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Enhancing soil nutrients for yield and nutritional quality of carrot through the joint effect of a complementary technology package in the rainforest region of Nigeria

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ABSTRACT

Field experiments were conducted to assess the effects of integrated application of poultry manure (PM), cocoa pod husk (CPH), and NPK 15:15:15 fertilizer on carrot root yield and nutritional quality during 2023 and 2024 cropping seasons at Adeyemi Federal University of Education (07°04'N, 04°49'E), Ondo in the rainforest ecology of southwest Nigeria. Poultry waste and CPH were combined at three different quantities (0, 5, 10 t ha^{-1}), with NPK fertilizer applied at three levels (0, 100, 200 kg ha^{-1}) in a factorial experiment set up in a randomized complete block layout. Each treatment was repeated three times. The gathered data were assessed using the Statistical Analysis System Institute Package. The site's soil had low levels of accessible P (4.87 mg kg^{-1}), nitrogen (0.7 g kg^{-1}), and a somewhat acidic pH (6.1). Plots with the combined application of the three soil amendments showed a significant ($P<0.05$) improvement in root yield metrics, proximate compositions, and phytochemicals. Compared to the sole application of NPK fertilizer in the second cropping season, the residual effect of PM and CPH alone and their combination with or without NPK fertilizer on root yield characteristics was larger. The maximum gross root yield, protein, fiber, vitamin C, and carotenoid content were found in plots that received an integrated application of 10 t ha^{-1} of PM, CPH, and 200 kg ha^{-1} of NPK. These parameters' values did not differ substantially ($P>0.05$) from the plots that received 200 kg ha^{-1} of NPK fertilizer, 5 t ha^{-1} of PM, and CPH fertilizer applied together. Compared to their respective single applications, the combination of PM, CPH, and NPK fertilizer was more successful in increasing carrot root yield and nutritional quality.

Keywords: Carrot, Cocoa pod husk, NPK fertilizer, Yield, Nutritional quality

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Introduction

Around the world, carrots are cultivated every year for human use and are a common crop in the Apiaceae family (Paparella *et al.*, 2024). Although the crop was traditionally grown from September to November in tropical and subtropical climates, temperate climates provide a range of year-round production options. The temperature needs to be lower for carrot seeds to thrive. Carrot roots contain pigments called carotenoids and flavonoids, which give them their color and antioxidant qualities Tlahig *et al.*

(2023). The root crop of the carrot family is grown every year for nourishment, but the inflorescence blooms every two years. The percentage of cortical core, which decreases with ripeness, is one of the primary factors affecting root output.

The phloem and xylem vascular systems result from secondary alteration to the inner and outer borders of the roots. The cortex, or outer layer, of the root, contains most of the bioactive components. It is ranked among the top ten fruits and vegetables in terms of nutrition since it includes vitamins, bioactive compounds, and trace components (Ikram *et al.,* 2024). Carotenoids are abundant in carrot roots but contain terpenoids and polyacetylenes. Although monoterpenoids and sesquiterpenoids are the most common terpenes, falcarinol structures comprise polyacetylenes. An antioxidant known as anthocyanin gives carrots their black and purple hues. Lycopene, found in tomatoes and red carrots, is largely oxygen-free and is abundant in bodily fluids, helping to reduce the potential for various cancers (Pistol *et al.,* 2023). The color differences form the foundation for orange, red, yellow, violet, and both light and dark roots. There are numerous medical applications for the pigments present in various roots.

Despite much research on the involvement of other carotenes in provitamin A, vitamin A deficiency remains the leading cause of premature mortality in children. Carrots are a great source of vitamin A because they contain β-carotene, which the body readily converts to vitamin A (Yi *et al.,* 2023). Product development and marketing are crucial to providing people with the nutrients they require, especially as an affordable source of vitamin A, given the advantages to nutrition and health. A thorough synthesis of studies on the usefulness and health advantages of carrots and carrot pomace is lacking in the corpus of existing literature. This study aims to thoroughly evaluate and compile data regarding the usefulness and health advantages of carrots and carrot pomace. It provides useful details about their nutritional value and potential health advantages. Soil fertility must be controlled and preserved for a sustainable food production system. Nigerians are well aware that chemical fertilizers alone are not enough to promote sustainable crop growth. A steady high intake of nutrients from inorganic fertilizers under intensive cropping systems stresses the ecosystem and makes the nutrients more harmfully bioavailable to living things (Tyagi *et al.,* 2022). The management of soil using organic fertilizer sources to improve agricultural yield, soil health, and nutritional value is of great importance globally. For several crops in Nigeria, ash made from cocoa pod husk (CPH) is a good source of macro and micronutrients (Pinzon-Nuñez *et al.*, 2022).

There is currently no research on the use of CPH fertilizer on carrots in southwest Nigeria, even though it already benefits several arable crops. Research on using chicken manure (PM) as a fertilizer source to increase crop yield is widely available in the literature. Poultry dung increases agricultural yield by enriching the soil with all essential elements (Adekiya *et al.*, 2022).

Research experiments have revealed that carrot yields are higher worldwide (Walker and Barnal, 2004; Gatsinzi *et al.*, 2016). There is a dearth of research on using chicken manure in Nigerian carrot cultivation, particularly in southwest Nigeria. Studies have been done in Nigeria on how inorganic fertilizer affects carrot performance (Akpan *et al.,* 2021). It is well recognized that utilizing premium organic manures in combination with inorganic fertilizers is a practical method to maintain soil quality and increase crop yield for sustainable agricultural production, which is relevant to Nigeria's problems with crop productivity and soil fertility (Wato *et al.*, 2024). Combining chemical fertilizers with organic manure may be a workable way to get enough high-quality carrots. Research on how combining organic and inorganic fertilizers affects the nutritional content and root yield of carrots in Nigeria is lacking. The current study was conducted to ascertain the effects of the combined application of PM, CPH, and NPK 15:15:15 fertilizer on the root yield, nutritional value, and phytochemicals in carrot roots in Nigeria's rainforest agroecological zone.

Materials and Methods

Field experiments took place in Nigeria's rainforest agro-ecological zone during the 2023 and 2024 growing seasons at the Adeyemi Federal University of Education Teaching and Research Farm, located in Ondo (Latitude 07°04'N, Longitude 04°49'E). This region experiences a dual rainy season, featuring a short dry spell in August, followed by initial rainfall from March to

July and a later rainy period from August to October. The warmest months are February and March, with average daily temperatures ranging from 28 to 29°C, while the monthly average temperature is 27°C (FDACSA, 2021). The soil in this area, classified as Oxic Tropuldaf, has a pH level of 6.2 and a sandy composition. The geological features of the site are primarily made up of crystalline rocks, part of the basement complex found in southwestern Nigeria (Akinbola *et al.,* 2009). The location is situated within the lowland rainforest ecosystem of Nigeria, characterized by semi-deciduous flora. After being utilized for cultivating crops, the area remained uncultivated for two years before the initiation of field trials. The following area is populated with a variety of shrubs, along with wild sunflower (*Aspilia* spp.), siam weed (*Chromolaena odorata*), and goat weed (*Ageratum conyzoides*).

Treatment and experimental design

Three (3) treatments were used: NPK 15:15:15 Fertilizer (F) at three levels (0, 100, and 200 kg ha^{-1}), Cocoa Pod Husk (CPH) at three levels (0, 5, and 10 t ha^{-1}), and poultry manure (PM). In a 33-factorial experiment, the three components were explored to develop 27 therapy combinations. Each treatment combination was replicated three times in a randomized complete block design (RCBD). A 40 m by 5 m land area was set aside for the experiment. After being manually cleared and parked, the land was divided into three blocks, with alleyways that were 0.5 meters wide between each block. Each block was divided into twenty-seven (27) 1 m by 1 m plots, with a 0.5 m wide alleyway between each plot.

The plots were separated into 81 raised beds, each one meter by one meter, using a standard hoe. Using a local hoe, dried and ground PM and CPH were mixed into the soil and dispersed equally throughout the plots five (5) days after the area was prepared. Carrot seeds (Thema variety) were planted straight into the beds prepared a week after the organic manure was applied.

Three weeks after the carrot seedlings emerged, they were trimmed to maintain the same spacing after being drilled in rows 20 cm apart. Weeding and other cultural operations were performed three times a year for all treatments.

Soil analysis

A pre-treatment composite soil sample was extracted from the field experiment site using a soil auger. Before being processed for a standard chemical analysis of the initial soil characteristics, the sample was made up of 15 surface (0–15 cm) core samples that were bulked together, allowed to air dry, and sieved through a 2-mm mesh screen in compliance with the Association of Official Analytical Chemists' protocol (AOAC, 2000).

Yield analysis

Ten (10) carrot stands were randomly selected from each plot to estimate yield parameters. Metrics of carrot root yield were assessed at harvest according to treatment. The fresh weight of the roots per stand was determined in grams (g) using a weighing balance. The diameter of the root was measured at its fattest core part using a vernier caliper. The percentage was calculated from the total number of harvested roots after the number of forked, cracked, and rotting roots was counted separately for each treatment.

The marketable root yield was determined by dividing the total number of collected roots free of cracks, forking, deformity, and spots. The dry weight of the roots was determined by oven-drying roots to a consistent weight at 65°C.

Proximate analysis of carrot root

Fresh carrot root samples were chosen at harvest according to treatment and cleaned in tap water for proximate analysis. The Association of Official Analytical Chemists (AOAC, 2000) established criteria for evaluating moisture content, ash, crude fiber (CF), crude protein (CP), and crude fat (CF). As part of the treatment, fifty grams (50 g) of fresh carrot root samples were dried for 48 hours at 65°C in an oven. Separately, the dried samples were crushed into a powder and kept in screw-capped bottles at -5°C in the refrigerator. The Kjeldahl method was used to determine the nitrogen content, whereas the Soxhlet extraction method was used to determine the ether extract (fat) content.

The CP concentration was calculated by multiplying the nitrogen value by a factor of 6.25. Ten grams of the ground sample were dried for 48 hours at 650°C in an oven to determine the moisture content. The proportionate weight difference expressed as a percentage was the moisture content. To find out how much ash was in the sample, five grams of the ground samples were digested in a muffle furnace for six hours at 550°C. The proportionate change in weight is represented by the percentage of ash content. To find the CF, five grams of the ground materials were digested in 1.25% H_2SO_4 and 1.25% NaOH. Gravimetric analysis was used to determine the digest's CF, and the formula for nitrogen-free extract (NFE) was NFE = 100% - (% CP + % fat + CF + % Ash + % MC).

Phytochemicals analysis

The carotenoid, ascorbic acid (vitamin C), riboflavin, and phenolic acid concentrations of fresh carrot roots were assessed by phytochemical analysis on a treatment basis using the AOAC (2000) technique. The ascorbic acid concentration was determined by soaking 10g of fresh root samples in 90 ml of distilled water for an hour. The liquid was filtered and then refrigerated at -5°C. The sample filtrate was titrated using 2, 6-dichloro-indophenol in an acidic environment. The titer value was used to calculate the amount of ascorbic acid present in the carrot roots.

Using a pestle and mortar, 5 g of fresh carrot root was extracted on a treatment basis in 50 ml of 80:20 v/v acetones to determine the total carotenoids. After the extraction process, the mixture was filtered until a colorless residue was formed. Acetone was used to make fifty milliliters of the extracts. A UV-visible spectrophotometer model UV 160/version 2.40 was used to quantify the concentration of carotenoids at 440 nm after one milliliter of the extract was diluted to ten milliliters using 80:20 v/v acetones.

Results and Discussion

The physical and chemical properties of the soil at the experiment site before treatment are shown in Table 1. The somewhat acidic soil had low levels of accessible phosphorus, organic carbon, nitrogen, exchangeable magnesium (Mg), exchangeable potassium (K), exchangeable calcium (Ca), and effective cation exchange capacity (ECEC). Fe, Cu, Mn, and Zn were comparatively high micronutrients, according to Adeoye and Agboola (1985).

Table 1. Pre-treatment soil physical and chemical properties of the experimental site.

Variables	Value
Sand (g kg^{-1})	901
Silt (g kg^{-1})	55
Clay (g kg^{-1})	42
Textural class	Sandy soil
pH (H_2O) (1:2.5)	6.2
pH ($CaCl_2$) (1:5)	6.0
Organic carbon (g kg^{-1})	6.8
Total nitrogen (g kg^{-1})	0.8
Available phosphorus (mg kg^{-1})	5.0
Ca (cmol kg^{-1})	1.5
Mg(cmol kg^{-1})	0.2
Na (cmol kg^{-1})	0.4
K (cmol kg^{-1})	0.2
Exch. Ac. (cmol kg^{-1})	0.1
ECEC (cmol kg^{-1})	2.3
B. Sat (%)	97
Mn (mg kg^{-1})	15
Fe (mg kg^{-1})	19
Cu (mg kg^{-1})	2.3
Zn (mg kg^{-1})	3.2

Exch. Ac = Exchangeable acidity, ECEC – Effective cation exchange capacity, B. Sat = Base saturation

Table 2 shows the integration effect of PM, CPH, and NPK 15:15:15 fertilizer on carrot root yield characteristics. The table's data showed that both cropping seasons had a substantial ($P<0.05$) impact on carrot root yield metrics. As the degree of soil amendment integration grew, so did the root length, gross root yield, dry matter, and marketable root yield. Carrot root yield characteristics were improved more in plots where PM, CPH, and NPK fertilizers were applied together than in plots where either soil amendment was applied alone. As the three soil amendment levels rose, so did the percentage of malformed roots. Plots that received only NPK 15:15:15 fertilizer during the second cropping season saw decreased marketable and gross root yields of 10–16%. During the second cropping season, the percentage of distorted roots decreased for every combination of treatments. In the second cropping season, plots receiving only PM, CPH, and their combinations with or without NPK fertilizer showed marginally higher carrot root yield metrics. Throughout the two cropping seasons, the plots with integrated applications of 10 t ha^{-1} of PM, CPH, and 200 kg ha^{-1} NPK fertilizer yielded carrots with the highest root yield parameters, while the plots with no treatment (control) consistently had the lowest root yield features.

Carrot root yield from plots with the combined application of 5 t ha^{-1} each of PM, CPH, and 200 kg ha^{-1} NPK fertilizer did not differ significantly ($p > 0.05$) from carrot root yield from plots with the combined application of 10 t ha-1 each of PM, CPH, and 200 kg ha^{-1} NPK fertilizer. For P0CP0F0, P0CP0F100, P0CP0F200, P5CP5F100, P5CP5F200, P10CP10F100, and P10CP10F200, the corresponding mean gross root yields for the two cropping seasons were 20.50, 20.86, 21.60, 21.42, 29.9, 30.9, and 31.61 t ha^{-1}.

Table 2. Effect of poultry manure, cocoa pod husk, and NPK compound fertilizer integrations on yield characteristics of carrots.

Treatment (t ha^{-1})	Root length (cm)		Root diameter (cm)		Root dry matter (%)		Gross root yield (t ha^{-1})		Deformed roots (%)		Marketable yield (t ha^{-1})	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
P0CP0F0	8.85c	8.41c	1.31e	1.25e	7.13d	6.56c	21.35c	19.64c	0.03g	0.18f	21.34c	19.60c
P0CP0F100	9.86c	9.37b	1.43e	1.36d	8.58c	7.83c	22.55c	19.17c	0.66f	0.41e	22.40c	19.09c
P0CP0F200	10.21b	9.70b	1.51d	1.39d	9.22b	8.48b	24.00b	19.20c	1.32e	0.83d	23.68b	19.04c
P0CP5F0	10.20b	10.81b	1.44e	1.53c	8.58c	9.09b	22.00c	23.32b	0.66f	0.38f	21.85c	23.23b
P0CP5F100	10.86b	10.32b	1.67c	1.70c	9.38b	9.57b	24.20b	24.69b	2.66c	1.68b	23.56b	24.28b
P0CP5F200	10.88b	10.98b	1.75c	1.77c	10.27a	10.37a	24.45b	25.20b	1.32e	0.85d	24.62b	24.99b
P0CP10F0	9.37c	9.93b	1.49e	1.58c	10.24a	10.85a	22.40c	23.75b	0.67f	0.47e	22.24c	23.64b
P0CP10F100	10.68b	10.90b	1.84b	1.88b	10.28a	9.49b	24.50b	24.99b	2.66c	1.68b	23.85b	24.57b
P0CP10F200	11.21a	11.32b	1.91b	1.93b	9.78b	9.88a	25.05b	25.30b	1.32e	0.84d	24.72b	25.09b
P5CP0F0	9.73c	10.31b	1.41e	1.49d	9.21b	9.76a	24.70b	26.18b	2.00d	1.26c	24.21b	25.85b
P5CP0F100	11.00ab	11.22b	1.67c	1.70c	9.78b	9.98a	25.45b	25.96b	4.60a	2.81a	24.28b	25.23b
P5CP0F200	11.04ab	11.15b	1.95b	1.97b	10.10a	10.20a	26.21b	26.46b	2.00d	1.28c	25.68b	26.12b
P5CP5F0	10.24b	10.84b	1.56d	1.65c	10.21a	10.82a	25.13b	26.71b	2.40c	1.51b	24.50b	26.31b
P5CP5F100	11.76a	11.99a	1.81c	1.85b	9.57b	9.76a	27.15b	27.69ab	2.04d	1.29c	26.60a	27.33ab
P5CP5F200	11.75a	11.87a	1.90b	1.92b	10.60a	10.71a	29.75a	30.05a	2.52c	1.59b	29.00a	29.57a
P5CP10F0	10.53b	11.16b	1.50d	1.59c	10.42a	11.05a	24.80b	26.29b	2.00d	1.27c	24.30b	25.96b
P5CP10F100	11.66a	11.89a	1.70c	1.73c	9.85ab	10.04a	28.10a	28.66a	0.66f	0.52e	27.91a	28.45a
P5CP10F200	11.33a	11.44ab	1.85b	1.87b	11.10a	11.21a	28.32a	28.60a	2.00d	1.51b	27.75a	28.17a
P10CP0F0	10.02b	10.62b	1.59d	1.69c	10.21a	10.82a	24.20b	25.65b	3.32b	2.09b	23.40b	25.11b
P10CP0F100	11.71a	11.94a	1.81c	1.85b	10.31a	10.52a	27.00b	27.54ab	1.33e	0.86d	26.64a	27.30ab
P10CP0F200	12.17a	12.29a	2.06b	2.08b	10.20a	10.30a	29.00a	29.29a	2.00d	1.45b	28.42a	28.87a
P10CP5F0	12.80a	13.57a	1.66c	1.76c	9.41b	9.97a	26.65b	28.25a	2.00d	1.48b	26.12a	27.83a
P10CP5F100	13.10a	13.36a	1.75c	1.79c	10.94a	11.16a	30.15a	30.76a	1.33e	1.26c	29.75a	30.37a
P10CP5F200	13.70a	13.84a	2.09b	2.11b	10.75a	10.86a	30.50a	31.11a	2.00d	1.34c	29.89a	30.69a
P10CP10F0	10.20b	10.81b	1.73c	1.83b	9.75b	10.34a	27.45b	29.10a	2.66c	1.23c	26.72a	28.73a
P10CP10F100	11.30a	11.53a	2.55a	2.60a	10.62a	10.83a	30.60a	31.21a	4.00a	2.56a	29.38a	30.41a
P10CP10F200	11.93a	12.05a	2.50a	2.54a	10.81a	10.92a	31.45a	31.76a	4.00a	2.48a	30.16a	30.97a
SE±	1.24	1.27	0.09	0.11	1.37	1.41	5.20	5.01	0.48	0.42	4.72	4.68

Means with the same letter in a column are not significantly different at $p \geq 0.05$.

P0 = 0 t ha^{-1} PM, P5 = 5 t ha^{-1} PM, P10 = 10 t ha^{-1} PM, CP0 = 0 t ha^{-1} CPH, CP5 = 5 t ha^{-1} CPH, CP10 = 10 t ha^{-1} CPH, F0 = 0 kg ha^{-1} NPK fertilizer, F100 = 100 kg ha^{-1} NPK fertilizer, F200 = 200 kg ha^{-1} NPK fertilizer

Table 3 illustrates how the combined application of PM, CPH, and NPK fertilizer affects the proximate composition of carrot roots. The combined application of the three inputs had a substantial (P<0.05) impact on the proximate composition of carrot roots in terms of protein, fat, fiber, ash, dry matter, and NFE. Carrot roots' contents of protein, fat, ash, and dry matter rose as the rates of the combined inputs increased, but their fiber and NFE contents fell as the rates of the treatments increased. The lowest amounts of protein, fat, ash, and dry matter were found in carrot roots from control plots.

These differences were significant ($P < 0.05$) for carrot roots treated with 10 t ha-1 of PM, CPH, and 200 kg ha-1 of NPK fertilizer but not significant ($P < 0.05$) for carrot roots treated with 5 t ha-1 of PM, CPH, and 200 kg ha-1 of NPK. The protein, ash, fat, and dry matter content of carrot roots in plots with combined treatments of PM and CPH, with or without NPK fertilizer, was higher than that of carrot roots in plots with only one application.

Table 3. Effect of poultry manure, cocoa pod husk, and NPK 15:15:15 fertilizer integration on proximate composition of carrot root.

Trt	Protein		Fat		Fibre		Ash (%)		Moisture		Dry matter		NFE	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
P0CP0F0	0.37f	0.36f	0.24f	0.23e	1.64c	1.55a	0.41g	0.38e	86.00a	88.16a	9.84d	9.84c	11.35a	9.32a
P0 CP0F100	0.39f	0.39e	0.27e	0.26d	1.40d	1.36c	0.46f	0.44d	86.74a	89.20a	9.34d	9.54c	10.74a	8.35b
P0 CP0F200	0.40f	0.41e	0.25e	0.25d	1.37e	1.32c	0.46f	0.46d	87.08a	89.02a	9.25d	9.80c	10.44b	8.55a
P0 CP5F0	0.56d	0.47d	0.32d	0.26d	1.84a	1.51a	0.75c	0.62c	86.09a	89.02a	11.26b	9.73c	10.44b	8.12b
P0 CP5F100	0.55d	0.49d	0.39c	0.34b	1.58c	1.40b	0.75c	0.66b	86.81a	89.32a	11.10b	10.34a	9.92b	7.80c
P0 CP5F200	0.57d	0.52c	0.29e	0.26d	1.62c	1.48b	0.82b	0.75a	87.50a	88.72a	11.23b	10.78a	9.20c	8.27b
P0 CP10F0	0.58d	0.48d	0.37c	0.30c	1.85a	1.52a	0.77c	0.63b	86.69a	88.44a	11.21b	9.68c	9.74c	8.63a
P0 CP10F100	0.63c	0.55c	0.35d	0.31c	1.76b	1.56a	0.71c	0.63b	87.81a	89.38a	10.88c	10.14b	8.74d	7.57c
P0 CP10F200	0.58d	0.54c	0.36c	0.32c	1.73b	1.51a	0.75c	0.68b	87.88a	88.96a	11.04b	10.59a	8.71d	7.93c
P5CP0F0	0.54d	0.46d	0.33d	0.20e	1.88a	1.50a	0.56e	0.46d	86.88a	89.00a	10.50c	9.94c	9.81b	8.41b
P5 CP0F100	0.53e	0.47d	0.33d	0.29c	1.82a	1.61a	0.64d	0.57c	87.46a	89.53a	11.03b	10.28b	9.21c	7.53c
P5 CP0F200	0.51e	0.48d	0.38c	0.34b	1.54c	1.41b	0.76c	0.69b	87.22a	89.12a	10.94c	10.50a	9.59c	7.97c
P5 CP5F0	0.64c	0.34f	0.35d	0.28d	1.85a	1.49b	0.71c	0.58c	87.64a	89.17a	10.14c	10.49a	8.82d	8.13b
P5 CP5F100	0.76b	0.60b	0.49a	0.39a	1.80a	1.43b	0.87a	0.70b	87.03a	89.28a	12.90a	10.85a	9.05d	7.60c
P5 CP5F200	0.84a	0.68a	0.46a	0.38a	1.65c	1.36c	0.91a	0.74a	87.67a	89.16a	12.50a	10.79a	8.47d	7.68c
P5 CP10F0	0.73b	0.55c	0.52a	0.39a	1.69b	1.27d	0.83b	0.62c	86.73a	88.86a	12.84a	10.21b	9.49c	8.31b
P5 CP10F100	0.73b	0.62b	0.43b	0.36b	1.58c	1.29d	0.80b	0.66b	87.99a	89.67a	12.59a	10.85a	8.47d	7.40d
P5 CP10F200	0.80a	0.67a	0.49a	0.40a	1.69b	1.39c	0.90a	0.73a	87.43a	89.26a	11.46b	10.75a	8.69d	7.55c
P10CP0F0	0.56d	0.46c	0.32d	0.26d	1.45d	1.42b	0.71c	0.59c	87.80a	89.60a	11.68b	10.08b	9.44c	7.68c
P10 CP0F100	0.62c	0.55c	0.39c	0.32c	1.48d	1.31c	0.71c	0.63b	87.09a	88.56a	10.95c	10.22b	9.71c	8.63a
P10 CP0F200	0.64c	0.59b	0.36c	0.32c	1.42d	1.29d	0.81b	0.74a	87.70a	88.00a	10.67c	10.23b	9.07d	9.11a
P10 CP5F0	0.66c	0.50d	0.50a	0.37b	1.43d	1.39c	0.72c	0.57c	87.50a	88.58a	13.19a	10.44a	9.37c	8.59a
P10 CP5F100	0.76b	0.60b	0.43b	0.34b	1.78b	1.39c	0.87a	0.69b	87.33a	89.24a	12.90a	10.85a	8.83d	7.74c
P10 CP5F200	0.70b	0.62b	0.44b	0.36b	1.67b	1.37c	0.87a	0.70b	88.32a	89.43a	12.26a	10.59a	7.99e	7.53c
P10 CP10F0	0.75b	0.56c	0.46a	0.34b	1.90a	1.42b	0.85b	0.64b	87.16a	89.19a	13.65a	10.81a	8.89d	7.84c
P10 CP10F100	0.84a	0.67a	0.47a	0.31b	1.56c	1.24d	0.87a	0.70b	88.75a	89.31a	12.93a	10.87a	7.51e	7.71c
P10 CP10F200	0.89a	0.73a	0.51a	0.42a	1.58c	1.30c	0.95a	0.78a	88.35a	89.37a	12.53a	10.82a	7.71e	7.41d
SE+	0.04	0.05	0.02	0.02	0.02	0.03	0.02	0.02	0.41	0.34	0.29	0.27	0.47	0.35

Means with the same letter in a column are not significantly different at $p \geq 0.05$.

P0 = 0 t ha-1PM, P5 = 5 t ha-1 PM, P10 = 10 t ha-1 PM, CP0 = 0 t ha-1 CPH, CP5 = 5 t ha-1 CPH, CP10 = 10 t ha-1 CPH, F10 = 0 kg ha-1 NPK fertilizer, F100 = 100 kg ha-1 NPK fertilizer, F100 = 200 kg ha-1 NPK fertilizer. NFE = Nitrogen free extract, Trt = Treatment

Table 4. Lists the phytochemicals found in carrot roots. The combined application of PM, CPH, and NPK fertilizer had a substantial ($P<0.05$) impact on the phytochemicals in carrot roots, namely the amounts of vitamin C, carotene, riboflavin, and phenolic acid. Plots with the integrated application of PM and CPH with or without NPK fertilizer exhibited considerably ($P < 0.05$) higher vitamin C, carotene, riboflavin, and phenolic acid levels than the control plots. The highest phytochemical concentrations were found in carrot roots from plots that received integrated applications of 200 kg ha-1 NPK fertilizer, 10 t ha-1 PM, and CPH fertilizer. Plots with the combined application of PM, CPH, and NPK fertilizer and plots with the single treatment of PM, CPH, and their mixtures showed marginal increases in phytochemical content during the second cropping season. Plots that received only NPK 15:15:15 fertilizer during the second cropping season showed decreased phytochemical levels.

Table 4. Effect of poultry manure, cocoa pod husk, and NPK compound fertilizer integration on phytochemical compounds of carrot roots.

Trt	Vitamin C		Carotenoid mg/100g		Riboflavin		Phenolic	
	2023	2024	2023	2024	2023	2024	2023	2024
P0CP0F0	3.92f	3.69g	3.57f	3.75g	0.02c	0.02d	17.91f	16.91f
P0 CP0F100	4.26f	3.94g	3.97f	4.19f	0.02c	0.02d	18.92e	17.82e
P0 CP0F200	4.12f	4.04g	4.35e	4.58f	0.02c	0.02d	19.63e	18.61e
P0 CP5F0	4.44e	4.66f	4.84e	5.10e	0.02c	0.02d	16.81f	17.82e
P0 CP5F100	4.65e	4.88e	6.13d	6.43c	0.02c	0.03c	25.32b	26.61c
P0 CP5F200	4.64e	5.25e	6.12d	6.44c	0.03b	0.03c	26.12b	27.42b
P0 CP10F0	6.02c	6.34c	5.48d	5.77d	0.03b	0.03c	22.91d	24.13c
P0 CP10F100	6.58c	6.93c	6.36c	6.69c	0.03b	0.03c	24.92c	26.21c
P0 CP10F200	6.73b	7.18b	7.02c	7.39b	0.03b	0.03c	27.81b	29.82b
P5CP0F0	4.53e	4.75e	4.42e	4.66f	0.02c	0.02d	17.42f	17.71e
P5 CP0F100	4.60e	5.21e	5.58d	5.88d	0.0.3b	0.03c	19.52e	20.42d
P5 CP0F200	4.89e	5.15e	6.19d	6.52c	0.02c	0.03c	20.23d	21.32d
P5 CP5F0	5.48d	5.81d	6.52c	6.86c	0.03b	0.02d	22.61d	23.81c
P5 CP5F100	6.78b	6.76c	7.01c	7.38b	0.04a	0.03c	27.82b	29.13b
P5 CP5F200	7.14b	7.55b	7.95b	8.43a	0.04a	0.04b	29.52a	31.22a
P5 CP10F0	6.58c	6.97c	6.42c	6.76c	0.03b	0.03c	26.81b	28.21b
P5 CP10F100	7.28b	7.64b	7.42b	7.81b	0.04a	0.04b	30.62a	32.22a
P5 CP10F200	7.30b	7.69b	7.00c	7.37b	0.04a	0.04b	30.81a	32.51a
P10CP0F0	4.09f	4.30f	4.94e	5.20e	0.02c	0.02d	21.42d	22.52d
P10 CP0F100	4.63e	4.87e	5.79d	6.10d	0.02c	0.03c	23.23c	24.41c
P10 CP0F200	5.82d	6.13d	6.04d	6.37c	0.03b	0.03c	24.22c	28.42b
P10 CP5F0	6.76b	7.19b	6.93c	7.29b	0.03b	0.03c	25.91b	27.41b
P10 CP5F100	6.88b	7.24b	7.48b	7.87b	0.03b	0.04b	27.32b	28.82b
P10 CP5F200	7.16b	7.61b	7.30b	7.68b	0.04a	0.04v	29.91a	31.51a
P10 CP10F0	6.70b	7.08b	6.62c	6.97b	0.03b	0.03c	26.92b	28.42b
P10 CP10F100	8.28a	8.72a	8.16a	8.50a	0.04a	0.04b	29.91a	31.42a
P10 CP10F200	9.09a	9.60a	9.17a	9.64a	0.04a	0.05a	30.92a	32.32a
SE+	0.36	0.40	0.36	0.37	0.002	0.002	0.47	0.57

Means with the same letter in a column are not significantly different at p ≥ 0.05.

P0 = 0 t ha⁻¹ PM, P5 = 5 t ha⁻¹ PM, P10 = 10 t ha⁻¹ PM, CP0 = 0 t ha⁻¹ CPH, CP5 = 5 t ha⁻¹ CPH, CP10 = 10 t ha⁻¹ CPH, F10 = 0 kg ha⁻¹NPK fertilizer, F100 = 100kg ha⁻¹NPK fertilizer, F100 = 200 kg ha⁻¹ NPK fertilizer. NFE = Nitrogen free extract, Trt = Treatment.

Discussion

The soil's nutrient status at the field experiment site is insufficient in quantity to meet the criteria for a high crop yield, according to Adeoye and Agboola's (1985) critical level of nutrients for the development of arable crops in southwest Nigeria. Carrots need an additional source of plant nutrients from outside sources to thrive. The considerable farming that took place there and the sandy soil, which would have encouraged the leaching of the exchangeable bases, could both contribute to the site's poor nutritional condition. The high quantities of micronutrients at the site could be due to the acidic state of the soil.

The root yield characteristics of carrots increased in tandem with the rates of inputs. The beneficial response of carrots in terms of root yield characteristics may be due to the low initial nutritional status of the soil at the study site.

The findings of Idem *et al.* (2012) in a similar vegetable crop align with our results. PM, CPH, and NPK fertilizer use boosted root yield. Their study showed crops respond better to fertilizer in nutrient-poor soils than in nutrient-rich ones. The higher yield in plots with combined PM, CPH, and NPK fertilizers might stem from the nutrients these inputs released into the soil for crops to use. This idea matches what Ahmed *et al.* (2014) and Khairul *et al.* (2015) thought.

They suggested that the balanced nutrition from inorganic fertilizer and organic manure could explain the improved carrot growth in plots where both were applied together.

The drop-in carrot production during the second cropping in NPK-plots shows NPK fertilizer's weak lasting effect. It couldn't support long-term carrot growth because inorganic fertilizer tends to leach in sandy soils. The poor carrot yield in areas treated with PM or CPH during the initial growing season shows that their use alone doesn't boost carrot production. Still better carrot root yield signs in the second growing season point to their ability to improve soil health over time. These outcomes matched the low nutrient levels, slow nutrient release, and soil mixing of PM and CPH. This explains why organic manure's fertilizing effects last longer than store-bought fertilizers.

The number of shaped roots increased as PM, CPH, and NPK fertilizer amounts increased. This might be due to the better soil moisture and nutrient levels in the changed plots. The higher rate of shaped roots could stem from more biological action in the soil, which may link to the higher moisture and nutrient levels. This idea fits with Khairul *et al.* (2015)'s discovery that the rate of shaped roots went up in chicken manure-treated plots with higher N levels. No treatment was used to increase biological activity, which might have caused root deformity. This could explain why the second cropping season had fewer deformed roots than the first. The high rates of the amendments helped to lower crude fiber and boost crude protein, fat, ash, and dry matter. Adding nutrients to the soil for the carrot seedlings may have led to these benefits. It increased the amounts of crude protein, fat, ash, and dry matter while decreasing the quantity of crude fiber in the carrot roots. The roots from plots treated with PM CPH and their combinations had higher levels of protein, fat, ash, and dry matter than those treated with NPK fertilizer. This shows that carrot roots from organic manured plots are of higher quality than those treated with inorganic fertilizers. As a result, carrot roots from organic manured plots seem to have a higher nutritional density than those from inorganic manured plots. The proximal composition values matched the range of values reported by other researchers (Olalude *et al.*, 2015; Wakili *et al.*, 2015; Megueni *et al.*, 2017).

Research by Gatsinzi *et al.* (2016) substantiates the discovery that carrot roots from plots enriched with PM and CPH combinations exhibit greater protein, fat, ash, and dry matter content than roots from plots treated with NPK fertilizer. Rahman *et al.* (2018), and Ingrid *et al.* (2020). Research results showed that carrot roots from PM, CPH, and NPK-treated plots exhibited decreased NFE concentrations compared to control plots, which matches the findings of Zakir *et al.* (2010) and Alice *et al.* (2014). Carrot roots grown in organic manured plots exhibit higher amounts of vitamin C, carotene, and phenolic acid than those grown in inorganic manured plots, pointing towards organic manured carrots being more beneficial for human health. Research conducted by Vinha *et al.* (2014) demonstrated that carrot roots grown in organic manured plots contained more vitamin C, carotenoids, and phenolic acid than roots grown in plots that only received NPK fertilizer.

The phytochemical values observed in the study reflect multiple factors beyond treatment differences, which include crop maturity during harvest and weather conditions before and after harvest, along with analytical techniques, storage conditions, and extraction materials (Ingrid *et al.*, 2020). To increase carrot root yield sustainably, poultry manure, cocoa pod husk, and NPK 15: Using poultry manure combined with cocoa pod husk and NPK 15:15:15 together is an effective alternative to solely using inorganic fertilizer. Combining organic and inorganic nutrient sources benefits both carrot production and nutritional quality.

Conclusion

It has been shown from the research that using a complementary technology package (inorganic and organic nutrient sources) helped the cultivation of crops and soil management, as it significantly enhances both the yield and nutritional quality of carrots cultivated in the tropical region of Nigeria. Apart from the increased root development that the integrated approach is giving to carrot production, there is also improvement in soil fertility and structure, higher yield for economic progress, and nutrient composition of essential minerals such as beta-carotene, vitamin C, and more. The output underscores the essence of utilizing soil fertility that is holistically sustainable in a particular agricultural zone.

Leveraging this joint complementary innovation, carrot farmers will navigate the limitation of soil nutrients and achieve improved productivity and good-quality carrot production. The study concluded that when correctly applied, a well-organized addition of technologies can be used as a viable strategy to improve carrot production while maintaining environmentally friendly approaches.

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