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Influence of Different Rates of Fertilizer and Biochar on Growth and Yield of Carrot *(Daucus carota)* in the Forest-Savannah Transitional Zone of Ghana

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Authors' contributions

This is a collaborative work involving all authors. Author KA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MEE and JMA managed the analyses of the study. Author MEE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Two field studies to evaluate the effect of biochar and fertilizer application rates on soil and on the growth and yield of carrot (*Daucus carota*) were carried out in 2016 and 2017 at Mampong-Ashanti in the forest-savannah transitional zone of Ghana. Three rates of biochar - 0, 5 and 10 tons ha^{-1} and five rates of inorganic fertilizers - NPK 15:15:15 at 200 kg ha^{-1}; P&K 50:50 at 50 kg ha^{-1}; P&K 50:100 at 50 kg ha^{-1}; Liquid Fertilizer at 1 L: 200 L water ha^{-1}; and the control - were applied using 3×5 factorial arranged in a randomized complete block design with 3 replicates. The analysis showed significant ($P<0.01$) interaction of fertilizer × biochar on bulk density, soil porosity, soil pH, organic carbon, total nitrogen and organic matter producing both positive and negative correlations between the soil variables and on total yield, partitioning coefficient and net assimilation rate. The significant two-way interactions and correlation results underscored the need to define expected production outcomes to inform which soil management system is needed to promote sustainable agriculture as different fertilizer and biochar rates affect growth and yield parameters differently.

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Keywords: Biochar; crop growth rate; fertilizer; net assimilation rate; partitioning coefficient; sustainable agriculture.

1. INTRODUCTION

The relevance of vegetable production to food security and improved nutrition cannot be underrated. Apart from stem and root elongation and thickening of carrot (*Daucus carota* L.) there is also an active synthesis of sucrose and β-carotene [1] which allow for effective examination of the relationships between and among climate variability, soil physicochemical properties, crop growth and yield [2]. This largely is due to its top and underground growth responses. An understanding of these relationships can help define and manage soil and crop systems for sustainable agriculture, agriculture-associated climate change mitigation and adaptation and food systems improvement.

The operationalization of the sustainable agricultural principles embedded in the Sustainable Development Goal (SDG) 2 of the United Nations' Agenda 2030's and the African Unions' Agenda 2063 remains elusive even after some years of implementation. This is particularly notable in the vegetable sector where the top soil has to be loosened, beds prepared and fertilizers applied. Most lands under vegetable production have, thus, been degraded along with surrounding water bodies over a few years of production.

Carrots generally respond well to both organic and inorganic fertilizers. However, on a global scale, the use of inorganic fertilizers notably nitrogen and phosphates stress the rhizosphere, aquatic and atmospheric environments including causing soil acidification, increased agriculture-associated greenhouse gas (GHG) emissions and increased eutrophication of water bodies beyond planetary boundaries [3]. On the other hand excessive amounts of soil organic matter has been found to promote forking, reduce market acceptability and consequently reduce profitability of carrots [4]. A practice that holds much prospect for soil productivity, market acceptability, soil carbon stock improvement and in keeping pace with planetary boundaries, among others is amendment of soil with biochar [4].

In the forest-savannah transitional zone of Ghana where vegetables, especially carrots, are grown commercially by most farmers, production experience among farmers are associated with soil fertility losses and high cost of irrigation during climate-induced drought and soil fertility losses from leaching, erosion and volatilization. This is due largely to limited technical information on soil management to guarantee sustainable vegetable production within the ecological zone. This has resulted in limited extension services to vegetable farmers on the soil management and crop production phases of the vegetable value chain. Practices such as slash and burn continue to reduce soil carbon stock and also expose top soil to erosion. There is minimal understanding of how different fertilizer rates interact with soil constituents and the feasibility of biochar in contributing to soil physicochemical properties, crop growth and yield parameters. It is based on these constraints that an experiment was conducted to explore the influence of different rates of fertilizer and biochar on soil and on the growth and yield of carrot in the forest-savannah transitional zone of Ghana.

2. MATERIALS AND METHODS

2.1 Experimental Site and Design

Two experiments were carried out in the minor (2016) and major cropping seasons (2017) at Asante Mampong located in the Forest-Savannah transitional zone of Ghana (Lat. 07º, 04'N; Long. 01º, 24'W) [5,1]. Total rainfall for the minor and major cropping seasons of 2016 and 2017 respectively were 681.6 mm and 791.4 mm while the average relative humidity for the minor and major were 79.6% and 80.1%. The minor cropping season had maximum and minimum average temperatures of 29.06°C and 22.82°C.

The experimental design was a 5 x 3 factorial experiment arranged in a randomized complete block design comprising five levels of fertilizer (NPK 15:15:15, P & K 50: 50, P&K 50:100, liquid fertilizer and the control) and 3 levels of biochar (0 ton ha^{-1}, 5 tons ha^{-1} and 10 tons ha^{-1}) and replicated three times.

2.2 Land and Biochar Preparation

The land was prepared, ploughed, harrowed, leveled and laid out on a field size of 26 m x 10 m. Beds measuring 2 m x 1.2 m were raised to 25 cm height and re-leveled. The path left between each bed and between each block was 1.0 m and 2.0 m respectively.

NPK was applied at 200 kg ha^{-1} while liquid fertilizer was applied at 1 dm^3 DI Grow to 200 dm^3 of water. A domed heap anoxic reactor of 5 m diameter and 2.5 m height was prepared purposefully for the biochar with woody branches of avocado biomass pyrolyzed at about 500°C. The charred biomass was crushed, milled to < 2 mm sized particles and applied a week after bed preparation by mixing with the soil at 10 cm deep and left for two weeks before planting.

2.3 Fertilizer Application

NPK 15:15:15 was applied at 200 kg ha^{-1} as practiced by majority of carrot growers in the Asante Mampong Municipality at 2 weeks after planting. Hence, for beds measuring 2.4 m^2 a proportional amount of 48 g of the NPK was applied via side dressing 3 cm to the established seedlings.

The fertilizer rate of 50 kg ha^{-1} P and 50 kg ha^{-1} K was prepared from 2 straight fertilizers-triple supper phosphate (CaH_2PO_4) containing 45% active ingredient and muriate of potash (KCl) containing 50% of the active ingredient. The fertilizer rate was calculated from the formula:

$$Amount\ of\ Fertilizer\ in\ kg/ha = \frac{Required\ Rate\ of\ Active\ Ingredient\ in\ kg/ha}{Percentage\ proportion\ of\ Active\ Ingredient\ in\ product}$$

For 50 kg ha^{-1} CaH_2PO_4 at 45% Active Ingredient,

$$Amount\ of\ P\ Fertilizer\ in\ kg/ha = (50kg/ha)/(0.45) = 111.1\ \mathrm{kg/ha}$$

Hence, 50 kg ha^{-1} CaH_2PO_4 produces 111.1 kg ha^{-1} which translates into 26.7g for the 2.4 m^2 bed.

Again, for the 50 kg ha^{-1} KCl at 50% active ingredient,

$$Amount\ of\ K\ Fertilizer\ in\ kg/ha = (50\ kg/ha)/(0.50) = 100\ \mathrm{kg/ha}$$

Hence, 50 kg ha^{-1} KCl at 50% active ingredient translates into 100 kg ha^{-1} of the whole product including fillers and 24 g for the 2.4 m^2 plot.

The CaH_2PO_4 and KCl were applied by side – dressing 2 weeks after planting at 3 cm from seedlings.

From the calculation above, the rate of application of P was maintained at 50 kg ha^{-1} translating into 26.7 g for 2.4 m^2. Since muriate of potash (KCl) contains 50% active ingredient, the 100 kg ha^{-1} rate of the KCl was calculated thus;

$$Amount\ of\ K\ Fertilizer\ in\ kg/ha = (100\ kg/(ha))/(0.50) = 200\ \mathrm{kg/ha}$$

Hence, 200 kg ha^{-1} K translates into 48 g of the fertilizer product for each 2.4 m^2 plot receiving K at rate 100 kg ha^{-1} active ingredient of K.

D.I. Grow, a foliar fertilizer with active ingredients: Nitrogen, P_2O_5, K_2O, Mg, Fe, Mg, Cu, Zn, B, Mo, Humic Acid in percentage proportions of 1.85, 1.85, 3.31, 0.49%, 742 ppm, 587 ppm, 105 ppm, 383 ppm, 43 ppm, 76 ppm, 0.68% respectively was applied to respective treatments. A recommended dilution rate of 1 liter D.I. Grow to 200 liters of water for 1 hectare was used.

2.4 Planting and Cultural Practices

Chantenay variety of carrot seeds was obtained from Chinese Woman Agrochemical Shop in Kumasi and were sown by drilling to a depth of about 2 cm at 30 cm between rows on beds covered with grass straw. The grass straw was removed 6 days after planting during which time emergence had occurred. Seedlings were thinned to 10 cm within plants at 12 days after planting. There were 4 rows per plot and 20 plants per row.

Watering was done once daily except when it rained. A fitted watering can per plot was applied up to 21 days after sowing (DAS) and was gradually increased to two watering cans per plot at establishment. Each plant received the same quantity of water. Weeds were hand-picked. The paths between the blocks and plots were weeded with cutlass and hoe three times during the experiment in both cropping seasons.

Earthing up was done every two weeks after weeding to cover exposed roots. The inter-row spaces were stirred up with hand fork at two weekly intervals throughout the growing period to improve soil aeration and consequently enhance growth of the crop.

2.5 Sampling and Data Collection

Initial soil samples were randomly taken at a depth of 0-15 cm for analysis a week to treatment application. Six weeks after assigning treatments, soil samples were taken from all the 15 treatment plots in each block and mixed thoroughly treatment by treatment before a sample was taken to represent each treatment for the analysis.

2.5.1 Soil physical properties

Data on bulk density, volumetric moisture content, gravimetric moisture content and total porosity were determined using methods described in [6]. Bulk density was taken two weeks after biochar application. The soil samples were taken by driving aluminum core sampler of known volumes into the soil at 0-15 cm depth. Samples taken from each plot were then oven-dried at 105°C to a constant weight. It was calculated using the relation;

$$Bulk\ density\ = \frac{Weight\ of\ undisturbed\ oven\ dry\ soil}{Volume\ of\ Soil}$$

Soil porosity was determined using the formula

$$f = \frac{1 - BD}{PD} X100$$

Where, f = Total porosity; BD = bulk density; PD = particle density = 2.65 g/cm^3

Gravimetric method [7] was used to determine the moisture content. Samples of soil weighing about 100 g were taken randomly from the various plots on the site at 0- 15 cm depth using the core sampler. The samples were weighed before subjecting them to oven drying at 105°C for 24 hours. These were weighed again after oven drying. Gravimetric moisture was then calculated by using the formula as follows;

$$(\theta)g = \frac{M1-M2}{M2} \text{ x } 100$$

Where, θ g is soil gravimetric moisture; M_1 is the weight of soil before oven drying; M_2 is the weight of soil after oven-drying.

2.5.2 Soil chemical analysis

Initial soil samples were taken from all the treatment plots in each block and mixed thoroughly treatment by treatment before a sample was taken to represent each treatment for the analysis. Soil samples from each treatment and replication were bulked, air dried and sub-sampled for analysis at the Soil Research Institute of CSIR, Kumasi before planting. Soil samples were also taken again six weeks after soil amendment by which time decomposition and mineralization had taken place as prescribed by Samuel and Ebenezer [8]. Soil pH was measured using a glass electrode (pH meter) in accordance with the methods described in [5]. Soil organic matter, available phosphorus, potassium, exchangeable cations, calcium, magnesium, potassium, sodium and Effective Cation Exchange Capacity (ECEC) were determined using procedures reported in [5].

2.5.3 Plant sampling and measurement

Carrots were harvested 12 weeks after planting from 15 plots of 1.2 m^2 each for three replications. Thirty six plants from the two middle rows of each plot were harvested and separated into root and vegetative parts and their separate weights taken for estimation of the harvest index as the ratio of the root yield to the total plant biomass yield as described by Agegnehu et al. [9].

2.6 Physiological Parameters

Physiological parameters considered were crop growth rate (shoot, root, and total biomass), partitioning coefficient, net assimilation rate, and relative growth rate.

2.6.1 Crop growth rate (CGR)

The mean crop growth rate for shoot (CGR_{shoot}), root (CGR_{root}) and total biomass (CGR_{total}) were determined from the formula below as used by Baumann et al. [10];

$$CGR = \frac{1}{GA} X (\frac{W2 - W1}{T2 - T1})$$

Where CGR=Crop growth rate; GA=Ground Area; W1=Initial Dry Weight of Plant or plant part; W2=Final Dry Weight of Plant or plant part; T1=Initial Time in terms of weeks after planting; T2= Final Time in weeks after planting

2.6.2 Partitioning coefficient

The partitioning coefficient expresses the efficiency in conversion of assimilate to economic yield i.e. root in the case of carrot. This was determined as the ratio of CGR_{root} to CGR_{total} [10].

2.6.3 Net assimilation rate (NAR)

Net assimilation rate (NAR) also known as Unit Leaf Rate, represents the net gain in assimilates, mostly photosynthetic, per unit leaf area and time

[11]. The mean NAR was determined from the formula as follows;

$$NAR = \left(\frac{W2 - W1}{T2 - T1}\right) X \left(\frac{InLA2 - InLA1}{LA2 - LA1}\right)$$

Where NAR=Net Assimilation Rate; W1=Initial Dry Weight; W2=Final Dry Weight; T1=Initial Time; T2=Final Time (in weeks after planting); LA1 and LA2=Initial and Final Leaf Area respectively

2.6.4 Relative growth rate (RGR)

In order to determine the dry weight increase in the 12-week harvest interval in relation to the initial weight, the classical approach [12,13] was used to determine the relative growth rate (RGR). Five tagged plants from the middle row of each plot were selected after germination during the first week and at the end of the 12th week during harvest. The mean RGR was determined from the formula as follows;

$$RGR = \frac{InW2 - InW1}{T2 - T1}$$

Where RGR=Relative Growth Rate; W1=Initial Dry Weight; W2=Final Dry Weight; T1=Initial Time Period (in weeks after planting); T2=Final Time Period (in weeks after planting).

2.7 Data Analysis

Experimental data collected were analyzed by Analysis of Variance (ANOVA) using Version 11.1 of GenStats software package (2008). Standard Error of differences of means obtained were used at 5% level. Soil data analysis was also carried out. Correlation analysis was carried out on soil physicochemical properties, growth and yield parameters. Correlation magnitude of 0-1 where categorizations are made for low, medium, high and perfect correlation as $\leq$0.30, $\geq$0.31-0.51, $\geq$0.51-0.85 and $\geq$0.86-1 respectively regardless of the sign employed.

3. RESULTS AND DISCUSSION

3.1 Background Soil Chemical Properties at Experimental Site

Table 1 indicates the background soil condition during the minor and major growing seasons in 2016 and 2017 respectively. The soil used in 2016 was moderately acidic (5.72) while that of 2017 was acidic. The organic matter content of the soil used in 2016 was moderate but that of the 2017 was low. The Nitrogen content of both soils used was moderate but those of calcium, magnesium and potassium were low. This could be due to nutrient loss from years of leaching and crop cultivation. Similar to observations reported in [14] effective cation exchange capacity for both growing seasons were found to be low.

3.2 Effect of Fertilizer and Biochar on Soil Physical Characteristics

Interactions between fertilizer and biochar on gravimetric moisture content was not significant (Table 2). However, there were significant fertilizer-biochar interaction on bulk density and soil porosity. For example, with the application of 200 kg ha^{-1} NPK 0 ton ha^{-1} biochar produced a significantly and consistently higher bulk density among biochar treatments while 5 and 10 tons ha^{-1} produced lower bulk density. With the application P & K 50:50, 10 tons ha^{-1} biochar significantly reduced the bulk density while 5 tons ha^{-1} biochar marginally increased bulk density. With the application of P&K 50:100, 5 tons ha^{-1} does better than 10 tons ha^{-1} in reducing bulk density. Additionally, since liquid fertilizer is applied mostly to the plant, 10 tons ha^{-1} significantly reduced bulk density compared to 5 tons ha^{-1} similar to the observation under no fertilizer environment. Hence, although a physical soil parameter, bulk density can be influenced by both biochar and fertilizer at different rates. Brantley et al. [15] argue that biochar use among farmers can reduce the cost of irrigation and increase profitability among farmers.

Giving that the pre-planting gravimetric moisture content, bulk density and soil porosity were 19.47%, 1.33 g cm^{-3} and 49.96% respectively, the post-planting parameters showed different effects with differences in fertilizer and biochar rates.

According to Bittelli [7], the more compact the soil is the less suitable it becomes for crop production as compaction reduces the amount of disposable oxygen for microbial activities, retards root penetration, water infiltration and plant growth in general. For roots and tuber crops, higher bulk density is associated with reduced yield. Satriawan and Handayanto [16] and Mukherjee et al. [17] made similar observations.

3.3 Effect of Fertilizer and Biochar on Soil Chemical Characteristics

From Tables 3 and 4, there were significant ($P < 0.01$) interaction effect between fertilizer and biochar on soil pH, organic carbon, total nitrogen and organic matter. For example, with the application of 200 kg NPK ha-1 there was a significant increase in soil pH with 10 tons ha^{-1} biochar followed by 0 ton ha^{-1} biochar and 5 tons ha^{-1} biochar. With P&K 50:50, 5 and 10 tons ha^{-1} biochar produced a significantly higher and similar pH value. In P&K 50:100 environment, the pattern of interaction of biochar on pH was 10 tons ha^{-1} biochar > 5 tons ha^{-1} biochar > 0 ton ha^{-1} biochar. Liquid fertilizer plots had a similar performance with P&K 50:100. Under no fertilizer environment, pH results for 0, 5 and 10 tons ha^{-1} biochar were approximately equal during the minor cropping season (Table 3).

During the major cropping season (Table 4), 0 and 10 tons ha^{-1} biochar produced a significant increase in pH while 5 tons ha^{-1} biochar significantly reduced the pH with the application of 200 kg NPK ha^{-1}. With the application of P&K 50:50, biochar response pattern to soil pH was 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 5 tons ha^{-1} biochar. Under P&K 50:100 biochar response pattern to soil pH was 5 tons ha^{-1} biochar > 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar. Under liquid fertilizer environment, 10 tons ha^{-1} biochar increased soil pH while 5 and 0 ton ha^{-1} biochar significantly reduced soil pH. Under no fertilizer environment, there was a significant increase in soil pH with the application of 10 tons ha^{-1} biochar while 0 and 5 tons ha^{-1} biochar reduced soil pH.

In terms of organic carbon, 200 kg NPK ha^{-1} environment produced similar content with the application of 0, 5 and 10 tons ha^{-1} biochar. P&K 50:50 environment produced a lower organic carbon with the application of 0 ton ha^{-1} biochar. 5 and 10 tons ha^{-1} biochar gave a higher and similar soil organic carbon content. However, with the application of P&K 50:100, 5 tons ha^{-1} biochar produced a significantly higher organic carbon content than 10 and 0 ton ha^{-1} biochar. The pattern of interaction of biochar on soil organic carbon with the application of liquid fertilizer revealed 5 tons ha^{-1} biochar > 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar. Under no fertilizer environment, biochar's influence on soil organic carbon shows 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 5 tons ha^{-1} biochar during the minor cropping seasons (Table 3).

During the major cropping season (Table 4), application of 200 kg ha^{-1} NPK produced different soil organic carbon with different rates of biochar as follows; 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 5 tons ha^{-1} biochar. On the other hand with the application of P&K 50:50 and P&K 50:100 there were no significance in 5 and 10 tons ha^{-1} biochar on soil organic carbon in spite of the significant increase in organic carbon from 5 and 10 tons ha^{-1} biochar over 0 ton ha^{-1} biochar. Under liquid fertilizer environment, organic carbon response to biochar showed 10 tons ha^{-1} biochar > 5 tons ha^{-1} biochar = 0 ton ha^{-1} biochar. Under no fertilizer environment, organic carbon response to biochar was 5 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 10 tons ha^{-1} biochar.

With the application of 200 kg ha^{-1} NPK nitrogen content of soil remained the same with the application of 0, 5 and 10 tons ha^{-1} biochar. However, when P&K 50:50 was applied, 5 and 10 tons ha^{-1} biochar gave the same nitrogen content which was significantly higher than 0 ton ha^{-1} biochar. With P&K 50:100, nitrogen content decreased significantly with the application of 0 and 10 tons ha^{-1} biochar and increased significantly with the application of 5 tons ha^{-1} biochar. When liquid fertilizer was applied, 5 tons ha^{-1} biochar > 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar in making nitrogen available in soils. Under no fertilizer environment, 0 ton ha^{-1} biochar > 10 tons ha^{-1} biochar > 5 tons ha^{-1} biochar in the presentation of nitrogen in soil solution during the minor cropping season (Table 3).

During the major cropping season (Table 4) with the application of 200 kg ha^{-1} NPK, P& K 50:50 and P&K 50:100 total nitrogen gave the same response with the application of biochar where 0 ton ha^{-1} biochar > 5 tons ha^{-1} biochar> 10 tons ha^{-1} biochar. Under liquid fertilizer environment, 5 tons ha^{-1} biochar=0 ton ha^{-1} biochar while without fertilizer the pattern showed 10 tons ha^{-1} biochar > 5 tons ha^{-1} biochar > 0 ton ha^{-1} biochar (Table 4).

Again, with the application of 200 kg ha^{-1} NPK organic matter content of soil significantly increased with 5 tons ha^{-1} biochar followed by 10 and 0 ton ha^{-1} biochar. With the application of P&K 50:50 resulted in the same organic matter content significantly higher than 0 ton ha^{-1} biochar. Under P&K 50:100 environment soil organic matter for 5 tons ha^{-1} biochar was significantly higher than 0 and 10 tons ha^{-1} biochar. With the application of liquid fertilizer, the response pattern of biochar on organic matter content was 5 tons ha^{-1} biochar > 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar. Under no fertilizer environment, 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 5 tons ha^{-1} biochar in the presentation of organic matter in soil solution during the minor cropping season (Table 3).

During the major cropping season (Table 4), organic matter response to biochar with the application 200 kg ha-1 NPK showed 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 5 tons ha^{-1} biochar. 5 and 10 tons ha^{-1} biochar increased organic matter content with the application of P& K 50:50 and P&K 50:100. Under liquid fertilizer environment, 10 tons ha^{-1} biochar significantly increased organic matter content over 0 and 5 tons ha^{-1} biochar. Plots which received no fertilizer showed an organic matter response to 5 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 10 tons ha^{-1} biochar.

With significant interaction effects of biochar and fertilizer on pH, it can be inferred that different levels of biochar and fertilizer affect soil pH, organic carbon, nitrogen and organic matter differently. This observation was also made by Peiris and Weerakkody [18] in their assessment of biochar and fertilizer on agronomic performance of maize. Earlier studies by Schulz and Glaser [19], reported that addition of biochar significantly increased soil pH in spite of the fact that pH value was generally lower during the second growth period (major season) probably due to leaching of base cations. It is implied that controlled use of biochar has a good potential for raising pH and making nutrients available which would otherwise not have been available to plants and thus reduce the incidence and cost of liming. From Tables 3 and 4, the mean pH of 5.47 and 5.28 respectively for treatment without biochar would result in decreased availability of Nitrogen, Phosphorus, Potassium, Sulfur, Calcium and Magnesium. Micronutrients like Iron, Manganese, Boron, Copper and Zinc would however be adequately available in the observed acidic pH. Similarly, NPK treatments which render a reduction of soil pH from 5.72 to 5.37 has a consequential reduction effect on the availability of macronutrients and an increment in micronutrient availability. Hence, effective management of soil pH is critical for plant nutrition [5], sustainable agriculture and in staying within planetary boundaries [3].

Interaction of fertilizer and biochar was significant for Total carbon, nitrogen and organic matter to signify the differential influence of both inorganic fertilizer and biochar to the organic properties of the soil as observed in the work of [20].

3.4 Effect of Fertilizer at Different Levels of Biochar on Relative Growth Rate, Harvest Index and Total Yield

From Tables 5 and 6, there were no significant interaction between fertilizer and biochar on relative growth rate, harvest index and total yield during the major cropping season. Interaction between fertilizer and biochar on total yield during the minor cropping season was however, significant (Table 5). With the application of 200 kg ha^{-1} NPK the application of 5 tons ha^{-1} biochar increased the total yield while 10 tons ha^{-1} biochar reduced the total yield. With the application of P&K 50:50 5 tons ha^{-1} biochar and 10 tons ha^{-1} biochar reduced the total yield. However, under P&K 50:100 10 tons ha^{-1} biochar significantly increased the total yield. Under liquid fertilizer environment, 5 tons ha^{-1} biochar increased total yield while 0 and 10 tons ha^{-1} biochar reduced the total yield. Under no fertilizer environment, total yield response to biochar application was 10 tons ha^{-1} biochar > 5 tons ha^{-1} biochar and 0 ton ha^{-1} biochar. Interaction between fertilizer and biochar on relative growth rate and harvest index were not significant.

At the end of 16 weeks after planting in the minor season, 2016, the effects of fertilizer and biochar on relative growth rate (RGR) and harvest index (HI) were not significant (Table 5). This could be explained by the uniformity in growth rate and the ratio of economic to total biomass. Interaction effect of fertilizer and biochar on total yield during the minor season was significant to show that soil amendment with chemical and organic materials influence yield [21]. This observation is explained by the capacity of moderate amounts of biochar to improve gravimetric moisture content, volumetric moisture content, soil porosity and reducing soil acidity towards the allocation of photosynthetic assimilates to sink tissues of the economic parts of plants as observed by Suppadit et al. [22] and Verheijen et al. [23].

3.5 Effect of Fertilizer at Different Levels of Biochar on Shoot, Root and Total CGR, NAR and Partitioning Coefficient

During the minor cropping season (Table 7) there were significant interaction of fertilizer and biochar on net assimilation rate. With the application of 200 kg ha^{-1} NPK, 5 tons ha^{-1} biochar significantly increases the net assimilation over 0 and 10 tons ha^{-1} biochar. With the application of P&K 50:50, 5 tons ha^{-1} biochar significantly reduced assimilation rate of carrot compared to 0 and 10 tons ha^{-1} biochar. Under P&K 50:100, 0 ton ha^{-1} biochar significantly increased the net assimilation rate while 10 and 5 tons ha^{-1} biochar decreased the net assimilation rate in descending order. Similarly, with the application of liquid fertilizer, 0 ton ha^{-1} biochar significantly increased the net assimilation rate while 10 tons ha^{-1} biochar provided the lowest net assimilation rate. Under no fertilizer environment, the response trend for net assimilation rate with the application of biochar was 5 tons ha^{-1} biochar > 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar.

During the major cropping season (Table 8), there were significant interaction effects between fertilizer and biochar on partitioning coefficient and net assimilation rate. For example with the application of 200 kg ha^{-1} NPK and P&K 50:50, 0, 5 and 10 tons ha^{-1} biochar showed similar effect on partitioning coefficient. However, with the application of P&K 50:100, influence from biochar on partitioning coefficient was 5 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 10 tons ha^{-1} biochar. With the application of liquid fertilizer, there was a significant increase in the partitioning coefficient with 5 tons ha^{-1} biochar while 0 and 10 tons ha^{-1} biochar remained low.

On net assimilation rate, 200 kg ha^{-1} NPK application resulted in a increase with increasing biochar from 0 ton ha^{-1} biochar < 5 tons ha^{-1} biochar < 10 tons ha^{-1} biochar. The reverse response occurred with the application of P&K 50:50 and P&K 50:100 where 0 ton ha^{-1} biochar < 5 tons ha^{-1} biochar < 10 tons ha^{-1} biochar. With the application of liquid fertilizer, 0 and 5 tons ha^{-1} biochar showed an increase in net assimilation rate over 10 tons ha^{-1} biochar. Under no fertilizer environment, the pattern was 10 tons ha^{-1} biochar > 0 ton ha^{-1} biochar > 5 tons ha^{-1} biochar (Table 8).

During the minor cropping season, 2016, effect of fertilizer and fertilizer-biochar interaction were not significant on crop growth rate for shoot.

However, biochar had a significant ($P<0.05$) effect on crop growth rates. Consequently, biochar at 10 tons ha^{-1} gave the highest mean crop growth rate of 20.18 shoot growth/week followed by biochar at 5 tons ha^{-1} biochar producing 18.26 cm shoot growth/week. The crop growth rates for roots, total crop growth rates (shoot plus root) and partitioning coefficient were not significant. The significant ($P < 0.05$) interaction effect on the net assimilation rate (NAR) (Table 7) shows that soil amendment with organic and inorganic materials affect the rate at which photosynthetic assimilates are translocated to source and sink tissues of plants [24].

During the major cropping season, 2017, fertilizer, biochar and their interaction were not significant on CGR-shoot, CGR-root and Total CGR (Table 8). This is largely due to the similarities and uniformity of growth performance as crops receive adequate environmental resources from soil and water from precipitation characteristic of the major cropping season. The significant ($P<0.05$) interaction of fertilizer and biochar demonstrates that the translocation of photosynthetic assimilates is influenced by the interactions between organic and inorganic resources in plant growth media [5] (Table 8).

In the major cropping season, 2017, significant interaction of fertilizer and biochar on partitioning coefficient and net assimilation rate indicates that under different fertilizer and biochar environment, differences in the partitioning and assimilation of photosynthates should be expected [20].

3.6 Correlational Analysis of Soil Properties with Crop Growth and Yield Parameters

Table 9 shows the correlational matrix among selected soil, growth and yield of carrot for the minor and major cropping seasons pooled together. Physical and chemical soil factors are seen to variously influence the crop factors.

On soil physical properties, soil porosity was highly and directly correlated with gravimetric moisture content (0.69) and perfect inversely correlated with bulk density (-1). This becomes significant in climate change adaptation to amend soils with materials that do not only improve soil fertility but also gravimetric moisture content.

Further, soil pH had low correlation with crop growth rate (total) (-0.09) and moderate correlation with organic carbon (0.34) and crop growth rate (shoot) (0.38). The pH is also moderately correlated with total nitrogen (-0.37) and crop growth rate (root) (-0.35). Percentage organic carbon was moderately correlated with relative growth rate (-0.49) and total crop growth rate (-0.41) and highly correlated with harvest index (-0.61), crop growth rate (root) (-0.57), partitioning coefficient (-0.61) and net assimilation rate (-0.59) (Table 9).

Table 1. Soil chemical properties at experimental sites before field studies, 2016 and 2017

Year	pH, H_2O 1:2.5	Org. C %	Total N %	Org. M %	Exch. Cations (me/100 g)				T.E.B cmol/kg	Exch. A(Al+) cmol/kg	ECEC me/100 g	Base Sat %	Available		SO_4^{2-} (mg/kg)
					Ca	Mg	K	Na					P	K	
2016	5.72	0.94	0.11	1.61	2.14	2.40	0.21	0.05	4.80	0.50	5.30	90.56	5.46	9.28	16
2017	5.35	0.71	0.11	1.23	5.07	2.67	0.27	0.09	7.83	0.72	6.97	89.95	13.47	9.96	30

Org. C=organic carbon, N=Nitrogen; Org. M=Organic Matter: Exch. Cations=Exchangeable cations (Ca, Mg, K, Na); T.E.B=Total Exchangeable Bases; Exch. A=Exchangeable Acidity; Base Sat=Base Saturation

Table 2. Soil physical properties at experimental site after biochar and fertilizer application and fertilizer decomposition

Soil physical properties	Treatments	Biochar			Mean	S.E.D ±		
		0 t ha^{-1}	5 t ha^{-1}	10 t ha^{-1}		Fertilizer	Biochar	Fertilizer x Biochar
Gravimetric Moisture Content (%)	NPK 200 kg ha^{-1}	18.76	25.03	24.78	22.85			
	P&K 50:50	17.98	20.91	31.39	23.43			
	P&K 50:100	20.99	22.11	26.77	23.29			
	Liquid Fertilizer	7.39	18.43	20.93	15.58	0.02921*	0.02262**	0.05059
	No Fertilizer	19.47	15.32	20.83	18.54			
	Mean	16.92	20.36	24.94	20.74			
Bulk Density (g cm^{-3})	NPK 200 kg ha^{-1}	1.34	1.18	1.25	1.26			
	P&K 50:50	1.41	1.34	1.18	1.31			
	P&K 50:100	1.36	1.20	1.29	1.28			
	Liquid Fertilizer	1.42	1.26	1.17	1.29	0.0305	0.02362**	0.05282**
	No Fertilizer	1.33	1.35	1.22	1.30			
	Mean	1.37	1.27	1.22	1.29			
Soil Porosity (%)	NPK 200 kg ha^{-1}	49.61	55.32	52.68	52.53			
	P&K 50:50	46.82	49.43	55.51	50.59			
	P&K 50:100	48.77	54.76	51.27	51.60			
	Liquid Fertilizer	46.47	52.30	55.73	51.50	1.151	0.892**	1.994**
	No Fertilizer	49.96	48.94	54.00	50.97			
	Mean	48.33	52.15	53.84	51.44			

*S.E.D. Standard Error of the Differences of mean; *, ** Mean significant at 5 % and 1 % probability levels respectively*

Table 3. Effects of fertilizer and biochar on Soil Chemical Properties, 2016

	Treatment	**Biochar**			**Mean**	**S.E.D. ±**		
Soil chemical properties 2016		**0 t ha^{-1}**	**5 t ha^{-1}**	**10 t ha^{-1}**		**Fertilizer**	**Biochar**	**Fertilizer x Biochar**
Soil pH	NPK 200 kg ha^{-1}	5.34	5.00	5.77	5.37	0.004**	0.003**	0.008**
	P&K 50:50	5.67	6.00	6.08	5.92			
	P&K 50:100	5.26	5.71	6.14	5.70			
	Liquid Fertilizer	5.37	5.84	6.01	5.74			
	No Fertilizer	5.72	6.01	5.93	5.89			
	Mean	5.47	5.71	5.99	5.72			
Organic Carbon (%)	NPK 200 kg ha^{-1}	0.79	0.86	0.82	0.82			
	P&K 50:50	0.71	0.90	0.90	0.84			
	P&K 50:100	0.75	0.94	0.71	0.80			
	Liquid Fertilizer	0.82	0.98	0.90	0.90	0.00357**	0.00277**	0.00619**
	No Fertilizer	0.94	0.80	1.01	0.92			
	Mean	0.80	0.90	0.87	0.86			
Total Nitrogen (%)	NPK 200 kg ha^{-1}	0.07	0.07	0.07	0.07			
	P&K 50:50	0.06	0.08	0.08	0.07			
	P&K 50:100	0.06	0.09	0.06	0.07			
	Liquid Fertilizer	0.07	0.10	0.09	0.09	0.002023**	0.001567**	0.003504**
	No Fertilizer	0.11	0.08	0.09	0.09			
	Mean	0.07	0.08	0.08	0.08			
Organic Matter (%)	NPK 200 kg ha^{-1}	1.36	1.48	1.42	1.42			
	P&K 50:50	1.23	1.57	1.55	1.45			
	P&K 50:100	1.29	1.61	1.23	1.38			
	Liquid Fertilizer	1.42	1.68	1.55	1.55	0.00356**	0.00276**	0.00616**
	No Fertilizer	1.61	1.36	1.74	1.57			
	Mean	1.38	1.54	1.50	1.47			

*S.E.D. Standard Error of the Differences of mean; **Mean significant at 1 % probability level*

Table 4. Effects of fertilizer and biochar on Soil Chemical properties, 2017

Soil data	Treatment	Biochar			Mean	S.E.D.		
Soil chemical properties 2017		**0 t ha^{-1}**	**5 t ha^{-1}**	**10 t ha^{-1}**		**Fertilizer**	**Biochar**	**Fertilizer x Biochar**
Soil Ph	NPK 200 kg ha^{-1}	5.50	5.22	5.52	5.41			
	P&K 50:50	5.25	5.15	5.32	5.24			
	P&K 50:100	5.13	5.35	5.28	5.25	0.0020**	0.0016**	0.0035**
	Liquid Fertilizer	5.15	5.21	5.37	5.24			
	No Fertilizer	5.35	5.23	6.05	5.54			
	Mean	5.28	5.23	5.51	5.34			
Organic Carbon (%)	NPK 200 kg ha^{-1}	0.80	0.55	0.91	0.75			
	P&K 50:50	0.64	0.77	0.72	0.71			
	P&K 50:100	0.62	0.82	0.81	0.75			
	Liquid Fertilizer	0.70	0.66	0.95	0.77	0.0029**	0.0022**	0.0050**
	No Fertilizer	0.72	0.82	0.55	0.70			
	Mean	0.69	0.72	0.79	0.74			
Total Nitrogen (%)	NPK 200 kg ha^{-1}	0.14	0.13	0.12	0.13			
	P&K 50:50	0.14	0.13	0.11	0.13			
	P&K 50:100	0.13	0.12	0.11	0.12			
	Liquid Fertilizer	0.11	0.11	0.13	0.12	0.0010**	0.0007**	0.0017**
	No Fertilizer	0.11	0.12	0.13	0.12			
	Mean	0.13	0.12	0.12	0.12			
Organic Matter (%)	NPK 200 kg ha^{-1}	1.38	0.94	1.57	1.30			
	P&K 50:50	1.10	1.32	1.23	1.22			
	P&K 50:100	1.07	1.42	1.38	1.29			
	Liquid Fertilizer	1.19	1.13	1.63	1.32	0.0016**	0.0012**	0.0028**
	No Fertilizer	1.23	1.41	0.94	1.19			
	Mean	1.19	1.24	1.35	1.26			

*S.E.D. Standard Error of the Differences of mean; **Mean significant at 1 % probability level*

Table 5. Relative growth rate, harvest index and total yield as influenced by fertilizer and biochar, 2016

Agronomic data	Treatment	Biochar			Mean	S.E.D.		
		0 t ha^{-1}	5 t ha^{-1}	10 t ha^{-1}		Fertilizer	Biochar	Fertilizer ×Biochar
Relative Growth Rate/Week	NPK 200 kg ha^{-1}	0.55	0.56	0.57	0.56			
	P&K 50:50	0.55	0.53	0.57	0.55			
	P&K 50:100	0.52	0.51	0.56	0.53			
	Liquid Fertilizer	0.54	0.55	0.54	0.54	0.01429	0.01107	0.02475
	No Fertilizer	0.52	0.57	0.57	0.55			
	Mean	0.54	0.54	0.56	0.55			
Harvest Index	NPK 200 kg ha^{-1}	0.56	0.46	0.49	0.50			
	P&K 50:50	0.52	0.43	0.44	0.46			
	P&K 50:100	0.45	0.46	0.45	0.45			
	Liquid Fertilizer	0.49	0.35	0.42	0.42	0.0354	0.0274	0.0614
	No Fertilizer	0.42	0.41	0.44	0.42			
	Mean	0.49	0.42	0.45	0.45			
Total Yield (Kg ha^{-1})	NPK 200 kg ha^{-1}	7192	8622	6238	7351			
	P&K 50:50	7446	5887	5666	6333			
	P&K 50:100	3658	3660	9771	5696			
	Liquid Fertilizer	6052	7392	5530	6325	1145.1	887	1983.4*
	No Fertilizer	4688	6416	8853	6652			
	Mean	5807	6395	7212	6471			

*S.E.D. Standard Error of the Differences of mean; *, ** Mean significant at 5 % and 1 % probability levels respectively*

Table 6. Relative growth rate, harvest index and total yield as influenced by fertilizer and biochar, 2017

Agronomic data	Treatment	Biochar			Mean	S.E.D.		
		0 t ha^{-1}	5 t ha^{-1}	10 t ha^{-1}		Fertilizer	Biochar	Fertilizer x Biochar
Relative Growth Rate/Week	NPK 200 kg ha^{-1}	0.58	0.59	0.48	0.55			
	P&K 50:50	0.59	0.58	0.61	0.60			
	P&K 50:100	0.61	0.61	0.55	0.59			
	Liquid Fertilizer	0.68	0.58	0.61	0.62	0.02534	0.01963	0.04389
	No Fertilizer	0.56	0.60	0.62	0.59			
	Mean	0.60	0.59	0.57	0.59	520		
Harvest Index	NPK 200 kg ha^{-1}	0.61	0.58	0.58	0.59			
	P&K 50:50	0.63	0.60	0.61	0.61			
	P&K 50:100	0.62	0.59	0.56	0.59			
	Liquid Fertilizer	0.61	0.68	0.57	0.62	0.03274	0.02536*	0.05671
	No Fertilizer	0.59	0.62	0.59	0.60			
	Mean	0.61	0.62	0.58	0.60			
Total Yield (kg ha-1)	NPK 200 kg ha^{-1}	7865	8156	11046	9022			
	P&K 50:50	12431	12651	11378	12153			
	P&K 50:100	12202	11426	5734	9788			
	Liquid Fertilizer	9956	11395	8459	9937	1746.8	1353.1	3025.6
	No Fertilizer	6916	5510	12666	8364			
	Mean	9874	9828	9857	9853			

*S.E.D. Standard Error of the Differences of mean; * Mean significant at 5 % probability level*

Table 7. CGR-Shoot, CGR-Root, Total CGR and partitioning coefficient and NAR as Influenced by fertilizer, 2016

Agronomic Data	Treatment	Biochar			Mean	S.E.D.		
		0 t ha^{-1}	5 t ha^{-1}	10 t ha^{-1}		Fertilizer	Biochar	Fertilizer x biochar
Crop Growth Rate-Shoot/Wk-	NPK 200 kg ha^{-1}	14.68	18.79	19.03	17.50			
	P&K 50:50	15.94	14.60	22.58	17.71			
	P&K 50:100	13.70	10.44	20.43	14.85			
	Liquid Fertilizer	14.92	23.02	17.53	18.49	2.561	1.984*	4.436
	No Fertilizer	13.26	24.94	21.34	19.85			
	Mean	14.50	18.36	20.18	17.68			
Crop Growth Rate-Root/Wk	NPK 200 kg ha^{-1}	17.80	16.68	19.04	17.84			
	P&K 50:50	19.18	10.67	17.29	15.71			
	P&K 50:100	12.02	9.67	17.22	12.97			
	Liquid Fertilizer	14.65	11.66	13.10	13.14	2.906	2.251	5.033
	No Fertilizer	10.13	17.34	18.19	15.22			
	Mean	14.75	13.21	16.97	14.98			
Crop Growth Rate –Total/Wk	NPK 200 kg ha^{-1}	32.50	35.50	38.10	35.30			
	P&K 50:50	35.10	25.30	39.90	33.40			
	P&K 50:100	25.70	20.10	37.60	27.80			
	Liquid Fertilizer	29.60	34.70	30.60	31.60	4.9	3.79	8.48
	No Fertilizer	23.40	42.30	39.50	35.10			
	Mean	29.30	31.60	37.10	32.70			
Partitioning Coefficient	NPK 200 kg ha^{-1}	0.56	0.46	0.49	0.50			
	P&K 50:50	0.53	0.43	0.44	0.47			
	P&K 50:100	0.45	0.46	0.45	0.45			
	Liquid Fertilizer	0.49	0.35	0.42	0.42	0.0355	0.0275	0.0615
	No Fertilizer	0.42	0.41	0.44	0.42			
	Mean	0.49	0.42	0.45	0.45			
Net Assimilation Rate	NPK 200 kg ha^{-1}	17.31	19.74	16.93	17.99			
	P&K 50:50	18.47	10.19	17.79	15.48			
	P&K 50:100	25.39	11.13	12.75	16.42			
	Liquid Fertilizer	25.73	16.21	14.70	18.88	2.815	2.18	4.875*
	No Fertilizer	15.09	23.32	16.65	18.36			
	Mean	20.40	16.12	15.76	17.43			

*S.E.D. Standard Error of the Differences of mean; * Mean significant at 5 % probability level*

Table 8. CGR-Shoot, CGR-Root, Total CGR and partitioning coefficient and NAR as Influenced by fertilizer and biochar, 2017

Agronomic Data	Treatment	Biochar			Mean	S.E.D.		
		0 t ha^{-1}	5 t ha^{-1}	10 t ha^{-1}		Fertilizer	Biochar	Fertilizer x Biochar
Crop Growth Rate Shoot/Wk	NPK 200 kg ha^{-1}	12.29	14.84	20.11	15.74			
	P&K 50:50	19.00	22.15	17.84	19.66			
	P&K 50:100	19.02	19.52	10.86	16.47			
	Liquid Fertilizer	16.12	13.40	15.40	14.97			
	No Fertilizer	11.86	8.01	19.57	13.15	2.753	2.132	4.768
	Mean	15.66	15.59	16.75	16.00			
Crop Growth Rate-Root/Wk	NPK 200 kg ha^{-1}	19.70	20.40	27.60	22.50			
	P&K 50:50	31.10	31.60	28.40	30.40			
	P&K 50:100	30.50	28.60	14.30	24.50			
	Liquid Fertilizer	24.90	28.50	21.10	24.80	4.36	3.38	7.56
	No Fertilizer	17.30	13.80	31.60	20.90			
	Mean	24.70	24.60	24.60	24.60			
Crop Growth Rate Total/Wk	NPK 200 kg ha^{-1}	31.90	35.20	47.70	38.30			
	P&K 50:50	50.10	53.70	46.30	50.00			
	P&K 50:100	49.50	48.10	25.20	40.90			
	Liquid Fertilizer	41.00	41.90	36.50	39.80	6.99	5.42	12.11
	No Fertilizer	29.10	21.80	51.20	34.00			
	Mean	40.30	40.10	41.40	40.60			
Partitioning Coefficient	NPK 200 kg ha^{-1}	0.61	0.58	0.59	0.59			
	P&K 50:50	0.63	0.60	0.61	0.61			
	P&K 50:100	0.62	0.59	0.56	0.59			
	Liquid Fertilizer	0.61	0.68	0.58	0.62	0.01598	0.01238*	0.02768*
	No Fertilizer	0.59	0.62	0.59	0.60			
	Mean	0.61	0.62	0.58	0.60			
Net Assimilation Rate	NPK 200 kg ha^{-1}	35.60	42.10	64.80	47.50			
	P&K 50:50	68.00	58.00	41.00	55.60			
	P&K 50:100	65.70	52.30	29.70	49.20			
	Liquid Fertilizer	36.10	37.80	22.40	32.10	7.39*	5.72	12.80**
	No Fertilizer	34.10	18.80	69.00	40.60			
	Mean	47.90	41.80	45.40	45.00			

*S.E.D. Standard Error of the Differences of mean; *, ** Mean significant at 5 % and 1 % probability levels respectively*

Table 9. Correlation Matrix of soil parameters with carrot growth and yield parameters for the minor (2016) and major (2017) cropping seasons

	GMC (%)	BD (g/cm^3)	SP	Soil pH	OC (%)	TN (%)	OM (%)	RGRW	HI	TY (Kg ha^{-1})	CGR-S/Wk	CGR-R/Wk	CGRTotal/Wk	PCo	NAR
Gravimetric Moisture Content (%)	1.00														
Bulk Density (g/cm3)	-0.69	1.00													
Soil Porosity	0.69	-1.00	1.00												
Soil pH	0.19	-0.22	0.22	1.00											
Organic Carbon (%)	0.06	-0.27	0.27	0.34	1.00										
Total Nitrogen (%)	-0.03	-0.08	0.08	-0.37	-0.27	1.00									
Organic Matter (%)	0.06	-0.27	0.27	0.34	1.00	-0.28	1.00								
Relative Growth Rate/Week	-0.21	0.05	-0.05	-0.30	-0.49	0.43	-0.50	1.00							
Harvest Index	-0.10	0.15	-0.15	-0.65	-0.61	0.66	-0.61	0.51	1.00						
Total Yield (Kg ha^{-1})	0.07	-0.04	0.04	-0.28	-0.50	0.54	-0.50	0.52	0.62	1.00					
Crop Growth Rate-Shoot/Wk	0.20	-0.19	0.19	0.38	0.06	-0.11	0.06	0.12	-0.32	0.44	1.00				
Crop Growth Rate-Root/Wk	0.06	-0.01	0.01	-0.35	-0.58	0.58	-0.58	0.55	0.74	0.94	0.37	1.00			
Crop Growth Rate – Total/Wk	0.14	-0.09	0.09	-0.09	-0.41	0.38	-0.41	0.46	0.41	0.90	0.72	0.91	1.00		
Partitioning Coefficient	-0.09	0.14	-0.14	-0.65	-0.61	0.66	-0.61	0.51	1.00	0.62	-0.32	0.74	0.41	1.00	
Net Assimilation Rate	0.01	0.09	-0.09	-0.40	-0.59	0.70	-0.59	0.35	0.69	0.80	0.22	0.88	0.75	0.69	1

GMC=Gravimetric Moisture Content; BD=Bulk Density; SP=Soil Porosity; OC=Organic carbon; OM Organic Matter; RGRW=Relative Growth Rate per Week; HI=Harvest Index; TY=Total Yield; CGR-S/Wk=Crop Growth Rate for Shoot per Week; CGR-R/Wk=Crop Growth Rate for Root per week; CGRT/wk=Crop Growth Rate Total (Shoot and Root) per week; PCo=Partitioning Coefficient; NAR=Net Assimilation Rate

Percentage total nitrogen showed moderate correction coefficient with relative growth rate (0.43) and crop growth rate (total) (0.38) and high positive correlation with harvest index (0.66), total yield (0.54), crop growth rate (root) (0.58), partitioning coefficient (0.66) and net assimilation rate (0.70) (Table 9). In these relationships, soil physical and chemical properties show different magnitudes and directions. The correlation of the soil on crop parameters with crop growth and yield parameters reveal the need to closely manage both soil and crop to achieve a balance in nutrient transport systems between phloem and xylem tissues of plant and guarantee sustainable productivity of both soil and crop. Bélanger et al. (1999) cited [25] in made similar observations.

Under growth and yield responses, there were generally moderate to high and perfect positive correlation between response variables notably relative growth rate, harvest index, total yield, crop growth rate (shoot), crop growth rate (root), crop growth rate (total), partitioning coefficient and net assimilation rate. This could be attributed to the relationship between the below - and above-ground biomass which enable effective translocation of inorganic and organic molecules through the xylem and phloem tissues. According to Smith et al. [26] yield is the cumulative result of both source and sink strength for photoassimilates and nutrients and that source strength for photoassimilates is dictated by both net photosynthetic rate and the rate of photoassimilate remobilisation from source tissues. There was moderate negative correlation between harvest index and crop growth rate (shoot) and between crop growth rate shoot and partitioning coefficient showing that when the economic part of a crop is in the root, effective soil amendments would favour a relatively reduced shoot growth for root growth. For example, Voisin et al. [27] reported that application of excess nitrogen increases the above-ground biomass. Similarly, low positive correlation between crop growth rate (shoot) and net assimilation rate was observed to show that the sink tissues of the roots attracted more photosynthetic assimilates during the growth process against the shoot in carrots. Other plants with sink tissues on the stem may have different effects as observed by Herold [28].

4. CONCLUSION

Both organic and inorganic resources such as biochar and inorganic fertilizers affect soil chemical properties. Biochar and fertilizer interaction significantly affected soil chemical properties such as pH, % Organic Carbon and Total Nitrogen and Organic matter. Consequently, soil amendment with different levels of biochar and fertilizer affect chemical properties and render rhizosphre environment either more or less conducive for crop growth and yield. At different fertilizer and biochar environments carrot growth parameters such as crop growth rate (shoot), crop growth rate (root) and crop growth rate (total) are affected in unique ways. Vegetative and reproductive state metrics such as relative growth rates, harvest index, partitioning coefficient and net assimilation rates were also significantly affected by soil amendment with biochar and fertilizers. 5 tons ha^{-1} and 10 tons ha^{-1} biochar enhanced soil physical and chemical properties. 200 kg ha^{-1} NPK, P&K 50:50, P&K 50:100, liquid fertilizer and the no-amendment acted together with 0, 5 and 10 tons ha^{-1} biochar to produce differences in bulk density, soil porosity, soil pH, % organic carbon, total nitrogen, total yield, net assimilation rate and partitioning coefficient. The cropping seasons also appeared to influence interactions in some of the dependent variables such as total yield and partitioning coefficient as a result of climate variability in precipitation and average temperatures. For carrot production to be sustainable, the season, the expected yield, nutrient and carbon levels of the soil should inform the soil and crop management practices. In the experiment, both negative and positive correlations between soil physicochemical and crop responses are seen to influence the growth and yield of carrots. As such, a careful understanding and management of these relationships can inure to the benefit of commercial carrot producers contemplating to operationalize sustainable agriculture and climate change mitigation and adaptation. Further research should be carried out to determine the influence of fertilizer and biochar on rhizosphere biodiversity for a better understanding of the biological control systems arising from fertilizer and biochar application.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Atakora K, Agyarko K, Asiedu EK. Influence of grasscutter, Chicken manure and NPK fertilizer on the physical properties of a chromic luvisol, growth and yield of carrot (*Daucus carota*). International Journal of Plant & Soil Science. 2014;3(2):197–204.
2. Abuzar S, Haseeb A, Adesina Adegbite A, Olubunmi Agbaje G, Abidoye RAJI J. Effect of nitrogen, phosphorus and potassium fertilizers on growth and yield characteristics of radish (R*aphinus sativus* L.). Plant Disease. 2013;7(4):270–279. Available:https://doi.org/10.1017/CBO9781107415324.004
3. Hughes TP, Carpenter S, Rockström J, Scheffer M, Walker B. Multiscale regime shifts and planetary boundaries. Trends in Ecology and Evolution. 2013;28(7):389–395. Available:https://doi.org/10.1016/j.tree.2013.05.019
4. Makries JL, Warncke DD. Timing nitrogen applications for quality tops and healthy root production in carrot. Communications in Soil Science and Plant Analvsis, 2013;44:2860–2874. Available:https://doi.org/10.1080/00103624.2013.823987
5. Asante K, Manu-Aduening J, Essilfie ME. Nutritional quality response of carrot (*Daucus carota*) to different rates of inorganic fertilizer and biochar. Asian Journal of Soil Science and Plant Nutrition, 2019;1–14. Available:https://doi.org/10.9734/ajsspn/2019/v5i230060
6. Bashour II, Sayegh AH. Methods of analysis for soils of arid and semi-arid regions (V. delle T. di Caracalla (ed.); 1st ed.). Electronic Publishing Policy and Support Branch, Communication Division, FAO; 2007.
7. Bittelli M. Measuring soil water content: A review. Hort Technology. 2011;21(3):293–300. Available:https://doi.org/10.21273/horttech.21.3.293
8. Samuel AL, Ebenezer AO. Mineralization rates of soil forms of nitrogen, Phosphorus, and potassium as affected by organomineral fertilizer in sandy loam. Advances in Agriculture. 2014;2–29.
9. Agegnehu G, Bass AM, Nelson PN, Bird MI. Benefits of biochar, compost and biochar-compost for soil quality , maize yield and greenhouse gas emissions in a tropical agricultural soil. Science of the Total Environment. 2016;543:295–306. Available:https://doi.org/10.1016/j.scitotenv.2015.11.054
10. Baumann DT, Bastiaans L, Goudriaan J. Analysing crop yield and plant quality in an intercropping system using an eco-physiological model for interplant competition. Agricultural Systems. 2002; 73:173–203.
11. Ekbladh G. Plant analysis as a tool to determine crop nitrogen status–towards leaf area based measurements. Acta Universitatis Agriculturae Sueciae, 2007; 1–50.
12. Anten NPR, Ackerly DD. A new method of growth analysis for plants that experience periodic losses of leaf mass. Functional Ecology, 2001;15(6):804–811. Available:https://doi.org/10.1046/j.0269-8463.2001.00582.x
13. Poorter, H. Interspecific variation in relative growth rate: On ecological causes and physiological consequences. Causes and Consequences of Variation in Growth Rate and Productivity of Higher Plants, 1989; 45–68.
14. Danje AA, Essilfie ME, Asiedu EK. Growth and yield response of two onion (*Allium cepa* L.) Varieties to organic and inorganic fertilizers in the forest- Savannah Transitional Zone of Ghana. 2019;4(4):1–14. Available:https://doi.org/10.9734/AJAHR/2019/v4i430028
15. Brantley KE, Brye KR, Savin MC, Longer DE. Biochar source and application rate effects on soil water retention determined using wetting curves. Open Journal of Soil Science, 2015;5:1–10. Available:https://doi.org/10.4236/ojss.2015.51001
16. Satriawan BD, Handayanto E. Effects of biochar and crop residues application on chemical properties of a degraded soil of South Malang, and P uptake by maize. Journal of Degraded and Mining Lands Management, 2015;2(2):271–280. Available:https://doi.org/10.15243/jdmlm.2014.022.271

17. Mukherjee A, Lal R, Zimmerman AR. Science of the total environment effects of biochar and other amendments on the physical properties and greenhouse gas emissions of an artificially degraded soil. Science of the Total Environment, 2014;487, 26–36. Available:https://doi.org/10.1016/j.scitotenv.2014.03.141
18. Peiris PUS, Weerakkody WAP. Effect of Organic based liquid fertilizers on growth performance of leaf lettuce (*Lactuca Sativa* L). International Conference on Agricultural, Ecological and Medical Sciences. 2015;1:39–41.
19. Schulz H, Glaser B. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment; 2014. Available:https://doi.org/10.1002/jpln.201100143.
20. Dennis KJ, Kelvin CS. Evaluating the agronomic benefits of biochar amended soils in an organic system. Sustainable Food Systems. 2014;2:32.
21. Akom M, Boateng CO, Otoo E, Dawoe E. Effect of biochar and inorganic fertilizer in Yam (*Dioscorea rotundata P*oir) Production in a Forest Agroecological Zone. Journal of Agricultural Science. 2015;7(3):211–222. Available:https://doi.org/10.5539/jas.v7n3p211.
22. Suppadit T, Phumkokrak N, Poungsuk P. The effect of using quail litter biochar on soybean (*Glycine max* L. Merr.) Production. *C*hilean Journal of Agricultural Research, 2012;72(2):244–251. Available:https://doi.org/10.4067/S0718-58392012000200013
23. Verheijen FGA, Jeffery S, Bastos AC, van der Velde M, Diafas I. Biochar application to soils - A critical scientific review of effects on soil properties, Processes and Functions; 2010. Available:https://doi.org/10.2788/472
24. Poorter-Hendrik, Remkes C. Leaf area ratio and net assimilation rate of 24 wild species differing in relative growth rate. Oecologia. 1990;83(4):553–559. Available:https://doi.org/10.1007/BF00317209.
25. FAO. Measuring and modelling soil carbon stocks and stock changes in livestock production systems. Livestock Environmental Assessment and Performance (LEAP) Partnership; 2018.
26. Smith MR, Rao IM, Merchant A, Smith MR. Source-sink relationships in crop plants and their influence on yield development and nutritional quality. Frontiers in Plant Science, 2018;1–10. Available:https://doi.org/10.3389/fpls.2018.01889.
27. Voisin A, Salon C, Munier-jolain NG, Ney B. Effect of mineral nitrogen on nitrogen nutrition and biomass partitioning between the shoot and roots of pea *(Pisum sativum L .).* 2002;251–262.
28. Herold A. Regulation of photosynthesis By sink activity.Pdf. New Phytol. 1980;86(11–02):131–144.

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