Journal of Horticultural Research 2017, vol. 25(1): 81–88
DOI: 10.1515/johr-2017-0009

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IMPACT OF POULTRY MANURE AND NPK FERTILIZER ON SOIL PHYSICAL PROPERTIES AND GROWTH AND YIELD OF CARROT

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Received: March 2017; Accepted: Mai 2017

ABSTRACT

A field experiment was conducted in the forest-savanna transition zone of Nigeria from May to July 2014 and September to November 2015 to determine the impacts of poultry manure (PM) and NPK fertilizer on soil physical properties, and growth and yield of carrot (*Daucus carota* L.). The five treatments included no manure or fertilizer (control); 10, 20, and 30 megagrams (Mg)·ha^{-1} of PM; and 300 kg·ha^{-1} of 15 N-15 P-15 K fertilizer. All levels of PM reduced soil bulk density and temperature, and improved total porosity and moisture content compared to the NPK fertilizer and the control. Plant height, number of leaves, root diameter, root length, and fresh root yield in the PM and NPK fertilizer treatments were improved compared to the control. Growth and yield parameters of carrot plants treated with 20 and 30 Mg·ha^{-1} PM were higher than the other treatments. The 10 Mg·ha^{-1} PM and NPK fertilizer treatments produced similar growth and yield responses. There was an interaction for year (Y) × fertilizer (F) on plant height, number of leaves, and fresh root yield. Relative to the control 10, 20, or 30 Mg·ha^{-1} PM and NPK fertilizer increased fresh root yield of carrot by 39.9%, 62.0%, 64.9%, and 37.3%, respectively. The 20 Mg·ha^{-1} PM treatment best improved soil properties and carrot productivity as indicated by the benefit-to-cost ratio.

Key words: *Daucus carota*, benefit-to-cost ratio, bulk density, total porosity, moisture content, fresh root yield

INTRODUCTION

Carrot (*Daucus carota* L.) contains carotene, thiamine, and riboflavin in addition to energetic value and some therapeutic functions (Pant & Manandhar 2007) as it enhances resistance against blood, eye (Pant and Manandhar, 2007) and other human diseases (Appiah et al., 2015).

Carrot production can be a beneficial enterprise for small-scale, resource-poor farmers because it is a short duration crop and higher yields can be obtained per unit area (Ahmad et al. 2005). However, Sarkindiya and Yakubu (2006) reported low average yields in Nigeria. In most developing countries, carrot yield per unit area remains below the world average (FAO 1999). One reason for low yield is low soil fertility and low technological know-how in production methods. In order to obtain high and sustainable carrot yields, good soil fertility and constant growth are required to facilitate production and translocation of carbohydrates from leaves to roots.

The key limiting factors in crop growth, development, and yield are nitrogen, phosphorous, potassium, and water. In most cases, carrot growers use chemical fertilizers as the major supply of nutrients to attain higher growth and yield (Hochmuth et al. 1999; Amjad et al. 2005). Continuous application of synthetic fertilizer may lead to soil acidity, human health problems, and soil degradation because they release nutrients at a faster rate. Increasing costs of synthetic fertilizers have made them generally unaffordable to most resource-poor, small-scale growers.

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Manure can serve as a substitute to synthetic fertilizers. Application of manure supplies the required nutrients; improves soil structure, water holding capacity, porosity, bulk density, moisture retention; increases microbial population; and maintains crop quality (Suresh et al. 2004; Dauda et al. 2008; Adekiya & Agbede 2009; Adeleye et al. 2010; Agbede et al. 2013, 2014). Despite the large quantities of plant nutrients contained in synthetic fertilizers, compared to organic nutrients, the presence of growth promoting agents in organic fertilizers make them important in enhancing soil fertility and productivity (Sanwal et al. 2007).

Poultry manure (PM) is an effective source of nutrients for carrot (Kankam et al. 2014; Habimana et al. 2014). There has been a continuous use of PM to fertilize crops by some farmers in Nigeria with no, or limited, documentation on performance. In Nigeria, proper disposal of poultry waste is a challenge to poultry farmers (Agbede & Adekiya 2011) and its use in carrot production could be a solution.

The application rate of PM for carrot has not been documented. The objective of this work was to evaluate the impacts of PM and NPK fertilizer on soil physical properties, growth and yield of carrot.

MATERIALS AND METHODS

Site description

The experiment was carried out at the Teaching and Research Farm of Rufus Giwa Polytechnic, Owo, Nigeria, in the forest-savanna transition zone in May to July 2014 and September to November 2015 on the same plots. Owo is located at latitude 7°12′N and longitude 5°35′E. The soil at Owo is in the Okemesi Series and is an Alfisol classified as Oxic Tropuldalf (Soil Survey Staff 2014) or Luvisol (FAO 1998) derived from quartzite, gneiss, and schist (Agbede 2006). There are two rainy seasons at the location, from March to July and from mid-August to November. Average annual rainfall is 1,000–1,500 mm. The soil at the site had been under rotational cropping for at least 8 years.

Poultry manure preparation

PM obtained from the poultry section of the Polytechnic was decomposed using the passive aeration composting technique as described by Taiwo and Oso (2004). A plastic barrel measuring 2.5 m in diameter and 3 m long with nine holes perforated at intervals of 30 cm apart on the bottom sides was used for composting. PM was moistened with water and placed into the plastic barrel and the ambient temperature was continuously monitored on weekly basis by inserting a thermometer into the composting plastic barrel until complete decomposition was attained when temperature was stabilized.

Land preparation and crop establishment

The land was plowed and disked to a depth of 0.20 m and prepared into a fine tilth using rakes. Plots (raised beds) of size 4 m long × 1 m wide were prepared with a hoe to height of 0.20 m and leveled with a rake. Blocks were 1 m apart and plots were 0.5 m apart. The design was a randomized complete block with five treatments and three replications. The treatments were control (no PM or NPK fertilizer); decomposed PM at 10, 20, and 30 $Mg \cdot ha^{-1}$, and N 15-15 P-15 K at 300 $kg \cdot ha^{-1}$. For the synthetic fertilizer, the N was from urea, P from single superphosphate and K from muriate of potash. The soil was moistened to field capacity and leveling done using a rake.

Seeds of carrot 'Touchon' were sourced from Agricultural Input Supply Company, Ondo State, Nigeria. The seeds were treated with a seed-dressing fungicide (Apron plus 50 DS) against seed-borne or soil-borne pathogens before sowing by drilling to a depth of 1 cm at 25 cm between rows on beds on 1 May 2014 and 1 September 2015, respectively, for the first and second trials. The beds were covered with straw to prevent excessive heat and retain seed on beds. The straw was removed at sixth day after sowing. Seedlings were thinned at twenty first day after emergence to an intra-row spacing of 10 cm between plants, giving a plant population of 160 plants per plot. The NPK fertilizer was applied in a ring around plants at third week after sowing. Weeding was done by hand. Paths between blocks and plots were weeded with a machete and hoe four times during the experiment.

Soil sampling and poultry manure analysis

In 2014, prior to the experiment, surface soil (0–15 cm depth) samples were randomly collected with a soil auger from 10 different points in the site. The soil and PM samples were bulked, air dried, and sieved separately using a 2-mm sieve for chemical analyses. Particle size analysis was performed using a hydrometer. Soil pH was determined in a soil–water (1:2 v:v) suspension using a digital electronic pH meter. Organic carbon from soil and manure was determined by the Walkley and Black procedure (Nelson & Sommers 1996), the dichromate wet oxidation method. The organic matter (OM) was determined by multiplying organic carbon by 1.724. Total N was determined following the micro-Kjeldahl method as described by Okalebo et al. (2002). Available P was determined colorimetrically using a spectrophotometer. Exchangeable K, Ca, and Mg were extracted using 1 M ammonium acetate. The K was determined using a flame photometer, and Ca and Mg were determined using an atomic absorption spectrophotometer (Okalebo et al. 2002).

Determination of soil physical properties

One month after sowing carrot, certain soil physical properties in all plots were determined and measured monthly for three successive months. Five undisturbed samples (4 cm in diameter, 10 cm high) were collected at 0–10 cm depth from each plot with a core soil sampler and used for the evaluation of bulk density, total porosity, and gravimetric moisture content after drying in an oven at 100 °C for 24 h. Total porosity was calculated from the values of bulk density and particle density of 2.65 $Mg \cdot m^{-3}$. Soil temperature was determined at 15:00 h with a soil thermometer inserted to 10 cm depth. Five readings were made per plot at each sampling time.

Determination of growth and yield parameters

Ten plants per plot were randomly selected from the middle rows and tagged for data collection. Plant heights were taken biweekly with measurements being from the ground level to the top of the apex of the longest leaf. On the same plants, numbers of leaves were determined.

At crop maturity, 10 carrot plants were randomly selected to determine the root length, root diameter, and yield. Roots of sampled plants were detached from shoots and the fresh root weight was determined. Root length and root diameter at 2 cm from the top were recorded immediately after harvest.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using the Genstat statistical package (GENSTAT 2005). If the season by treatment interaction was significant, it was used to explain the data. If the interaction was not significant, means were separated using Duncan's multiple range test.

Cost-to-benefit analysis

A cost-to-benefit analysis was done to determine the relative economic returns on treatments using 2014 and 2015 annual market prices. Total yield and cost benefit analyses were determined in US \$ (1\$US = ₦162.00 Nigerian currency in the year 2014 and ₦178.00 in the year 2015) using the harvest from the central bed (1 m^2) of each plot. Costs of farm services were from Oja Oba market in Owo Local Government Area of Ondo State, Nigeria.

RESULTS

Physical and chemical properties of the soil before sowing in 2014 and chemical composition of PM used for the experiment varied (Table 1). The soil was sandy loam in texture, was slightly acidic, and had high bulk density and low total porosity. Soil OM, total N, available P, exchangeable K, exchangeable Ca, and exchangeable Mg were very low according to the critical levels of 3.0% OM, 0.20% N, 10.0 $mg \cdot kg^{-1}$ available P, 0.16–0.20 $cmol \cdot kg^{-1}$ exchangeable K, 2.0 $cmol \cdot kg^{-1}$ exchangeable Ca, and 0.40 $cmol \cdot kg^{-1}$ exchangeable Mg according to recommendations (Akinrinde & Obigbesan 2000), indicating poor soil fertility. It will, therefore, be unable to sustain crop yield without the addition of external input.

The chemical composition of PM was relatively high in N, P, K, Ca, Mg, and organic carbon at the level required for the growth of carrot (Table 1). Application of PM and NPK fertilizer in the short term is expected to benefit the crop and soil.

Treatment with PM and NPK fertilizer influenced soil physical properties (Table 2). Year 1 (2014) had higher bulk density and moisture content and lower total porosity and temperature compared with year 2 (2015). Application of PM at 10, 20, or 30 $Mg \cdot ha^{-1}$ caused lower soil bulk density and temperature and higher total porosity and moisture content compared with the control. With the increased amounts of PM, soil moisture and total porosity increased, while soil bulk density and temperature decreased. Application of NPK fertilizer did not influence soil bulk density, total porosity, moisture content, and temperature. The NPK fertilizer, and the control, caused similar soil bulk density, total porosity, moisture content, and temperature values.

PM at 20 or 30 Mg·ha^{-1} caused the lowest soil bulk density and temperature, highest total porosity, and moisture contents. Averaged over cropping seasons, the 30 Mg·ha^{-1} PM reduced soil bulk density and temperature and increased total porosity and moisture content by 38%, 24%, 36%, and 43%, respectively, compared with NPK fertilizer and the control. Application of 20 Mg·ha^{-1} PM reduced the soil bulk density and temperature and increased the total porosity and moisture content by 32%, 18%, 31%, and 35%, respectively, compared with NPK fertilizer and the control.

When studied as individual factors, year (Y) and fertilizer (F) were significant for bulk density, total porosity, moisture content, and temperature (Table 2). The Y × F interaction was significant for bulk density and total porosity but not for moisture content and temperature.

Table 1. Physical and chemical properties of soil (0–15 cm depth) before the experiment and the chemical composition of poultry manure used

Soil property	Value	Poultry manure property	Value
Sand (g·kg^{-1})	680	pH (H_2O)	6.8
Silt (g·kg^{-1})	145	Organic c (%)	20.5
Clay (g·kg^{-1})	175	Nitrogen (%)	3.03
Textural class	Sandy loam	C : N	6.8
Bulk density (Mg·m^{-3})	1.62	Phosphorus (%)	0.83
Total porosity (%)	38.9	Potassium (%)	2.3
pH (H_2O)	5.8	Calcium (%)	1.2
Organic matter (%)	1.46	Magnesium (%)	0.58
Total N (%)	0.15		
Available P (mg·kg^{-1})	7.6		
Exchangeable K (cmol·kg^{-1})	0.11		
Exchangeable Ca (cmol·kg^{-1})	1.32		
Exchangeable Mg (cmol·kg^{-1})	0.25		

Table 2. Effect of year and fertilizer on soil physical properties (0-10 cm depth)

Effect	Bulk density (Mg·m^{-3})	Total porosity (%)	Moisture content (%)	Temperature (°C)
Year				
2014	1.34a	49.2b	13.4a	28.7b
2015	1.30b	50.9a	11.2b	29.7a
Fertilizer				
Control (no fertilizer of any kind)	1.52a	42.7e	10.4d	32.1a
10 Mg·ha^{-1} poultry manure	1.33b	50.0c	12.2c	28.7b
20 Mg·ha^{-1} poultry manure	1.15c	56.2b	13.9b	27.2c
30 Mg·ha^{-1} poultry manure	1.10d	58.5a	14.7a	25.9d
300 kg·ha^{-1} NPK 15-15-15 fertilizer	1.51a	43.0d	10.2d	32.2a
P				
Year (Y)	0.000	0.000	0.000	0.000
Fertilizer (F)	0.000	0.000	0.000	0.000
Y × F	0.000	0.000	1.000	0.998

p is the probability of F statistic from ANOVA; means in column for each effect followed by similar letter are not significantly different at p = 0.05 according to Duncan's multiple range test

Application of PM and NPK fertilizer influenced growth and yield of carrot (Table 3). Plants in both years were similar in height and with similar number of leaves but had higher root diameters, longer roots, and higher root yield in the second year. The PM and NPK increased plant height (Fig. 1, Table 3), number of leaves, root diameter, root length (Table 3), and root yield of carrot (Fig. 2, Table 3) compared with the control. A general trend of increase in all growth and yield parameters with increasing level of PM was observed during the 2 years. The 10 Mg·ha^{-1} PM and 300 kg·ha^{-1} NPK 15-15-15 fertilizer caused similar plant heights, numbers of leaves, root diameters, root lengths, and fresh root yield of carrot during the 2 years. In both the years, use of 20 and 30 Mg·ha^{-1} PM produced the tallest plants, most leaves, longest and widest roots, and fresh root yield higher than 300 kg·ha^{-1} NPK 15-15-15 fertilizer. In both the years, plants fertilized with 20 and 30 Mg·ha^{-1} PM produced root yield higher by 17.9% and 20.1%, respectively, compared with plants fertilized by 300 kg·ha^{-1} NPK. Relative to the control 10, 20, and 30 Mg·ha^{-1} PM and 300 kg·ha^{-1} NPK 15-15-15 increased fresh root yield of carrot by 39.9%, 62.0%, 64.9%, and 37.3%, respectively.

Table 3. Effect of year and fertilizer on carrot plant height, number of leaves, root diameter, root length, and fresh root yield

Effect	Plant height (cm)	Number of leaves	Root diameter (cm)	Root length (cm)	Fresh root yield (Mg·ha^{-1})
Year					
2014	24.4a	12.2a	1.4b	16.0b	37.7b
2015	25.3a	12.6a	1.5a	18.2a	40.0a
Fertilizer					
Control (no fertilizer of any kind)	18.0c	8.6d	1.1c	13.1c	27.6c
10 Mg·ha^{-1} poultry manure	25.4b	12.8b	1.5b	17.2b	38.6b
20 Mg·ha^{-1} poultry manure	27.7a	14.6a	1.6a	19.3a	44.7a
30 Mg·ha^{-1} poultry manure	28.0a	14.7a	1.6a	20.0a	45.5a
300 kg·ha^{-1} NPK 15-15-15 fertilizer	25.1b	12.5b	1.5b	16.8b	37.9b
P					
Year (Y)	0.073	0.000	0.801	0.003	0.000
Fertilizer (F)	0.000	0.000	0.018	0.000	0.000
Y × F	0.027	0.000	1.000	0.973	0.001

Note see Table 2

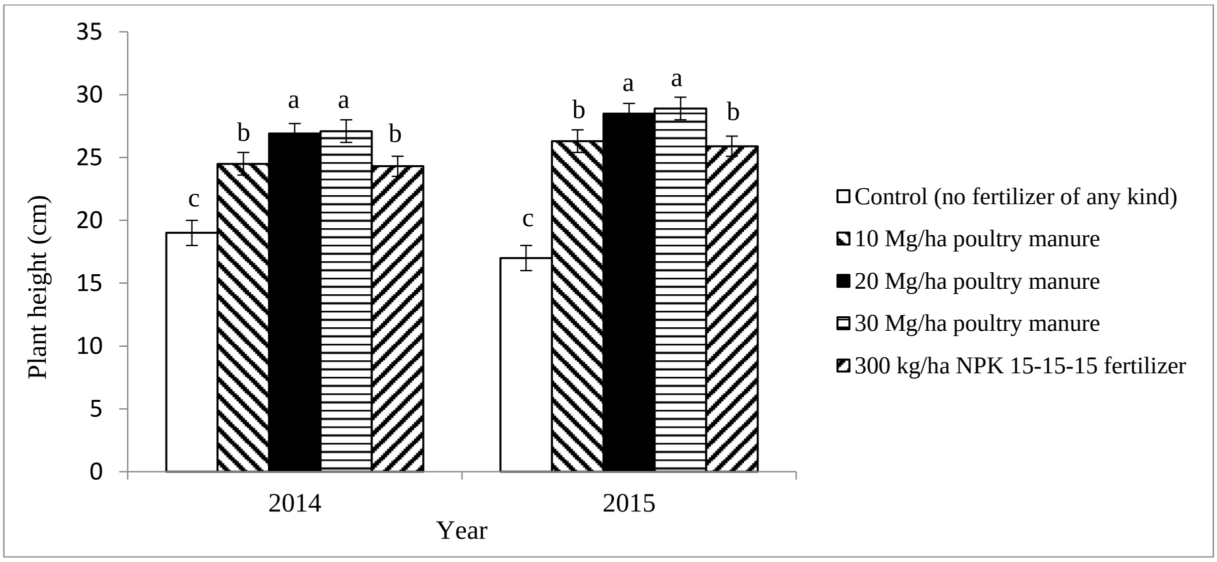

Fig. 1. Effect of poultry manure and NPK 15-15-15 fertilizer on carrot plant height in 2014 and 2015

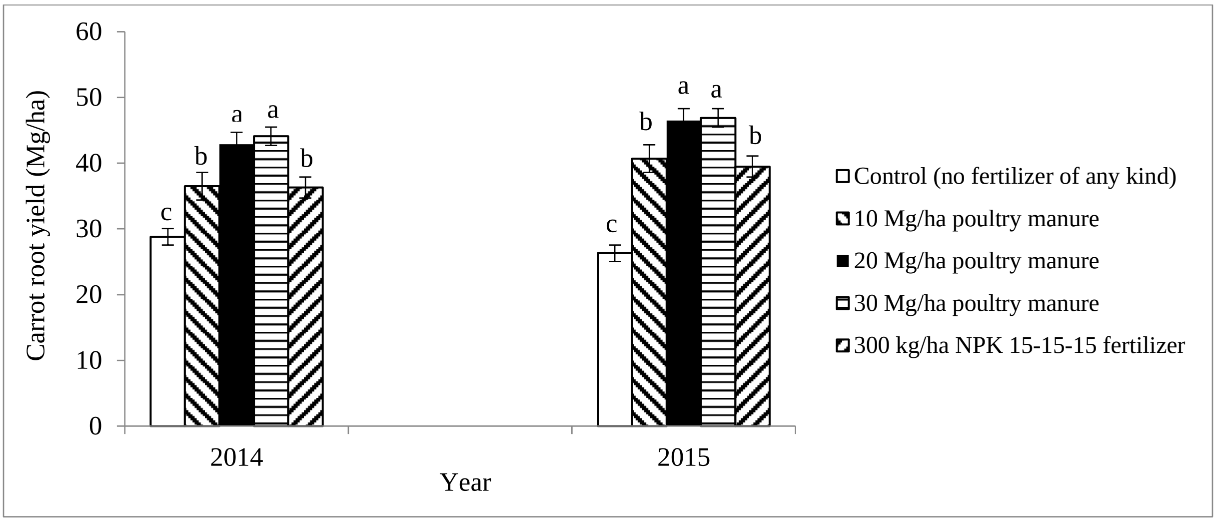

Fig. 2. Effect of poultry manure and NPK 15-15-15 fertilizer on carrot root yield in 2014 and 2015

Table 4. Economics of producing carrot under each level of poultry manure and NPK fertilizer tested in the first year (2014) and second year (2015)

Treatment	Gross return/monetary gain ($·ha^{-1})	Production increase value ($·ha^{-1})	Production increase (%)	Cost of transportation of poultry manure/cost of NPK fertilizer ($·ha^{-1})	Net return over each fertilization ($·ha^{-1})	Return rate or value/cost ratio of each fertilization
Control (no fertilizer of any kind)	8 247.35	-	-	-	-	-
10 Mg·ha^{-1} poultry manure	11 609.65	3 362.29	40.8	61.76	3 300.53	54.4
20 Mg·ha^{-1} poultry manure	13 435.41	5 188.06	62.9	88.24	5 099.82	58.8
30 Mg·ha^{-1} poultry manure	13 669.76	5 422.41	65.8	120.59	5 301.82	45.0
300 kg·ha^{-1} NPK 15-15-15 fertilizer	11 392.59	3 145.24	38.1	194.12	2 951.12	16.2

Notes: In the year of 2014, the price of fresh root yield of carrot was 300 $US·Mg^{-1} and NPK 15-15-15 fertilizer was 0.69 $US·kg^{-1}. In the year of 2015, the price of fresh root yield of carrot was 300 $US·Mg^{-1} and NPK 15-15-15 fertilizer was 0.62 $US·kg^{-1}.

When considered as individual factors, year (Y) affected number of leaves, root length, and fresh root yield but not plant height and root diameter, and fertilization (F) affected plant height, number of leaves, root diameter, root length, and fresh root yield (Table 3). The interaction of Y × F did not affect root diameter and root length but affected plant height, number of leaves, and fresh root yield.

Cost of purchasing of fertilizer was higher than that of transportation for each level of PM treatment (Table 4), which increased with a rate of manure. Use of 30 Mg·ha^{-1} PM produced the highest gross return ($13 669.76·ha^{-1}) and net return ($5 301.82·ha^{-1}) followed by 20 Mg·ha^{-1} PM treatment with a gross return of $13 435.41·ha^{-1} and net return of $5 099.82·ha^{-1}; the lowest gross return ($8 247.35·ha^{-1}) was from the control (₦ is the Naira, Nigerian currency, 1$US = 162.00 ₦ in year 1 (2014) and 1$US = 178.00 ₦ in year 2 (2015). All levels of PM and the NPK fertilizer produced higher net profit than the control. The economic returns and net benefits from levels of PM were higher than those for the NPK fertilizer treatment. The 20 Mg·ha^{-1} PM treatment was more cost effective and profitable in the production of carrot than all other treatments, as indicated by its high return rate or value-to-cost ratio of 58.8.

DISCUSSION

The reduced bulk density and temperature and increased moisture and porosity observed in PM-treated plots compared with the control could be attributed to the increased soil organic matter from the PM. Organic matter can improve soil structure and aeration, reduce soil bulk density, enhance water infiltration and retention, and increase microbial populations (Agbede et al. 2013, 2014; Atakora et al. 2014). Bulk density is important to water infiltration, root distribution, and root function which in turn affects water uptake and growth (Mbah et al. 2004; Adeleye et al. 2010). Reduction in soil bulk density could make differences in root growth of carrot. Improvement in soil total porosity because of manure might be as a result of the improved soil particle aggregation brought about by the improved soil organic matter content. The 10, 20 and 30 $Mg \cdot ha^{-1}$ of the PM added influenced physical parameters, as the highest level of the PM produced the lowest bulk density and temperature and the highest soil moisture content and total porosity.

The poor performance of carrot in the control plots compared with plots treated with PM and NPK fertilizer may be connected with low OM, N, P, K, Ca, and Mg status of the soil before experimentation (Table 1). The better performance of PM than the NPK fertilizer could be attributed to the better soil physical conditions caused by PM. The role of organic manures in plant growth cannot be underscored. Animal manures have been shown to supply required plant nutrients, improve soil structure and water holding capacity, increase microbial population, and promote plant growth (Dauda et al. 2008; Agbede et al. 2013, 2014). The plant height, number of leaves, root length, root diameter, and root yield of carrot increased with increasing PM levels could be related to the increase in soil moisture content and total porosity and the reduction of soil bulk density and temperature. The higher yield in the second year of experiment could be attributed to the accumulation of effects after repeated addition of beneficial fertilizer. Increased root length and root yield had been reported in carrot with the increase in doses of different organic fertilizers (Mbatha 2008).

Although the carrot cultivar used is a short-term crop, PM was able to beneficially affect soil physical properties, growth, and yield. The organic nutrients in PM mineralized faster than other animal manures and are proven to be superior in many instances than others (Mbatha 2008). This was likely due to its relatively low C:N ratio. Adekiya and Agbede (2009) recorded a C:N ratio of 6.7 for PM and noted that it had higher content of most nutrients, decomposed faster, and gave higher yield compared with NPK fertilizer. PM can be used as a substitute for NPK fertilizer in carrot, especially at 20 $Mg \cdot ha^{-1}$.

CONCLUSIONS

The study showed that application of poultry manure improved the physical characteristics of the soil and increased the growth and yield parameters of carrot more than the NPK fertilizer. The quantity of the PM added had influence on the above parameters; however, 30 $Mg \cdot ha^{-1}$ PM did not give any appreciable effect in comparison with 20 $Mg \cdot ha^{-1}$ PM. The application of PM at 20 $Mg \cdot ha^{-1}$ was found to be more cost effective in the production of carrot than all the other treatments. It can be concluded that PM, especially at 20 $Mg \cdot ha^{-1}$, can be used as a substitute for NPK fertilizer for carrot production on any degraded tropical soil.

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