 20 t PM, 20 t FYM, and 20 t mixed (10 t PM+10 t FYM) ha^{-1}) and three mulching materials (no mulching, sawdust mulching and grass mulching), for a total of 12 treatment combinations. The treatments were arranged in a 4 × 3 factorial combination in a RCBD with four replications (Table 1).

Table 1. Treatment combinations.

Treatments		Treatment combinations
Organic manures	Mulching	
OM_0	M_0	Control
OM_0	M_1	Control × Sawdust mulching
OM_0	M_2	Control × Grass mulching
OM_1	M_0	20 t PM
OM_1	M_1	20 t PM with sawdust mulching
OM_1	M_2	20 t PM with grass mulching
OM_2	M_0	20 t FYM
OM_2	M_1	20 t FYM with sawdust mulching
OM_2	M_2	20 t FYM with grass mulching
OM_3	M_0	20 t (10 t FYM + 10 t PM)
OM_3	M_1	20 t (10 t FYM + 10 t PM) with saw dust mulching
OM_3	M_2	20 t (10 t FYM + 10 t PM) with grass mulching

Note: OM_0=Control; OM_1=20 t PM ha^{-1}; OM_2=20 t FYM 20t ha^{-1}; OM_3=20 t Mixed manure (10 t FYM+10 t PM) ha^{-1}; M_0=No mulching; M_1=Sawdust mulching; M_2=Grass mulching.

Soil sampling and analysis

Before sowing, soil samples were taken from the entire experimental field to a depth of 0-30 cm *via* the zig-zag method *via* a soil augur. The samples were air-dried, ground, passed through a 2 mm sieve and thoroughly mixed to obtain one composite sample. The following parameters were determined in the Soil Laboratory of the Areka Agricultural Research Center. The soil samples were then analyzed for soil texture, organic carbon, total nitrogen, available phosphorus, available potassium, available calcium, available magnesium, available sodium, available sulphur, available boron, soil pH and CEC. The pH of the soil was determined according to [1], *via* a 1:2.5 (weight/volume) soil sample-to-water ratio and a glass electrode attached to a digital pH meter. The organic carbon content was determined *via* the volumetric method as described in the FAO of the United Nations Guide for Laboratory Establishment for Plant Neutrophil Analysis [1]. Available phosphorus was determined according to [12], *via* the Olsen method *via* a spectrophotometer. The total nitrogen content was determined *via* the Kjeldahl method as described previously [14].

Organic manure sampling and analysis

Before incorporation into the soil, organic manure samples were taken. The samples were air-dried, ground, passed through a 2 mm sieve and thoroughly mixed to obtain one composite sample. The following parameters were determined in the Soil Laboratory of the Areka Agricultural Research Center. The pH, organic carbon, available nitrogen, phosphorus and potassium contents of the manure samples were analyzed *via* a digital pH meter, the Walkley and Black rapid titration method, Olsen's method and the flame photometer method, respectively.

Experimental procedures

Organic manures and mulching materials were prepared near the study area from December to February. By using the sealed Pit method, FYM was prepared in the back yard of a model farmer who has a cattle farm in the study area through the anaerobic decomposition of farm wastes (dung, urine and litter) in underground pits by sealing the surface of the pit with dung slurry for three months and poultry manure was purchased from egg and meat poultry entrepreneurs.

The plants in the experimental field were plowed with oxen to a fine tilth four times and the blocks were level. According to the design, a field layout was established and each treatment was assigned randomly to the experimental units within a block. A total of 48 experimental plots were laid out as indicated above, with 0.2 m × 0.1 m spacing between rows and plants. The spaces between the plot and the block were 0.5 m and 0.8 m, respectively. The total experimental area was 29.5 m in length and 8.8 m in width (259.6 m^2). The seeds were sown at a depth of 1.5 cm within a plot with a length of 2 m, width of 1.6 m and plot area of 3.2 m^2 in rows according to the treatment. In the experimental plot with five rows, the seeds were sown on 19 February, 2022, to prepare holes. The organic manures were applied one month before the sowing date to allow for the requirement of substantial time for mineralization of manures and mulching applied after sowing. Two thinning's were performed to maintain the optimum plant population. The first thinning was performed 30 days after sowing and the second thinning was performed 10 days after the first thinning. Earthling of the plants was performed twice, at 30 and 60 DAS, to protect them from direct sunlight, which could cause undesirable green coloration. Cultural practices were applied uniformly to all the plots throughout the growing period. Continuous weeding by hand pulling was performed to ensure clean fields. Harvesting was performed on 26 May, 2023 when the leaves began to log down.

Data collection and measurement

Yield parameters: The parameters are following as

Root length (cm): The length of the roots was measured *via* a meter ruler for ten randomly selected plants from the net plot at harvest from the base of the root to the top of the root and the mean values were computed.

Root diameter (cm): The size of the roots was measured *via* a side caliper for ten randomly selected plants from the net plot area and divided by the number of sampled plants to obtain the mean values, which were subsequently computed.

Fresh weight of the roots (g): The roots of ten sample plants were uprooted and cut from the base of the petiole and any loose soil was removed. The surface moisture was removed and the plants were weighed immediately to a sensitive balance; the values are expressed in grams. The mean values were used for further analysis.

Dry weight of the roots (g): Ten randomly selected plant roots at harvest were removed and chopped into small pieces with the help of a stainless steel knife. The samples were placed on drying materials, kept in a laboratory room for three days, placed in paper bags and dried in an oven at 70°C for 48 h. After drying, each sample was weighed *via* a sensitive digital balance and the average weight was computed and recorded as the dry weight of the roots.

Marketable root yield (t ha^{-1}): Roots that were free from mechanical damage, disease and insect pest damage; uniform in color; and medium to large in size were considered marketable. The yield was determined as the weight of the healthy and saleable yield of ten sample plants from central rows, avoiding border effects and by converting this yield to tons per hectare, the data were used for further analysis.

Unmarketable root yield (t ha^{-1}): Roots that were cracked, hairy, misshaped, decayed, discolored, diseased or physiologically disordered were considered unmarketable. The weights of the roots obtained from the net plot area of each plot were measured in kilograms *via* a scaled balance and are expressed in tons per hectare.

Total yield (t ha^{-1}): Summations of the marketable and unmarketable root yields from the net plot area were recorded. The yield of every plot was weighed and divided by the number of plants to determine the yield per plant and the yield t ha^{-1} was estimated.

Dry matter content (%): Dry matter content was measured by weighing randomly selected roots from the net plot and is expressed as a percentage.

$$\text{DMC (\%)} = \frac{\text{Dry weight of roots}}{\text{Fresh weight of roots}} \times 100$$

Quality parameters

Forked root (%): Roots that were misshaped at the tip, slightly shortened and multi-rooted with several divergent tap roots were considered forked roots. The number of forked roots per plot harvested from the net plot area was recorded for each treatment and the percentage was calculated according to the formula given below.

$$\text{PFR (\%)} = \frac{\text{Number of forked roots}}{\text{Number of total roots}} \times 100$$

Cracked root (%): Roots that were cracked vertically along the length of the tap root, bent, twisted or splinted were considered cracked roots. The number of such roots per plot was recorded for each treatment and the percentage was calculated according to the formula below.

$$\text{PCR (\%)} = \frac{\text{Number of cracked roots}}{\text{Number of total roots}} \times 100$$

Total Soluble Solids (TSS): The total soluble solids of all the roots of five randomly selected plants from the net plot were chopped, and the TSS were tested in the Wolaita Sodo University Horticulture Department Laboratory by placing three drops of transparent juice on a prism refract meter. Before being used for subsequent readings, the refractometer prism was dried with tissue paper and cleaned with distilled water between samples. The refractometer was calibrated at 0.0°C using distilled water, readings were observed on a scale and averages were expressed in °Brix.

Partial budget analysis

The partial budget analysis was considered *via* the methods described with the mean marketable yield of each treatment, the gross benefit and the field price of inputs of organic manures, mulching materials and seeds of carrot [15].

Gross Average Yield (t ha^{-1}) (AvY): The average yield of each treatment.

Adjusted Yield (AjY): Is the average yield adjusted downward by 10% to reflect the difference between the experimental yield and yield of farmers?

Gross Field Benefit (GFB): Obtained by multiplying the field price that farmers receive for the crop when they sell it by the adjusted yield.

Total Variable Costs (TVC) (ETB ha^{-1}): Summation of the total cost of organic manure, carrot seeds, labor cost, weeding cost and application costs of organic fertilizers for the experiment.

Net Benefit (NB): The NB was calculated as the amount of money left when the TVC were deducted from the GFB. The MRR % was calculated as the change in NB divided by the change in TVC of the successive net benefit and total variable cost levels [15].

Statistical analysis

The data were subjected to ANOVA *via* the SAS version 9.3. The $LSD_{0.05}$ test was used for mean separation when the analyses of variance indicated the presence of a significant difference.

RESULTS AND DISCUSSION

Physicochemical characteristics of the experimental soil

The physicochemical properties of the experimental soil were assessed to understand its suitability for agricultural practices and overall soil health. The following table summarizes the key properties, their measured values and corresponding ratings (Table 2).

Table 2. Physicochemical characteristics of the experimental soil before planting.

Soil properties	Values	Rating
pH	6.1	Slightly acidic
Organic carbon (%)	2.7	Low
Available phosphorus (ppm)	11.4	Medium
Total nitrogen (%)	0.15	Moderate
Available sulfur (ppm)	12.05	Medium
Total boron (%)	0.47	Low
CEC (cmol) (+) (kg)	23.5	Medium
Calcium (meq/100 g)	12.1	Medium
Magnesium (meq/100 g)	2.2	Medium
Sodium (meq/100 g)	0.36	Low
Potassium (meq/100 g)	0.83	Low
Particle size distribution		
Sand (%)	61	High
Silt (%)	65	High
Clay (%)	32	Medium
Textural class	Sandy clay loam	

Physicochemical properties of organic manures

The physicochemical properties of organic manures are essential for assessing their potential benefits when incorporated into the soil. Table 3 summarizes the key properties of three types of organic manures: PM, FYM and a combination of both (PM+FYM). Understanding these properties aids in determining their nutrient contributions and overall effectiveness for soil improvement (Table 3).

Table 3. Physicochemical properties of organic manures before incorporation into the soil.

OM properties	PM	FYM	PM+FYM
pH	6.86	9.24	8.76
OC (%)	8.66	3.47	7.43
TN (%)	0.89	0.22	0.54
P (ppm)	17.68	13.42	16.2
K (meq/100 g)	1.64	4.86	4.25

Yield and yield-related components

Investigations on the effects of different types of organic manures and mulching materials on root length (cm): The longest root length (22.45 cm) was recorded in the 20 t mixed manure treatment, whereas the shortest root length (13.16 cm) was recorded in the control treatment. Root length differed significantly due to the different mulch applications. The maximum root length (21.15 cm) was recorded in the M_2 (grass) mulch treatment, which was significantly different from that in the other treatments. The minimum root length (13.16 cm) was found in the no mulch treatment (Table 4).

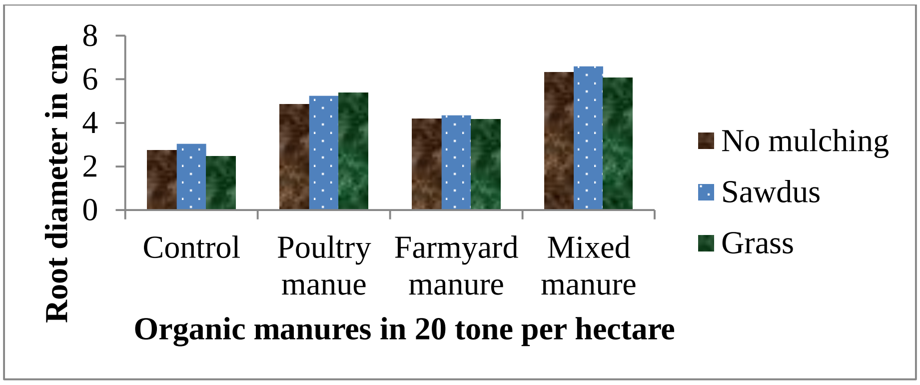
Table 4. Main investigations on the effects of different types of organic manure and mulching materials on root length (cm).

Organic manures	Root length (cm)
OM_0	13.16[d]
OM_1	21.35[b]
OM_2	19.13[c]
OM_3	22.45[a]
$LSD_{0.05}$	1.22
Mulching	**Root length (cm)**
M_0	13.16[b]
M_1	19.13[b]
M_2	21.15[a]
CV (%)	6.29
$LSD_{0.05}$	1.6

Note: [a]Indicating a significant enhancement in root growth due to the treatment with organic manure; [b]Demonstrating a significant improvement over OM_0; [c]OM_2 also exhibited increased root length compared to the control but was not as effective as OM_1; [d]The lowest among the treatments. The means followed by the same letters in the columns are not significantly different at the 5% level: OM_0=no organic manure; OM_1=20 t PM; OM_2=20 t FYM; OM_3=20 t mixed (10 t PM+10 t FYM) manure; M_0=no mulch; M_1=sawdust mulch; M_2=grass mulch; CV (%)=Coefficient of Variation; $LSD_{0.05}$=Least Significant Difference at the 5% level.

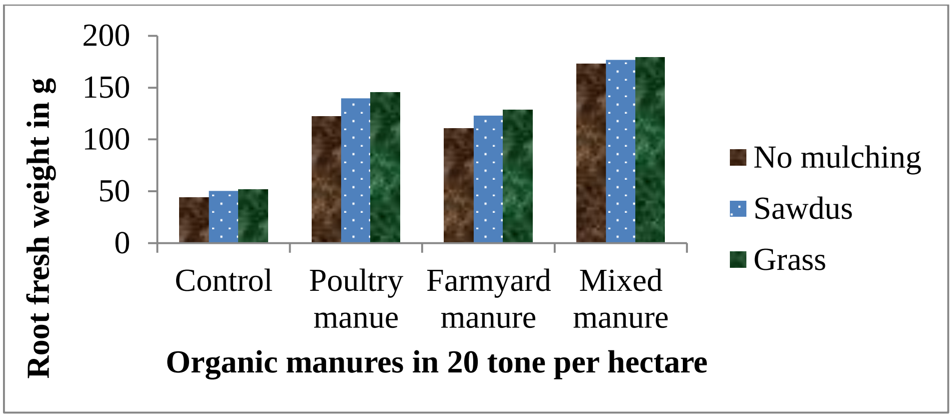
The maximum diameter of the roots (6.60 cm) was recorded from the 20 t of mixed manure with sawdust mulch applied ha^{-1}, which was significantly different than that of the other organic manure treatments. On the other hand, the minimum root diameter (2.47 cm) was observed in the treatment in which no organic manure was applied with grass mulch (Figure 2).

Figure 2. Investigations on the effects of different types of organic manure and mulching materials on the root diameter (cm).



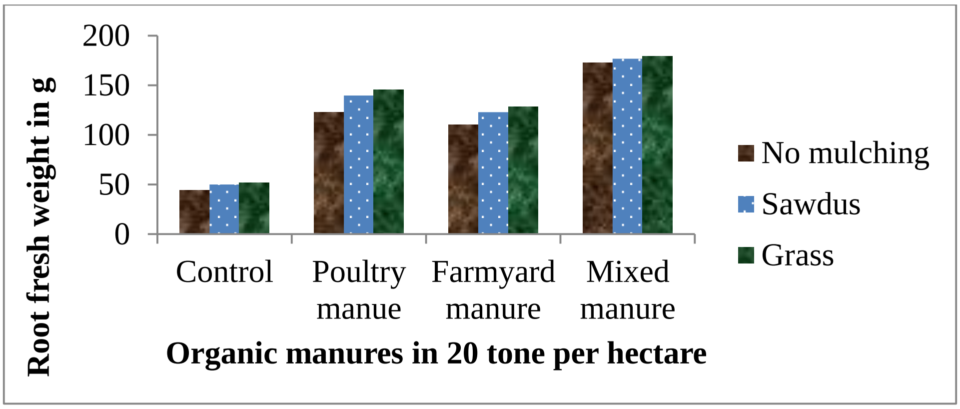
The maximum fresh weight per plant (179.25 g) was observed in the treatment in which 20 t of mixed manure was combined with grass mulch ha^{-1}. The minimum root weight per plant (44.32 g) was recorded for the control plot (Figure 3).

Figure 3. Investigations on the effects of different types of organic manures and mulching materials on root fresh weight (g).



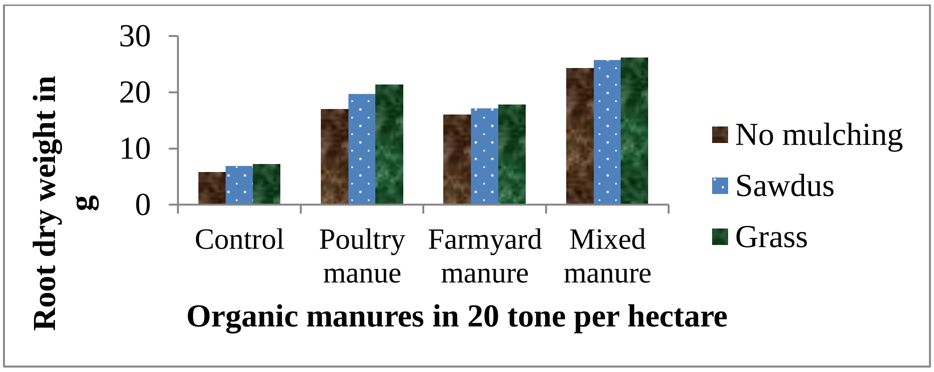
The maximum root dry weight (26.16 g) was observed in the 20 t of mixed manure with grass mulch/ha treatment. The minimum dry weight per plant (5.82 g) was recorded for the control treatment (Figure 4).

Figure 4. Investigations on the effects of different types of organic manures and mulching materials on root dry weight (g).



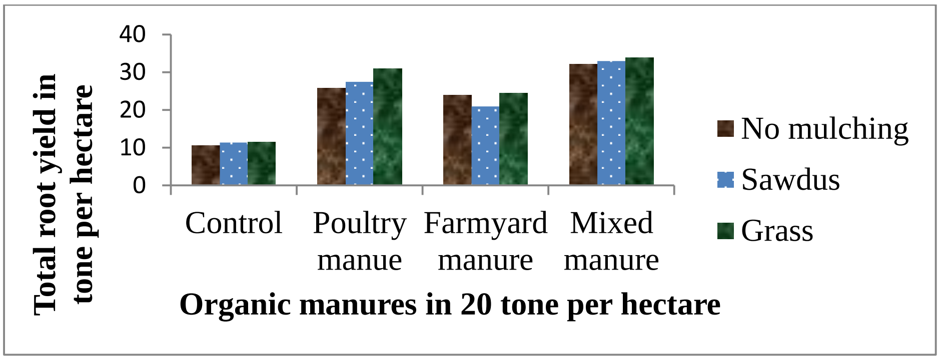
The maximum marketable root yield (27.90 t ha^{-1}) was obtained from the treatment in which 20 t of mixed manure was combined with grass mulch ha^{-1}, which was significantly different from that of the other treatments; in contrast, the minimum marketable yield (8.21 t ha^{-1}) was recorded from the control treatment (Figure 5).

Figure 5. Investigations on the effects of different types of organic manures and mulching materials on marketable yields (t ha^{-1}).



The maximum total root yield (33.92 t ha^{-1}) was obtained from the treatment in which 20 t of mixed manure was combined with grass mulch ha^{-1}, which was significantly different from that of the other treatments, whereas the minimum yield (10.56 t ha^{-1}) was recorded from the control treatment.

Figure 6. Investigations on the effects of different types of organic manure and mulching materials on total root yield (t ha^{-1}).



Investigations on the effects of different types of organic manures and mulching materials on unmarketable yield (t ha^{-1}): The maximum unmarketable root yield (5.83 t ha^{-1}) was recorded from the 20 t mixed manure treatment, whereas the minimum unmarketable root yield (2.60 t ha^{-1}) was recorded from the control.

Investigations on the effects of different types of organic manures and mulching materials on the root dry matter content (%): The maximum amount of root dry matter (14.59%) was recorded in the 20 t of mixed manure/ha treatment, whereas the minimum amount of root dry matter (13.65%) was obtained in the control treatment (Table 5).

Table 5. Main Investigations on the effects of organic manure and mulching on the unmarketable yield (t ha^{-1}) and root dry matter content (%) of carrot plants.

Organic manure	UMY (t ha^{-1})	RDM (%)
OM_0	2.60[d]	13.65[c]
OM_1	4.92[b]	14.20[b]
OM_2	3.52[c]	14.10[b]
OM_3	5.83[a]	14.59[a]
CV (%)	6.29	3.02
$LSD_{0.05}$	0.83	0.44

Note: [a]Indicating a significant enhancement in root growth due to the treatment with organic manure; [b]Demonstrating a significant improvement over OM_0; [c]OM_2 also exhibited increased root length compared to the control but was not as effective as OM_1; [d]The lowest among the treatments. The means followed by the same letters in the column are not significantly different at the 5% level; OM_0=No organic manure; OM_1=20 t PM; OM_2=20 t FYM; OM_3=20 t Mixed (10 t PM+10 t FYM) manure; CV (%)=Coefficient of Variation; $LSD_{0.05}$=Least Significant Difference at the 5% level.

Quality components

To evaluate carrot quality, the following parameters were measured: The percentage of forked roots, percentage of cracked roots and total soluble solids.

Investigations on the effects of different types of organic manure and mulching materials on the percentage of forked roots (%): The percentage of forked roots was significantly influenced by the application of different concentrations of organic manure. The maximum percentage of forked roots (4.45%) was recorded in the control treatment, which was significantly different than that in the other organic manure treatments. On the other hand, the lowest percentage of forked roots (1.35%) was observed in the 20 t mixed manure/ha treatment.

Investigations on the effects of different types of organic manures and mulching materials on the percentage of cracked roots (%): The percentage of cracked roots was affected by organic manure. For amendments, the effect of the 20 t poultry manure treatment (3.73%) was greatest in both periods, followed by that of the 20 t mixed manure treatment, 20 t FYM treatment and control treatment, which were also significantly greater than those of all the other treatments.

Investigations on the effects of different types of organic manures and mulching materials on total soluble solids (°Brix): The highest total soluble solid concentration (10.56 °Brix) was obtained for the carrots planted in the plots that received the 20 t FYM ha^{-1} treatment, whereas the lowest TSS concentration (6.56 °Brix) was obtained for the carrots in the control treatment (Table 6).

Table 6. Main investigations on the effects of organic manure and mulching on carrot component quality.

Organic manures	PFR (%)	PCR (%)	TSS (°Brix)
OM_0	4.45^d	1.35^c	6.56^d
OM_1	2.34^b	3.73^a	7.23^c
OM_2	2.12^c	1.66^{bc}	10.56^a
OM_3	1.35^a	2.95^b	8.75^b
CV (%)	6.29	5.67	8.97
$LSD_{0.05}$	1.22	2.67	0.71
Mulching	**PFR (%)**		
M_0	4.34^a		
M_1	2.12^b		
M_2	1.35^c		

Note: [a]Indicating a significant enhancement in root growth due to the treatment with organic manure; [b]Demonstrating a significant improvement over OM_0; [c]OM_2 also exhibited increased root length compared to the control but was not as effective as OM_1; [d]The lowest among the treatments. The means followed by the same letters in the same column are not significantly different at the 5% level: OM_0=No organic manure; OM_1=20 t PM; OM_2=20 t FYM; OM_3=20 t Mixed (10 t PM+10 t FYM) manure; M_0=No mulch; M_1=Sawdust dust mulch; M_2=Grass mulch; CV (%)=Coefficient of Variation; $LSD_{0.05}$=Least Significant Difference at the 5% level.

Partial budget analysis

The results were analyzed *via* the technique described to assess the costs and benefits of the treatments. The greatest net benefit of 399,980 Birr ha^{-1}, with an MRR of 656%, was obtained from the treatment in which 20 t of mixed manure was combined with grass mulch/ha. On the other hand, the lowest net benefit was obtained from the control treatment. The minimum acceptable MRR % should be between 50% and 100% [1]. Therefore, the most attractive organic manure type for producers or farmers with relatively high net returns was 20 t FYM ha^{-1} with grass mulch, for which the MRR was 3803% (Table 7) [10].

Table 7. Partial budget analysis of the different types of organic manure and mulching materials on carrots.

Organic manure (t ha^{-1})	Mulching	MY (t ha^{-1})	AMY (t ha^{-1})	GI (ETB)	TVC (ETB)	NB (ETB)	MRR (%)
0	No mulch	8.21	7.39	133020	14500	118520	0
	Saw dust	8.73	7.86	141480	16000	125480	464%
	Grass	8.93	8.03	144540	17500	127040	104%
20 t PM	No mulch	21.09	18.98	341640	75000	266640	D
	Saw dust	22.42	20.17	363060	76500	286560	1328%
	Grass	25.89	23.3	419400	78000	341400	3656%
20 t FYM	No mulch	20.56	18.5	333000	35000	298000	D
	Saw dust	20.97	18.87	339966	36500	303466	3644%
	Grass	24.6	22.14	398520	38000	360520	3803%
20 t Mixed	No mulch	27.1	24.39	439020	49500	389520	D
	Saw dust	27.2	24.48	440640	50500	390140	51.30%
	Grass	27.9	25.11	451980	52000	399980	656%

Note: MY=Marketable Yield; AMY=Adjusted Marketable Yield; GI=Gross Income; TVC=Total Variable Cost; NB=Net Benefit; MRR (%)=Marginal Rate of Return; D=Dominated; Cost of PM per quintal=50 Birr; FYM per quintal =20 Birr; Cost of carrot seed kg^{-1}=1500 Birr; Sale price of carrot per kg=18 Birr; Labor cost per man-day=150 Birr.

DISCUSSION

Investigations on the effects of different types of organic manures and mulching materials on the height (cm) of carrot plants

The plants treated with organic manure had taller plant heights than did the control plants. The increase in vegetative growth might be due to the role of nitrogen in promoting vegetative growth, enhancing cell division and elongation, and enhancing chlorophyll synthesis. Phosphorus is easily mobilized in plants and translocated to the meristematic zone, increasing leaf formation and development in carrots and potassium activates many enzymes involved in respiration and photosynthesis. FYM and PM improved the physical, chemical and biological properties of the soil, which promoted better nutrient absorption and utilization by plants, resulting in improved plant growth. The application of organic manure likely improved the uptake of nutrients by plants [16]. In line with the results of the present study [17], organic manure application significantly increased plant height. This value decreased as the type of organic manure differed, and ultimately, the lowest value of this growth parameter was recorded in the carrot control treatment [18]. The increase in plant height due to mulching might be attributed to the favorable soil moisture and temperature conditions needed for proper plant growth.

Investigations on the effects of different types of organic manures and mulching materials on the number of carrot leaves per carrot plant

The number of carrot leaves significantly increased. This might be because mixed manure enhances soil fertility by increasing soil porosity, aeration, moisture holding capacity and available plant nutrients; by acting as complex fertilizer granules; and by accelerating nitrogen mineralization, which in turn improves plant canopy growth.

The increased number of leaves with different mulch types might be attributed to the supply of moisture, which possibly accelerated cell division and elongation, leading to the production of more leaves, leaf development and an increased number of leaves. Mahmood et al., reported that grass mulch treatment was the best among various mulch treatments and recorded a maximum (16.82 cm) number of leaves per carrot plant [17].

Investigations on the effects of different types of organic manures and mulching materials on the leaf length (cm) of carrots

The leaf length significantly increased. This might be because FYM+PM enhanced the nutrient content of the soil, providing a balanced supply of essential elements required for carrot plants to thrive. These manures contain a wide range of macronutrients, such as Nitrogen (N), Phosphorus (P) and Potassium (K), as well as micronutrients such as calcium, magnesium and iron. The gradual release of nutrients from organic manure ensures a sustained and steady supply, preventing nutrient deficiencies and promoting optimum plant growth. These findings are in agreement with the results of [19], who reported that carrot leaf length varied with different types of manure application. The use of mulching in crops not only increases growth but also plays a vital role in soil moisture conservation by creating a physical barrier between the soil and the environment. Moreover, these methods are helpful for weed control, water and soil conservation and for increasing the production and quality of crops. This result is in accordance with the findings of [20].

Investigations on the effects of different types of organic manure and mulching materials on root length (cm)

The highest root length in OM_3 might be due to the positive effects of FYM and PM on the physical characteristics of the soil. These findings are consistent with those of [21], who reported that the maximum root length (21.0 cm) from half PM+half FYM varied with the type of manure applied (FYM, PM or leaf manure). These findings agree with those of [22], who reported that organic manure (PM and FYM) improves the soil structure and maintains uniform soil moisture and nutrient levels, which allows carrots to extend their root length to deeper soil layers. A favorable soil-water-plant relationship is created by placing mulch over the soil surface. The microclimate surrounding plants and soil is significantly affected by mulch, i.e., the thermodynamic environment, moisture, erosion, physical soil structure, incidence of pests and diseases and crop growth and yield. Dawuda et al., reported that different types of organic mulch generated higher soil temperatures and soil moisture under mulch than did the control [23]. The results obtained in this study clearly indicated that carrots responded well to organic manures and organic mulching materials.

Investigations on the effects of different types of organic manure and mulching materials on root diameter (cm)

The difference in root size might be due to increased microbial activity in the root zone because of the adequate moisture availability and optimum temperature combined with the stabilized soil pH, which decomposed organic manure and fixed unavailable forms of mineral nutrients into available forms in the soil, thereby substantiating crop requirements, improving the organic carbon level and stabilizing soil reactions. These findings are also in accordance with those of [24], who reported that different combinations of organic manures significantly affect the diameter and size of carrot roots. The minimum size of the carrot roots was observed in the control treatment compared with all the other treatments. Organic manure and mulching have been shown to supply the required plant nutrients, improve the soil structure and water holding capacity, increase microbial activity, reduce evaporation, improve soil moisture and simultaneously promote plant growth and productivity [25]. In general, the combination of PM and FYM with sawdust mulch resulted in significantly greater growth and yield characteristics of crops during the whole growing season. The increase in root diameter due to organic manure with mulching might be attributed to favorable soil fertility, favorable soil moisture and favorable soil temperature conditions for proper plant growth [19]. This result is in accordance with the findings of [8]. The application of 20 t of mixed (PM with FYM) manure improved vegetative growth and increased root diameter and size in carrot plants, as reported by [24], which was in agreement with our findings.

Investigations on the effects of different types of organic manure and mulching materials on the fresh weight (g) of roots

The increased fresh weight of plants cultivated with different manures combined with mulch might be attributed to the supply of mineral nutrients by organic manures and moisture supplied by organic mulch, which possibly accelerated cell division and elongation activities, thereby increasing their weight and development, leading to increased fresh weight. The difference in root weight due to the application of different manures implies that manures differ in terms of nutrient content and in their ability to increase root weight. A greater nutrient content in manure resulted in greater root weight. Among the different manures, mixed manure was the most effective, followed by poultry and farmyard manure. Reported that the application of 20 t ha^{-1} organic manure (PM, FYM and chicken manure) increased carrot yields (10%-20%) [26]. These results are consistent with the findings of [16], who reported that animal waste generated with mulching materials contains considerable amounts of plant nutrients.

Investigations on the effects of different types of organic manure and mulching materials on root dry weight (g)

This result can be attributed to the slow release of nutrients from organic manures and their better utilization by carrots throughout the growing period, which might have resulted in a greater dry weight of the carrot roots. The increase in dry weight per plant in response to the application of PM+FYM may be attributed to the greater nitrogen, phosphorus and potassium availability in these plants than in those receiving other bulky organic manures. In line with the present study, reported that the use of different organic manures (poultry, farmyard manure and cow dung) with mulch (grass, sugarcane straw and leaf mulch) on carrots resulted in significantly different root dry weights [27]. These results are supported by the findings of [28], who reported that the dry weight of roots was influenced by organics and mulching compared with those of the control group; however, in contrast with the findings of [6], who reported that under high nitrogen application, the plant grew well but had a low yield because vegetative growth was favored over root growth.

Investigations on the effects of different types of organic manures and mulching materials on marketable yield (t ha^{-1})

This difference in marketable yield due to organic manure with mulching material application might be due to the steady and readily available nutrients to the crops being present in greater quantities than during the slow release of organic manure. In the case of manures, substantial time is required for the plant to release available nutrients. The single application of manures through FYM and/or PM or their combination had a lower yield than the combination of manures with mulching. The improvement in yield attributed to FYM+PM with grass mulch might be due to improved soil moisture holding capacity, soil moisture, and soil temperature; adequate availability of major nutrients and micronutrients due to favorable soil conditions; and an increase in the rate of photosynthesis, which further increases vegetative growth and yield by providing additional sites for the translocation of photosynthesis. These results are in accordance with the findings [11,18,20].

Similar findings that higher yields of carrot roots were obtained when 15 t FYM ha-1 and 15 t PM ha^{-1} were used [23]. This could be because nitrogen is the major constituent of chlorophyll, proteins and amino acids, the synthesis of which is accelerated by the increased supply of nitrogen in the soil [27]. An analogous yield increase due to the amendments of poultry and FYM manure application was also reported in previous studies [29], which reported a significant yield increase in carrot plants following the application of manures in addition to grass mulching.

Investigations on the effects of different types of organic manure and mulching materials on total root yield (t ha^{-1})

The yield of mixed poultry and farmyard manure combined with grass mulching surpassed that of all the other treatments by increasing the root yield, followed by poultry manure alone. This difference might be due to the greater quantity of nutrients being steadily available than they were from other organic sources. The addition of organic manure by mulching improved the soil structure, increased its WHC and facilitated aeration in the soil. Sugarcane also helps in the gradual release of nutrients into the soil, which makes it an ideal input for good carrot crop growth. The ability of (FYM+PM) to significantly influence growth and yield may be because it supplies nitrogen and phosphorous, as reported by and because of its ability to improve the physicochemical properties of soils, resulting in improved soil conditions and better nutrient availability [2,20].

The increased total yield of carrots cultivated with different organic manures and mulches might be attributed to the increase in soil fertility, soil structure, temperature and moisture, which possibly accelerated cell division and elongation activities, producing more leaves and leading to increased carrot root yield [7]. The results of the present study revealed that poultry manure mixed with FYM influenced the increase in the root yield of carrots under mulch conditions during the crop growth period. Poultry manure in combination with farmyard manure under grass mulch increases carrot yields [21].

Investigations on the effects of different types of organic manures and mulching materials on unmarketable yield (t ha^{-1})

This difference might be caused by a range of factors, including attack by insects, diseases or nematodes; mechanical damage from deep and/or too close cultivation; physical obstructions; poor soil conditions; or excessively close plant density.

Investigations on the effects of different types of organic manure and mulching materials on root dry matter (%). The data in Table 6 demonstrate that the application of 20 t of mixed manure resulted in significantly greater mean root dry matter; this might be because FYM+PM contributed to the improvement of the soil structure, particularly in terms of its water-holding capacity and drainage. They help increase the ability of the soil to retain moisture, prevent waterlogging and reduce the risk of root rot. Additionally, FYM and poultry manure enhance soil aeration, promoting the development of a healthy root system and facilitating nutrient uptake by carrot plants. These results are supported by the findings of [26], who reported variations in macronutrients and micronutrients among organic manures and industrial and municipal wastes and their effects on the growth and yield of crops. In line with the findings of [8], root dry matter percentages were greater in plants treated with higher doses of potassium along with mulching.

Investigations on the effects of different types of organic manure and mulching materials on the percentage of forked roots (%)

Interestingly, the percentage of forked roots varied significantly between amendments, suggesting that non-biotic factors may contribute to the development of this disorder. In the present study, plants that received manure presented lower percentages of branched roots than did the control plants. The high nitrogen content in the organic manure and organic mulch might have contributed to the low percentage of forked roots. These findings are in line with those of [30,31], who reported that forking carrot plants is promoted by factors such as poor soil structure (compacted heavy clay soil), the application of fresh manure, the application of excess nitrogen and improper irrigation management. Research on the influence of organic fertilizers on the yield and quality of carrots [27], reported that an increase in the organic fertilizer rate promoted the development of hairy and forked carrots, which contradicts the current findings. The percentage of forked roots also significantly varied due to the use of different mulching materials on the carrot plants. The highest percentage of forked roots (4.34%) was obtained in the M_0 treatment (no mulch). The lowest percentage of forked roots (1.35%) was obtained in the grass mulch treatment M_2 (grass). This result indicated that the decrease in the percentage of forking roots in the mulch treatments might be due to the effect of soil moisture combined with readily available nutrients. Organic manure application combined with mulch usually enhances soil physical, chemical and biological activities and moisture, which could also explain the suppression of forked root production.

Investigations on the effects of different types of organic manure and mulching materials on the percentage of cracked roots (%)

The increasing trend of the cracking percentage of roots with increasing root size per plant might be due to the larger roots that occurred among the mulching and organic manure-treated plants. These plants supplied low amounts of nutrients, and moist plants produced thinner roots with minimum diameters, which might have contributed to their resistance to cracking. The mulched and amended roots had enough room to expand, reaching the limit of internal turgor pressure and resulting in cracking [30].

This finding aligns with the report of [32], that carrots split when the cell walls rupture, forming longitudinal fractures in the phloem parenchyma as a result of internal turgor pressure. They stated that carrot susceptibility to cracking increases following maturity of the roots and that the timing of harvest is critical. This difference in growth pattern may influence susceptibility to cracking, as outer rows are often highly susceptible to cracking. This result for cracked roots was also supported by the findings of [33], who reported that the percentage of cracked roots increased due to low moisture and high nitrogen levels.

Investigations on the effects of different types of organic manure and mulching materials on the total soluble solids (˚Brix) of carrots

The TSS content significantly increased with different organic manures because organic manures, particularly FYM, FYM+PM and PM, contain fair amounts of micronutrients, especially ferrous or iron. It is an essential constituent of many respiratory enzymes, such as catalase and cytochrome (A-C) and is involved in the respiratory process of the cell system. Through respiration in the plant system, reserve food materials are converted to simple soluble components that can be utilized for growth or maintenance. These findings are in good accordance with the results [1,10].

Increased nitrogen through manures apparently helps in vigorous vegetative growth and favors photosynthetic activity for greater accumulation of food material, i.e., carbohydrates that increase the TSS content in carrots. These results are in close conformity with those of [16]. When the nutritional quality of carrots as influenced by farmyard manure was studied, it was observed that farmyard manure did not significantly improve the total soluble sugar content in carrots, which contradicts the current findings [34]. In contrast, other researchers reported that the TSSs in carrots [28], that received organic fertilizers were greater than those in those that received inorganic fertilizer. These findings are in line with those of [26], who revealed that mulching had no significant effect on the TSS. Kumar et al., confirmed that a higher content of total sugars in organic vegetables, including carrots, beets and potatoes, contributes to an increase in the technological and sensory quality (taste) of organic products [12].

Partial budget analysis

The results of the present study were in agreement with those of, who reported that economic analysis revealed that the highest marginal rate of return was obtained from carrot plants treated with 20 t FYM with grass mulch, followed by those treated with 20 t FYM with sawdust mulch, with values of 3803% and 3644%, respectively [31,35]. Therefore, the best alternative net return, 20 t FYM with grass mulching, is recommended as the best economically rewarding treatment rate for the study area.

CONCLUSION

Carrot is one of the most important root crops cultivated throughout the country. The type and management of organic manure with mulching are important factors that strongly affect the growth and yield of carrot crops. The application of organic manure, such as poultry manure and farmyard manure, is necessary to improve the production and productivity of carrots in the study area. However, appropriate application practices that involve the combination of organic manure with mulching materials are lacking in the study area. Thus, a study was conducted to assess the effects of different types of organic manure with mulching on the growth, yield and quality of carrots and to assess the cost-benefit of different organic manures with mulching materials for the production of carrots.

A field experiment was conducted at Waraza Lasho Kebele in Diguna Fango district, Wolaita Zone of Southern Ethiopia, in 2022/2023. The basic seeds of the carrot variety Nantes (orange) were used as the experimental material. The variety was imported from the Netherlands with certification. The treatment consisted of four organic manures (0.0, 20 t poultry manure, 20 t farmyard manure and 20 t mixed manure/ha=(10 t PM+10 t FYM) ha^{-1}) and three levels of organic mulching (no, sawdust and grass mulching) were used for the experiment.

The experiment was performed in accordance with a RCBD with four replications in a factorial arrangement. The size of each plot was 1.6 m × 2 m (3.2 m^2), accommodating 5 single rows with 6 plants per row. The spacing between rows was 20 cm, the spacing between plants was 10 cm and the spacing's between blocks and between plots were 0.8 m and 0.5 m, respectively. All basic growth and yield data were collected and subjected to ANOVA and partial budget analysis.

The effects of organic manure and mulching methods on carrot performance suggested that organic manure and mulching materials significantly enhanced the growth and yield attributes of carrot production. This study revealed that the interaction between organic manure and mulching material significantly affected the root diameter, fresh weight, dry weight, marketable yield and total yield. In this study, the highest marketable root yield (27.90 t ha^{-1}) was achieved *via* the combination of 20 t of mixed manure with grass mulch (10 t PM+10 t FYM with grass mulch), for which the yield increased by 656% compared with the lowest marketable yield (8.21 t ha^{-1}), which was obtained from the control. On the basis of the partial budget analysis, the greatest net benefit (360,520 Birr ha^{-1}), with an MRR of 3803%, was obtained from the treatment in which 20 t FYM was combined with grass mulch ha^{-1}. The minimum acceptable MRR % should be between 50% and 100%. Therefore, the use of 20 t FYM with grass mulch ha^{-1} application with greater net return could be suggested for carrot production in the study area. It may be concluded that 20 t of FYM ha^{-1} can be used as organic manure and grass mulch material and the combination of 20 t of FYM with grass mulch ha^{-1} can be used to increase the yield and quality of carrots.

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