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MAMPONG-ASHANTI

INFLUENCE OF DIFFERENT RATES OF FERTILIZER AND BIOCHAR AMENDMENTS ON SOIL, CARROT *(Daucus carota)* YIELD AND TUBER QUALITY IN RESPONSE TO CAPACITY NEEDS OF FARMERS IN THE TRANSITIONAL ZONE OF GHANA

BY

KWAKU ASANTE

MASTER OF PHILOSOPHY THESIS

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UNIVERSITY OF EDUCATION, WINNEBA

DECLARATION

I, Kwaku Asante declare that this dissertation with the exception of quotations and references contained in published works which have all been identified and acknowledged is entirely my own original work and it has not been submitted either in part or whole for another degree elsewhere.

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DEDICATION

I dedicate this work to my wife (Mrs. Diana Asante), my daughter (Awurama Korang Asante) and my sons (Nana Susubiribi Onwona Asante and Osei Brimpong Sikapa Asante).

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LIST OF ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CGR	Crop Growth Rate
CO_2eq	Carbon dioxide equivalent
CRI	Crops Research Institute
DAS	Days after Sowing
ECEC	Effective Cation Exchange Capacity
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GHGs	Greenhouse Gases
HI	Harvest Index
IPM	Integrated Pest Management
ISFM	Integrated Soil Fertility Management
K	Potassium
LAI	Leaf Area Index
MoFA	Ministry of Food and Agriculture
N	Nitrogen
NAMAs	Nationally Appropriate Mitigation Action
NAR	Net Assimilation Rate
O.C	Organic Carbon
P	Phosphorus
PAHs	Polycyclic Aromatic Hydrocarbons
RCBD	Randomized Complete Block Design
RGR	Relative Growth Rate
SDGs	Sustainable Development Goals
SPSS	Statistical Package for Social Sciences
UNDP	United Nations Development Program
WAP	Weeks After Planting

ABSTRACT

Integrated Nutrient Management with biochar and inorganic fertilizer is critical to sustainable agriculture including the enhancement of production systems for climate change mitigation and adaptation. The objective of this research was to evaluate how soil management could be improved to respond to increasing environmental pressure on soil and crop in carrot production and to examine how anthropogenic changes in and management of soil affect crop growth, yield and nutritional quality. Mixed method approaches -sociological and field experimental research, were employed in the study. In the sociological study, action research was conducted to explore farmers' perceptions, production constraints and production output to inform the choice of treatment for two field experimental studies conducted in 2016 and 2017 at the Multipurpose Crop Nursery of the College of Agriculture Education, University of Education, Winneba, Mampong Campus. The sociological study made use of cross-sectional, focus group discussion and stakeholder engagements. Respondents in the cross-sectional study were randomly sampled while those of focus group and stakeholder engagements were purposively sampled. The cross-sectional study engaged 25 carrot growers in Asante Mampong Municipality. The field experimental study was a 3 x 5 factorial arranged in Randomized Complete Block Design (RCBD) and replicated three times. Three levels of biochar at rates 0 ton/ha, 5 ton/ha and 10 ton/ha and 5 levels of inorganic fertilizer (NPK 15:15:15 at 200 kg/ha; P&K 50:50 at 50 kg/ha; P&K 50:100 at 50 kg/ha; D.I. Grow Liquid Fertilizer at 1L D.I. Grow: 200 L Water/ha; and No fertilizer) were used. The results showed that avocado biochar could be used to amend and improve soil density, porosity and moisture content and carbon stock to improve farmers' capacity to adapt to environmental stresses and to mitigate climate change. Biochar integration with inorganic fertilizers also proved to significantly and variably affect soil physicochemical properties, crop growth, yield, yield components and nutritional quality.

In view of the varied market preferences of tuber quality, it is recommended for farmers to manage soils, crops and weather to specifically suite consumers and market preferences. It is recommended that farmers apply 10ton/ha biochar with P&K 50:50 at 50 kg/ha for improved water holding capacity, organic carbon composition and pH. It is also strongly recommended that during the minor and major cropping season farmers respectively apply NPK 200kg/h + 5 ton/ha biochar and P&K 50:100 at 50 kg/ha without biochar for best marketable yield. In terms of root diameter, 5 ton/ha biochar without fertilizer is recommended for soils with average soil nutrients during the minor season. During the major season, it is recommended to apply P&K 50:100 at 50 kg/ha +10 ton/ha biochar for best root length. For best root diameter performance, it is recommended for farmers to apply P&K 50:50 at 50 kg/ha without biochar during the minor cropping season and P&K 50:50 at 50 kg/ha +10 ton/ha during the major season. For nutrition-informed carrot production NPK 200 kg/ha+10 ton/ha biochar is recommended for high protein carrot during the minor cropping season while major cropping season carrots should be produced with liquid fertilizer+10 ton/ha biochar. For high carotenoid carrots, it is recommended to apply liquid fertilizer+ 5 ton/ha biochar during the minor cropping season and NPK 200kg/ha +5 ton/ha biochar applied during the major season. Correlation between soil properties, carrot growth, yield and nutritional quality was also variable. There was significant effect of climate variability on carrot growth, yield, and nutritional parameters.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Carrot (*Daucus carota* L.) is an important vegetable among succulent vegetables consumed across the globe. Apart from its high potential for import and export in continental trade, it is one of the exotic vegetables with high nutritive and economic value and of great demand in urban centers of the country (Dawuda *et al.*, 2011). Carrot responds favourably to both organic and inorganic fertilizers (Ahmed *et al*., 2014). However, while excessive amount of inorganic fertilizer results in soil acidification (Ahmed *et al.*, 2014), increased greenhouse gas (GHG) emissions (Smith *et al.*, 2014) and increased eutrophication of water bodies (Laird *et al*, 2010), excessive amounts of soil organic matter also promotes forking and reduces market acceptability and profitability (Makries and Warncke, 2013). As a way to mitigate the environmental pressure resulting from inorganic fertilizers and simultaneously improve carrot quality and yield, a new area of research that holds much prospect for soil productivity, market acceptability, soil carbon stock improvement among others is amendment of soil with biochar (Aslam *et al.,* 2014).

In a study conducted on biochar effects on carrot forking, the results showed that application of biochar resulted in decreased number of forked carrots and that 20ton/acre of biochar treatment significantly decreased the number of forked carrots in both sandy and loamy soils (Carpenter, 2016).

In Ghana, most of the studies on carrot have centered on spacing effects (Dawuda *et al.*, 2011) and soil amendments with organic and inorganic fertilizers. Additionally, preliminary studies revealed that majority of farmers lacked knowledge on how to practically implement sustainable agricultural principles to conserve soil nutrients, soil water content, adapt to climate change and prevent agriculture-associated greenhouse gas emissions. This research work is therefore focused on findings from the initial research carried out on carrot production constraints and climate change adaptation.

Gaps identified from focus group discussions and cross-sectional study revealed generally that most farmers do not know the type and rate of fertilizer that can guarantee maximum yield. Most farmers do not also know how to adequately improve soil structure and texture other than by mulching and application of organic manure. For those aware of mulching and organic manure less than 10% percent actually practice it. Biochar application was not considered an option at all in spite of the global interest attached to it as a material capable of improving soil productivity and soil carbon stock.

1.2 Problem Statement

Effective soil nutrient and crop management are critical to carrot productivity and quality. Among most small holder farmers in Ghana, poor soil and crop management are observed. These are largely attributable to the inadequate knowledge of integrated nutrient management mechanisms stemming from inadequate extension service, limited technical knowledge on how to overcome production constraints, and ineffective farmer cooperatives to advocate for better services to farmers. Additionally, there is poor adaptation among small holder farmers to climate change stresses on soil and crops attributable to limited use of climate smart products, inadequate information on the influence of climate variability on soil and crop performance and inadequate integration of inorganic fertilizer and organic products into production. Further, there is limited linkages of soil fertility to yield and quality arising mainly from limited patronage and knowledge on available soil testing services, limited understanding of how soil properties inform yield and eventually how soil amendment influence carrot yield and tuber quality.

If nothing is done, Ghana risks worsening the state of decreased soil productivity, reduced soil fertility, erosion, deforestation and increased cost of production among small holder farmers who constitute more than 50% of the Ghanaian work force. These would ultimately result in increased poverty, unemployment, inequality, hunger and malnutrition and high import bills and food insecurity.

To effectively prioritize the issues needed to be addressed an exploratory study was conducted to establish which production and climate adaptation constraints affected farmers the most. The results led to the treatment selection of three levels of biochar to be combined with five levels of inorganic fertilizer in a factorial experiment to study the individual and combined effect of treatments to better inform farmers and stakeholders of which management practice works best for specific soil environments and production objectives viz. growth, yield and nutritional composition.

1.3 Justification/Significance of the Study

This study focused on carrot because it is the main crop grown by farmers in and around Mampong Municipality. It is a common practice among most small holder and commercial farmers to employ slash and burn and inorganic fertilizers in crop production. These practices degrade the soil, pollute water bodies and emit tones of greenhouse gases (GHGs) into the atmosphere. In this work, biochar is used as a soil conditioner because of its documented positive influence on soil physical and chemical properties. Inorganic fertilizers were also studied because of the present debate on their negative influence on soil chemical properties and plant support mechanisms. The conversion of woody branches of avocado trees (a forest product) into biochar (a climate-smart product) with different rates and types of fertilizer were assessed for their effects on soil physical and chemical properties, biomass accumulation and the overall yield and tuber nutritional quality of carrot. This work was thus intended to contribute to shedding light on how soil management can contribute to crop growth, yield and nutritional quality and further highlight how climate change mitigation and adaptation can be integrated into crop production to promote sustainable agricultural principles in line with the Sustainable Development Goals (SDGs). Consequently the study shall contribute to global discussions around SDGs 1, 2, 3, 7, 12, 13, 14 and 15.

Further, in line with the aspiration of African Union Agenda 2063 for a prosperous Africa based on inclusive growth and sustainable development, it is envisaged that by 2063 modern and sustainable agricultural technologies shall be a norm for increased production, productivity and value addition towards contributing to farmer and national prosperity and Africa's collective food security (African Union Commission, 2015).

1.4 Research Objectives

The overall objective of this research was to investigate how carrot growth, yield and nutritional quality would respond to different soil management regimes with different levels of fertilizer and biochar to inform environmental management practices including climate change mitigation and adaptation for sustainable agriculture.

This research work had two primary objectives with different specific objectives as follows;

Primary Objective 1

O1. To assess the mechanisms for improving knowledge on integrated soil and crop management in carrot production.

Specific objectives

O1.1 To evaluate farmers perception on availability and efficiency of support services in carrot production

O1.2 To assess the nature of soil and crop management constraints in carrot production including knowledge gaps

O1.3 To examine the effectiveness of farmer cooperatives towards contributing to knowledge sharing, marketing and food security

Primary Objective 2

O2. To evaluate the relationship between soil physicochemical properties and carrot growth, yield and nutritional quality

Specific Objectives

O2.1 To explore how soil chemical properties are impacted by nutrient management practices in soil amendments and how these changes influence carrot growth performance

O2.2 To assess how soil chemical changes due to amendment affect carrot yield and nutritional composition

O2.3 To determine the relationship among soil properties, carrot growth, yield and tuber quality

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of Carrot

There is a general belief that carrot (*Daucus carota* L.) originated in Afghanistan where it remains the centre of diversity (LeBlanc and Thebeau, 1995). Known to the Greeks and the Romans, their early use was mainly medicinal particularly in the treatment of stomach disorders, wounds, ulcers, liver and kidney ailments (Sharma *et al.,* 2016). Early writings in classical Greek and Roman times refer to edible white roots, but these may have also been parsnips, or both (Kwiatkowski *et al.,* 2013). There are white rooted carrots in existence today, often used as animal feed or a novelty crop (Veitch *et al.* 2014).

The earliest vegetable definitely known to be a carrot dates from the 10th century in Persia and Asia Minor and would have been quite unlike the orange rooted carrot of today. It is considered that carrots were originally purple or white with a thin root, then a mutant occurred which removed the purple pigmentation resulting in a new race of yellow carrots, from which orange carrots were subsequently developed (Abuzar *et al.,* 2013). At the beginning of the seventeenth century, repeated selections resulted in carrots with fleshy orange roots in the Netherlands which provided the basis for modern cultivars of *sativus* species. The crop was introduced by Europeans around 1930 into Ghana (Dawuda *et al*., 2011).

By the thirteenth century, carrots were established as a food crop in India, China and Japan (Atakora *et al.*, 2014a). The greatest development and improvement of the original wild carrot that had thin, long roots took place in France (World Carrot Museum, 2011). It has also been reported that carrots with purple roots were domesticated in Afghanistan and spread to the Eastern Mediterranean area under Arab influence in the tenth to twelfth centuries and to Western Europe in fourteenth and fifteenth centuries. The greatest development and improvement of the original wild carrot that had thin, long roots took place in France (Abuzar *et al.*, 2013). Carrots are now a popular vegetable grown all over the world. The modern carrot cultivar is believed to have been derived from wild carrot (*Daucus carota* L.) found in Europe, Asia and Africa.

2.2 Botany

Daucus carota is a biennial plant that grows a rosette of leaves while building up assimilates in the taproot resulting in the storage of amounts of sugars to provide energy for the plant to flower in the second year (Abuzar *et al*., 2013). Following germination, carrot seedlings show a distinct demarcation between taproot and stem: the stem appears thicker and lacks lateral roots (Bashan *et al*., 2010). At the upper end of the stem is the seed leaf. The first true leaf appears about 10–15 days after germination. Subsequent leaves, produced from the stem nodes, are alternating (with a single leaf attached to a node) and compound, and arranged in a spiral (Veitch *et al*., 2014). The stem, located just above the ground, is compressed and the internodes are not distinct (Stolarczyk and Janick, 2001). As the seed stalk elongates for flowering, the tip of the stem narrows and becomes pointed, extends upward, and becomes a highly branched inflorescence. The tall stems grow to 60–200 cm tall (Stolarczyk and Janick, 2001).

Most of the taproot consists of a pulpy outer cortex (phloem) and an inner core (xylem). High-quality carrots have a large proportion of cortex compared to core (Abuzar *et al*., 2013). Taproots typically have a long conical shape, although cylindrical and round cultivars are available (Northolt *et al.,* 2004). The root diameter can range from 1 cm to as much as 10 cm at the widest part. The root length ranges from 5 to 50 cm, although most are between 10 and 25 cm (Konieczka *et al.,* 2009).

Carrot is a diploid species, and has nine relatively short, uniform length chromosomes (2*n*=18). The genome size is estimated to be 473 mega base pairs (Arscott and Tanumihardjo, 2010).

2.3 Varieties

It is difficult to provide the exact number of cultivars and types of carrot as different authors from different geographical locations provide different types of carrots. In terms of root shape, there are several different varieties of carrots. Notable among them are Amsterdam, Nairobi and Nantes and plant breeders have used these to produce most of the dominant hybrids on the market (Varming *et al*., 2004). According to Abdel (2015), carrots are classified into four major cultivars based on root shape and storage capacity as Chantenay, Nantes, Danvers and Imperator. In another work by Budrewicz *et al*. (2005), Bangor, Canada, Carlo, Fayette, Kazan, Kathmandu and Maxima are named as varieties of carrot experimented with. Abuzar *et al*. (2013) add Kuroda to the list of varieties. Other authors included Zeno, Pusa Yamdagini, Temperate Type (Nantes Half Long), No. 29, Oregon, Selection 223, Pusa Meghali and Pusa Kesar (Abdel, 2015). Each of these varieties are described by unique characteristics including colour, maturity period, degree of tapering, root length, shelf life, smoothness, fibre content and juiciness.

2.4 Climatic and Edaphic Requirements

Carrots are a cool-weather crop that require the right temperatures to produce a healthy crop. Warmer temperatures are only acceptable early in the growing process. The best climate for carrot production includes a fairly mild spring and dry summer with temperatures that routinely reach 30ºC and above but not above 35ºC until late summer, after the seed is set and near maturity. According to Abuzar *et al*. (2013), carrot seeds are rarely produced in tropical conditions since mean day temperature requirements for seed production are less than 20°C. Experiences in Ghana have indicated that farmers cultivate carrot only for the root vegetable apparently because of the prevailing high temperatures (Dawuda *et al*., 2011).

2.5 Production Estimate

Carrot yield or production estimate is dependent on genetic and several environmental factors. Notable among them are spacing, soil chemical composition, carbon content, rhizosphere biodiversity, water content, soil structure, presence of physical obstacles such stones, etc (Taylor *et al*., 2014; Atakora *et al*., 2014b). It is also arguable that the purpose of producing carrot affects the kind of management and consequently the yield. Baby carrots produced for culinary purposes Atakora *et al*. (2014b) reported a maximum yield of 15.7t/ha after amending soil with 20t/ha Grass cutter manure and planting at 25cm between row. Abdel (2015) presents Pusa Kesar and Pusa Meghali varieties to yield 20ton/ha. According to Abuzar *et al*. (2013), an average yields of fresh market and processing carrots combined are reported to be about 50 to 70 t/ha for hybrid varieties, with yields of up to 100 t/ha having been achieved by some successful growers. In contrast, it is argued that open pollinated varieties yield on average 30 to 40 t/ha.

2.6 Crop Propagation

The only known method of propagating carrots is by seeds. Sowing carrots in Ghana is heavily influenced by climate variability. However in general, sowing can be carried out in the minor season from August to November and major season from April-to July. One of the major problems confronting most carrot growers is to achieve the correct plant population (Mengistu and Yamoah, 2010). Where the population is too low, roots tend to become large, are generally subject to more splitting or cracking, and marketable yields are detrimentally affected. On the other hand, where the population is excessive, roots tend to become smaller, are often twisted around one another, giving a poorer quality root, and marketable yields of good quality may also be lowered (Abuzar *et al*., 2013). For larger, processing type carrots: 600000-900,000 plants per hectare is recommended. For standard pre-pack sized carrots: 900,000–1,500,000 plants per hectare is recommended and for Imperators/baby carrots: 2,000,000–3,500,000 plants per hectare is recommended (Varming *et al*., 2004). Abdel (2015) further recommend that rows should generally be spaced from 200mm to 400 mm apart. However, in double or triple rows, the width between sets of rows should range from 400 to 600 mm. Row spacing in baby carrots production may be 100 mm. A planting density of 150 to 160/m^2 gives good results in double rows whereas a density of 100/m^2 is ideal for single rows (Jeptoo *et al.*, 2013). The seeds are directly sown in the field on ridges or raised beds. Row planting is preferred to broadcast sowing.

2.7 Agronomic Practices

Carrots do very well in raised beds and can also be grown in containers (Bajpai and Punia, 2015). Conventionally, carrots require sandy soils, sandy loam and silted loam. Heavy, clay soils or compacted soils may produce stunted roots. It is more appropriate to plant dwarf varieties of carrots in soils that grow dense below 1 foot of depth. It is also recommended to amend clayey soils with loamy soil or organic materials to create lighter, better-draining soil and that amending the soil with all-purpose NPK 5-5-5 fertilizer or minimal amount of Nitrogen (about 80Kg/ha) has positive effect on yield and quality of carrot (Kivuva *et al.,* 2014). Carrots also grow best in a well-draining, loose, sandy soil which is free of large rocks and has a pH between 5.5 and 7.0. Water requirement for carrot is dependent on soil moisture level and climatic conditions.

In terms of nutrient requirement by uptake, it is argued (Abdel, 2015) that at harvest, the aboveground biomass for an Oregon seed carrot crop contains between 200 to 250 kg N/ha with 20 kg/ha of this amount in the seed whereas the French production of Nantes-type carrots for seed are reported to contain less Nitrogen in aboveground biomass, 170 kg/ha. However, a carrot root yield of 60 to 80 Mg/ha contains 225 to 350 kg N/ha. Even though the N concentration is similar in roots and tops, 1.5 to 2 mg/kg, the N content in roots is about three times greater compared to the above-ground due to much greater root mass (Abuzar *et al*., 2013). Potassium content of seed carrot crops is approximately the same as the N content. The K content of root carrot crops can be as much as double the N content. P content of both types of carrot crops is about 10% of the N content. Potassium uptake slightly precedes N accumulation. In spite of accumulating more than 200 kg N/ha in a seed carrot crop, N rate for seed production is maximized at rates below 100 kg/ha (Abdel, 2015).

2.8 Effects of Fertilizers and their Rates on Carrot Yield

Inorganic fertilizers are widely used in carrot production because of their ability to improve the macro nutrients levels resulting in increased growth and yield of carrot. Smith *et al*. (2014) argued that growth increases could be due the availability of nitrogen, phosphorus and potassium to the soil at a faster rate and needed by plants in large quantities for growth and yield.

Inorganic fertilizers are produced to supply nutrients found to be lacking in a particular soil and have the ability to make nitrogen, phosphorus and potassium immediately available to crop in required quantities. Ahmed *et al.* (2014) argue that while NPK 15-15-15 supplies adequate macronutrients, it lacks the ability to improve the soil physical properties. Akom *et al.* (2015a) reported that 180kg of P_2O_5 ha^{-1} gave higher yield effect, while Clough *et al*. (2013) observed some yield increase when 90 kg P_2O_5 ha^{-1} was used. Dawuda *et al.*, (2011) also reported that, the application of 45 kg P_2O_5 ha^{-1} using single superphosphate resulted in a significant increase in both marketable and total yields of carrot.

Atakora *et al.*, (2014) argued that plants supplied with more compound fertilizers rich in K can produce larger tubers relative to those with less of this fertilizer. Different studies continue to affirm that the application of nitrogen fertilizer can increase dry matter content and total and/or marketable tuber yield of carrot (Dawuda *et al*., 2011).

Bundinienė *et al*., (2014) and Atakora *et al.*, (2014) argued that the nutrients required by carrots are Nitrogen (N), Phosphorus (P) and Potassium (K) and that inadequate supply of any of these nutrients during crop growth is known to have negative impact on the productive capability, growth and yield of the plant and supplementary amount of nutrients can be added to soil in the form of inorganic fertilizer to correct inadequate supply of nutrients to the crop.

2.9 Effects of Fertilizer on Produce Quality

Nutrients enhance the quality of tubers and make them more marketable and nutritious. According to Dunsin *et al.* (2016), poorly developed tubers were consistent with lack of nutrients. Other studies have shown that N applications can increase protein and vitamin content of carrot tubers as a result of the enhanced capacity of nitrogen to mediate and facilitate increased assimilation of essential amino acid synthesis.

Akom *et al.*, (2015a) found that tuber growth is enhanced by K and increases the proportion of large tubers relative to small ones by increasing water accumulation in tubers resulting in a lowering of dry matter content and specific gravity.

Abuzar *et al*. (2013) reported that chemical fertilizers bring about an increase in crop quality by their enhanced solubility, transport and availability to plants. Huggins *et al.* (2016), however, argues that inappropriate use of inorganic fertilizer could present soil and plant toxicity challenges and pose danger to the ecosystem.

2.10 Sustainable Agricultural Principles in the Management of Production Constraints

As an ecosystem approach to agriculture, sustainable agriculture holds promise in the management of carrot production constraints. Despite remarkable increases in food production in the second half of this century, profound challenges still face farmers and those engaged in agricultural development. Modern farming, characterized by increased use of such external inputs and technologies as fertilizers, pesticides, seeds and machinery, has also brought enormous pressure and cost to ecosystem services (Pretty, 1994).

Concurrent with consumers beginning to ask for pesticide-free food products, farmers, who had begun to experience the repercussions of conventional agriculture with a decline in soil and environmental health, the loss of profits due to the expanding global market for food, and the loss of rural culture are increasingly being drawn to organic practices (Gliessman and Rosemeyer, 2012).

It is also argued as an approach to sustainable agriculture that the evolution of integrated pest management (IPM) and integrated soil fertility management (ISFM) which have proceeded separately without realising that low-input agroecosystems rely on synergies of plant diversity and the continuing function of the soil microbial community, and its relationship with organic matter to maintain the integrity of the agroecosystem (Altieri and Nicholls, 2005).

According to Pretty (1994), sustainable agriculture pursues a thorough incorporation of natural processes such as nutrient cycling, nitrogen fixation, and pest-predator relationships; a minimisation of the use of external and non-renewable inputs that damage the environment or harm the health of farmers and consumers; the participation of farmers and rural people in all processes of problem analysis, technology development, adaptation and extension, and monitoring and evaluation; a more equitable access to productive resources and opportunities; a greater productive use of local knowledge, practices and resources; the incorporation of a diversity of natural resources and enterprises within farms; and an increase in self-reliance amongst farmers and rural communities.

2.11 Biochar Systems

Biochar is a material created by pyrolysis of biomass for incorporation into soils to increase the amount of stable organic matter and consequently improve soil fertility (Dennis and Kelvin, 2014). The key idea behind biochar is the enrichment of soils with stable organic carbon compounds (Varming *et al*., 2004). In recent times agro-ecological systems are being promoted to achieve agricultural sustainability. In order to reduce vulnerability of agriculture to climate change and increasing primary productivity there is a need to establish mitigation and adaptation strategies to generate profitable co-benefits (Verheijen *et al.,* 2010). The conversion of woody-wastes and crop biomass by pyrolysis to produce biochar is an activity with a very high potential for enhancing natural rates of carbon sequestration in soils, reducing farm waste, and substituting renewable energy sources for fossil-derived fuel inputs. Adoption of biochar systems has the potential to increase conventional agricultural productivity and enhance the ability of farmers to participate in carbon markets beyond traditional approach by directly applying carbon into soil (Smith *et al*., 2014).

2.12 Nutrient Contribution from Biochar

From an agronomic perspective, the loss of soil organic carbon from crop removal and the associated degradation of soil quality makes the harvesting of biomass for any form of bioenergy production non-sustainable unless other sources of organic carbon are added to the soil to compensate for the biomass residue carbon that is removed (Dennis and Kelvin, 2014). Processing biomass through a distributed network of relatively small pyrolysis plants and use of the biochar co-product of pyrolysis as a soil amendment appears to provide a simple and practical means of solving these problems.

Feedstock quality, including concentrations of ash, lignin, cellulose, and hemicellulose, as well as the pyrolysis process and temperature all play a pivotal role in influencing the physical and chemical properties of the biochar product. If biochar is burned, the caloric content and ash content are key determinants of quality as they contain different chemical constituents (Laird *et al.*, 2010).

2.13 Effect of Biochar on Soil Physical and Chemical Properties

Biochar is attracting international attention mainly on the premise that biochars can be used as soil amendments for improving soil properties and increase crop yield. Storing biochars in soils is regarded as a means of permanently sequestering carbon and a potential abatement option for anthropogenic carbon emissions (Suppadit *et al.,* 2012). While biochars are a spectrum of pyrolysis-derived materials, they do share some distinctive physical and chemical properties such as a stable carbon fraction and high surface area. Biochars are actively being investigated for diverse applications ranging from plant and animal agriculture to toxicant filtration to soil rehabilitation (Mukherjee *et al.*, 2014).

In a work on the effect of fast pyrolysis biochar on physical and chemical properties of a clay soil, it was observed that biochar additions resulted in a decrease in soil bulk density which consequently increases soil porosity and soil aeration (Brantley *et al.,* 2015), and may have a positive effect on root and microbial respiration (Mukherjee *et al.*, 2014).

Additionally, Jeffery *et al.* (2015) assert that depending on the distribution of particle size in the soil, the rate and nature of biochar applied and the time since application, soil pore-size distribution and water holding capacity may be affected. The chemical properties of the soil are also influenced by progressive abiotic and biotic surface oxidation of charcoal which results in surface proliferation of carboxyl groups and an increasing ability to sorb cations. This explains the high cation exchange in archaeological soils (Brownsort *et al.*, 2012). Negative charge provides the possibility for reversible storage of available nitrogen relevant to soil-based N_2O emissions and nitrate leaching (Brownsort *et al.*, 2012). It is argued that charcoal has the capacity to sorb polar compounds including many environmental contaminants (Appiah *et al*., 2009), particularly polycyclic aromatic hydrocarbons (PAH) for which it may be the dominant sink in soils and sediments (Carter *et al.*, 2013; Huggins *et al.* 2016).

2.14 Effect of Biochar and Inorganic Fertilizers on Soil Characteristics, Plant Growth and Yield

There is a growing interest in the use of biochar as a soil amendment as a result of its high potential to increase nutrient availability. Biochar, used as an alternative organic fertilizer additionally with chemical fertilizer holds promise for the future of sustainable crop production and agriculture.

According to Alvum-Toll *et al*. (2011), the combination of biochar and fertilizer optimize nutrient use efficiency, compared to if applied separately. In the study, yield increases were not observed in radish when biochar from biomass waste was applied in absence of N-fertilizers. This strengthens the theory that biochar improves the nitrogen use efficiency from fertilizers.

Zidane *et al.* (2015), in their work on the impact of rice husk biochar and macronutrient fertilizer on fodder maize and soil properties discovered that the average maize height was increased with the addition of biochar as well as inorganic NPK fertilizers and that the highest plant height was obtained with the combined application of 25% less than recommended rate of NPK and 10t ha^{-1} biochar.

It is further argued by Deenik and Cooney (2016), that the potential benefits and limitations of corn cob and sewage sludge biochars in an infertile Oxisol, that the combination of biochar and fertilizer produced significant benefits to corn growth compared with inorganic fertilizer applied alone in the 1st and 3rd crop cycles where in the first crop, fertilizer and biochar combinations for both biochar types doubled corn growth and more than tripled growth in the 3rd crop for the sewage sludge biochars. In a study using biochar as a soil amendment on corn it was revealed that after harvest, the soil organic matter, soil pH, available phosphorus P1 and P2, and CEC generally increased in the field plots treated with biochar (Zheng *et al.*, 2010). The authors further indicated that the increase in soil organic matter and CEC showed that fairly large amounts of carbon and exchangeable cations were introduced by biochar application and that the high level of available phosphorus P1 and P2 after biochar application indicates that the use of biochar as a soil amendment led to a high retention of nutrients in the soil. However, the contents of nitrate-N in these biochar-amended plots were significantly reduced even when undergoing nitrogen fertilizer application. Zheng *et al*. (2010) adds that biochar can sorb nitrogen fertilizers and inhibit their nitrification resulting in a reduction in the concentrations of nitrate in fields with biochar addition.

2.15 Effects of Biochar on Crop Performance

In a study on the effects of biochar and inorganic fertilizer application on soil fertility and agronomic performance of maize, Peiris and Weerakkody (2015), found that Nitrogen uptake significantly increased in maize plants that received biochar with or without inorganic N fertilizer application. Sole biochar application increased N uptake by 222.8% when applied at 10t/ha in the minor season. The author further indicated that in both major and minor cropping seasons, biochar at 10 t/ha with inorganic fertilizer N resulted in highest grain yield. Yang *et al.* (2015) in a study on enhancement of crop yield by rice straw and corn stalk-derived biochar in Northern China stated that biochar from rice straw showed a more positive effect on the yield of corn, peanut and winter wheat than using stalk biochar and that biochar applied at 2ton/ha or 1ton/ha could enhance yield by 5%-15% whilst biochar applied at 4 ton/ha could increase yield by 20%.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Action Research

A preliminary exploratory study was conducted using action research methodologies. The methods used in the action research include desktop studies to review literature on carrots and cross-sectional studies. Responses in cross-sectional studies were triangulated using focus group discussion with carrot producers and marketers and in-depth interview with key stakeholders. Panel studies of a full-year weekly harvest of carrot brought to Asante Mampong Carrot Market for onward sales and distribution was conducted. The cross-sectional study made use of probability sampling of 25 carrot farmers from the list of members constituting the Association of Carrot Growers and Sellers in Asante Mampong. Key stakeholders were selected using purposive sampling. The stakeholders interviewed include the Mampong Municipal Crop Officer, the Chairman of Mampong Carrot Growers and Sellers Association and a researcher working on carrot at the Crops Research Institute of the Council for Scientific and Industrial Research (CSIR), Fumesua. The results from the Action research provided the basis for much of the experimental research carried out in 2016 and 2017. Both quantitative and qualitative data were collected. Data analysis was done with SPSS version 17. The data collection instrument for the cross-sectional study is attached as Appendix G. Results from the study was presented in tables and figures after the analysis.

3.2 Experimental Site

Two field experiments were conducted in different cropping seasons. The first experiment was carried out in the minor cropping season from September to December, 2016 and the second experiment, April to July, 2017 in the major cropping season. The two experiments were carried out at the Multipurpose Crop Nursery of the College of Agriculture Education, University of Education, Winneba, Mampong- Ashanti campus located in the forest-savannah transition zone of Ghana (Lat. 07º, 04'N; Long. 01º, 24'W) (GSS, 2014; Atakora *et al.*, 2014b)

The area has bimodal rainfall pattern with the major rainy season occurring from March to July and minor rainy season from September to November. Between the two seasons is a short dry spell in August. The soil at the project site is classified by the FAO legend as Chromic Luvisol (Abuzar *et al*., 2013; Atakora *et al*., 2014b) and locally as the Bediesi series. The soil is sandy loam, well drained with thin layer of organic matter (Awoonor, 2012). The pH ranges from 6.5-7.0. It is permeable, and has moderate water holding capacity (Atakora *et al.*, 2014b).

3.3 Experimental Design and Treatment

3.3.1 Experimental design

A 5x3 factorial arranged in randomized complete block design (RCBD) was used. There were fifteen (15) treatments replicated three (3) times. The 15 treatments, made up of five fertilizer rates, three biochar rates and the control (without any amendment) were assigned to each block. Each treatment plot measured 2.0 m × 1.2 m.

3.3.2 Treatments

The treatment combinations are indicated in Table 3.1

Table 3. 1 Treatments for the experiment

Treatments	Inorganic Fertilizer	Biochar
T1	NPK 15:15:15@200 Kg/ha (Recommended)	5 ton/ha
T2	P&K 50:50 @ 50 kg/ha*	10 ton/ha
T3	P&K 50:100 @ 50 Kg/ha*	No Biochar (Control)
T4	Liquid Fertilizer (Digrow)	5 ton/ha
T5	No Fertilizer (Control)	10 ton/ha
T6	NPK 15:15:15@ 200 Kg/ha (Recommended)	No Biochar (Control)
T7	P&K 50:50 @ 50 kg/ha	5 ton/ha
T8	P&K 50:100 @ 50 Kg/ha	10 ton/ha
T9	Liquid Fertilizer (Digrow)	No Biochar (Control)
T10	No Fertilizer (Control)	5 ton/ha
T11	NPK 15:15:15@ 200 Kg/ha (Recommended)	10 ton/ha
T12	P&K 50:50 @ 50 kg/ha	No Biochar (Control)
T13	P&K 50:100 @ 50 Kg/ha	5 ton/ha
T14	Liquid Fertilizer (Digrow)	10 ton/ha
T15	No Fertilizer (Control)	No Biochar (Control)

* P&K 50:50= 50 kg/ha P and 50 kg/ha K or 50 parts P and 50 parts K

** P&K 50: 100 = 50 kg/ha P and 100 kg/ha K or 50 parts P and 100 parts K

3.4 Land and Biochar Preparation and Application

3.4.1 Land Preparation

The land was ploughed and harrowed for the first experiment in October 2016 and in April 2017 for the second experiment. The field was later levelled and laid out according to a pre-determined field size of 26 m x 10 m. Beds measuring 2m x 1.2m were prepared with hoe to a height of 25cm and levelled with rake. There was a 1.0 m path between each bed and 2 meter interval between each block.

3.4.2 Biochar Preparation and Application

Biomass from woody branches of avocado was slowly pyrolyzed at about 500ºC in an anoxic pit reactor prepared at the College of Agriculture Education, Asante Mampong Campus solely for the purpose of the experiment. The biochar was then crushed and milled to <2mm-sized particles. The powdered biochar was then applied a week after bed preparation by mixing with the soil at 10cm deep to respective treatment and left for two weeks before planting.

3.5 Soil Sampling and Biochar Analysis

Soil samples were randomly taken from different spots (5 points) at a soil depth of 0-15cm from each treatment plot and replication. Soil samples from each treatment plot and replication were bulked, air dried and sub-samples taken for analysis at the Soil Research Institute, Kumasi before planting. Soil plus biochar samples were then taken again at six weeks after soil amendment to allow for adequate decomposition, mineralization and assessment of soil nutrients available in solution. Soil pH, Cation Exchange Capacity (CEC), Organic Carbon, total Nitrogen, available Phosphorus, available Potassium, exchangeable Calcium and Magnesium, Sulphur, total Potassium and Phosphorus were assessed in accordance with methods described in item 3.8.3 below.

3.6 Planting, Fertilizer Preparation and Application

3.6.1 Planting

Seeds of carrot were sown by drilling to a depth of about 2cm at 30 cm between rows on each bed. The planting materials used was Chantenay Variety traded under the Tokita Brand name. This variety was selected because it is used by most carrot farmers in Asante Mampong and Ghana at large. The seeds were obtained from Chinese Woman Agrochemical Shop in Kumasi.

The beds were covered with straw to prevent excessive heat and possible washing off of the tiny seeds during heavy rains. The straw was removed after seedling emergence. Emergence was observed six days after sowing. At 12 days after planting, seedlings were thinned to 10 cm between plants.

3.6.2 Fertilizer Preparation and Application

NPK 15:15:15 was applied at 200 kg/ha 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 48g of the NPK was applied via side dressing 3 cm to the established seedlings.

The fertilizer rate of 50kg/ha P and 50 kg/ha K was prepared from 2 straight fertilizers-triple supper phosphate (CaH_2PO_4) containing 45 % active ingredient and murate 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 50kg/ha CaH_2PO_4 at 45% Active Ingredient,

$$Amount\ of\ P\ Fertilizer\ in\ kg/ha = \frac{50kg/ha}{0.45} = 111.1\text{kg/ha}$$

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

Again, for the 50Kg/ha KCl at 50% active ingredient,

$$Amount\ of\ K\ Fertilizer\ in\ kg/ha = \frac{50kg/ha}{0.50} = 100\text{kg/ha}$$

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

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

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

$$Amount\ of\ K\ Fertilizer\ in\ kg/ha = \frac{100kg/ha}{0.50} = 200\text{kg/ha}$$

Hence, 200kg/ha K translates into 48g of the fertilizer product for each 2.4m^2 plot receiving K at rate 100kg/ha 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%, 742ppm, 587ppm, 105ppm, 383ppm, 43ppm, 76ppm, 0.68% was applied to respective treatments. A recommended dilution rate of 1liter D.I. Grow to 200 liters of water for 1 hectare was used.

3.7 Cultural Practices

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.

Earthening-up was done every two weeks after weeding and watering 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.

3.8 Data Collection

3.8.1 Action Research

A data collection instrument was developed after a desk review of the carrot landscape and interacting with farmers within Mampong Municipality. With the help of the Municipal Crop Officer, the list of carrot farmers in Mampong was obtained and used as a sampling frame from which 25 farmers were randomly selected and interviewed. Data on climate variability in temperature, rainfall and relative humidity and carrot production output as presented by farmers reporting at Mampong Carrot Market were also collected within a 12 month from October 2016 to September 2017. Focus group discussions were also held as a means of triangulation with the data collection instrument.

3.8.2 Soil Physical Properties

Data on bulk density, volumetric moisture content, gravimetric moisture content and total porosity was determined using methods described in Bashour and Sayegh (2007). Bulk density was taken two weeks after biochar application. The soil samples were taken with core samplers of known volumes into the soil at 0-15cm depth. Samples taken from each plot were then oven-dried at 105ºC to a constant weight. It was calculated using the relation;

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

Soil porosity was determined using the formula $f = \frac{1-BD}{PD} X100$

where f = Total porosity BD = bulk density PD = particle density = 2.65g/cm^3

Gardner gravimetric method was used to determine the moisture content. Samples of soil weighing about 100g were taken randomly from the various treatments plots on the site at 0- 15cm depth using the aluminium auger. The samples were weighed before subjecting them to oven drying at 105ºC for 24 hours. These were weighed again after oven drying. Gravimetric moisture was then calculated by using the formula;

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

where θg is soil gravimetric moisture

M_1 is the weight of soil before oven drying

M_2 is the weight of soil after oven-drying

3.8.3 Soil Chemical Analysis

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. Samples from each treatment and replication were bulked, air dried and sub-sampled for analysis at the Soil Research Institute, Kumasi before planting. Soil samples were also taken six weeks after soil amendment.

3.8.3.1 Cation Exchange Capacity (CEC)

5g of soil was weighed and transferred into a 50-ml centrifuge tube. 25 ml of 1.0M sodium acetate solution was added to the tube and a stopper was fixed and shaken in a mechanical shaker for 5 minutes. The solutions were centrifuged at 2000 rpm for 5 minutes till supernatant liquid became clear. The liquid was decanted and the extraction was repeated three times. The mechanical shaker, the centrifuge, and decantation process with ethanol was repeated until the electrical conductivity (EC) of the decant read less than 40 mS/cm (Bashour and Sayegh, 2007).

3.8.3.2 Soil pH

Soil pH was determined by the use of the pH meter.

The pH meter was calibrated using two buffer solutions.

10.0g of soil sample was placed in a 50-ml beaker and 20ml of $CaCl_2$ solution was added. The soil was allowed to absorb the $CaCl_2$ solution without stirring. It was then stirred thoroughly for 10 seconds using glass rod. The suspension was stirred for 30 minutes. The pH was recorded on the calibrated pH meter (FAO, 1991).

3.8.3.3 Organic Carbon / Organic Matter

The Walkley-Black Method was used.

1g of soil was weighed and placed in a 250 ml. Erlenmeyer flask. Under the hood, 5 ml of potassium dichromate and 10 ml of concentrated sulphuric acid was added. The solution was allowed to rest for 3 hours. Then 75-100 ml of deionized water, 2-3 drops of ferroin and titrate with Mohr's salt was added. At the same time a blank with 5 ml of dichromate and 10 ml of sulphuric acid was prepared.

Calculation: from the result, organic carbon or as organic matter.

$O.C\% = \frac{(b - a) \times N \times f \times 0.39)}{W}$

Where: b = ml of Mohr's salt used for the blank

a = ml of Mohr's salt used for the sample

N = normality of Mohr's salt

F = normality correction factor

W = weight of the sample

Consequently, Organic matter was calculated from the relation as follows (Bashour & Sayegh, 2007);

$$O.M\% = O.C.X1.724$$

3.8.3.4 Total Nitrogen

1g of soil sample was weighed and placed in a Kjeldahl flask. 0.7g of copper sulphate, 1.5g of K_2SO_4 and 30ml of H_2SO_4 was added. The set up was heated gently until frothing ceased. It was then boiled briskly until the solution was clear and digested for 30 minutes. The flask was removed from the heater and cooled, 50ml of water was added and was transferred to a distilling flask. 20 – 25ml of standard acid (0.1MHCl) was placed in the receiving conical flask to get an excess of at least 5ml of the acid. 3 drops of methyl red indicator was added and enough water was added to cover the end of the condenser outlet tubes. Tap water was run through the condenser before 30ml of 35 percent NaOH in the distilling flask was added. The content was heated to distil the ammonia for about 30 – 40 minutes.

The receiving flask was removed and the outlet tube was rinsed into the receiving flask with a small amount of distilled water. The excess acid was titrated in the distillate with 0.1MNaOH. The blank was determined on reagents by using the same quantity of standard acid in a receiving conical flask (Rashidi *et al*., 2010).

$$N\% = \frac{((25 - a) \times 14)}{W(gr)} \times 100$$

Where:

25 = ml of 0.1 N H_2SO_4 used in the beaker

a = ml of 0.1 NaOH used in the titration

W = weight of the soil in grams

14 = molecular weight of nitrogen

3.8.3.5 <u>Available Phosphorus</u>

Bray's method was used.

The preparation of the standard curve was done by Bray's method No. 1. The extraction process was carried out by adding 50ml of the bicarbonate extractant to a 100-ml conical flask containing

2.5g of soil sample. 1g of activated carbon was added and shaken for 30minutes on the mechanical shaker and filtered.

The development of the colour was carried out by Bray's method No.1 and the calculation was done by the standard curve with fresh molybdate reagent. The colour was measured photometrically at 660nm wavelength. The concentration of P was calculated as:

mgP/kg Soil= mgPkg^{-1} in Solution ×50 (FAO, 1988).

3.8.3.6 Available Potassium

This was determined by the use of the photometric method (FAO, 1988). A standard curve was carried out by setting up a flame photometer atomizing 0 and 20 Ug K/ml solutions alternatively to reading of 0 and 100. The extraction process was carried out by adding 25ml of the ammonium acetate extractant to a conical flask fixed with a wooden rack containing 5g of soil sample. It was shaken for 5minutes and filtered. The potash in the filtrate was determined with the flame photometer as follows;

$$\%K = (a - b) x \frac{M}{Factor}$$

Where

a=MgK/ml in Sample,

b=MgK/ml in blank,

M=moisture concentration factor.

Factor=200/Dil. factor

3.8.3.7 Exchangeable Calcium and Magnesium

Five (5) grams of air-dried soil sample was put in a 150-ml conical flask and 25ml of neutral normal ammonium acetate solution was added and mechanically shaken for 5minutes and was filtered through No.1 filter paper. An aliquot of 5ml was taken and 3 crystals of carbamate and 5ml of 16percent NaOH solution and 40mg of indicator powder was added. The set up was titrated with 0.01N EDTA solution until the colour changed gradually from orange-red to reddish-violet (purple). A drop of EDTA solution was added at 5-10 seconds since the change of colour was not instantaneous and the end point was compared with a blank reading (FAO, 1991).

The calculation is:

If N_1 is normality of Ca^{2+}/Mg^{2+} and V_1 is volume of aliquot taken and N_2V_2 are the normality and volume of EDTA respectively used, then;

$$N1V1 = N2V2$$

Which implies that

$$N1 = \frac{N2V2}{V1} = \frac{Normality\ of\ EDTAxVol.of\ EDTA}{ml\ of\ aliquot\ taken}$$

3.8.3.8 <u>Sulphur (S) (Soil)</u>

The standard curve was prepared and 1g of soil sample was digested in di-acid and the volume was made up to 100ml.

10ml of the aliquot was transferred to a 100-ml volumetric flask. 1g of sieved $BaCl_2$ was added and shaken for 1minute. 1M of gum acacia acetic – acid solution was added and the volume was made up to the required mark and shaken for 1minute.

A blank solution in an identical manner was run and the turbidity 25 – 30 minutes after the precipitation at 440nm was measured. The sulphur content in the sample from the standard curve was read against the similar absorbance as noted for the sample (Bashour & Sayegh, 2007).

3.8.3.9 <u>Potassium (K)</u>

The AAS was set up and standardized, followed by the preparation of the standard curve. An acid-digest 1g of plant sample was made up to 100ml and kept for estimation range of 5-10 g K/ml. A blank sample was prepared in the same way without adding plant digested material. An aliquot of 5ml was taken for estimation and made up of 100ml and atomized on the calibrated AAS. The absorbance was recorded against each sample and the concentration of K was observed from the standard curve (FAO, 2000).

3.8.3.10 Phosphorus (P)

A standard curve was prepared. 1g of soil sample was taken and digested by the wet digestion method and the volume was made up to 100ml. 5 ml of the digest was put in a 50-ml volumetric flask and 10ml of vanadomolybdate reagent was added. The volume was increased with distilled water and shaken thoroughly and was kept for 30 minutes. A yellow colour developed and was read at 420nm on spectrophotometer. The observed absorbance of P was determined from the standard curve (Bashour & Sayegh, 2007).

3.8.4 Plant Sampling and Measurement

3.8.4.1 Vegetative growth

Five plants were randomly selected from the middle rows and tagged for record taking. Plant height and number of leaves per plant were taken from 2 weeks after planting (2WAP) to 12 WAP. Root length and root diameter at 2cm from the top were recorded immediately after harvest using a meter rule and vernier calipers. Plant height was taken with a meter rule from the soil level to the tip of the longest leaf and canopy width was also determined with a meter rule by measuring the longest possible distance between two points on the canopy from 4WAP to 12 WAP. The yield of taproots and shoot from each plot was weighed with an electronic balance. 15 destructive samples were taken from the border rows, 3 per plot in 5 bi-weekly intervals, to determine the dry matter accumulated. The dry matter was determined by oven-drying at 78ºC±2 for 72 hours in accordance with the method described in Bundinienė *et al.* (2014).

3.8.4.2 Yield and yield components

Clean roots which showed no deformities such as cracked, nematode infected, forked, diseased, malformed shape and size or with spots and those weighing above 35 grams were selected from each plot and weighed as "Standard" or Grade 1 carrots as practiced by carrot farmers in Ghana. The Grade 1 carrots are also known as marketable yield. Roots which showed deformities such as cracked, forked, diseased, malformed shape and size, with spots and having weights below 35 grams were selected from each plot and weighed. Broadly, this group of carrots are termed as non-marketable yield and classified by carrot growers in Ghana as "Social". The "social" group of carrots are also inclusive of a subgroup known as "broken" which is the least grade with the poorest price.

At harvest, 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.* (2016).

3.8.5 Canopy Area and Leaf Area Index (LAI)

With no known documented methodology for determining carrot leaf area index (the ratio of the total area of the leaves to the ground area (Bueno, 1979)), the canopy width was determined with a meter rule at 12 weeks after planting and used to derive the canopy area at maturity under the following assumptions;

At 12 weeks after planting, carrots assume a generally and approximately cylindrical and overlapping canopy

The total area of leaves (leaf area) is approximately equal to canopy area.

Knowing the canopy width at 12 WAP can be approximated to canopy diameter

Canopy radius was then determined as half of canopy diameter.

Using the formula for area of a cylinder, carrot canopy area was determined as πr^2.

The initial canopy area is approximately equal to zero

The leaf area index was determined using methods described in Wolf *et al.* (1970) and was calculated from the formula as follows (Landon, 1998);

$$LAI = \left(\frac{LA2 - LA1}{2}\right) X \frac{1}{GA}$$

Where LAI =Leaf Area Index at 12 WAP

LA2 =Maximum or Final Leaf Area at 12 WAP

LA1=Initial Leaf Area

GA=Ground Area

3.8.6 Crop Growth Rate (CGR)

The 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*., (2002);

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

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

3.8.7 Partitioning Coefficient

The partitioning coefficient expresses the efficiency in conversion of assimilate to economic yield i.e. root. This was determined as the ratio of CGR_{econ} to CGR_{total} (D T Baumann et al., 2002).

3.8.8 Net Assimilation Rate (NAR)

Also known as Unit Leaf Rate, the NAR represents the net gain in assimilate, mostly photosynthetic, per unit leaf area and time (Ekbladh, 2007). 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 Period (in weeks after planting)

T2=Final Time Period (in weeks after planting)

LA1 and LA2=Initial Leaf Area and Final Leaf Area respectively

3.8.9 Relative Growth Rate (RGR)

RGR expresses the dry weight increase in a time interval in relation to the initial weight. 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)

3.8.10 Plant Tissue Analysis

Using proximate analysis procedures as described in Bajpai and Punia (2015), the moisture, ash, protein, fat, carbohydrate and crude fibre contents of carrots were determined. Specifically, crude protein was determined by Kjeldahl Method (Shaw and Beadle, 1948);

3.8.11 Crude Fat Determination

2 g of the dried sample was weighed into an extraction thimble. The thimble was placed inside a Soxhlet apparatus. A dry pre-weighed solvent flask beneath the apparatus was connected and the required quantity of solvent added (about 150-200ml of petroleum ether) and connected to a condenser to extract for 2-3 hours. On completion, the thimble was removed and ether reclaimed using the apparatus. The removal of ether was completed on a boiling bath and dried in a flask at 105°C for 30 min and allowed to cool in a desiccator and weighed.

Calculation: The percentage of crude fat (% of DM) is determined from the relation;

$$Crude\ fat = \frac{Weight\ of\ fat}{Weight\ of\ Sample} x100$$

3.8.12 Crude Fibre Determination

2 g of the dried, fat-free sample was transferred into a digestion flask. 200 ml of hot sulphuric acid was added and the digestion flask placed under the condenser and brought to boiling point within 1 min. The sample was boiled gently for exactly 30 min. An antifoam was used whenever foam became excessive. The mixture was filtered immediately through linen and washed well with

boiling water. The residue was transferred back to the digestion flask and 200 ml hot sodium hydroxide solution added. The new sample was replaced under the condenser and again brought to boiling point within 1 min. After boiling for exactly 30 minutes the mixture was filtered through porous crucible and washed with boiling water and about 15ml 95% alcohol. The sample was dried at 105°C until constant weight, cooled and weighed. The sample was ashed at 550°C for 30min, cooled, and weighed. The weight of fibre was calculated by difference.

Calculation:

Crude fibre (% of fat-free DM)

$$= \frac{(Weight\ of\ crucible + dried\ residue) - (Weight\ of\ Crucible + ashed\ residue)}{Weight\ of\ sample}$$

3.8.12 Ash Determination

2g sample was weighed into a dry, tared porcelain dish and then place in a muffle furnace at 550°C for 4 h. The sample was then cooled in a desiccator and weighed.

Calculation:

The percentage of Ash (%) in the sample was determined by the relation below as

$$Ash(\%) = \frac{weight\ of\ ash}{weight\ of\ sample} x100\%$$

3.8.13 Nitrogen-Free Extract (NFE)

Nitrogen-Free Extract (NFE) represents the non-structural carbohydrates such as starches and sugars, and was found by difference. NFE was determined by calculation after the determination of the various components of the proximate analysis using the formula below:

$$\%NFE(on\ dry\ matter\ basis) = 100 - (\%CP + \%CF + \%Ash + \%EE)$$

Where, NFE = nitrogen free extract; EE = ether extract or crude lipid

CP = crude protein; CF = crude fiber

3.8.14 Energy

The total energy of the various treatments was also determined by calculation using the values determined for protein, NFE and fat in the formula below:

$$Energy\ (kcal/100g) = (4\ x\ \%Protein) + (4\ x\ \%NFE) + (9\ x\ \%Fat)$$

3.8.14 Carbohydrate Determination

The determination of percentage total carbohydrate was carried using the values obtained for NFE and crude fibre in the formula below:

$$\%Carbohydrate = \%\ NFE + \%Fibre$$

3.8.15 Beta Carotene and Total Carotenoid Content

Plant total carotenoid analysis was carried out at the Biochemistry Department of Kwame Nkrumah University of Science and Technology in Kumasi. An amount of 5ml of 70% methanol was added to 5g of sampled carrot extract and thoroughly shaken for a minute. The content of the resulting mixture was filtered through Whatman No. 4 filter paper. The absorbance of the filtrates were then measured at wavelength (λ) 453, 505 and 663nm using a spectrophotometer. In accordance with procedures described in Kamffer, (2009), the formula below was then used to determine the carotene content (mg/100ml).

β-Carotene (mg/100ml)=0.26A663-0.304A505+0.452(453)

where A=absorbance at a specific wavelength

3.9 Data Analyses

Action research data involving cross-sectional studies of carrot farmers was analyzed with SPSS Version 17. 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% and 1% significance level. Correlation analysis was carried out on soil physicochemical properties, growth/yield parameters and nutritional composition. T-tests were conducted for the minor and major rainy seasons in 2016 and 2017. Soil data analysis was also carried out.

CHAPTER FOUR

4.0 RESULTS

4.1 Action Research on Carrot Production in Asante Mampong

4.1.1 Availability and benefits from support services in carrot production

In order to establish the source of production constraint, an initial assessment of how farmers perceive institutional support was carried out. The extent of benefit perceived by carrot farmers for various agricultural services are illustrated in Tables 4.1, 4.2 and Figure 4.1 and 4.2. On the extent of benefit from extension services as presented in Table 4.1a, only 4% of carrot farmers perceive it is beneficial. 96 percent of carrot farmers generally perceive that extension services are not beneficial at all. In Figure 4.1b, the extent of benefit from laboratory services was assessed in which only 4% of respondents perceive laboratory services are beneficial. On financial advice (Table 4.2a) and marketing services (Table 4.2b) only 8 percent of farmers perceive that institutional provision of those services were beneficial while 92 percent of the respondents perceive institutional provision of those services are not beneficial.

Assessing the extent of institutional support from Ministry of Food and Agriculture (MOFA) and Crops Research Institute (CRI) of the Council for Scientific and Industrial Research (CSIR), Figure 4.1a shows that 76% and 24% of respondents respectively perceive support as not at all beneficial and not beneficial. No respondent thought of any benefit from MOFA concerning carrot production. In the case Fig 4.2c, only 4% of respondents felt support from private sector have been beneficial.

Table 4. 1 Extent to which farmers benefit from support services

Table 4.1a Extent of benefit from extension services

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all beneficial	18	72.0	72.0	72.0
	Not beneficial	6	24.0	24.0	96.0
	Beneficial	1	4.0	4.0	100.0
	Highly beneficial	0	0	0	100.0
	Total	25	100.0	100.0	

Table 4.1b Extent of benefit from laboratory services

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all beneficial	14	56.0	56.0	56.0
	Not beneficial	10	40.0	40.0	96.0
	Beneficial	1	4.0	4.0	100.0
	Highly Beneficial	0	0	0	100.0
	Total	25	100.0	100.0	

Table 4.1c Extent of benefit from technical advice

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all beneficial	13	52.0	52.0	52.0
	Not beneficial	11	44.0	44.0	96.0
	Beneficial	1	4.0	4.0	100.0
	Highly Beneficial	0	0	0	100.0
	Total	25	100.0	100.0	

Table 4. 2 Extent of Benefit from Financial Advice and Marketing Service

Table 4.2a Extent of benefit from financial advice

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all beneficial	16	64.0	64.0	64.0
	Not beneficial	7	28.0	28.0	92.0
	Beneficial	1	4.0	4.0	96.0
	Highly beneficial	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Table 4.2b Extent of benefit from marketing service

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all beneficial	14	56.0	56.0	56.0
	Not beneficial	9	36.0	36.0	92.0
	Highly beneficial	2	8.0	8.0	100.0
	Total	25	100.0	100.0	

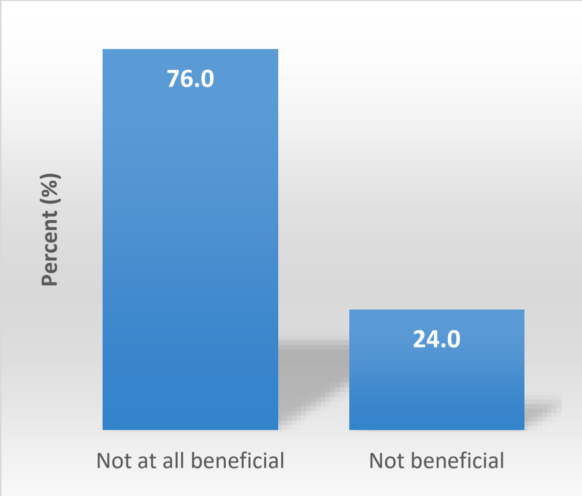


Fig. 4.1a Extent of Support Provided By MOFA

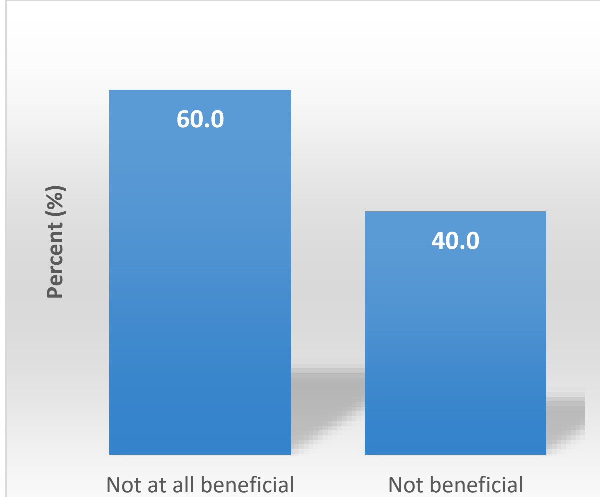


Fig. 4.1b Extent of Support Provided By CRI

Figure 4. 1 Extent of benefit from MoFA and CRI

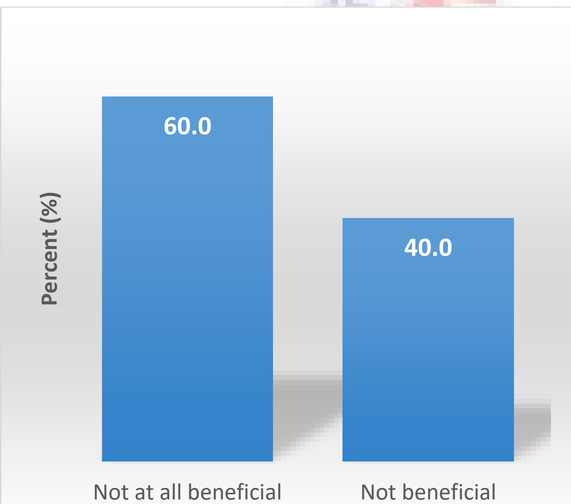


Fig 4.2a Extent of support provided by FAO

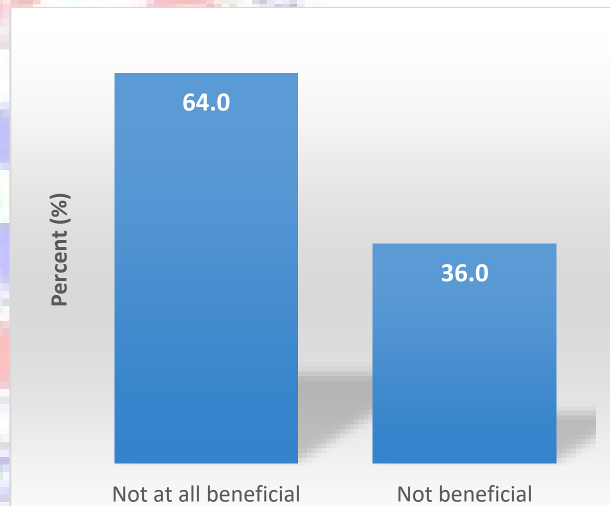


Fig. 4.2b Extent of support provided by NGOs

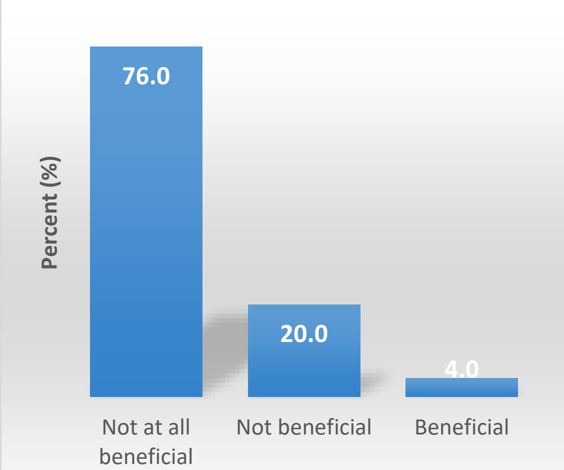


Fig 4.2c Extent of Support Provided By the Private Sector

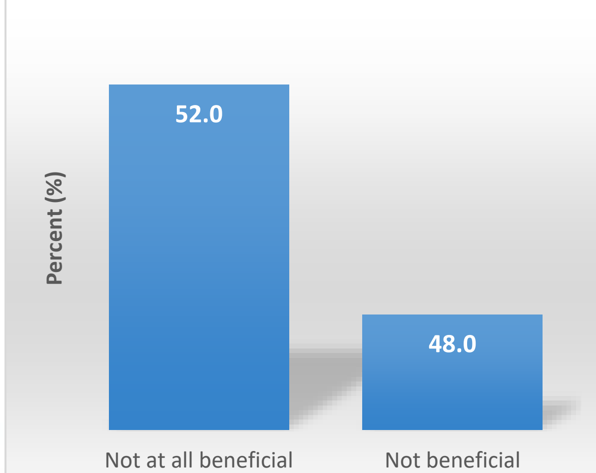


Fig 4.2d Extent of support provided by traditional authority

Figure 4. 2 Nature of Institutional Support Services for Carrot Production as provided by FAO, NGOs, Private Sector and Traditional Authority

4.1.2 Expenditure on Inputs during the minor cropping season, 2016

Table 4.3 shows the amount expended on carrot productioninputs. Overall, average expenditure per farmer on fuel used in pumping machines to irrigate carrot farms was the highest (GHC4,756.00) within the growing season followed by labour (GHC3,297.00) seeds (GHC1,991.24), fertilizer (GHC1,360.00) and biocides (GHC759.2).

Table 4. 3 Carrot Production Expenditure on inputs incurred by farmers during a cross-sectional study

Amount Spent	N	Mean Amount (GhC)	Std. Error	Std. Dev.	Rank
On fertilizer in the last growing period	25	1360	215.1744	1075.872	4
On biocides in the last growing period	25	759.2	144.4471	722.2357	5
On labour in the last growing period	25	3297	1190.301	5951.507	2
On seeds in the last growing period	25	1991.24	686.3059	3431.53	3
On irrigation fuel in the last growing period	25	4756	1173.571	5867.856	1

4.1.3 Nature of Constraints

Perceptions of carrot constraints were assessed under soil crusting from drought, limited cropping area from poor land tenure arrangements, poor root penetration resulting from poor soil structure and texture, ill health among farmers, distance to farm, proximity to water, disability, weeds, disease and pests, predators, and the non-traditional nature of carrots. Tables 4.4 and 4.5 showed that more that 80% of respondents agreed to the fact that carrot production was affected by the constraints enumerated above during the last growing season. Figure 4.3 is also indicative of the weight of ignorance among carrot farmers on some key inputs needed in carrot production. Table 4.7 shows the output of carrot producers within the last two growing seasons 2016 to 2017.

For the non-traditional nature of carrot 40% of respondents strongly disagreed and 32% disagreed that it was a constraint.

Additionally, from Figure 4.3, knowledge gaps in the application of production inputs were assessed using weight of ignorance by a scale of 1 to 10 where 1 indicates the lowest ignorance and 10 indicates the highest ignorance. Consequently, the results demonstrates that with the exception of sprayer calibration where the majority showed low ignorance, there were high ignorance level when farmers had to deal with the type and quantity of inorganic fertilizer to apply for maximum yield, the type and quantity of organic fertilizer that assures maximum yield, the planting distance required for maximum yield, the effect of shading and green house cultivation and the exact irrigation needs of carrot required to provide optimal yield. Hence, the need for research to provide these information is critical to strengthen the carrot value chain system.

Table 4. 4 Carrot Production Constraints

Table 4.4a Extent of agreement that soil crusting is a problem in carrot production

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	2	8.0	8.0	8.0
	Disagree	1	4.0	4.0	12.0
	Agree	9	36.0	36.0	48.0
	Strongly agree	13	52.0	52.0	100.0
	Total	25	100.0	100.0	

Table 4.4b Extent of agreement that limited cropping area is a constraint in production

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	2	8.0	8.0	8.0
	Disagree	1	4.0	4.0	12.0
	Agree	8	32.0	32.0	44.0
	Strongly agree	14	56.0	56.0	100.0
	Total	25	100.0	100.0	

Table 4. 5 Farmers' perception of production constraints-poor root penetration, crop failure and proximity

Table 4.5a Extent of agreement that poor root penetration constrains production

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	2	8.0	8.0	8.0
	Disagree	2	8.0	8.0	16.0
	Agree	9	36.0	36.0	52.0
	Strongly agree	12	48.0	48.0	100.0
	Total	25	100.0	100.0	

Table 4.5b Extent of agreement that crop failure in soil constitutes a constraint

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	1	4.0	4.0	4.0
	Disagree	1	4.0	4.0	8.0
	Agree	10	40.0	40.0	48.0
	Strongly agree	13	52.0	52.0	100.0
	Total	25	100.0	100.0	

Table 4.5c Extent of agreement that proximity to water constitutes a constraint

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	3	12.0	12.0	12.0
	Agree	7	28.0	28.0	40.0
	Strongly agree	15	60.0	60.0	100.0
	Total	25	100.0	100.0	

From Tables 4.6, 4.6 and 4.7 and Figures 4.3 and 4.4, show farmers' perception on the nature of carrot production constraints were assessed. During both focus group discussions and a cross-sectional study among carrot producers in Mampong Municipality, responses and statements from stakeholders and farmers revealed that carrot producers do not have any sort of governmental support and that nematodes and leaf blight are common diseases on carrot fields. The focus group discussion revealed a non-existent policy and governmental support, lack of access to institutional support and services from the Ministry of Food and Agriculture (MoFA) and inadequate research information on systems and standard practices to adopt towards ensuring maximum carrot yield and simultaneously achieve environmental sustainability. Lack of access to detailed information on climatic and edaphic factor requirements for carrots production in Ghana were also cited.

Table 4. 6 Production Constraints- Weeds, diseases, pests and predators

Table 4.6a Extent of agreement that weeds constitute a production constraint

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	14	56.0	56.0	56.0
	Strongly agree	11	44.0	44.0	100.0
	Total	25	100.0	100.0	

Table 4.6b Extent of agreement that diseases constitute a production constraint

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	8	32.0	32.0	32.0
	Strongly agree	17	68.0	68.0	100.0
	Total	25	100.0	100.0	

Table 4.6ac Extent of agreement that pests constitute a production constraint

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	11	44.0	44.0	44.0
	Strongly agree	14	56.0	56.0	100.0
	Total	25	100.0	100.0	

Table 4.6d Extent of agreement that predators constitute a production constraint

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	3	12.0	12.0	12.0
	Disagree	4	16.0	16.0	28.0
	Agree	6	24.0	24.0	52.0
	Strongly agree	12	48.0	48.0	100.0
	Total	25	100.0	100.0	

Table 4.6e Extent of agreement that the non-traditional nature of carrot constitutes a production constraint

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	10	40.0	40.0	40.0
	Disagree	8	32.0	32.0	72.0
	Strongly agree	7	28.0	28.0	100.0
	Total	25	100.0	100.0	

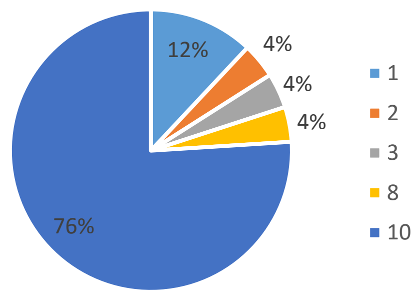


Fig. 4.3a Weight of ignorance on type and quantity of fertilizer to apply for maximum yield

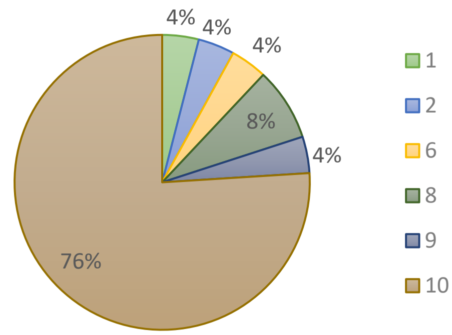


Fig. 4.3b Weight of ignorance on type and quantity of organic fertilizer to apply for maximum yield

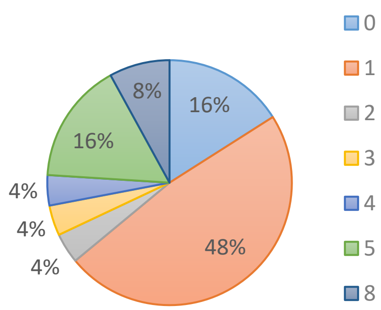


Fig. 4.3c Weight of ignorance on sprayer calibration

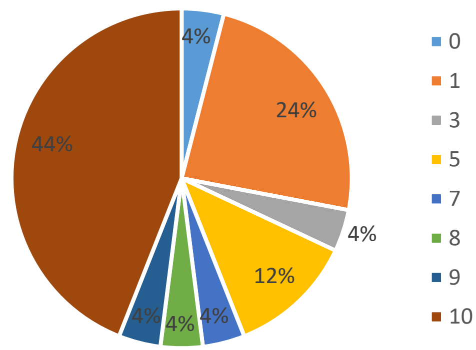


Fig. 4.3d Weight of ignorance on planting distance required for optimal yield

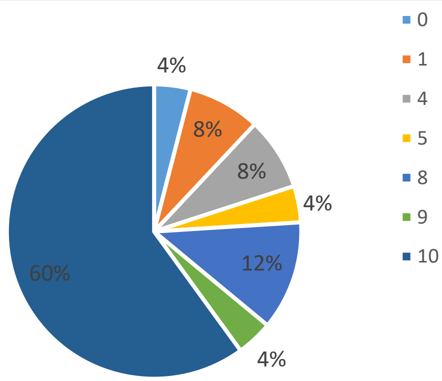


Fig. 4.3e Weight of ignorance on effect of shading and green house cultivation

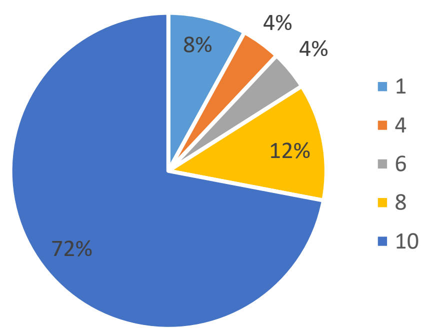


Fig. 4.3f Weight of ignorance on exact irrigation requirement for optimal yield

Figure 4. 3 Weight of Ignorance on the application of production inputs using a scale of 0-10 where 10 is the highest and 0 is least

4.1.4 Contribution of Farmer Cooperatives to Carrot Production

Further, an assessment of carrot output from the Mampong Carrot Market revealed that 7,157 tons of carrot are aggregated at the market from carrot producers within the Municipality. Among the carrot farmers, Grade 1, 2 and 3 carrots are called the Standard, Social and Broken respectively. The average weight per bag of the standard, social and broken as measured with the Mampong Municipal Crop Officer is 41.68, 40.53 and 56.47 kg respectively. Using an average price of GhC85.00, GhC70.00 and GhC50.00 per bag of Standard, Social and Broken respectively, a gross produce of GhC12,234,350.00 or $2,597,526.54 are produced per annum. Tables 4.7 and 4.8 present the details of the carrot output.

Table 4. 7 Output from farmers as presented at the Asante Mampong Carrot Market

MONTH	NUMBER OF BAGS			OUTPUT IN TONS			
	Standard	Social	Broken	Standard	Social	Broken	Total Output (ton)
October 2016	4132	2263	1954	172.22	91.72	110.34	374.28
November 2016	9346	3998	3450	389.54	162.04	194.82	746.4
December 2016	12199	4596	3811	508.45	186.28	215.21	909.94
January 2017	10558	4213	3001	440.06	170.75	169.47	780.28
February 2017	7730	3435	2441	322.19	139.22	137.84	599.25
March 2017	6203	3158	2258	258.54	127.99	127.51	514.04
April 2017	6892	2834	2277	287.26	114.86	128.58	530.7
May 2017	7597	1876	1297	316.64	76.03	73.24	465.92
June 2017	6981	2189	1676	290.97	88.72	94.64	474.33
July 2017	8676	3103	2448	361.62	125.76	138.24	625.62
August 2017	7632	2829	2226	318.1	114.66	125.7	558.46
September 2017	8122	2937	2129	338.52	119.04	120.22	577.79
TOTAL OUTPUT	**96068**	**37431**	**28968**	**4004.11**	**1517.07**	**1635.81**	**7157.02**

Table 4. 8 Output from farmers in Asante Mampong in number of bags per acre and hectare

	N	Mean (bags)	Yield in Kg/ac	Yield in Ton/ha
No. of bags of big tubers (Standard) per acre	25	157.8	6577.104	16.245
No. of bags of small tubers (Social) per acre	25	25.08	1016.492	2.511
No. of bags of broken tubers (Broken) per acre	25	16	903.52	2.232
Gross Yield (Standard+Social+Broken)	25	198.88	9194.222	22.710
Valid N (listwise)	25			

4.1.5 Introduction of biochar as a sustainable agriculture and climate smart product

Table 4.9 provides the chemical composition of avocado biochar used in the experiment. Using classification and interpretation scheme by the Soil Research Institute of CSIR (Appendix A), the pH of avocado biochar was observed to be slightly acidic (6.37). With a percentage organic carbon content of 34.5%, contribution to soil organic matter content is very high. The biochar was also observed to have high Nitrogen content. The phosphate, potassium and magnesium content were also low.

Table 4. 9 Chemical properties of biochar used in field studies

	pH 1:5	% Org. Carbon	Mg%	P%	K%	N%	Ec uS/cm 1:5
Biochar	6.37	34.50	0.10	0.11	0.11	0.50	946

4.2 Effect of Fertilizer and Biochar on Soil Physical Characteristics

Table 4.10 shows the means for NPK, P&K 50:50, P&K 50:100, Liquid Fertilizer and No Fertilizer with 5ton/ha, 10ton/ha and 0ton/ha for Gravimetric moisture content, volumetric moisture content, bulk density, percentage solid space and soil porosity. From table 4.10, the gravimetric moisture content is significant at 1% for biochar and 5% for fertilizer. There were no interaction effects.

Consequently, biochar applied at 10ton/ha provided the overall highest mean water holding capacity (0.2494) and fertilizer P&K applied at 50:50 showed the highest water holding capacity among all fertilizers (0.2343). This means that soils with high biochar content can store water and nutrients for longer periods for plants to use. For volumetric moisture content, bulk density, percentage solid space, and bulk density, there were significant interaction effects between biochar and fertilizers.

Table 4. 10 Soil physical properties at experimental site after biochar and fertilizer application and fertilizer decomposition

SOIL DATA	TREATMENT	BIOCHAR	MEAN	S.E.D.				
Soil Physical Properties		0t/ha	5t/ha	10t/ha	Mean	FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Gravimetric Moisture Content (%)	NPK 200kg/ha	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	2.921*	2.262**	5.059
	No Fertilizer	19.47	15.32	20.83	18.54			
	Mean	16.92	20.36	24.94	20.74			
Volumetric Moisture Content (%)	NPK 200kg/ha	25.20	29.70	30.80	28.60			
	P&K 50:50	24.70	28.10	36.90	29.90			
	P&K 50:100	28.10	26.40	34.60	29.70			
	Liquid Fertilizer	10.50	23.40	24.60	19.50	3.76*	2.91*	6.51
	No Fertilizer	25.80	20.20	25.40	23.80			
	Mean	22.80	25.50	30.50	26.30			
Bulk Density (g/cm^3)	NPK 200kg/ha	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			
Solid Space (%)	NPK 200kg/ha	50.39	44.68	47.32	47.47			
	P&K 50:50	53.17	50.57	44.49	49.41			
	P&K 50:100	51.23	45.24	48.73	48.40			
	Liquid Fertilizer	53.53	47.70	44.27	48.50	1.151	0.892**	1.994**
	No Fertilizer	50.04	51.06	46.00	49.03			
	Mean	51.67	47.85	46.16	48.56			
Soil Porosity (%)	NPK 200kg/ha	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			

4.3 Background Soil Chemical Properties at Experimental Site

Table 4.11 indicates the background soil condition during the minor and major growing seasons in 2016 and 2017. 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 were moderate but those of calcium, magnesium and potassium were low. Effective cation exchange capacity for both growing seasons were also low.

Table 4. 11 Background soil chemical properties at experimental sites, 2016 and 2017

Year	pH, H_2O 1:2.5	Org.C %	Total N %	Org. M %	Exch. Cations (me/100g)				T.E.B cmol/kg	Exch. A(Al+) cmol/kg	ECEC me/100g	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

4.4 Effect of Fertilizer and Biochar on Soil Chemical Characteristics

4.4.1 Influence of Fertilizer and Biochar on soil pH, %O.C., Total Nitrogen, and %Organic Matter

From Table 4.12, there was significant ($P<0.01$) interaction effect between fertilizer and biochar on soil pH. The pH was variously influenced by fertilizer and biochar. Soils amended with 10ton/ha biochar had the highest pH (5.99) followed by 5ton/ha biochar (5.71). Soils without biochar were relatively more acidic (5.47). NPK fertilizer resulted the most acidic pH on the soil (5.37). P&K 50:50 gave the least acidic pH among the fertilizers.

Percentage organic carbon present in P&K 50:50 combination with 5 ton/ha and 10 ton/ha were the same (0.9) but a slight improvement over P&K 50:50 applied alone (0.71). For P&K 50:100, biochar at 5 ton/ha gave the highest %organic carbon (0.94) with biochar at 10 ton/ha showing the least %O.C. Liquid fertilizer treated plots showed a generally higher %O.C in the presence of 5 ton/ha and 10 ton/ha biochar. In the absence of fertilizer, biochar applied at 10ton/ha showed the highest %O.C.

Table 4. 12 Effects of fertilizer and biochar on Soil Chemical Properties, 2016

SOIL DATA	TREATMENT	BIOCHAR			MEAN	S.E.D.		
Soil Chemical Properties 2016		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER X BIOCHAR
Soil pH	NPK 200kg/ha	5.34	5	5.77	5.37			
	P&K 50:50	5.67	6	6.08	5.92			
	P&K 50:100	5.26	5.71	6.14	5.7			
	Liquid Fertilizer	5.37	5.84	6.01	5.74	0.004**	0.003**	0.008**
	No Fertilizer	5.72	6.01	5.93	5.89			
	Mean	5.47	5.71	5.99	5.72			
Organic Carbon (%)	NPK 200kg/ha	0.79	0.86	0.82	0.82			
	P&K 50:50	0.71	0.9	0.9	0.84			
	P&K 50:100	0.75	0.94	0.71	0.8			
	Liquid Fertilizer	0.82	0.98	0.9	0.9	0.00357**	0.00277**	0.00619**
	No Fertilizer	0.94	0.8	1.01	0.92			
	Mean	0.8	0.9	0.87	0.86			
Total Nitrogen (%)	NPK 200kg/ha	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	0.1	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 200kg/ha	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	1.5	1.47			

Table 4. 13 Effects of fertilizer and biochar on Soil Chemical properties, 2017

SOIL DATA	TREATMENT	BIOCHAR			MEAN	S.E.D.		
Soil Chemical Properties 2017		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER X BIOCHAR
Soil pH	NPK 200kg/ha	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 200kg/ha	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 200kg/ha	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 200kg/ha	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			

4.4.2 Influence of Fertilizer and Biochar on soil Calcium, Magnesium, Potassium and Sodium

In Figures 4.4 and 4.5, significant ($P<0.01$) interaction effect of fertilizer and biochar on calcium, magnesium, potassium, and sodium are observed. Biochar applied at 10 ton/ha in the presence of P&K 50:50, P&K 50:100 and liquid fertilizer during the minor rainy season enabled more calcium in solution than biochar at 5 ton/ha and 0 ton/ha biochar. In NPK environment, biochar at 5 ton/ha resulted in relatively high amount of calcium in solution than 10 ton/ha and 0ton/ha biochar. During the major rainy season however, the no fertilizer environment at 5 ton/ha biochar resulted in the highest calcium and magnesium in solution. In Figure 4.5, 5 ton/ha biochar in P&K 50:100 environment resulted in the highest potassium content in the minor season. During the major rainy season, 5 ton/ha biochar resulted in the highest magnesium content under no fertilizer environment.

Figure 4. 4 Influence of Fertilizer and biochar on soil calcium and magnesium

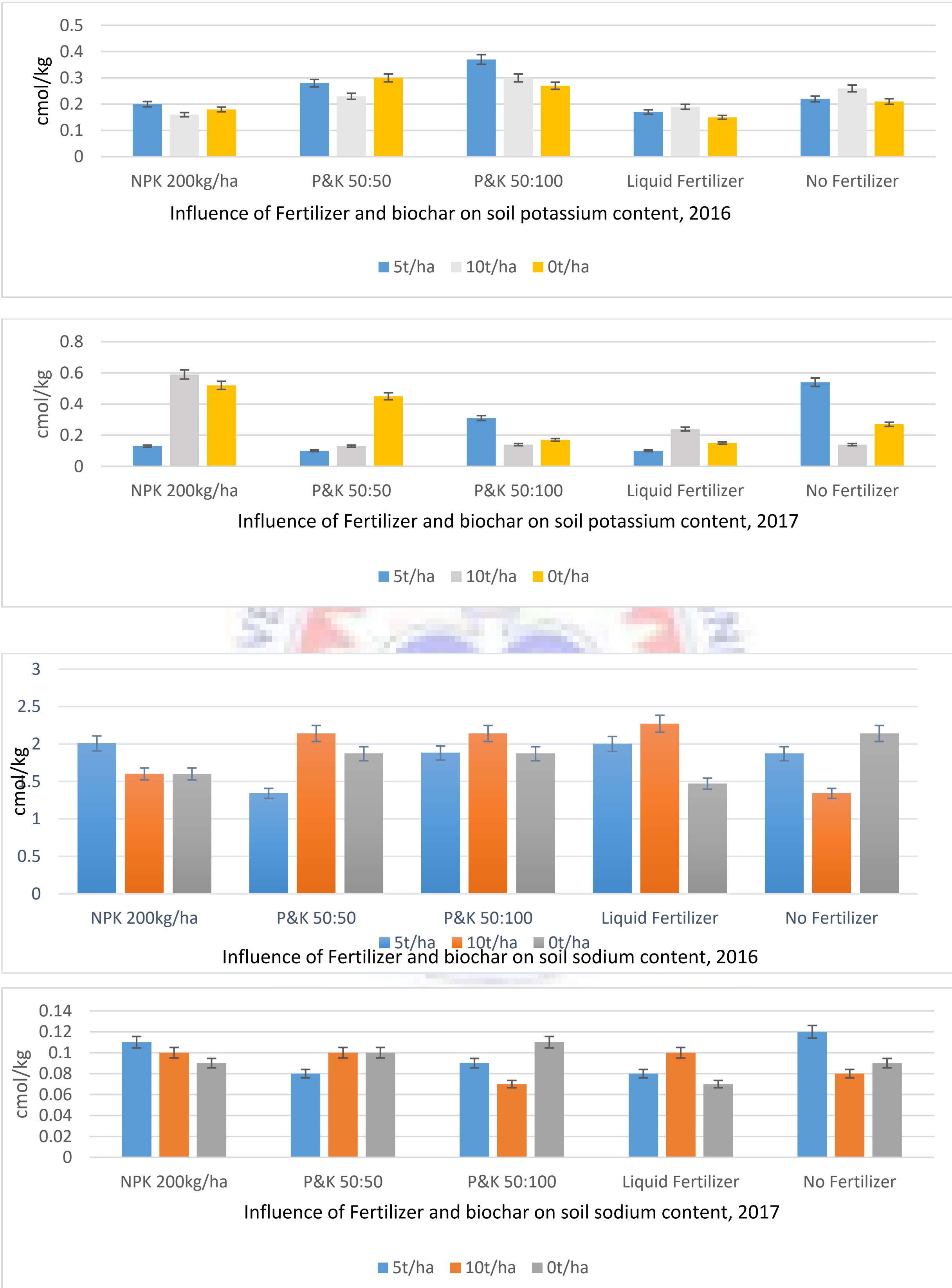


Figure 4. 5 Influence of Fertilizer and biochar on soil potassium and sodium composition

4.4.2 Influence of Fertilizer and Biochar on soil Total Exchangeable Bases (TEB), Exchangeable Acidity, Effective CEC, Base Saturation, Phosphorus, and Sulphate ions.

Tables 4.14 and 4.15 show the means and interactions between fertilizer and biochar on total exchangeable bases, exchangeable acidity, effective cation exchange capacity, base saturation, parts per million phosphorus and milligram per kilogram sulphate for minor and major rainy seasons in 2016 and 2017 respectively. Among biochar treatments, 10t/ha gave the highest TEB, 2016. Under fertilizer environments, No fertilizer treatment gave the highest TEB followed by liquid fertilizer and P&K 50: 50 in 2016. In 2017, 5 ton/ha biochar gave the highest TEB under no fertilizer environment.

Under exchangeable acidity, 5 ton/ha gave the highest exchangeable acidity among biochar treatments in 2016. NPK 200kg/had also gave the highest exchangeable acidity among fertilizer treatments. In 2017 however, plots receiving liquid fertilizer treatments gave the highest exchangeable acidity among fertilizer-treated plots. Similar to 2016, biochar at 5 ton/ha gave the highest exchangeable acidity.

Effective Cation Exchange Capacity (ECEC) in 2016 was highest in plots receiving 0 ton/ha biochar followed by 5 ton/ha biochar. Among fertilizer treatments, NPK 200 kg/ha gave the highest ECEC followed by plots receiving liquid fertilizer and no fertilizer. The major rainy season also saw 5 t/ha biochar producing the highest ECEC among biochar treatments. Among all the treatments, plots receiving 5 ton/ha biochar without fertilizer gave the highest ECEC (23.44 cmol/kg).

Again, during the minor rainy season, P&K 50:50 with 10 ton/ha biochar gave the highest base saturation compared to 10 ton/ha biochar without fertilizer giving the highest base saturation in the major rainy season. Similarly, plots treated with P&K 50:50 and 5 ton/ha biochar gave the highest phosphorus content in the minor rainy season while the same P&K 50:50 plus 10 ton/ha biochar gave the highest phosphorus content in the major rainy season. Liquid fertilizer without biochar gave the least phosphorus content. For suphate composition, plots receiving P&K 50:100 without biochar gave the highest during both minor and major rainy seasons with liquid fertilizer giving the least.

Table 4. 14 Influence of Fertilizer and Biochar on soil Total Exchangeable Bases, Exchangeable Acidity, Effective CEC, Base Saturation, Phosphorus and Sulphate ions (2016)

SOIL DATA	TREATMENT	BIOCHAR			MEAN	S.E.D.		
Soil Chemical Properties		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Total Exchangeable Bases	NPK 200kg/ha	3.960	4.303	4.090	4.118	0.002873**	0.002225**	0.004976**
	P&K 50:50	4.350	3.797	4.420	4.189			
	P&K 50:100	3.660	4.220	4.340	4.073			
	Liquid Fertilizer	3.930	4.240	4.810	4.327			
	No Fertilizer	4.800	4.550	3.780	4.377			
	Mean	4.140	4.222	4.288	4.217			
Exchangeable Acidity	NPK 200kg/ha	0.700	0.800	0.500	0.667	0.00319**	0.00247**	0.00552**
	P&K 50:50	0.550	0.357	0.150	0.352			
	P&K 50:100	0.750	0.500	0.150	0.467			
	Liquid Fertilizer	0.700	0.450	0.200	0.450			
	No Fertilizer	0.513	0.200	0.350	0.354			
	Mean	0.643	0.461	0.270	0.458			
Effective Cation Exchange Capacity (ECEC)	NPK 200kg/ha	4.660	5.103	4.590	4.784	0.001859**	0.001440**	0.003220**
	P&K 50:50	4.900	4.150	4.570	4.540			
	P&K 50:100	4.410	4.720	4.490	4.540			
	Liquid Fertilizer	4.630	4.690	5.010	4.777			
	No Fertilizer	5.300	4.750	4.130	4.727			
	Mean	4.780	4.683	4.558	4.674			
%Base Saturation	NPK 200kg/ha	84.860	84.170	89.070	86.040	0.321**	0.249**	0.556**
	P&K 50:50	88.720	91.550	96.780	92.350			
	P&K 50:100	82.830	89.360	96.720	89.640			
	Liquid Fertilizer	84.760	90.370	96.050	90.400			
	No Fertilizer	90.540	95.840	91.510	92.630			
	Mean	86.340	90.260	94.030	90.210			
Parts per million phosphate	NPK 200kg/ha	7.611	4.112	5.205	5.642	0.00702**	0.00544**	0.01217**
	P&K 50:50	5.695	11.056	7.110	7.954			
	P&K 50:100	5.979	6.238	5.819	6.012			
	Liquid Fertilizer	3.397	4.285	4.062	3.915			
	No Fertilizer	5.468	4.212	5.368	5.016			
	Mean	5.630	5.981	5.513	5.708			
Mg/kg SO_4	NPK 200kg/ha	38.000	24.000	20.000	27.333	0.0703**	0.0544**	0.1217**
	P&K 50:50	13.000	28.000	21.000	20.667			
	P&K 50:100	43.000	33.000	22.000	32.667			
	Liquid Fertilizer	29.000	12.667	19.000	20.222			
	No Fertilizer	16.000	17.000	47.000	26.667			
	Mean	27.800	22.933	25.800	25.511			

Table 4. 15 Influence of Fertilizer and Biochar on soil Total Exchangeable Bases, Exchangeable Acidity, Effective CEC, Base Saturation, Phosphorus and Sulphate ions (2017)

SOIL DATA	TREATMENT	BIOCHAR			MEAN	S.E.D.		
Soil Chemical Properties 2017		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Total Exchangeable Bases	NPK 200kg/ha	5.160	5.720	5.440	5.440			
	P&K 50:50	5.450	5.950	4.370	5.260			
	P&K 50:100	5.980	4.620	5.420	5.340	0.0014**	0.0011**	0.0024**
	Liquid Fertilizer	6.210	3.560	5.170	4.980			
	No Fertilizer	7.830	28.420	7.030	14.430			
	Mean	6.130	9.650	5.490	7.090			
Exchangeable Acidity	NPK 200kg/ha	0.610	0.750	0.600	0.650			
	P&K 50:50	0.750	0.900	0.700	0.790			
	P&K 50:100	0.900	0.710	0.750	0.790			
	Liquid Fertilizer	0.900	0.850	0.650	0.800			
	No Fertilizer	0.710	0.750	0.150	0.540	0.0022**	0.0017**	0.0038**
	Mean	0.770	0.790	0.570	0.720			
Effective Cation Exchange Capacity (ECEC)	NPK 200kg/ha	4.740	5.340	4.960	5.010			
	P&K 50:50	5.130	5.660	4.200	5.000			
	P&K 50:100	5.700	4.410	5.080	5.060	0.0047**	0.0037**	0.0082**
	Liquid Fertilizer	5.870	3.710	4.790	4.790			
	No Fertilizer	6.970	23.440	5.770	12.060			
	Mean	5.680	8.510	4.960	6.380			
%Base Saturation	NPK 200kg/ha	87.330	85.940	87.910	87.060			
	P&K 50:50	85.340	84.120	83.350	84.270			
	P&K 50:100	84.190	84.120	85.240	84.520	0.004**	0.003**	0.007**
	Liquid Fertilizer	84.660	77.050	86.440	82.720			
	No Fertilizer	89.950	96.800	97.400	94.720			
	Mean	86.290	85.610	88.070	86.660			
Parts per million phosphate	NPK 200kg/ha	25.750	35.560	37.150	32.820			
	P&K 50:50	29.910	20.970	93.280	48.050			
	P&K 50:100	29.260	29.580	29.340	29.390	0.0041**	0.0031**	0.0070**
	Liquid Fertilizer	19.450	21.450	21.300	20.730			
	No Fertilizer	13.470	23.680	24.480	20.540			
	Mean	23.570	26.250	41.110	30.310			
Mg/kg SO_4	NPK 200kg/ha	95.000	60.000	35.330	63.440			
	P&K 50:50	30.000	55.000	65.000	50.000			
	P&K 50:100	135.000	35.670	35.000	68.560			
	Liquid Fertilizer	35.330	50.000	45.000	43.440			
	No Fertilizer	30.000	60.000	75.000	55.000	0.171**	0.133**	0.296**
	Mean	65.070	52.130	51.070	56.090			

4.5 Effect of Fertilizer and Biochar on Carrot Growth and Yield

4.5.1 Plant height

Figures 4.6 and 4.7 show the differences in plant height responses to different fertilizers for 2016 and 2017 respectively together with 5 ton/ha biochar. The P&K 50:50 treatment produced the greatest plant height. Figures 4.8 and 4.9 also indicate plant height when 10 ton/ha biochar was applied, whilst Figures 4.10 and 4.11 show the influence of different fertilizers on plant height in an environment without biochar for 2016 and 2017 respectively in which NPK treated plots gave the highest plant height.

On the whole, P&K 50:50 saw the greatest growth rate for plant height in both minor and major rainy season in 5 ton/ha biochar environment.

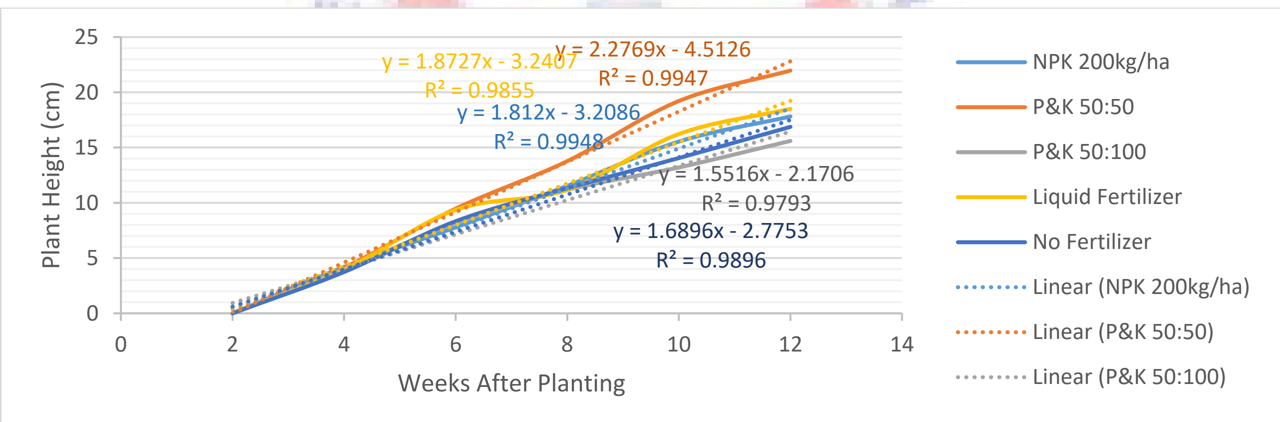


Figure 4. 6 Plant Height as influenced by different fertilizers at 5ton/ha biochar in 2016

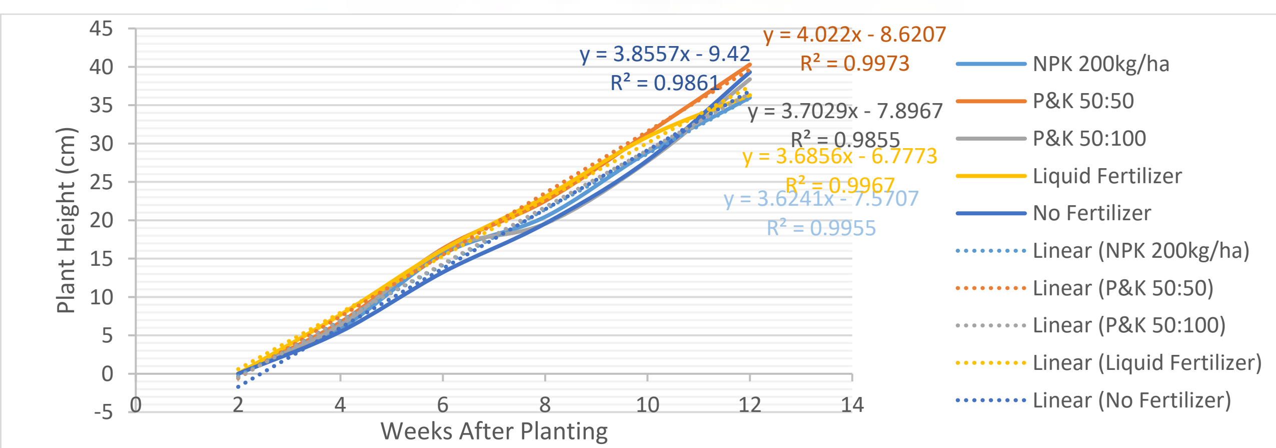


Figure 4. 7 Plant Height as influenced by different fertilizers at 5 ton/ha biochar in 2017

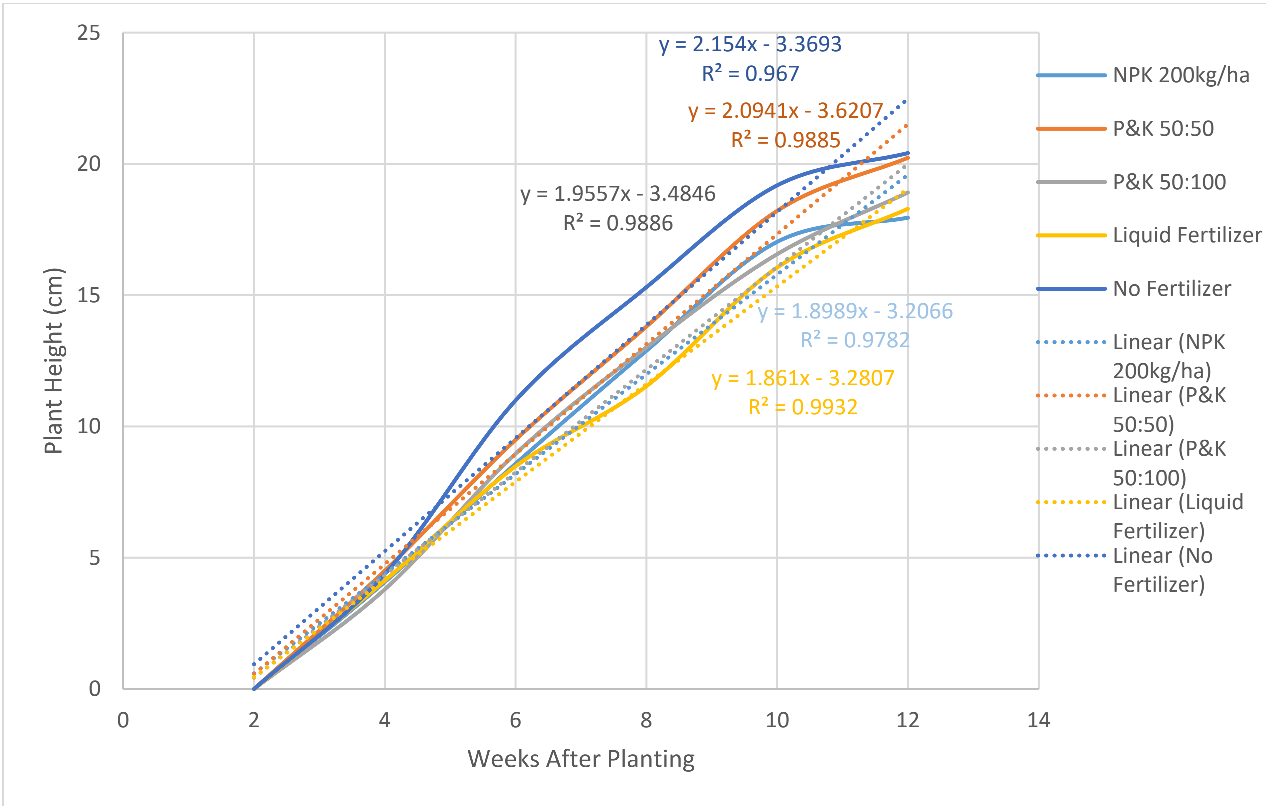


Figure 4. 8 Plant Height as influenced by different fertilizers at 10 ton/ha biochar in 2016

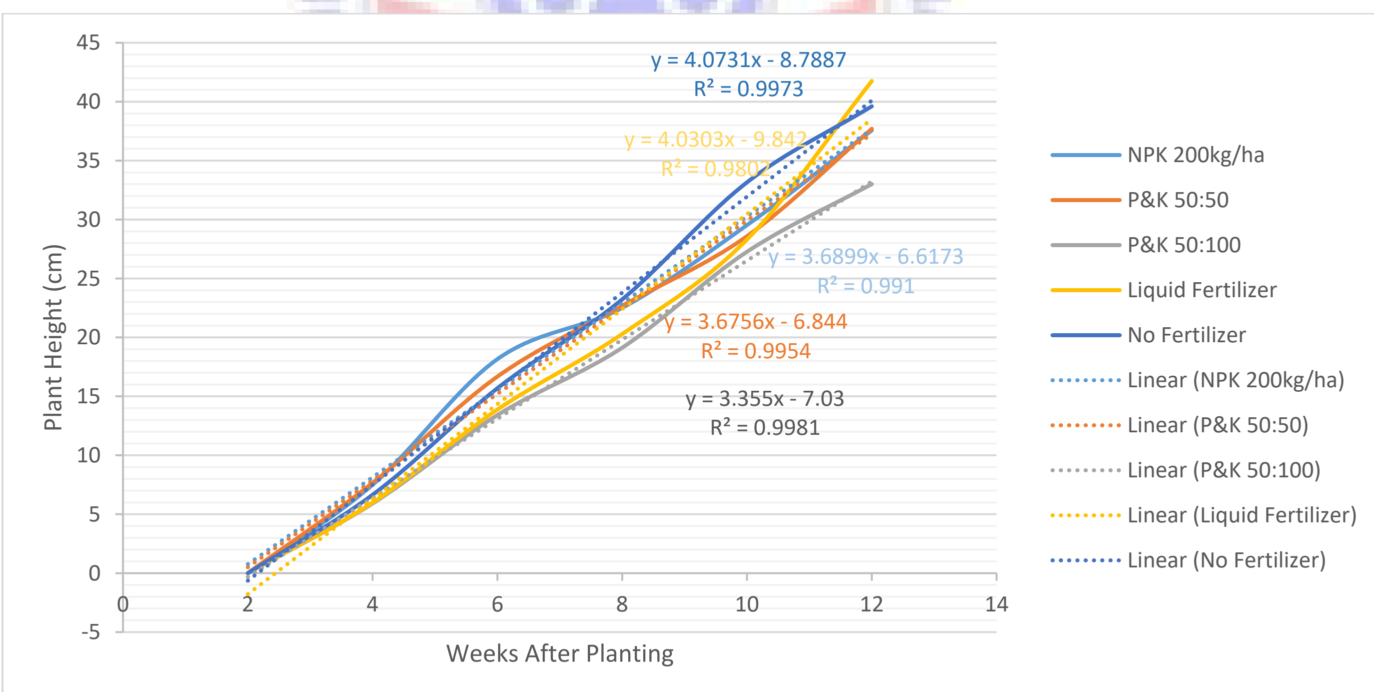


Figure 4. 9 Plant Height as influenced by different fertilizers at 10 ton/ha biochar in 2017

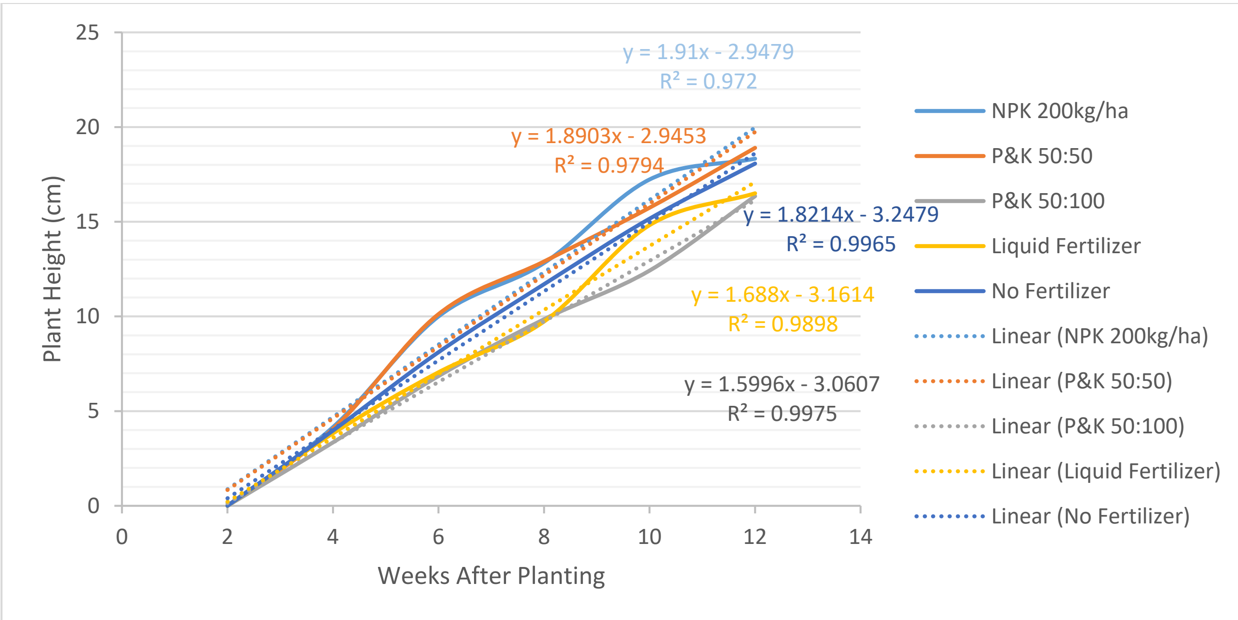


Figure 4. 10 Plant Height as influenced by different fertilizers without biochar in 2016

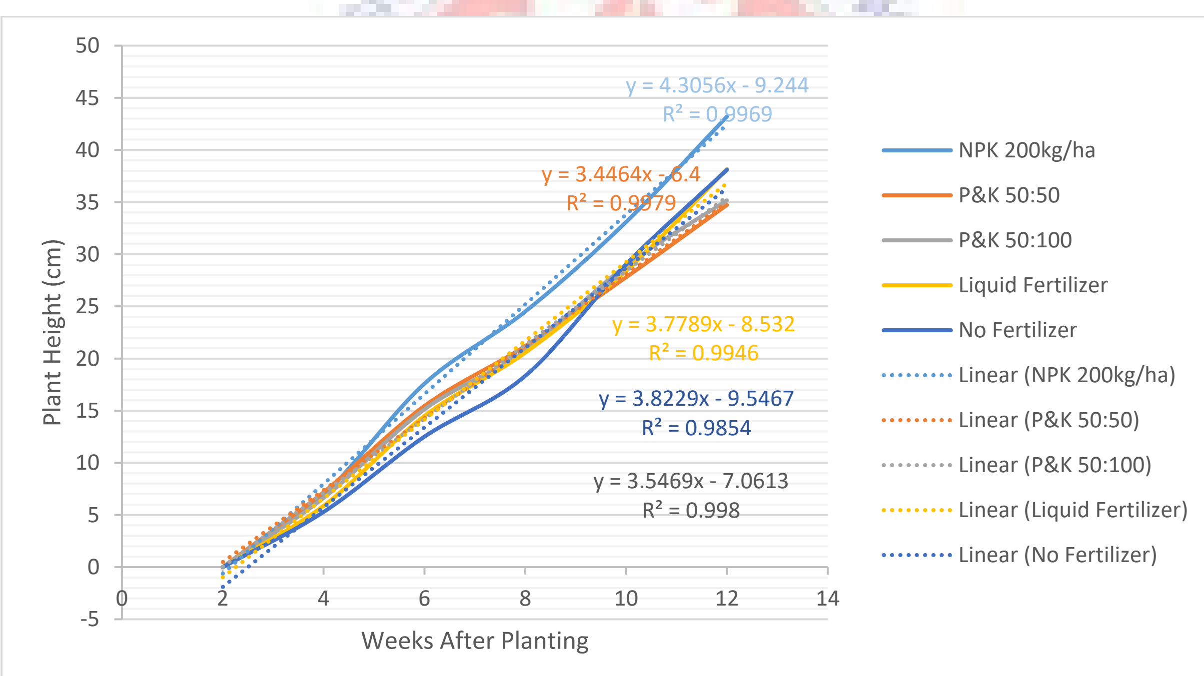


Figure 4. 11 Plant Height as influenced by different fertilizers without biochar in 2017

4.5.2 Canopy width performance as affected by fertilizer at different levels of biochar at different weeks after planting (WAP)

Figures 4.12 to 4.21 show the canopy width performance as influenced by different levels of biochar and fertilizer during the minor and major growing seasons from 4WAP to 12 WAP. 0 ton/ha and 10 ton/ha under no fertilizer gave the greatest canopy width followed by P&K 50:50, NPK and P&K 50:100 at 4 WAP in 2016. 0 ton/ha biochar resulted in the least canopy width under P&K 50:100 environment (Fig 4.12).

During the major season at 4 WAP, the greatest canopy width was measured in 5 ton/ha biochar in liquid fertilizer. This was followed by 0ton/ha biochar under NPK environment. The remaining treatments fell below 5cm for the canopy width. The least canopy width was 5ton/ha under NPK environment followed by 0ton/ha under no fertilizer (Fig 4.13).

6WAP in the minor season, NPK, P&K 50:60 and P&K 50:100 had canopy width around 14cm for 5ton/ha, 10ton/ha and 0ton/ha biochar (Fig 4.14). Under liquid fertilizer environment, 5ton/ha appears higher than 10ton/ha and 0ton/ha. Under no fertilizer condition, biochar at 10ton/ha gave the highest canopy width followed by 5ton/ha and 0ton/ha biochar. There were no significant effects of treatments on canopy width.

Figure 4.16 also shows the influence of biochar and fertilizer on canopy width during the major season 6 WAP. There were significant fertilizer effects on canopy width during the 6 WAP. Biochar and fertilize-biochar treatments were however not significant. The general mean for the canopy width was 15.36. The highest plant height was observed for biochar at 10 ton/ha in NPK environment.

In figure 4.16, canopy width at 8WAP during the minor season was greatest for 10ton/ha biochar in a P&K 50:50. There were no significant treatment effects on the canopy width. A grand mean of 28.5cm was observed. Differences of canopy width by treatment is illustrated by the figure.

During the major season 8 WAP, there were no significant treatment effects on canopy width. A grand mean of 31.23 was observed. The highest canopy width was noted for 0ton/ha biochar under NPK environment (Fig 4.17).

In the minor season 10 WAP, there was significant ($P<0.05$) interaction effect of biochar and fertilizer on canopy width. The grand mean for canopy width observed was 37.86cm. The highest canopy width was observed under P&K 50:50 environment for 5ton/ha biochar (Fig 4.18).

In the major season 10 WAP, there was no significant treatment effect of biochar and fertilizer on canopy width (Fig 4.19). The grand mean for canopy width observed was 29.38cm. The highest canopy width was observed under NPK for 0 ton/ha biochar and no fertilizer with 10ton/ha biochar.

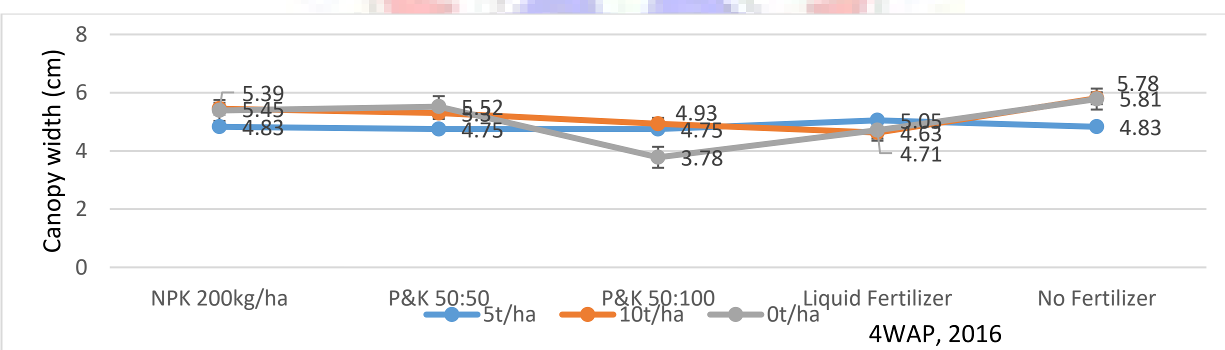


Figure 4. 12 Canopy width as influenced by biochar and fertilizer 4 weeks after planting in 2016

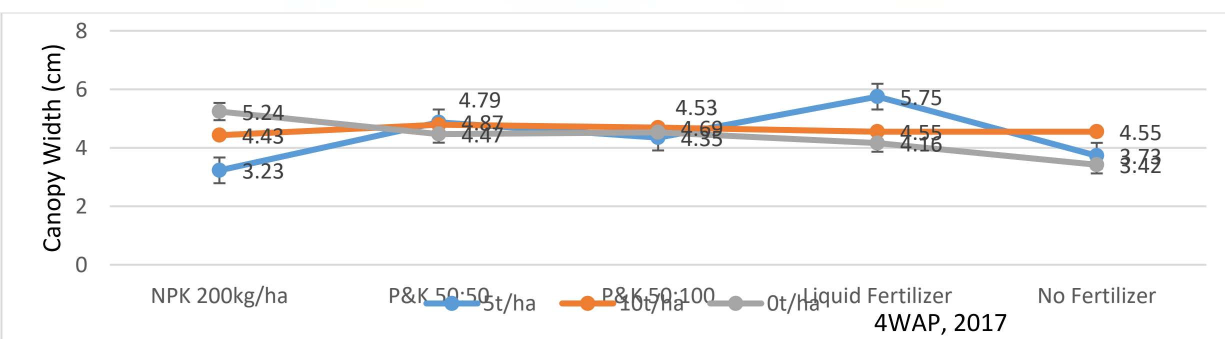


Figure 4. 13 Canopy width as influenced by biochar and fertilizer 4 weeks after planting in 2017

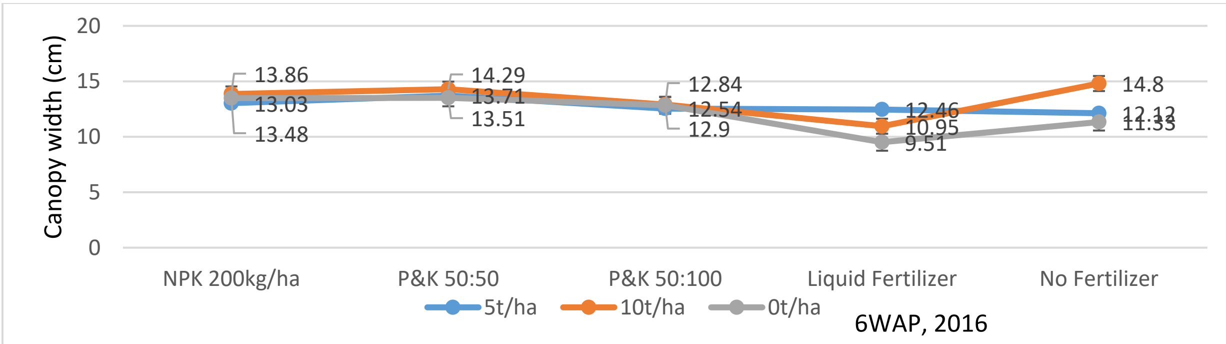


Figure 4. 14 Canopy Width as influenced by biochar and fertilizer 6 weeks after planting in 2016

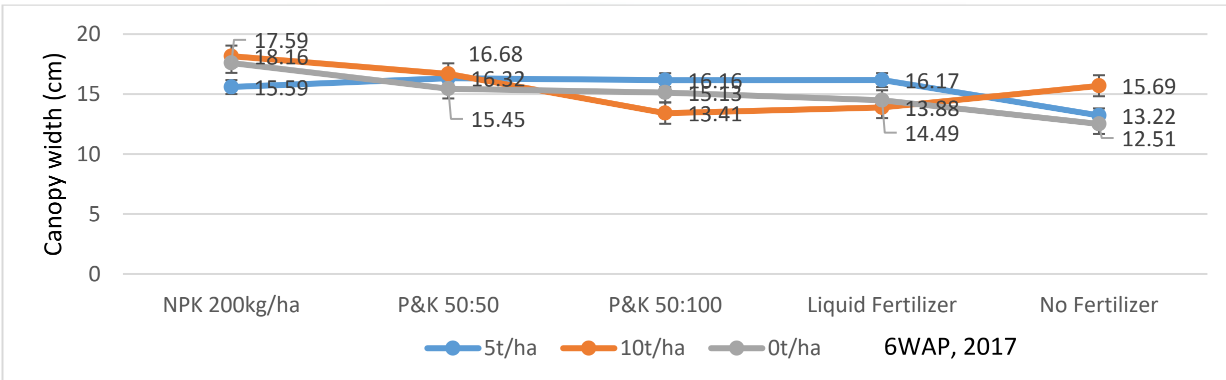


Figure 4. 15 Canopy Width as influenced by biochar and fertilizer 6 weeks after planting in 2017

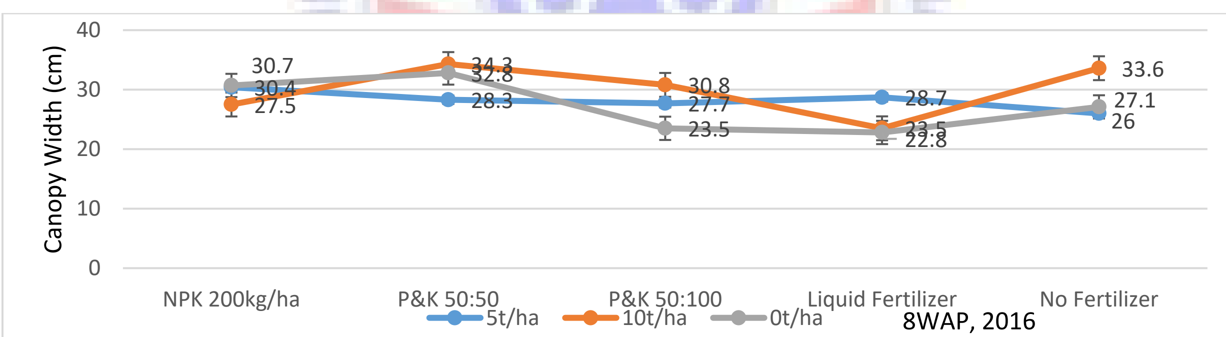


Figure 4. 16 Canopy width as influenced by biochar and fertilizer 8 weeks after planting in 2016

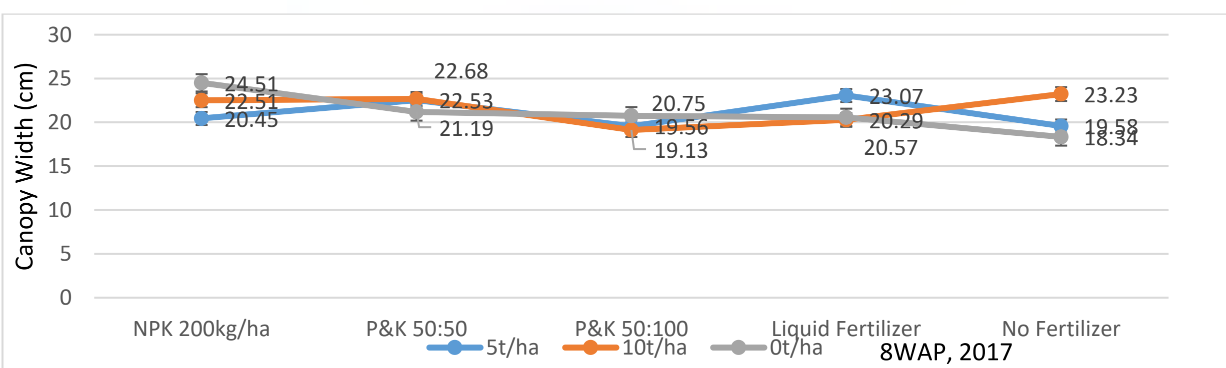
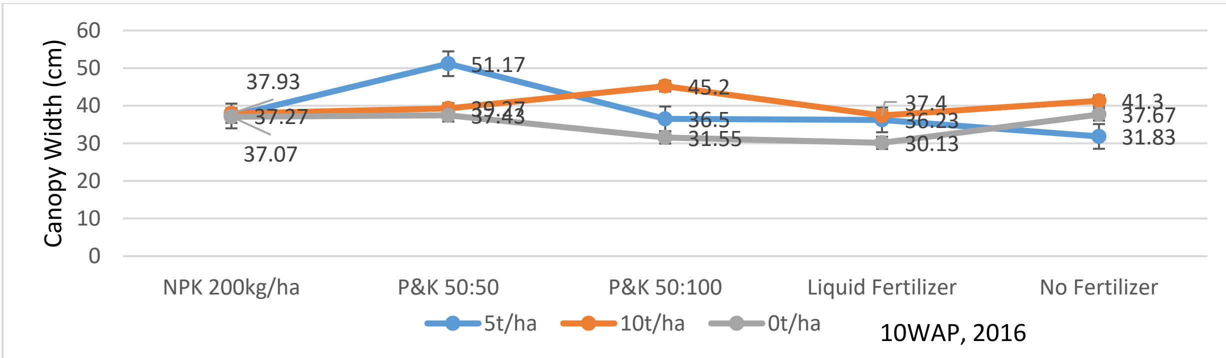


Figure 4. 17 Canopy width as influenced by biochar and fertilizer 8 weeks after planting in 2017



igure 4. 18 Canopy width as influenced by biochar and fertilizer 10 weeks after planting in 2016

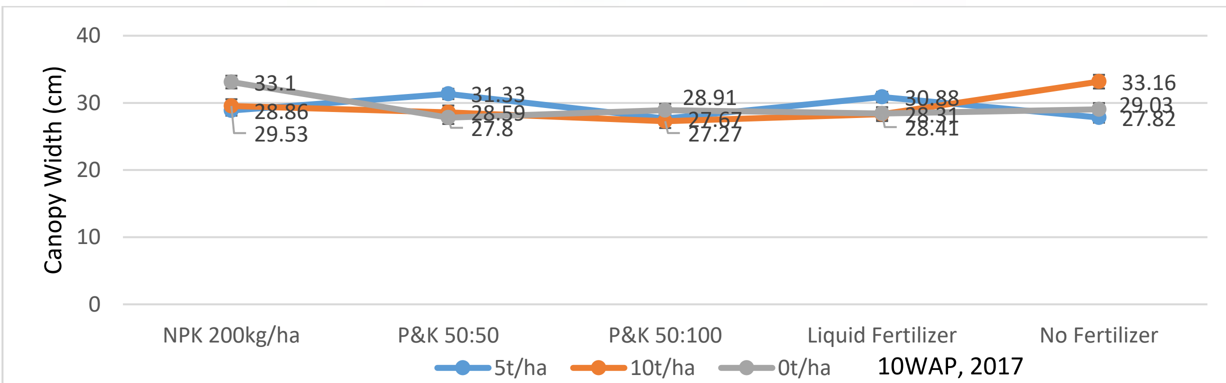


Figure 4. 19 Canopy width as influenced by biochar and fertilizer 10 weeks after planting in 2017

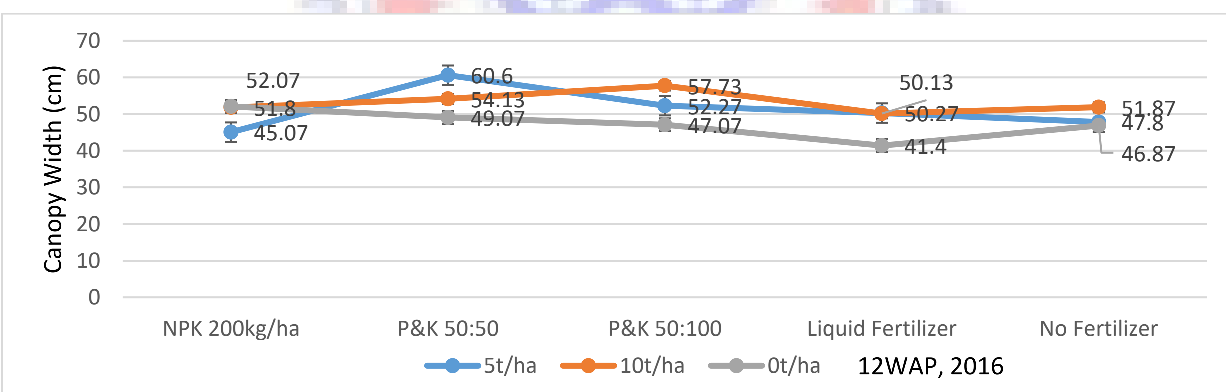


Figure 4. 20 Canopy width as influenced by biochar and fertilizer 12 weeks after planting in 2016

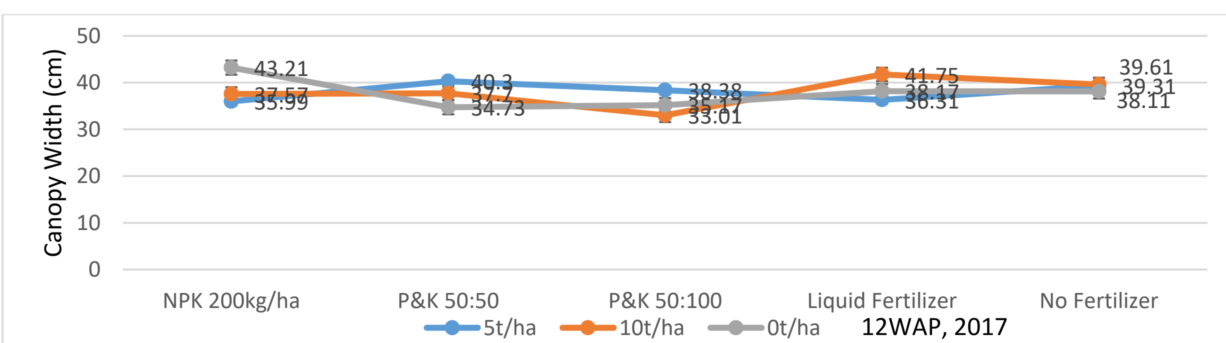


Figure 4. 21 Canopy width as influenced by biochar and fertilizer 12 weeks after planting in 2017

4.5.3 Total biomass (root and shoot) as affected by fertilizer at different levels of biochar

Figures 4.23 and 4.24 show the total biomass accumulated for the entire minor and major growing seasons under different fertilizer and biochar conditions. On the whole, significant biomass was observed from 8th WAP until 12WAP. During 8 WAP and 10 WAP, plots treated with P&K 50:50 gave the highest biomass as part of the growth performance across biochar treatments. At the final growth stage (12WAP), P&K 50:100 inched up with biochar at 5ton/ha during the minor season and showed the greatest dry biomass in spite of the fact that all biochar levels under P&K 50:50 showed biomass above 14 g.

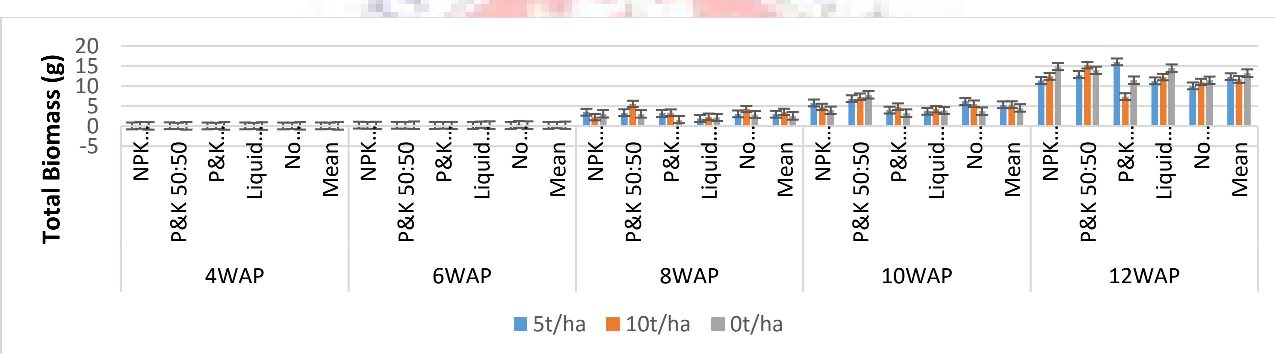


Figure 4. 22 Total Biomass as influenced by different rates of biochar and fertilizers in 2016

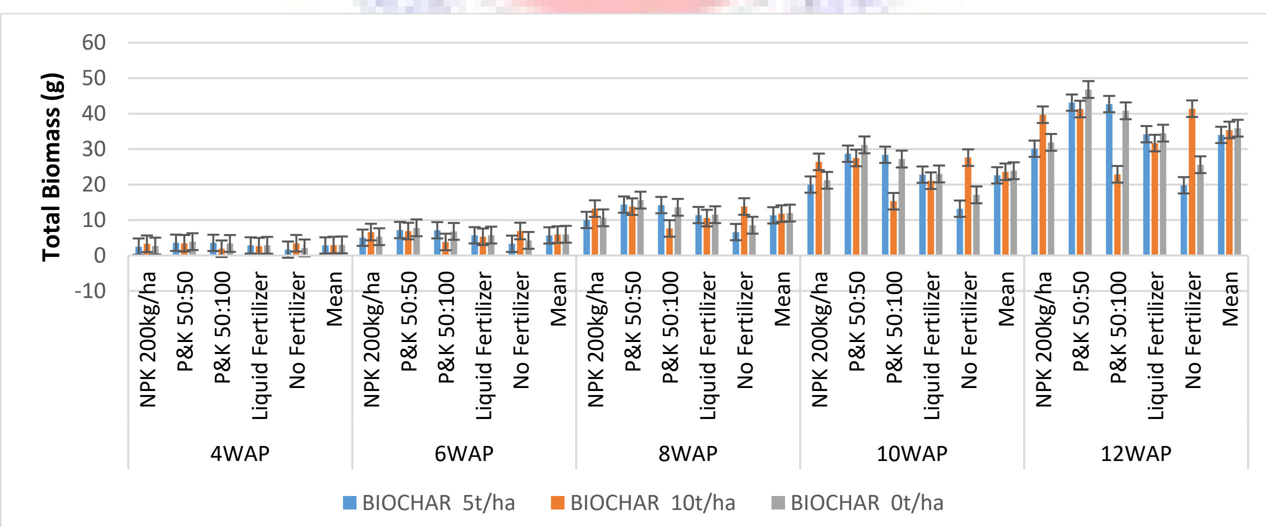


Figure 4. 23 Total Biomass as influenced by different rates of biochar and fertilizers in 2017

4.5.4 Marketable, Non-marketable and Total Yield

Tables 4.16 and 4.17 show the mean yield from biochar and fertilizer treatments in both years. In 2017, treatment effects on marketable, non-marketable and total carrot yield were not significant. The means for marketable, non-marketable and total yield are 7007 kg/ha, 2846 kg/ha, and 9853 kg/ha respectively. For marketable yield, P&K 50:100 without biochar gave the highest marketable yield of 10075kg/ha. Similarly, P&K 50:100 with 10ton/ha biochar gave the least marketable yield. In addition, non-marketable yield was highest for 10 ton/ha without fertilizer and lowest under 5ton/ha biochar without fertilizer. Total yield for both marketable and non-marketable yield was highest for 10ton/ha biochar without fertilizer.

Table 4. 16 Mean marketable, Non-marketable and Total Yield as influenced by fertilizer and biochar in 2016

Yield Data	Treatment	Biochar			Mean	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Marketable Yield (kg/ha)	NPK 200kg/ha	2236	5180	3852	3756			
	P&K 50:50	2829	2563	3668	3020			
	P&K 50:100	1322	1837	4878	2679			
	Liquid Fertilizer	2994	3469	4052	3505	706.3	547.1**	1223.3
	No Fertilizer	1565	4353	4909	3609			
	Mean	2189	3480	4272	3314			
Non-Marketable Yield (kg/ha)	NPK 200kg/ha	4956	3442	2386	3595			
	P&K 50:50	4617	3324	1998	3313			
	P&K 50:100	2337	1823	4892	3017	822.0	636.7	1423.8
	Liquid Fertilizer	3058	3923	1478	2820			
	No Fertilizer	3124	2062	3944	3043			
	Mean	3618	2915	2940	3158			
Total Yield (Kg/ha)	NPK 200kg/ha	7192	8622	6238	7351			
	P&K 50:50	7446	5887	5666	6333			
	P&K 50:100	3658	3660	9771	5696	1145.1	887.0	1983.4*
	Liquid Fertilizer	6052	7392	5530	6325			
	No Fertilizer	4688	6416	8853	6652			
	Mean	5807	6395	7212	6471			

Table 4. 17 Mean marketable, Non-marketable and Total Yield as influenced by fertilizer and biochar in 2017

Yield Data	TREATMENT	BIOCHAR			MEAN	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER X BIOCHAR
Marketable Yield (kg/ha)	NPK 200kg/ha	4699	5811	7758	6089			
	P&K 50:50	9260	9227	7831	8773			
	P&K 50:100	10075	9144	3114	7444			
	Liquid Fertilizer	7386	7468	5255	6703	1507.5	1167.7	2611.0
	No Fertilizer	4867	4503	8711	6027			
	Mean	7257	7231	6534	7007			
Non-Marketable Yield (kg/ha)	NPK 200kg/ha	3166	2345	3288	2933			
	P&K 50:50	3171	3424	3547	3380			
	P&K 50:100	2128	2282	2620	2343	597.0	462.4	1034.0
	Liquid Fertilizer	2570	3927	3204	3234.			
	No Fertilizer	2048	1008	3955	2337			
	Mean	2616	2597	3323	2846.			
Total Yield (kg/ha)	NPK 200kg/ha	7865	8156	11046	9022			
	P&K 50:50	12431	12651	11378	12153			
	P&K 50:100	12202	11426	5734	9788	1746.8	1353.1	3025.6
	Liquid Fertilizer	9956	11395	8459	9937			
	No Fertilizer	6916	5510	12666	8364			
	Mean	9874	9828	9857	9853			

4.5.5 Root length, root diameter, canopy width, canopy area and Leaf Area Index

In 2016, root length and root diameter were not significant for fertilizer treatments, biochar treatments and fertilizer x biochar interactions (Table 4.18). In 2017, P&K 50:100 with 10 ton/ha biochar treatment produced the greatest root length whilst the control treatment produced the least. In 2017, the P&K 50:50 treatment with 10 ton/ha biochar produced the greatest root diameter (Table 4.19).

For canopy width, area and leaf area index, interaction effects were not significant in 2016. In 2017, plots treated with liquid fertilizer and 10 ton/ha biochar produced the highest canopy width and area while 10ton/ha biochar without fertilizer produced the least. Results for leaf area index was similar to that of canopy width and area (Tables 4.18 and 4.19).

Table 4. 18 Effect of fertilizer and biochar on root length, root diameter, canopy width, canopy area and leaf area index at harvest in 2016

Harvest Data	TREATMENT	BIOCHAR			MEAN	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Root Length (cm)	NPK 200kg/ha	17.760	17.670	14.740	16.720			
	P&K 50:50	16.780	16.540	18.470	17.260			
	P&K 50:100	17.620	15.520	17.430	16.860	0.905	0.701	1.567
	Liquid Fertilizer	18.020	18.080	15.970	17.360			
	No Fertilizer	17.590	19.930	17.530	18.350			
	Mean	17.550	17.550	16.830	17.310			
Root Diameter (cm)	NPK 200kg/ha	3.500	3.280	3.227	3.336			
	P&K 50:50	3.707	3.480	3.680	3.622			
	P&K 50:100	3.047	2.827	3.447	3.107	0.1967	0.1524	0.3407
	Liquid Fertilizer	3.180	3.273	3.260	3.238			
	No Fertilizer	3.040	2.953	3.600	3.198			
	Mean	3.295	3.163	3.443	3.300			
Canopy Width at harvest (cm)	NPK 200kg/ha	52.070	45.070	51.800	49.640			
	P&K 50:50	49.070	60.600	54.130	54.600			
	P&K 50:100	47.070	52.270	57.730	52.360	2.832	2.193*	4.904
	Liquid Fertilizer	41.400	50.270	50.130	47.270			
	No Fertilizer	46.870	47.800	51.870	48.840			
	Mean	47.290	51.200	53.130	50.540			
Canopy Area (cm^2)	NPK 200kg/ha	0.219	0.164	0.213	0.199			
	P&K 50:50	0.192	0.289	0.230	0.237			
	P&K 50:100	0.176	0.215	0.264	0.218	0.02262	0.01752*	0.03918
	Liquid Fertilizer	0.137	0.199	0.200	0.179			
	No Fertilizer	0.173	0.183	0.212	0.189			
	Mean	0.179	0.210	0.224	0.204			
Leaf Area Index	NPK 200kg/ha	0.091	0.068	0.089	0.083			
	P&K 50:50	0.080	0.121	0.096	0.099			
	P&K 50:100	0.073	0.090	0.110	0.091	0.00943	0.00730*	0.01633
	Liquid Fertilizer	0.057	0.083	0.083	0.075			
	No Fertilizer	0.072	0.076	0.089	0.079			
	Mean	0.075	0.088	0.093	0.085			

Table 4. 19 Effect of fertilizer and biochar on root length, root diameter, canopy width, canopy area and leaf area index at harvest in 2017

HARVEST DATA	TREATMENT	BIOCHAR			MEAN	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Root Length (cm)	NPK 200kg/ha	15.120	18.610	17.910	17.210			
	P&K 50:50	20.200	21.500	19.730	20.480			
	P&K 50:100	16.220	21.100	19.500	18.940			
	Liquid Fertilizer	19.690	14.810	17.600	17.370	0.850**	0.659	1.473**
	No Fertilizer	15.700	16.090	18.830	16.870			
	Mean	17.390	18.420	18.710	18.170			
Root Diameter (cm)	NPK 200kg/ha	3.000	3.133	2.967	3.033			
	P&K 50:50	3.433	3.173	3.480	3.362			
	P&K 50:100	3.313	3.180	2.633	3.042	0.1858	0.1439	0.3218*
	Liquid Fertilizer	3.087	3.420	2.960	3.156			
	No Fertilizer	2.907	2.193	3.333	2.811			
	Mean	3.148	3.020	3.075	3.081			
Canopy Width at harvest (cm)	NPK 200kg/ha	47.720	42.660	39.900	43.427			
	P&K 50:50	41.880	43.480	50.640	45.333			
	P&K 50:100	39.740	45.580	44.300	43.207	0.2909**	0.2254**	0.5039**
	Liquid Fertilizer	49.360	48.020	60.040	52.473			
	No Fertilizer	43.740	51.720	39.100	44.853			
	Mean	44.488	46.292	46.796	45.859			
Canopy Area (cm^2)	NPK 200kg/ha	0.179	0.143	0.125	0.149			
	P&K 50:50	0.138	0.149	0.201	0.163			
	P&K 50:100	0.124	0.163	0.154	0.147	0.00179**	0.00139**	0.00311**
	Liquid Fertilizer	0.191	0.181	0.283	0.219			
	No Fertilizer	0.150	0.210	0.120	0.160			
	Mean	0.157	0.169	0.177	0.168			
Leaf Area Index	NPK 200kg/ha	0.179	0.143	0.125	0.149			
	P&K 50:50	0.138	0.149	0.202	0.163			
	P&K 50:100	0.124	0.163	0.154	0.147	0.00179**	0.00139**	0.00311**
	Liquid Fertilizer	0.191	0.181	0.283	0.219			
	No Fertilizer	0.150	0.210	0.120	0.160			
	Mean	0.157	0.169	0.177	0.168			

4.5.6 Total dry matter, relative growth rate and harvest index

Tables 4.20 and 4.21 show the mean effects of fertilizer and biochar on total dry matter accumulated, relative growth and harvest index during the two seasons. For total dry matter accumulated, relative growth rate/week and harvest index, there were no significant fertilizer, biochar and interaction effects in 2016 (Table 4.2). In 2017 only biochar effect were significant on harvest index resulting in treatments with 5 ton/ha biochar producing the highest mean harvest index and 10 ton/ha showing the least harvest index.

Table 4. 20 Dry matter, relative growth rate and harvest index as influenced by fertilizer and biochar in 2016

Agronomic Data	TREATMENT	BIOCHAR			MEAN	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Total Dry Matter Accumulated (g)	NPK 200kg/ha	17.040	14.980	17.460	16.50	2.076	1.608	3.595
	P&K 50:50	16.260	15.090	20.630	17.33			
	P&K 50:100	22.080	11.970	16.980	17.01			
	Liquid Fertilizer	15.970	15.780	14.350	15.37			
	No Fertilizer	12.750	20.230	17.300	16.76			
	Mean	16.820	15.610	17.340	16.59			
Relative Growth Rate/Week	NPK 200kg/ha	0.549	0.557	0.565	0.557	0.01429	0.01107	0.02475
	P&K 50:50	0.549	0.525	0.567	0.547			
	P&K 50:100	0.522	0.505	0.563	0.530			
	Liquid Fertilizer	0.541	0.551	0.541	0.544			
	No Fertilizer	0.519	0.574	0.567	0.553			
	Mean	0.536	0.542	0.561	0.546			
Harvest Index	NPK 200kg/ha	0.558	0.458	0.490	0.502	0.0354	0.0274	0.0614
	P&K 50:50	0.524	0.430	0.439	0.464			
	P&K 50:100	0.450	0.463	0.448	0.454			
	Liquid Fertilizer	0.494	0.352	0.421	0.422			
	No Fertilizer	0.419	0.410	0.443	0.424			
	Mean	0.489	0.423	0.448	0.453			

Table 4. 21 Dry matter, relative growth rate and harvest index as influenced by fertilizer and biochar in 2017

Agronomic Data	TREATMENT	BIOCHAR			MEAN	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER X BIOCHAR
Total Dry Matter Accumulated	NPK 200kg/ha	31.900	30.100	39.700	33.900	5.36	4.15	9.29
	P&K 50:50	46.800	43.100	41.300	43.700			
	P&K 50:100	40.800	42.700	22.900	35.400			
	Liquid Fertilizer	34.500	34.200	31.700	33.500			
	No Fertilizer	25.600	19.800	41.400	28.900			
	Mean	35.900	34.000	35.400	35.100			
Relative Growth Rate/Week	NPK 200kg/ha	0.575	0.589	0.477	0.547	0.02534	0.0196	0.0439
	P&K 50:50	0.590	0.581	0.613	0.595			
	P&K 50:100	0.607	0.608	0.553	0.590			
	Liquid Fertilizer	0.683	0.577	0.607	0.623			
	No Fertilizer	0.556	0.603	0.616	0.591			
	Mean	0.602	0.592	0.573	0.589			
Harvest Index	NPK 200kg/ha	0.613	0.578	0.583	0.592	0.03274	0.0254*	0.0567
	P&K 50:50	0.626	0.599	0.610	0.611			
	P&K 50:100	0.617	0.594	0.556	0.589			
	Liquid Fertilizer	0.607	0.682	0.574	0.621			
	No Fertilizer	0.593	0.622	0.594	0.603			
	Mean	0.611	0.615	0.583	0.6032			

4.5.7 Shoot, Root and Total CGR, NAR and Partitioning Coefficient

Tables 4.22 and 4.23 show the mean crop growth rate for shoot and root, total crop growth rate, net assimilation rate and partitioning coefficient in 2016 and 2017.

Specifically, interaction and fertilizer effect on shoot growth rate, root growth rate and total crop growth rate were not significant in 2016. Biochar effect was significant on shoot growth rate. Hence, 10 ton/ha biochar gave the greatest mean whiles 0 ton/ha biochar gave the least. Interaction effect was significant on net assimilation rate. Hence, liquid fertilizer with 0 ton/ha biochar gave the highest and net assimilation rate and P&K 50:50 with 5 ton/ha gave the least (Table 4.22).

In 2017, there were no significant fertilizer, biochar and interaction effects on shoot, root and total crop growth rate. However, plots treated with liquid fertilizer+5ton/ha biochar resulted in highest partitioning coefficient while plots receiving P&K 50:100+10ton/ha biochar showed the least. Additionally, plots treated with P&K 50:50 without biochar produced the highest net assimilation rate while plots receiving liquid fertilizer+10ton/ha biochar showed the least (Table 4.23).

Table 4. 22 CGR-Shoot, CGR-Root, Total CGR and partitioning coefficient and NAR as Influenced by fertilizer and biochar in 2016

Agronomic Data	Treatment	Biochar			Mean	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Crop Growth Rate-Shoot/Wk-	NPK 200kg/ha	14.680	18.790	19.030	17.500			
	P&K 50:50	15.940	14.600	22.580	17.710			
	P&K 50:100	13.700	10.440	20.430	14.850	2.561	1.984*	4.436
	Liquid Fertilizer	14.920	23.020	17.530	18.490			
	No Fertilizer	13.260	24.940	21.340	19.850			
	Mean	14.500	18.360	20.180	17.680			
Crop Growth Rate-Root/Wk	NPK 200kg/ha	17.800	16.680	19.040	17.840			
	P&K 50:50	19.180	10.670	17.290	15.710			
	P&K 50:100	12.020	9.670	17.220	12.970	2.906	2.251	5.033
	Liquid Fertilizer	14.650	11.660	13.100	13.140			
	No Fertilizer	10.130	17.340	18.190	15.220			
	Mean	14.750	13.210	16.970	14.980			
Crop Growth Rate –Total/Wk	NPK 200kg/ha	32.500	35.500	38.100	35.300			
	P&K 50:50	35.100	25.300	39.900	33.400			
	P&K 50:100	25.700	20.100	37.600	27.800	4.90	3.79	8.48
	Liquid Fertilizer	29.600	34.700	30.600	31.600			
	No Fertilizer	23.400	42.300	39.500	35.100			
	Mean	29.300	31.600	37.100	32.700			
Partitioning Coefficient	NPK 200kg/ha	0.559	0.458	0.494	0.504			
	P&K 50:50	0.525	0.430	0.440	0.465			
	P&K 50:100	0.451	0.464	0.448	0.454	0.0355	0.0275	0.0615
	Liquid Fertilizer	0.494	0.352	0.421	0.423			
	No Fertilizer	0.419	0.410	0.442	0.424			
	Mean	0.489	0.423	0.449	0.454			
Net Assimilation Rate	NPK 200kg/ha	17.310	19.740	16.930	17.990			
	P&K 50:50	18.470	10.190	17.790	15.480			
	P&K 50:100	25.390	11.130	12.750	16.420	2.815	2.180	4.875*
	Liquid Fertilizer	25.730	16.210	14.700	18.880			

Agronomic Data	Treatment	Biochar			Mean	S.E.D.
	No Fertilizer	15.090	23.320	16.650	18.360	
	Mean	20.400	16.120	15.760	17.430	

Table 4. 23 CGR-Shoot, CGR-Root, Total CGR and partitioning coefficient and NAR as Influenced by fertilizer and biochar in 2017

Agronomic Data	Treatment	Biochar			Mean	S.E.D.		
		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER X BIOCHAR
Crop Growth Rate Shoot/Wk	NPK 200kg/ha	12.290	14.840	20.110	15.740			
	P&K 50:50	19.000	22.150	17.840	19.660			
	P&K 50:100	19.020	19.520	10.860	16.470	2.753	2.132	4.768
	Liquid Fertilizer	16.120	13.400	15.400	14.970			
	No Fertilizer	11.860	8.010	19.570	13.150			
	Mean	15.660	15.590	16.750	16.000			
Crop Growth Rate-Root/Wk	NPK 200kg/ha	19.700	20.400	27.600	22.500			
	P&K 50:50	31.100	31.600	28.400	30.400			
	P&K 50:100	30.500	28.600	14.300	24.500	4.36	3.38	7.56
	Liquid Fertilizer	24.900	28.500	21.100	24.800			
	No Fertilizer	17.300	13.800	31.600	20.900			
	Mean	24.700	24.600	24.600	24.600			
Crop Growth Rate Total/Wk	NPK 200kg/ha	31.900	35.200	47.700	38.300			
	P&K 50:50	50.100	53.700	46.300	50.000			
	P&K 50:100	49.500	48.100	25.200	40.900	6.99	5.42	12.11
	Liquid Fertilizer	41.000	41.900	36.500	39.800			
	No Fertilizer	29.100	21.800	51.200	34.000			
	Mean	40.300	40.100	41.400	40.600			
Partitioning Coefficient	NPK 200kg/ha	0.614	0.579	0.585	0.593			
	P&K 50:50	0.626	0.599	0.610	0.612			
	P&K 50:100	0.618	0.594	0.556	0.589	0.01598	0.01238*	0.02768*
	Liquid Fertilizer	0.607	0.683	0.575	0.621			
	No Fertilizer	0.593	0.623	0.594	0.603			
	Mean	0.612	0.616	0.584	0.604			
Net Assimilation Rate	NPK 200kg/ha	35.600	42.100	64.800	47.500			
	P&K 50:50	68.000	58.000	41.000	55.600			
	P&K 50:100	65.700	52.300	29.700	49.200	7.39*	5.72	12.80**
	Liquid Fertilizer	36.100	37.800	22.400	32.100			
	No Fertilizer	34.100	18.800	69.000	40.600			

Agronomic Data	Treatment	Biochar			Mean	S.E.D.
	Mean	47.900	41.800	45.400	45.000	

4.5.8 Tissue Composition

Tables 4.24 and 4.25 below show the means for carrot tissue nutritional composition of the treatments in both seasons. For percentage fat composition, plots treated with liquid fertilizer+5 ton/ha biochar showed the highest while liquid fertilizer without biochar gave the least in 2016. In 2017, plots treated with P&K 50:100 + 5ton/ha biochar gave the highest fat composition in carrot tubers while plots receiving NPK 200kg/ha+10ton/ha biochar showed the least.

For percentage fibre composition, plots treated with liquid fertilizer without biochar gave the highest fibre composition in 2016 while NPK 200kg/ha+10 ton/ha biochar treatment showed the least. Plots treated with liquid fertilizer+5 ton/ha biochar also showed the highest fibre content while P&K 50:50 without biochar gave the least in 2017.

In 2016, there were no significant fertilizer, biochar or interaction effect on ash and protein. Interaction effect were however significant in 2017. Hence, the control (no fertilizer nor biochar) gave the highest ash content. Again, in 2017, plots treated with liquid fertilizer and 10 ton/ha biochar gave the highest protein content while plots receiving P&K 50:50 + 10 ton/ha biochar showed the least.

In 2016, the 10 ton/ha biochar without fertilizer treatment showed the greatest moisture content while P&K 50:100 gave the least. In 2017 treatment P&K 50:100+5ton/ha biochar had the greatest content while liquid fertilizer without biochar treatment had the least.

For percentage carbohydrate, plots which received P&K 50:50 + 5 ton/ha biochar showed the highest content while liquid fertilizer+5 ton/ha biochar showed the least in 2016. In 2017, plots treated with P&K 50:50+10 ton/ha biochar showing the highest protein content while plots receiving liquid fertilizer with 5ton/ha biochar showed the least.

Table 4. 24 Influence of fertilizer and biochar on proximate composition in 2016

Proximate Analysis 2016	Treatment	Biochar			Mean	S.E.D.		
%Nutrient Composition		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Fat	NPK 200kg/ha	2.500	2.540	2.090	2.377			
	P&K 50:50	2.527	2.893	3.037	2.819			
	P&K 50:100	2.280	2.537	3.230	2.682			
	Liquid Fertilizer	1.847	3.663	3.263	2.924	0.2376	0.1841**	0.4116*
	No Fertilizer	2.470	2.950	3.313	2.911			
	Mean	2.325	2.917	2.987	2.743			
Fibre	NPK 200kg/ha	5.744	4.583	6.027	5.452			
	P&K 50:50	5.814	4.812	4.960	5.195			
	P&K 50:100	5.328	5.587	5.338	5.418			
	Liquid Fertilizer	6.428	5.583	6.369	6.127	0.2353**	0.1822	0.4075**
	No Fertilizer	5.380	6.112	4.501	5.331			
	Mean	5.739	5.335	5.439	5.504			
Ash	NPK 200kg/ha	26.320	26.340	26.300	26.320			
	P&K 50:50	26.040	25.610	26.010	25.890			
	P&K 50:100	25.690	29.190	25.740	26.870			
	Liquid Fertilizer	26.180	25.840	25.760	25.930	0.903	0.7	1.565
	No Fertilizer	26.580	28.530	25.080	26.730			
	Mean	26.160	27.100	25.780	26.350			
Moisture	NPK 200kg/ha	47.900	46.980	44.230	46.370			
	P&K 50:50	48.990	46.120	47.290	47.470			
	P&K 50:100	45.930	47.230	45.740	46.300			
	Liquid Fertilizer	45.590	50.110	46.150	47.280	0.927	0.718	1.605**
	No Fertilizer	46.480	45.160	51.760	47.800			
	Mean	46.980	47.120	47.040	47.040			
Protein	NPK 200kg/ha	10.470	9.650	11.890	10.670			
	P&K 50:50	9.330	10.170	11.850	10.450			
	P&K 50:100	11.720	10.100	10.790	10.870			
	Liquid Fertilizer	10.580	9.730	10.530	10.280	0.435	0.337**	0.753
	No Fertilizer	9.760	9.650	9.590	9.670			
	Mean	10.370	9.860	10.930	10.390			
Carbohydrates	NPK 200kg/ha	7.070	9.900	9.460	8.810			
	P&K 50:50	7.300	10.390	6.850	8.180			
	P&K 50:100	9.050	5.360	9.170	7.860			
	Liquid Fertilizer	9.380	5.070	7.920	7.460	0.851	0.659	1.474**

No Fertilizer	9.330	7.600	5.750	7.560
Mean	8.430	7.660	7.830	7.970

Table 4. 25 Influence of fertilizer and biochar on proximate composition in 2017

Proximate Analysis 2017 %Nutrient Composition	Treatment	Biochar 0t/ha	5t/ha	10t/ha	Mean	S.E.D. FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Fat	NPK 200kg/ha	1.750	1.070	0.337	1.052			
	P&K 50:50	1.770	1.480	0.880	1.377			
	P&K 50:100	1.750	2.510	1.940	2.067			
	Liquid Fertilizer	1.530	1.070	1.493	1.364	0.02034**	0.01576**	0.03523**
	No Fertilizer	0.940	1.130	2.010	1.360			
	Mean	1.548	1.452	1.332	1.444			
Fibre	NPK 200kg/ha	7.020	12.880	8.560	9.487			
	P&K 50:50	6.620	9.190	7.790	7.867			
	P&K 50:100	7.450	10.000	8.667	8.706	0.0361**	0.0279**	0.0625**
	Liquid Fertilizer	7.130	15.640	10.033	10.934			
	No Fertilizer	12.000	12.360	7.810	10.723			
	Mean	8.044	12.014	8.572	9.543			
Ash	NPK 200kg/ha	6.096	5.086	6.375	5.852			
	P&K 50:50	6.985	7.004	6.640	6.876			
	P&K 50:100	8.016	6.614	7.593	7.408	0.02555**	0.01979**	0.04426**
	Liquid Fertilizer	8.224	7.611	8.128	7.988			
	No Fertilizer	8.858	7.595	6.370	7.608			
	Mean	7.636	6.782	7.021	7.146			
Moisture	NPK 200kg/ha	66.749	69.574	68.445	68.256			
	P&K 50:50	68.597	67.393	69.489	68.493			
	P&K 50:100	67.742	66.779	68.989	67.837	0.0534**	0.0413**	0.0924**
	Liquid Fertilizer	66.190	67.020	67.412	66.874			
	No Fertilizer	67.410	68.770	67.779	67.986			
	Mean	67.338	67.907	68.423	67.889			
Protein	NPK 200kg/ha	7.005	7.881	8.537	7.808			
	P&K 50:50	7.441	10.510	4.378	7.443			
	P&K 50:100	9.194	6.613	8.318	8.042	0.01001**	0.00775**	0.01734**
	Liquid Fertilizer	8.537	7.443	10.967	8.982			
	No Fertilizer	7.881	7.881	8.537	8.100			
	Mean	8.012	8.066	8.147	8.075			
Carbohydrates	NPK 200kg/ha	11.380	3.509	7.746	7.545			
	P&K 50:50	8.587	4.423	10.823	7.944			
	P&K 50:100	5.848	7.484	4.493	5.942	0.00808**	0.00626**	0.01400**
	Liquid Fertilizer	8.389	1.216	1.966	3.857			
	No Fertilizer	2.911	2.264	7.494	4.223			
	Mean	7.423	3.779	6.505	5.902			

4.5.9 Carotenoid Composition

Tables 4.26 and 4.27 show the influence of fertilizer and biochar on the mean performance of carotenoids during the minor and major rainy seasons.

Beta carotene content was highest in carrots which liquid fertilizer and least for plots which did not receive fertilizer and biochar (control) in 2016. The major rainy season, however, saw plots treated with NPK 200kg/ha +5ton/ha biochar showing the highest content while plots receiving P&K 50:100 gave the least.

On total carotenoids, P&K 50:50 +5 ton/ha biochar treatment produced the highest while P&K 50:100+5 ton/ha biochar showed the least during the minor rainy season. During the major rainy season, NPK 200kg/ha +5 ton/ha biochar treatment showed the highest total carotenoid content while P&K 50:100 + 5 ton/ha biochar showed the least.

Table 4. 26 Influence of fertilizer and biochar on carotenoid composition during minor season, 2016

SOIL DATA	TREATMENT	BIOCHAR			MEAN	S.E.D.		
Carotenoid Content 2016		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Beta Carotene Content mg/ml	NPK 200kg/ha	0.190	0.078	0.152	0.140	0.00703**	0.00544**	0.01217**
	P&K 50:50	0.113	0.042	0.227	0.127			
	P&K 50:100	0.064	0.412	0.474	0.316			
	Liquid Fertilizer	0.089	0.599	0.059	0.249			
	No Fertilizer	0.093	0.099	0.134	0.108			
	Mean	0.110	0.246	0.209	0.188			
Total carotenoids mg/ml	NPK 200kg/ha	0.380	0.156	0.304	0.280	0.000703**	0.000544**	0.001217**
	P&K 50:50	0.226	0.084	0.383	0.231			
	P&K 50:100	0.127	0.823	0.948	0.633			
	Liquid Fertilizer	0.179	1.197	0.118	0.498			
	No Fertilizer	0.185	0.197	0.267	0.217			
	Mean	0.219	0.492	0.404	0.372			

Table 4. 27 Influence of fertilizer and biochar on carotenoid composition during the major season, 2017

SOIL DATA	TREATMENT	BIOCHAR			MEAN	S.E.D.		
Carotenoid Content 2017		0t/ha	5t/ha	10t/ha		FERTILIZER	BIOCHAR	FERTILIZER xBIOCHAR
Beta Carotene Content mg/ml	NPK 200kg/ha	0.350	0.570	0.226	0.382			
	P&K 50:50	0.118	0.097	0.415	0.210			
	P&K 50:100	0.595	0.064	0.414	0.358	0.000706**	0.000547**	0.001223**
	Liquid Fertilizer	0.114	0.099	0.142	0.118			
	No Fertilizer	0.190	0.152	0.402	0.248			
	Mean	0.274	0.196	0.320	0.263			
Total carotenoids mg/ml	NPK 200kg/ha	0.701	1.139	0.453	0.764			
	P&K 50:50	0.236	0.195	0.831	0.421			
	P&K 50:100	1.191	0.128	0.829	0.716	0.0000721**	0.0000558**	0.0001248**
	Liquid Fertilizer	0.227	0.197	0.283	0.236			
	No Fertilizer	0.381	0.297	0.804	0.494			
	Mean	0.547	0.391	0.640	0.526			

4.6 Correlation Analysis of Soil Physical and Chemical Properties, Crop Growth, Yield and Tissue Composition

Table 4.28 shows the correlational matrix of selected soil, growth, yield and nutritional parameters for the minor and major growing seasons put together. From Table 4.28 and Appendix F, physical and chemical soil factors are seen to variously influence the plant factors and consequently the nutritional composition. As established earlier the application of biochar and fertilizers had significant influence on porosity, gravimetric moisture content, and the %solid particles. 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 was employed.

In this experiment, porosity which is a function of biochar application shall be discussed comprehensively with a few other significant relationships. Overall, soil porosity was highly correlated with gravimetric moisture content and perfectly and negatively correlated with bulk density and %solids.

Among the soil chemical relationships, it is noticeable that porosity is positively and moderately correlated with pH, organic carbon, organic matter, sodium and base saturation. Total N, Calcium and total exchangeable bases (TEB) were lowly correlated with porosity. There were, however, negative moderate correlation between porosity and exchangeable acidity and that of porosity and Effective Cation Exchange Capacity (ECEC). Magnesium, Potassium and milligram/kg SO_4 were lowly and negatively correlated with porosity. Among soil chemical properties, TEB were strongly correlated with pH, total N, Organic C and %Organic Matter. Base saturation was also perfectly correlated with pH and highly correlated with total N, %organic carbon and organic matter. Magnesium was also highly correlated with Total N, %Organic C and Organic matter.

Additionally, it is obvious from the correlational matrix that the above-stated soil physicochemical relationships also explain a lot of the agronomic observations from plant growth to harvest. For instance, plant height is seen to moderately correlate with gravimetric moisture content, magnesium and TEB but highly correlated with soil pH, base saturation and ppmP. Again, we also see soil porosity having moderate correlation with canopy width, number of branches and canopy area and perfectly correlated with marketable yield of carrots. Total N, %organic matter, Mg and TEB being highly correlated with root length. Again, root diameter is moderately correlated with gravimetric moisture content highly correlated with ppmP. Similarly, exchangeable acidity is noted to strongly correlate with partitioning coefficient, net assimilation rate (NAR) and Harvest Index (HI)

Carbohydrate is also highly correlated with exchangeable acidity and moderately correlated with ppmP. Among plant parameters, carbohydrate is also perfectly correlated with partitioning coefficient and H

Table 4. 28 Correlation Matrix of the Influence of Soil Parameters, Carrot Growth, Yield and Nutritional Composition

	Bulk Density	*%Poro*	*%O.C*	*% ORGANIC MATTER*	*EX. ACIDITY*	*ECEC*	*BASE SAT.*	*Total Yield in Ton/ha-s1*	*RGR/week-s1*	*Harvest Index-s1*	*CGR-Root-s1*	*CGR-Total-s1*	*Partitioning Coefficient-s1*	*NAR Rate-s1*	*FAT1*	*FIBRE 1*	*ASH1*	*MOISTURE 1*	*PROTEIN 1*	*CARBO 1*	*Beta Caro_s 1*
Bulk Density	1.00																				
%Porosity	-1.00	1.00																			
%O.C	-0.12	0.12	1.00																		
% ORGANIC MATTER	-0.17	0.17	0.98	1.00																	
EX. ACIDITY	0.41	-0.41	-0.08	-0.11	1.00																
ECEC	0.19	-0.19	0.34	0.19	0.26	1.00															
BASE SAT.	-0.38	0.38	0.19	0.18	-0.95	0.02	1.00														
Total Yield in Ton/ha-s1	-0.23	0.23	-0.15	-0.13	-0.13	-0.23	0.08	1.00													
RGR/week-s1	-0.35	0.35	-0.17	-0.16	-0.26	-0.22	0.19	0.66	1.00												
Harvest Index-s1	-0.03	0.03	-0.33	-0.33	0.29	-0.02	-0.31	0.19	0.19	1.00											
CGR-Root-1	-0.27	0.27	-0.29	-0.28	-0.09	-0.19	0.01	0.67	0.87	0.58	1.00										
CGR-Total-s1	-0.32	0.32	-0.17	-0.16	-0.27	-0.22	0.19	0.69	0.98	0.18	0.89	1.00									
Partitioning Coefficient 1	-0.03	0.03	-0.33	-0.33	0.29	-0.02	-0.31	0.19	0.19	1.00	0.58	0.19	1.00								
NAR s1	0.35	-0.35	-0.12	-0.20	0.32	0.23	-0.27	0.01	0.33	0.05	0.29	0.33	0.05	1.00							
FAT1	-0.02	0.02	0.48	0.38	-0.34	0.42	0.46	0.15	0.05	-0.19	-0.03	0.08	-0.19	0.02	1.00						
FIBRE1	0.35	-0.35	0.14	0.00	0.14	0.75	0.06	-0.18	-0.18	0.07	-0.11	-0.18	0.07	0.27	0.31	1.00					
ASH1	-0.23	0.23	-0.34	-0.21	-0.16	-0.74	-0.05	0.36	0.23	0.06	0.24	0.26	0.06	-0.28	-0.47	-0.66	1.00				
MOISTURE 1	0.23	-0.23	0.36	0.24	0.16	0.71	0.05	-0.37	-0.23	-0.06	-0.25	-0.27	-0.06	0.27	0.47	0.62	-0.99	1.00			
PROTEIN1	0.14	-0.14	0.09	0.01	0.07	0.43	0.04	-0.18	-0.02	0.04	-0.02	-0.04	0.04	0.27	0.21	0.47	-0.53	0.46	1.00		
CARBO1	0.05	-0.05	-0.15	-0.19	0.22	0.34	-0.12	-0.12	-0.08	-0.06	-0.11	-0.12	-0.06	0.12	-0.20	0.29	-0.32	0.24	0.38	1.00	
Beta Carotene_s1	0.16	-0.16	0.11	0.12	-0.23	-0.08	0.22	0.16	0.03	-0.19	-0.07	0.05	-0.19	-0.26	0.28	-0.04	0.05	-0.02	-0.06	-0.41	1.00

CHAPTER FIVE

5.0 DISCUSSION

5.1 Action Research on Carrot Production in Mampong-Ashanti

5.1.1 Availability and efficiency of support services in carrot production

According to Thomas *et al*. (2012), policy and institutional support often addressed specific constraints within the context of specific projects rather than the development of the entire value chain. Specifically, as shown in Figure 4.1a, for the Ministry of Food and Agriculture, close to 80% of respondents perceive that support provided have not at all been beneficial. For Crop Research Institute (Figure 4.1b), Not at all beneficial and not beneficial scored 60% and 40% respectively. No respondent perceived any support from MoFA and CRI to be either very beneficial or beneficial within the context of carrot production.

Further, Figure 4.2 shows that the institutional support provided by the Food and Agriculture Organisation (FAO), Non-Governmental Organisations (NGOs), the Private Sector and Traditional Authority were not beneficial to carrot farmers. Overall, farmers feel these institutions are not supporting them. Focus group discussion further revealed that if government could build a carrot processing factory in Mampong, a great deal of jobs would be created. They argued that carrot could be processed into juice, pomade and soaps for export. Kersting and Wollni (2012) observed that insufficient institutional support makes it difficult for producers and exporters to meet safety standards and limits access to critical markets.

5.1.2 Expenditure on Inputs during the Minor Growing Season, 2016

Table 4.3 shows the amount spent on production inputs in 2016. Evidently, the amount spent on fuel for irrigation was highest followed by labour, seeds, fertilizers and biocides. From this results, it is clear that the climate bears heavily on production by increasing the amount of fuel required for irrigation and by extension the cost and profitability of agribusiness. Interventions that enable soil water conservation are therefore critical to enhancing farmer profitability by reducing the amount of fuel required for irrigation. Greiber, (2009) and Scharenbroch *et al*., (2013) argue that farmers suffer great losses from water stress and that investment in irrigation systems and technologies are obligatory in the promotion of ecosystem services and soil biodiversity and effective agricultural value chain.

5.1.3 Nature of Constraints

For the cross-sectional study results in Tables 4.4, 4.5 and 4.6 with the exception of disability, majority of the respondents generally agreed that they were constrained by soil crusting, limited cropping area, poor root penetration, occasional crop failure from the choice of soil type, distance to farm, proximity to water sources, weeds, diseases, pests and predators. Agnes *et al.,* (2012) also made similar observations and recommended an interdisciplinary approach towards resolving production constraints.

5.1.4 Contribution of Farmer Cooperatives Carrot Production

Apparently, it can be said that the output from the farmers has not benefited from any institutional support and they use production methods which are largely unsustainable. According to Kersting and Wollni (2012), institutional support for the vegetable sector is key to meeting both private and public food safety standards. It is, therefore important that farmers get both technical and financial support to transform the sector's value chain.

5.2 Introduction of Biochar as a Sustainable Agriculture and Climate Smart Product

In order to contribute to resolving the high cost of irrigation associated with long dry spells stemming from climate variability, an evaluation was carried out to determine how biomass waste from the woody branches of avocado fared when converted to biochar. Table 4.9 shows the chemical properties of avocado biochar. Evidently, the percentage organic carbon of 34.5% is high enough to improve the soil carbon stock when adequately incorporated into the soil leading to a lowered bulk density, improved root development and nutrient uptake and better yield particularly for carrots. With an increased carbon stock, soil porosity and gravimetric moisture contents are enhanced and microbial, microfaunal, mesofaunal and macrofaunal activities are rejuvenated leading to a general improvement in soil productivity (Gunarathne *et al.*, 2017). This has the potential to reduce the amount of irrigation required to keep the soil moist as more water and nutrients are retained in the soil for a relatively longer time (Brantley *et al.*, 2015). Again, with a pH of 6.37, the peak availability of Nitrogen, Phosphorus, Potassium, Sulfur, Calcium, Magnesium, Boron, Copper and Zink are well assured (Appendix B). Consequently, increased amount of biochar promises improvement in soil nutrient availability. Additionally, the electrical conductivity of 946µS/cm shows the speed with which nutrients on the surface of biochar particles are conducted in soil solution and made available to plant roots. By its nature, biochar also supplies some proportion of macronutrients in the form of Magnesium, Phosphorus, Potassium and nitrogen. The increased application of biochar in the soil will also ultimately enhance the volume of carbon stored in stable form within the soil which would normally have been gasified by combustion or decomposition releasing the carbon into the atmosphere and increasing GHGs (Filiberto and Gaunt, 2013).

5.3 Effect of Fertilizer and Biochar an Soil Physical Characteristics

The volumetric moisture content which determines the volume of water held in the pores of the soil provided similar results to the gravimetric moisture content signifying again that the soils treated with 10ton/ha biochar held more water than other treatments. The implication is that biochar use among farmers can reduce the cost of irrigation and increase profitability among farmers as more water is stored in the soil for plant use.

Further, the bulk density which is a measure of how compact the soil is was assessed for fertilizer and biochar treated soils. 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. The results from the treatments showed that there was significant interaction effect between biochar and fertilizer. This means that one cannot say biochar alone or fertilizer alone influences bulk density. Rather, bulk density is influenced by different rates of biochar and different rates and types of fertilizer. On the whole, biochar at 10 ton/ha gave the least bulk density (1.22) compared to (1.33) for treatment that received no fertilizer nor biochar.

Finally, the percentage solid space and soil porosity which indicate how much solid particles and pore spaces are available respectively for air and water were assessed. The significant interaction effect of fertilizer and biochar on the percentage solid space and soil porosity show that biochar and inorganic fertilizer to improve soil compaction by increasing the carbon stock, expanding the surface area of microbial activity, and increasing the space occupied by air and water as predicted by soil porosity results (Table 4.10). These results are in tandem with most works on biochar amendments on soil (Mukherjee *et al.*, 2014; Brantley *et al.*, 2015; Satriawan and Handayanto, 2015).

5.4 Effect of Fertilizer and Biochar on Soil Chemical Characteristics

With significant interaction effects of biochar and fertilizer on pH, it can be inferred that different levels of biochar and fertilizer affect soil pH differently. This observation was also made by Peiris and Weerakkody (2015) in their assessment of biochar and fertilizer on agronomic performance of maize. In a work done by Schulz and Glaser (2014), was 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 reducing the incidence and cost of liming. Using the chart in Appendix B, it is obvious from Table 4.12 that the mean pH of 5.47 for treatment without biochar would experience 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 renders 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 and sustainable agriculture.

On the %Organic carbon, there was a significant interaction effects from fertilizer and biochar. NPK combination with 5ton/ha and 10ton/ha show a slight improvement in organic carbon content than NPK applied alone. Biochar-treated soil generally had higher organic carbon than treatments without biochar. This is attributable to the increased carbon content of biochar used in the treatment. Liquid fertilizer treatments and no-fertilizer treatments showed relatively higher carbon content. The implication is that certain environmental conditions favour carbon accumulation in the soils in spite of the absence of amendment. This view is supported by works of Verheijen *et al*., (2010), Schulz and Glaser (2014) and Bhattarai *et al*. (2015) in their assertion that soil organic carbon stocks are influenced by land-use and management activities that affect carbon input rates and soil organic matter loss rates. In spite of the dominant processes governing the balance of soil organic carbon stocks, carbon inputs from biochar and other plant remains plus carbon emissions from decomposition and losses as particulate or dissolved carbon can be significantly altered if soil ecosystems are managed with biochar amendment.

Overall, different fertilizers and their biochar combinations had different nitrogen contents. The control (without biochar or fertilizer) had the highest nitrogen content. Veitch *et al*., (2014) reported that the reason for not seeing the effect of nitrogen among treatment plots but instead in the control could be due to the high base fertility of the soil environment under consideration. Hence the contribution of base cations of the different fertilizers and biochars appeared to have masked the presence of nitrogen. Clough and Condron, (2010) argued that following the pyrolysis of biomass, microbially toxic compounds such as polyaromatic hydrocarbons may be present in the biochar and that the presence of a nitrification-inhibiting compound like α-pinene found in unweathered biochars used may have initially caused nitrification rates to be lower in the biochar treatment. Consequently, it is argued that the chemical characterization of biochar, the degree of weathering or residence time of biochars in the soil, with respect to microbially toxic or nitrification-inhibiting products in biochar should be considered during studies on nitrogen cycling (Clough *et al.*, 2013). The observation for %organic matter is similar to that of the %organic carbon as reported by (Abuzar *et al.*, 2013). The results showed that biochar-amended soils gave higher organic matter content in 2016 and 2017 (Tables 4.12 and 4.13). This is largely attributable to the increased carbon input from biochar (Güereña *et al.*, 2015).

In a soil environment without fertilizer, 0 ton/ha does better in presenting calcium in solution than 5 ton/ha and 10ton/ha biochar (Figure 4.4). Ye *et al.*, (2016) reported that the adsorption of calcium to surfaces of biochar could account for the reduced presence in solution. It is argued that this property favours the long term availability of nutrients to plants as biochar allows nutrients to be released slowly for plant uptake. P&K 50:50 and P&K 50:100 favour the release of more calcium because of the fact that the addition of these fertilizers increase the amount of exchangeable cations in solutions and therefore the amount of soil solution calcium (Alshankiti and Gill, 2016). Additionally, since the environments created by P&K 50:50, P&K 50:100, liquid fertilizer and No fertilizer were relatively higher in calcium than that of NPK, the release of calcium into solution was adequately supported. This view is supported by Kjellenberg *et. al*. (2016).

Biochar at 10 ton/ha promotes the release of magnesium into solution for plant uptake than biochar at 5 ton/ha and 0 ton/ha. The reason is that, the K amount in P&K 50:100 produces a masking effect on magnesium in solution due to the fact that in the reactivity series of metals (APPENDIX F), K is more reactive than Mg first because of its size and second because of its valence electrons (Mohammed *et al.*, 2017). Consequently, the presence of elevated amount of K tends to minimize the availability of Mg in solution. In the work of Favacho *et al., (*2017), it is argued that one way to increase soil fertility when soils lack adequate levels of macronutrients is the proper and balanced use of appropriate type of mineral fertilizer as the presence of some elements in abundance minimize the availability of others for plant uptake. It is further argued that mineral fertilizers alone cannot sustain soil productivity and therefore the need for integrated nutrient management with biochar (Alshankiti and Gill, 2016).

Similar to magnesium, there was significant interaction effect between fertilizer and biochar on soil potassium composition. In a soil environment where P&K 50:100 is present, biochar at 5 ton/ha does better than 10 ton/ha and 0 ton/ha biochar. Undoubtedly, the potassium content of soils treated with P&K 50:100 gave the highest mean because apart from K being the most reactive in the reactivity series, it is the most concentrated in the proportion of P:K 50:100 among the fertilizer combinations applied as treatment on plots. K is also very reactive in water (Ahmed *et al*., 2014). Among biochar treatments, biochar 5 ton/ha provided a relatively high soil mean potassium than 10 ton/ha and 0 ton/ha (Figure 4.5). This is likely because increased biochar provides more surface area for adsorption to cations than soils with reduced biochar composition.

From Figure 4.4, biochar at 10 ton/ha presented a relatively high release of sodium in solution in soil environment containing P&K 50:50, P&K 50:100 and liquid fertilizer. This could be attributed to the increased displacement of Na+ ions by increased concentration of phosphate potassium ions in the biochar environment (Ye *et al*., 2016). In NPK environment however, 5 ton/ha biochar does better than 10 ton and 0 ton/ha biochar at making sodium available. Further, Table 4.13 shows the level of sodicity following treatment with biochar and fertilizer. Under biochar treatments, 5 ton/ha biochar provided the highest mean sodium content followed by 10 ton/ha. This culminates to the fact that biochar environment increases the electrical conductivity, puts more cations into solution and consequently makes more ions available for plant uptake consistent with findings from Abuzar *et al.* (2013), Pühringer (2016) and Güereña *et al. (*2015). However, it is important to note that elevated amount of sodium in soils has the potential of reducing the osmotic potential of the soil and preventing uptake of water into the roots of plant because of the comparatively lower salt concentration in the roots (Adcock *et al.,* 2007). Hence, sustainable agriculture would imply managing the soils in such a way as to balance the amount of sodium in the soil to prevent drought-like conditions for plants in spite of the availability of water. Kukal *et al.* (2014) recommend improving drainage and leaching systems for the dissolution and removal of excess sodium and salts from soil and planting cover crops and salt tolerant crops to mitigate high soil sodicity and salinity.

From Tables 4.14 and 4.15, there was significant interaction effect between fertilizer and biochar on total exchangeable bases, exchangeable acidity, effective cation exchange capacity, base saturation, phosphates and sulphate in both minor and major rainy seasons. This is may be due to the contribution of both fertilizer and biochar to the chemical properties of the soil as observed by Alshankiti and Gill (2016), Akom *et al.*, (2015a) and Clough *et al*,. (2013). In specific terms, NPK environment supports both 5 ton/ha biochar and 10 ton/ha biochar. P&K 50:100 environment provided improved exchangeable base outcomes for 5 ton/ha and 10 ton/ha biochar over 0 ton/ha biochar. This is attributable to increased mineralization of phosphorus and potassium fertilizers in biochar environment which elevate the amount of metals going into solutions for plant uptake (Lehmann *et al.*, 2011). Under liquid fertilizer environment, there was a rise in the T.E.B. resulting from the application of 10 ton/ha biochar than biochar at 5 ton/ha and 0 ton/ha as observed by Kamara *et al.*, (2015) and Carter *et al.*, (2013). It is further shown that in a no fertilizer environment, no biochar does better in presenting exchangeable bases in solution than 5 ton/ha and 10 ton/ha biochar in descending order. This may be due to adsorption of exchangeable bases to surfaces of biochar particles in the already nutrient-limited environment making the bases temporarily less available (Leye and Omotayo, 2014). The elevated T.E.B. for 10 ton/ha biochar among 5 ton/ha and 0 ton/ha shows that elevated biochar levels increase cation exchange capacity (CEC) and hence the amount of exchangeable bases in soil solution (Table 4.15). This observation was also made by Alshankiti and Gill (2016). Similarly, liquid fertilizer and no fertilizer environments have elevated mean T.E.B. partly because of the minimal soil chemical disturbance that allow more bases to stay in the root zone for plant uptake compared to soils receiving fertilizers and the accompanying alterations in soil acidity, CEC and electrical conductivity (Suppadit *et al*., 2012).

Further, in NPK environment, elevated biochar levels provided a reduced exchangeable acidity (Table 4.15). Under P&K 50:50, P&K 50:100, and liquid fertilizer, 10 ton/ha biochar produced a low exchangeable acidity. Similar observations were made by Njoku *et al.* (2016), Cornelissen *et al.*, (2013) and Jones *et al.* (2012). In a work done by Akom *et al.,* (2015), it is explained that the reduction in exchangeable acidity by the application of biochar derives from the effective replacement of Ca in biochar-CEC-enhanced environment by the monomeric Al species on the soil exchangeable sites and generates alkalinity. Subsequently, there is an increase in soil solution pH as a result of the reduction of the readily hydrolysable monomeric Al and the subsequent formation of the neutral [$Al(OH)_3$].

Additionally, ECEC is favoured by moderate (5 ton/ha) biochar in NPK environment (Table 4.14). Again, 10 ton/ha biochar produced the highest base saturation in NPK, P&K 50:50, P&K 50:100 and liquid fertilizer environments. 0 ton/ha biochar showed the least base saturation across all fertilizer environments. These go to show that elevated biochar composition in soils promote improved chemical properties as observed by Ye *et al.*, (2016) and Gunarathne *et al*., (2017).

For parts per million P and mg/kg SO_4 elevated (10 ton/ha) and moderate (5 ton/ha) levels of biochar showed improved performance across fertilizer environments. The ability of biochar in enhancing fertilizer availability is revealed (Dennis and Kelvin, 2014).

5.5 Effect of Fertilizer and Biochar on Carrot Growth, Yield and Nutritional Quality

In 2016, different fertilizers resulted in differences in plant height growth rates under 5 ton/ha biochar application. Overall P&K 50:50 gave the highest growth rate followed by liquid fertilizer. Thus, during the minor cropping season, P&K 50: 50 proves to be supportive for converting photosynthetic assimilates into actively developing sink tissues (Bashan *et al*., 2010). In their work on radish, Ahmed *et al*. (2014) observed that imbalance use of three major essential nutrients such as nitrogen, phosphorus and potassium along with other production factors was the main cause of low growth and yield. This affirms the observations made among the treatments that produced low growth rate (Figure 4.7).

In 2017, the differences in height growth rates from different fertilizers combined with 5 ton/ha biochar were narrow causing the curves to cluster around each other. This is largely due to the adequacy of precipitation received among treatments causing each treatment to perform fairly well in growth (Daniel *et al.*, 2001).

In 2017, NPK expressed the greatest above-ground growth rates providing the highest WAP coefficient of 4.31 under 0 ton/ha biochar environment. This could be due to the elevated nitrogen content in plots treated with NPK compared with the other treatments and the fact that under low nitrogen soils biochar may temporarily inhibit the availability of nitrogen as observed by Gunarathne *et al.*, (2017).

In 2016 at 12 WAP, there was significant effect of biochar on canopy width in which the highest canopy width was observed under 5 ton/ha biochar (Figures 4.21 and 4.22). This could be due to the reduced precipitation in the minor cropping season resulting in reduced availability of soil solution elements and low pH among other inhibitory factors (Zheng *et al*., 2010). Vuolo *et al. (*2013) made a similar observation by their assertion that canopy performance can be used to monitor nitrogen uptake in the plant. According to Baumann *et al.* (2002), since the maximum photosynthetic rate per unit of leaf area is related to the nitrogen concentration in the leaf, increased use of NPK can enhance canopy growth when soil moisture and nutrients are adequate.

In 2016, 10 ton/ha biochar produced the highest marketable yield (Table 4.16) as a result of the overall enhanced physicochemical effects of biochar on soil (Filiberto and Gaunt, 2013). This observation is explained by the capacity of biochar to improving gravimentric and volumetric moisture content, soil porosity, CEC and the reduction of soil acidity-a view consistent with Verheijen *et al.* (2010), Suppadit *et al*. (2012) and Kimber *et al*. (2009). Overall P&K 50:100 with 10ton/ha biochar provided the highest yield because of the significant ($P<0.05$) fertilizer-biochar synergistic effect (Ye *et al.*, 2016). The major season (Table 4.17) marketable, non-marketable and total yield were not significant apparently because of increased precipitation and reduced water stress that made treatments to produce higher mean yield over the minor season yield (Agegnehu *et al*., 2016).

In 2016, biochar effect was significant (Table 4.18) on canopy width at harvest, canopy area and leaf area index. Consequently, 10 ton/ha biochar produced the highest (53.13 cm) canopy width as a result of the improved carrot productivity resulting from improved soil nutrient available to plants and assimilate translocation to carrot leaf tissues (Bashan *et al*., 2010). Canopy area and Leaf Area Index were also significant during the minor season.

In 2017, fertilizer and biochar interaction were significant on root length, root diameter, canopy width at harvest, canopy area and leaf area index (Table 4.19). P&K 50:50 with 5 ton/ha biochar produced the highest root length. This shows that moderate biochar presence in soil promotes root elongation as a result of improved porosity, reduced bulk density and enhanced nutrient uptake (Seehausen *et al*., 2017). P&K 50:50 without biochar produced the best root diameter. This could be explained by the compacted nature of the P&K 50:50 environment without biochar resulting in horizontal growth of the tubers. Given that dwarf carrots constitute the best choice among some cultures and consumers, biochar use may not be supported under soils used to produce dwarf carrots (Ekman and Tesoriero, 2015).

In 2016, the canopy area and leaf area index were all significantly influenced by biochar. With increased leaf area index following biochar application, there is a resultant increased interception of light, increased accumulation of assimilate and hence increased yield. In the work done by Altieri *et al.*, (2017), it is argued that leaf area index is a function of days after planting, soil nutrient composition and stomatal conductance. In the case of carrots, the number of branches which is also taken as the number of leaves also informs the leaf area index. In effect, biochar does not only increase the soil carbon stock, but by increasing the leaf area index, there is a concomitant increase in stomatal conductance which leads to increased CO_2 uptake and improved O_2 release into the atmosphere (Younis *et al.*, 2015).

In 2017, there were significant synergistic effect of biochar and fertilizer on the root length root diameter canopy width at harvest, canopy area and leaf area index. These effects are more pronounced in the major cropping season largely because of the increased precipitation and improved soil nutrient availability by the increased transport rates and accumulation of assimilates through photosynthesis (Abdel, 2015).

In 2017, biochar applied at 5 ton/ha gave the highest harvest index (Table 4.21). Further investigation is needed to explain why 5 ton/ha biochar would perform better than 10 ton/ha biochar during the major cropping season although it goes to justify the contribution of biochar in harvest index.

In 2016, effect of fertilizer and fertilizer-biochar interaction were not significant on crop growth rate for shoot. However, biochar had a significant effect on crop growth rates. Consequently, biochar at 10ton/ha gave the highest mean crop growth rate of 20.18shoot growth/week followed by biochar at 5ton/ha biochar producing 18.26 shoot growth/week (Table 4.22). This observation is consistent with the findings of Güereña *et al.,* (2015); Filiberto and Gaunt (2013); and Burke *et al.*, (2012).

In 2017, fertilizer, biochar and their interaction were not significant on CGR-shoot, CGR-root and Total CGR. This is due to the adequacy of precipitation received by plots during the major season which ensured uniform growth performance across treatment plots as observed by Muñoz-rojas *et al.*, (2016).

Further on Table 4.23, the crop growth rate, was significantly affected by biochar because of the improved soil physical and chemical conditions following biochar application. In 2017, the biochar and fertilizer had significant interaction effects on partitioning coefficient and net assimilation rate to indicate that under different fertilizer and biochar environment, differences in the partitioning and assimilation of photosyntates should be expected (Gale *et al.,* 2017).

In 2017, there were significant interaction effects of biochar and fertilizer on fat, fibre, moisture and carbohydrates (Tables 4.24 and 4.25) as a result of the physical and chemical influence of both fertilizer and biochar in soil environment (Seehausen *et al.*, 2017).

There were significant interaction effect of treatments on carotenoid composition 2016 and 2017. Liquid fertilizer and 5 ton/ha biochar produced the highest B-carotene content. This may be due to the enhanced nutrient uptake from the liquid fertilizer and the soil physicochemical contribution of 5 ton/ha biochar (Abuzar *et al*., 2013). Similarly, total carotenoid yielded 0.37 mg/ml total carotenoids in the minor cropping season, 2016 against 0.526 mg/ml during the major season. Tables 4.26 and 4.27 show the details of the individual treatments for the minor and major seasons.

Further, fertilizers and biochar levels have different effects on the nutritional content and quality of carrots.

During the major season, B-carotene for 10 ton/ha biochar was considerably higher than 0 ton/ha and 5 ton/ha biochar. Among fertilizers, NPK and P&K 50:100 had relatively high B-carotene and total carotene content. This observation is due largely to the fact that 10 ton/ha biochar, NKP and P&K 50:100 offer adequate nutrients for the formation of chloroplasts to house chlorophyll and carotenoids in source tissues for subsequent translocation into sink structures of the roots (Dunsin *et al*., 2016). Providing the details of the mechanism involved, Grimm (2018) explains that just like chlorophylls, carotenoids of leaves are ubiquitous structural components of the photosynthetic apparatus of leaves arguing that in higher plants, chlorophylls and carotenoids are bound to specific proteins to form either reaction centre pigment–protein complexes or light-harvesting pigment– protein complexes (LHCs) of photosystem (PS) I and PSII (LHCII). The seasonal differences in the mean carotenoid composition is explained by Shah *et al.* (2017) who argues that abiotic stresses arising from drought, extreme temperatures, salinity, or nutrient deficiency adversely affect the photosynthesic process in higher plants, as well as their growth and development, yield and quality and therefore the overall performance and productivity of an ecosystem. It is further established that the photosynthetic machinery consists of various mechanisms, including gaseous exchange systems, photosynthetic pigments, photosystems, electron transport systems, carbon reduction pathways, and enzyme systems whose impairment to one or more of these processes would reduce the photosynthetic activity of the crop, their growth, their biomass production and nutrient composition (Ban and Šircelj, 2011).

With large population of Africans and particularly children suffering from poverty, malnutrition and under-nutrition, carrot production can be tailored to meet the growing demand for nutritious food, increased income, disease prevention and control and environmental management by providing the needed growing environment for the specific need. This way, the achievement of poverty, hunger and environment-related SDGs (SDG 1, 2, 3, 12, 13, 14 and 15) can be accelerated.

5.6 Correlational Analysis and Implication on Sustainable Agriculture and Development

On high correlation was observed between porosity and gravimetric moisture content. This leads to a direct positive relationship between soil porosity and gravimetric moisture content and inverse relationship between soil porosity and either bulk density and %solids. This is in line with findings of Bhattarai *et al*. (2015).

The soil physicochemical properties do not only explain growth and yield parameters, but also the nutritional composition. This is seen from the matrix showing pH, total N, %organic carbon and %organic matter being strongly (highly and perfectly) correlated with both fat and moisture content of carrot. Carrot ash content is also moderately correlated with soil K and mg/kg SO_4 and highly correlated with Na content. Finally, it is noticeable that protein composition of carrots is moderately correlated with porosity, calcium and mg/kg SO_4 and also highly correlated with gravimetric moisture content (Ma *et al.*, 2016).

Evidently, much of plant growth, yield and nutrient quality is explained by the health of the soil in both physical and chemical terms. With increasing rate of poverty, hunger and malnutritio being experienced across developing countries and economies partly from climate change and unsustainable production and consumption cultures, the need to ameliorate losses in soil productivity cannot be overemphasized. Consequently, soil amendment and protection with biochar, organic manure, green manure and mulch, plus soil enrichment with inorganic fertilizer are key to the recovery of soils from erosion, fertility losses and land degradation. Together, these management practices, also known as integrated nutrient management, has a huge potential not only for improving crop productivity and farmers income but also reducing deforestation and forest degradation stemming from soil fertility losses. Consequently, sustainable agriculture based on integrated nutrient management has a unique potential to accelerate the achievement of SDGs 1, 2, 3, 7, 12, 13, 14 and 15.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Carrot production is constrained by weak institutional support and knowledge gaps among farmers towards integrated management of the soil and crop. Majority of farmers indicated they never received any extension, laboratory, technical, financial and marketing support services in their history of production.

Additionally, soil and carrot management is constrained by knowledge gaps on how different fertilizer rates and types affect soil physical and chemical properties and how these translate into yield and quality of carrot. Farmers were also not aware of climate change mitigation and adaptation strategies to enable them reduce the cost they incur on fuel used in pumping machines for irrigation.

Overall, farmer cooperatives in carrot within Mampong Municipality produce around 7,000 metric tons of carrot per annum. This is composed of about 4000 tons of Grade 1 or standard carrot, 1500 tons of Grade 2 carrots and 1600 tons of Grade 3 or broken carrots.

The choice of experimental topic was informed by the outcome of the sociological study. Hence, the 'influence of different rates of fertilizer and biochar on soil, carrot yield and nutritional quality in response to capacity needs of farmers in the transitional zone of Ghana.

Results from the experimental study show that both inorganic fertilizer and biochar affect soil chemical properties. Chemical properties affected include pH, %Organic Carbon, Total Nitrogen, %Organic matter, Calcium, Magnesium, Potassium and Sodium, Total Exchangeable Bases, Exchangeable Acidity, Effective CEC, Base Saturation, ppmP and Mg/kg SO_4^{-2}. Consequently, it is demonstrated that soil amendment with different levels biochar and fertilizer affect soil chemical properties and render rhizosphre environment either more or less conducive for crop growth and that different fertilizer and biochar environments affect carrot growth parameters such as plant height, canopy width, dry shoot weight and total biomass differently. Growth allometrics such as relative growth rates, harvest index, crop growth rates, partitioning coefficient and net assimilation rates also appeared to be influenced by soil amendment with biochar and fertilizers.

It is further demonstrated that amendment-driven chemical changes affect marketable yield, non-marketable yield and total yield of carrots. Yield components such as root length, root diameter and total dry matter accumulated were also influenced by biochar and fertilizer amendments. Nutritional parameters such as fat, fibre, Ash, Moisture, Protein and Carbohydrates were also significantly affected by different levels biochar and inorganic fertilizers.

Positive and negative correlations among soil, growth, yield and nutritional parameters show that management and anthropogenic changes in soil can be helpful or detrimental to crop performance.

6.2. Recommendations

1. Given the widespread perception among farmers of the limited institutional involvement in the carrot sector, it is recommended that both private and public sector institutions in agriculture take interest in carrot value chain by bridging knowledge gaps between research and practice, providing extension services, financial support, production and processing equipment and strong market infrastructure for both local and international market.

2. In view of the environmental stress posed by climate change and the increasing land degradation and soil fertility losses, it is recommended that farmers and most specifically carrot growers to adopt sustainable agriculture principles by using 5 ton/ha biochar during the minor cropping season and 10 ton/ha biochar during the major cropping season with P&K 50:50 for improved agronomic performance.

3. All efforts should be made at increasing the soil carbon stock by biochar application as it improves soil carbon composition and promotes improved soil physical and chemical properties towards ensuring soil productivity and sustainable agriculture. In doing this, care should be exercised to know the season of application, the expected output and not to over apply biochar as temporal inhibition and interference in nutrient cycling can make nutrients unavailable to crops growing immediately on the biochar-amended soil.

4. For carrot production to be sustainable, the specific tuber quality specification and the season should inform the soil and crop management practices as local and international specifications and weather patterns greatly influence the success of soil nutrient management outcomes. Particularly, it is recommended that farmers apply 10 ton/ha biochar with P&K 50:50 at 50 kg/ha for improved water holding capacity, organic carbon composition and pH. It is also strongly recommended that during the minor and major cropping season farmers respectively apply NPK 200 kg/h + 5 ton/ha biochar and P&K 50:100 at 50 kg/ha without biochar for best marketable yield. In terms of root diameter, 5 ton/ha biochar without fertilizer is recommended for soils with average soil nutrients during the minor season. During the major season, it is recommended to apply P&K 50:100 at 50 kg/ha +10 ton/ha biochar for best root length. For best root diameter performance, it is highly recommended for farmers to apply P&K 50:50 at 50 kg/ha without biochar during the minor cropping season and P&K 50:50 at 50 kg/ha +10 ton/ha during the major season. For nutrition-informed carrot production NPK 200 kg/ha+10 ton/ha biochar is recommended for high protein carrot during the minor cropping season while major cropping season carrots should be produced with liquid fertilizer+10 ton/ha biochar. For high carotenoid carrots, it is recommended to apply liquid fertilizer+ 5 ton/ha biochar during the minor cropping season and NPK 200 kg/ha +5 ton/ha biochar applied during the major season.

5. 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.

6. Long-term studies is needed to explain how biochar-limited environment can sometimes do better than biochar-rich environment under certain conditions on some parameters.

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APPENDIX A

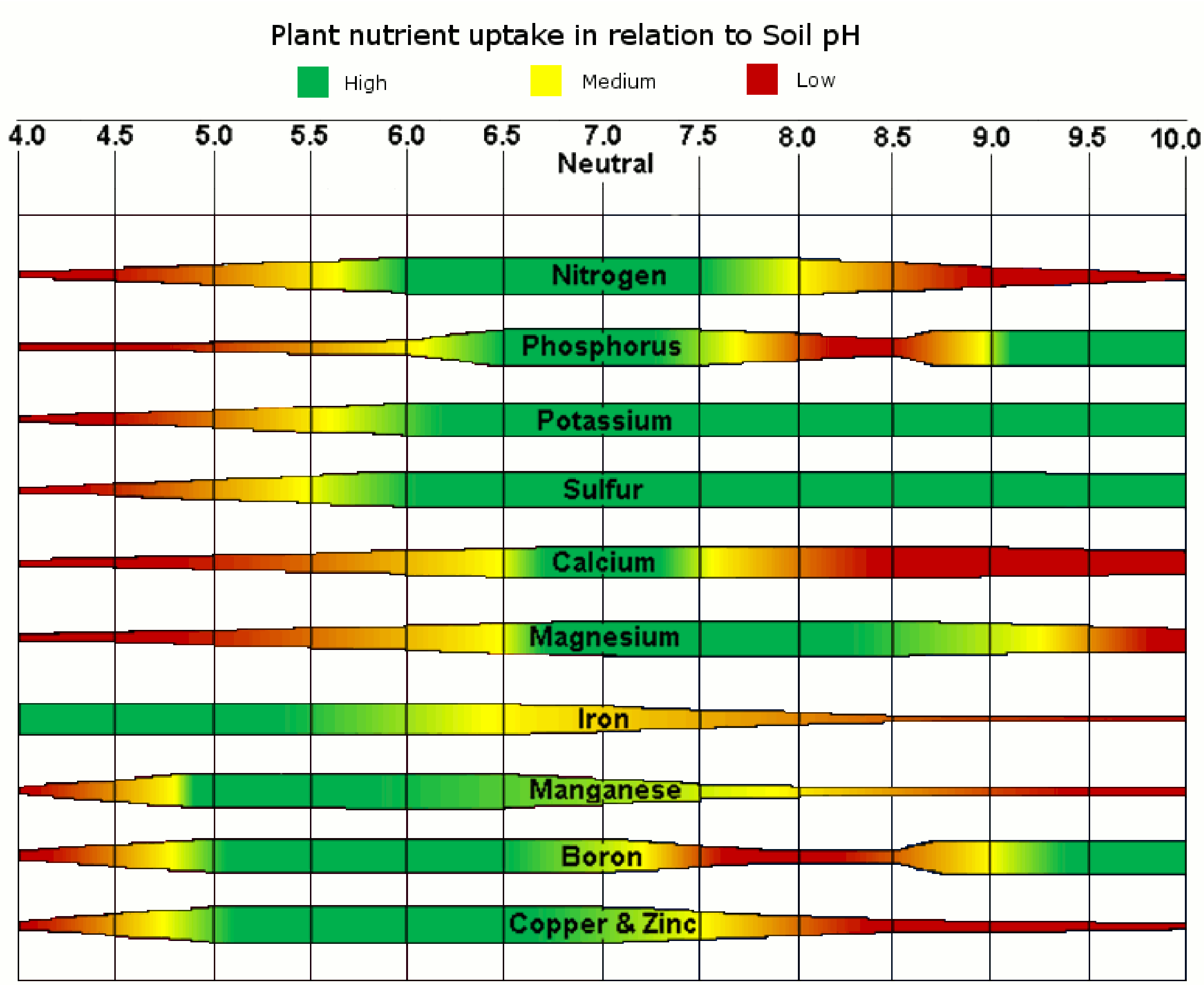
Guide to interpretation of soil analytical data in Ghana by soil research institute (2009)

Nutrient	Rank / Grade
Phosphorus, P (ppm), (Blay – 1) <10 10 -20 >20	 Low Moderate High
Potassium, K (ppm) <50 50 – 100 >100	 Low Moderate High
Calcium, Ca (ppm) / Mg = 0.25 Ca <10 5.0 – 10.0 >10	 Low Moderate High
ECEC (cmol (+) / Kg) <10 10 – 20 >20	 Low Moderate High

Soil pH (Distilled Water Method) <5.0 5.1 – 5.5 5.6 – 6.0 6.0 – 6.5 6.5 – 7.0 7.0 – 7.5 7.6 – 8.5 >8.5	 Very Acidic Acidic Moderately Acidic Slightly Acidic Neutral Slightly Alkaline Alkaline Very Alkaline
Organic Mater (%) <1.5 1.6 – 3.0 >3.0	 Low Moderate High
Nitrogen (%) <0.1 0.1 – 0.2 >0.2	 Low Moderate High
Exchangeable Potassium (cmol (+) / Kg) <0.2 0.2 – 0.4 >0.4	 Low Moderate High

Council for Scientific and Industrial Research-Soil Research Institute (CSIR-CRI), Ghana 2009.

APPENDIX B


Plant nutrient uptake in relation to Soil pH
High
Medium
Low
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Neutral
7.5
8.0
8.5
9.0
9.5
10.0
Nitrogen
Phosphorus
Potassium
Sulfur
Calcium
Magnesium
Iron
Manganese
Boron
Copper & Zinc

APPENDIX C

T-Test Analysis

Sample	Size	Mean	Variance	deviation	of mean	
Marketable_Yield_in_Ton_Ha_s1		45	3314	3490844	1868	278.5
Marketable_Yield_in_Ton_Ha_s2		45	7007	11610580	3407	507.9

Difference of means: -3693.6
Standard error of difference: 579.3

95% confidence interval for difference in means: (-4849, -2538)

Test of null hypothesis that mean of Marketable_Yield_in_Ton_Ha_s1 is equal to mean of Marketable_Yield_in_Ton_Ha_s2

Test statistic t = -6.38 on approximately 68.26 d.f.

Probability < 0.001

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Total_Yield_in_Ton_ha_s1	45	6471	8376463	2894	431.4
Total_Yield_in_Ton_ha_s2	45	9853	15118381	3888	579.6

Difference of means: -3381.4
Standard error of difference: 722.6

95% confidence interval for difference in means: (-4817, -1945)

Test of null hypothesis that mean of Total_Yield_in_Ton_ha_s1 is equal to mean of Total_Yield_in_Ton_ha_s2

Test statistic t = -4.68 on 88 d.f.

Probability < 0.001

Summary

Sample	Size	Standard Mean	Standard error Variance	deviation	of mean
Root_Length_s1	45	17.31	4.881	2.209	0.3293
Root_Length_s2	45	18.31	7.711	2.777	0.4139

Difference of means: -0.997
Standard error of difference: 0.529

95% confidence interval for difference in means: (-2.048, 0.05435)

Test of null hypothesis that mean of Root_Length_s1 is equal to mean of Root_Length_s2

Test statistic t = -1.88 on 88 d.f.

Probability = 0.063

Two-sample t-test

Variates: Root_Diameter_s1, Root_Diameter_s2.

Test for equality of sample variances

Test statistic F = 1.19 on 44 and 44 d.f.

Probability (under null hypothesis of equal variances) = 0.56

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Root_Diameter_s1	45	3.300	0.1850	0.4302	0.06412
Root_Diameter_s2	45	3.081	0.2207	0.4698	0.07003

Difference of means: 0.2191
Standard error of difference: 0.0950

95% confidence interval for difference in means: (0.03041, 0.4078)

Test of null hypothesis that mean of Root_Diameter_s1 is equal to mean of Root_Diameter_s2

Test statistic t = 2.31 on 88 d.f.

Probability = 0.023

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean	
TOTAL_GAIN_IN_PHOTOSYNTATES_s1	45		16.59	20.57	4.535	0.676
TOTAL_GAIN_IN_PHOTOSYNTATES_s2	45		35.09	154.96	12.448	1.856

Difference of means: -18.499
Standard error of difference: 1.975

95% confidence interval for difference in means: (-22.46, -14.54)

Test of null hypothesis that mean of total_gain_in_photosyntates_s1 is equal to mean of total_gain_in_photosyntates_s2

Test statistic t = -9.37 on approximately 55.48 d.f.

Probability < 0.001

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Harvest_Index_s1	45	0.4532	0.005978	0.07732	0.011525
Harvest_Index_s2	45	0.6032	0.001648	0.04060	0.006052

Difference of means: -0.1499
Standard error of difference: 0.0130

95% confidence interval for difference in means: (-0.1759, -0.1239)

Test of null hypothesis that mean of Harvest_Index_s1 is equal to mean of Harvest_Index_s2

Test statistic t = -11.52 on approximately 66.55 d.f.

Probability < 0.001

Two-sample t-test

Variates: Partitioning_Coefficient_s1, Net_Assimilation_Rate_s2.

Test for equality of sample variances

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Partitioning_Coefficient_s1	45	0.4539	0.006035	0.07769	0.011581
Partitioning_Coefficient_s2	45	0.6037	0.001644	0.04055	0.006045

Difference of means: -0.1498
Standard error of difference: 0.0131

95% confidence interval for difference in means: (-0.1759, -0.1237)

Test of null hypothesis that mean of Partitioning_Coefficient_s1 is equal to mean of Partitioning_Coefficient_s2

Test statistic t = -11.47 on approximately 66.32 d.f.

Probability < 0.001

Two-sample t-test

Variates: Net_Assimilation_Rate_s1, Net_Assimilation_Rate_s2.

Test for equality of sample variances

Test statistic F = 9.42 on 44 and 44 d.f.

Probability (under null hypothesis of equal variances) < 0.001

Note: strong evidence of unequal sample variances - variances estimated separately for each group.

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Net_Assimilation_Rate_s1	45	17.43	47.1	6.87	1.024
Net_Assimilation_Rate_s2	45	45.01	443.9	21.07	3.141

Difference of means: -27.588
Standard error of difference: 3.303

95% confidence interval for difference in means: (-34.21, -20.96)

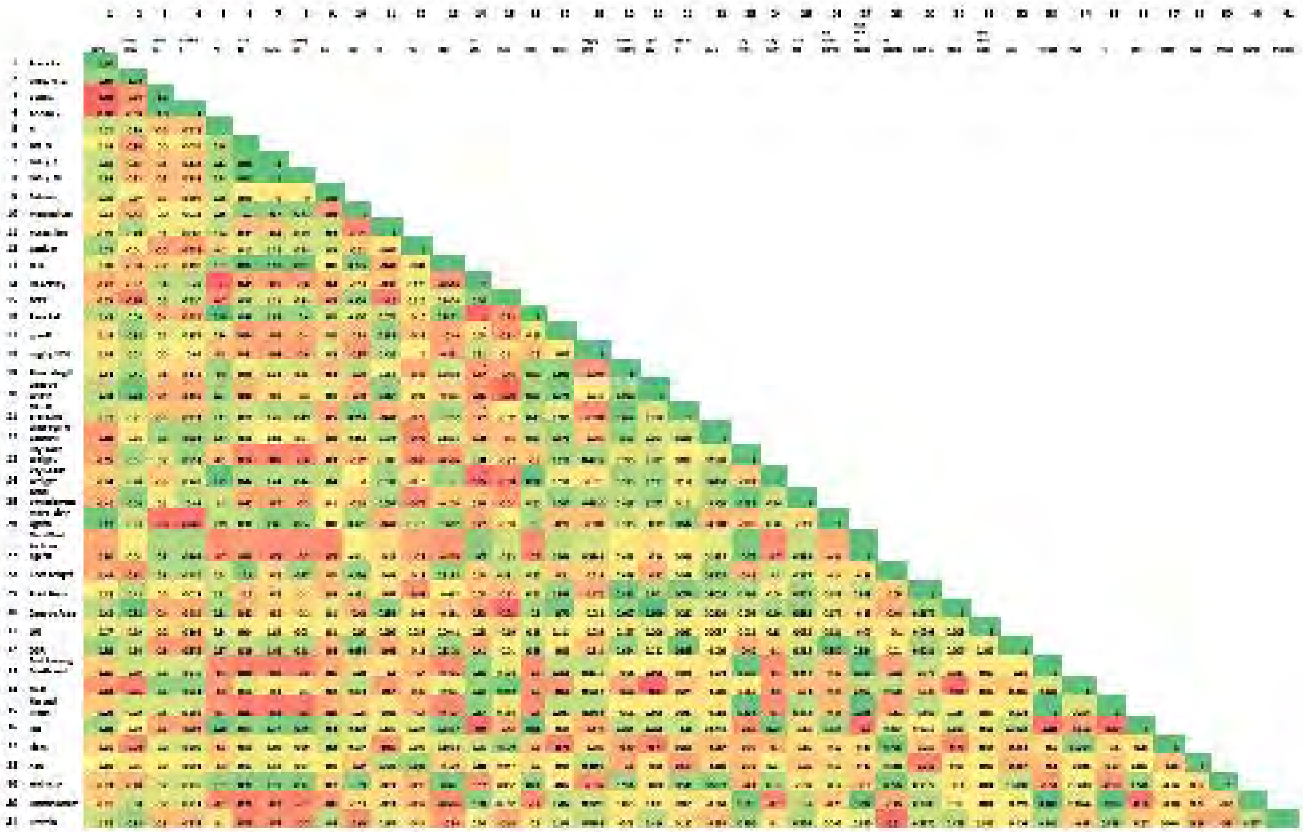
Test of null hypothesis that mean of Net_Assimilation_Rate_s1 is equal to mean of Net_Assimilation_Rate_s2

Test statistic t = -8.35 on approximately 53.24 d.f.

Probability < 0.001

APPENDIX D: SUSTAINABLE DEVELOPMENT GOALS

APPENDIX E: CORRELATION MATRIX



APENDIX F : REACTIVITY SERIES

APPENDIX G : SURVEY QUESTIONNAIRE

Good morning/afternoon. My name is ………………………………, of University of Education, Collage of Agriculture Education, Mampong. We are carrying out a survey on carrot production and constraints and we would be grateful if you could spare us some time to answer these questions. You are asked to participate in this confidential survey because we believe you have some experience in carrot production. Your participation is entirely voluntary. The information you provide would not be used against you in anyway but would rather help initiate some research towards getting some of constraints identified to be addressed.

Please be informed that there are no wrong or correct answers. What matters is your experiencer or opinion about the constraints to carrot production

Please indicate whether you give your voluntary, informed consent for participation in the study.

- ☐ I agree to participate in the study (Interviewer:-**Proceed to question 1**).
- ☐ I disagree to participate in the study: (Interviewer:-**Record this very response but do not initiate** the interview)

1. Do you produce carrots or in any way involved in carrot production? V2 Yes. 1 (**Continue**)

   No. 2 (**Discontinue**)

2. How old are you, please? ………………. V3 **Record actual age of respondent and code appropriately**

V4	Circle as appropriate	
Less than 15 years	1	Terminate
16-18 years	2	Recruit per quota
19-24 years	3	Recruit per quota
25-30 years	4	Recruit per quota
31-45 years	5	Recruit per quota
46-60 years	6	Recruit per quota
Over 60 years	7	Recruit per quota

3. Are you a member of an association of carrot producers? V5

   Yes. 1 (Proceed to question 4)

   No. 2 (Skip to question 8)

4. What is your status in the association? V6
   a. Executive
   b. Member
5. What is the name of the association? V7 ……………………………………………………………………………………..
6. How many members constitute the association? V8 ………………………..
7. Using as scale of 1-4 where 1 is not at all helpful, 2 is not helpful, 3 is helpful and 4 is very helpful, how would you rate the relevance of the association? V9 ………… **(write code)**
8. How long have you been into carrot production? V10 ……………… years…………months

9. To what extent do you benefit from the following services using as scale of 1 to 4 where 1 is not at all beneficial, 2 is not beneficial, 3 is beneficial and 4 is highly beneficial?

		NAB	NB	B	HB	DK
V11	Extension Service	1	2	3	4	8
V12	Laboratory Service	1	2	3	4	8
V13	Technical Advise	1	2	3	4	8
V14	Financial Advise	1	2	3	4	8
V15	Marketing Service	1	2	3	4	8

Section A: Constraints Perception

V16. Using a weight in the range from 0 to 10 where 0 is the least and 10 is the most, how would you rate the effect of the statements on carrot production?

It is difficult for me to know the exact quantity of fertilizer to apply on my carrot farm	
I am not able to calibrate my spraying machine to deliver known doses of herbicides, insecticides, fungicides and other biocides	
I do not know the exact planting distance that would give me the greatest yield	
I do not know the effect of full or partial or no shading on carrot production	
I do not know the exact volume of water to irrigate my crops during and outside of cropping season	

Given your experience in carrot production, to what extent to you agree or disagree that the following factors imped or constrain your production using a scale of 1-4, where 1 is strongly disagree and 4 is strongly agree.

Read out statements in grid below one at a time. Circle appropriate code for each statement. Circle one code only per statement. Rotate order of asking first statement, ticking where you started.

Physical Factors:

Tick	Code		SD	D	A	SA	DK
	V17	Soil Crusting	1	2	3	4	8
	V18	Limited Cropping area	1	2	3	4	8
	V19	Poor root penetration	1	2	3	4	8
	V20	Crop failure in soil type	1	2	3	4	8
	V21	Ailment among farmers and farm hands	1	2	3	4	8
	V22	Distance to farm	1	2	3	4	8
	V23	Proximity to water	1	2	3	4	8
	V24	Disability	1	2	3	4	8

Biological Constraints

Tick	Code		SD	D	A	SA	DK
	V25	Weeds	1	2	3	4	8
	V26	Disease	1	2	3	4	8
	V27	Pests	1	2	3	4	8
	V28	Predators	1	2	3	4	8

Cultural Constraints

Tick	Code		SD	D	A	SA	DK
	V29	Non-traditional nature of carrot	1	2	3	4	8
	V30	Need for irrigation	1	2	3	4	8
	V31	Need for fertilization	1	2	3	4	8
	V32	Need for commercialization	1	2	3	4	8
	V33	Need for high capital	1	2	3	4	8
	V34	Use of farm hands	1	2	3	4	8
	V35	Inadequate indigenous knowledge on production	1	2	3	4	8

Genetic Factors

Tick	Code		SD	D	A	SA	DK
	V36	Limited Genetic Variability	1	2	3	4	8
	V37	Limited varietal selection	1	2	3	4	8
	V38	Limited in-country breeding	1	2	3	4	8
	V39	Limited application of biotechnology	1	2	3	4	8
	V40	Susceptibility to pest and diseases	1	2	3	4	8
	V41	Poor storage ability	1	2	3	4	8
	V42	Poor nutrient use efficiency	1	2	3	4	8
	V43	Drought susceptibility	1	2	3	4	8
	V44	Poor water use efficiency	1	2	3	4	8

Socioeconomic Factors

Tick	Code		SD	D	A	SA	DK
	V45	Non-existent policy	1	2	3	4	8
	V46	Inadequate governmental support	1	2	3	4	8
	V47	High cost of production	1	2	3	4	8
	V48	Unavailable Research Information	1	2	3	4	8
	V49	Inadequate technical and laboratory support	1	2	3	4	8
	V50	Non-existent international support	1	2	3	4	8
	V51	Farm theft	1	2	3	4	8
	V52	Poor land tenure system	1	2	3	4	8

Environmental Factors

Tick	Code		SD	D	A	SA	DK
	V53	Low pH	1	2	3	4	8
	V54	High pH	1	2	3	4	8
	V55	Drought	1	2	3	4	8
	V56	Wind	1	2	3	4	8
	V57	Poor soil fertility	1	2	3	4	8
	V58	Temperature	1	2	3	4	8
	V59	Sunlight	1	2	3	4	8
	V60	Floods	1	2	3	4	8

Using a scale of 1-4, where 1 is not at all supportive, 2 is not supportive, 3 and supportive and 4 is very supportive, how would you rate the support provided by the following institutions in your work as a carrot producer?

Code	Institution	NAS	NS	S	VS
V61	MOFA				
V62	CRI				
V63	FAO				
V64	NGOs				
V65	Private Sector				
V66	Traditional Authority				

Section B: Production Constraints

Production Output

B1. In your experience as carrot producer, please indicate the number of times and when you encountered the problems listed below in the past year. Also indicate how they were prevented or managed.

Problem		Explanation and cause of problem	No. of times observed	Date it last happened			Knowledge of prevention and management of identified constraint (Score 5 or 0 per attached scheme)
				Day	Month	Year	
V67	1. Seedlings fail to emerge	Due to Soil crusting and high temperatures.				2015	
V68	2. Seeds rot or seedlings collapse with dark water-soaked stems as soon as they appear.	Damping off is a fungus that lives in the soil, particularly where humidity is high.				2015	
V69	3. Carrots emerge in clumps or not at all.	Warm weather or dry conditions cause seed to dry and not germinate.				2015	
V70	4. Leaves curl under, become deformed, and yellowish.	Aphids are tiny, oval, and yellowish to greenish pear-shaped insects that colonize on the undersides of leaves. They leave behind sticky excrement called honeydew which can turn into a black sooty mold.				2015	
V71	5. Small holes appear in leaves of seedlings.	Flea beetles are tiny bronze or black beetles that eat and cause small holes in the leaves of seedlings and small				2015	

Problem		Explanation and cause of problem	No. of times observed	Date it last happened			Knowledge of prevention and management of identified constraint (Score 5 or 0 per attached scheme)
				Day	Month	Year	
		transplants. The larvae feed on roots of germinating plants.					
V72	6. Leaves are chewed. .	Snails and slugs feed on leaves				2015	
V73	7. Leaves turn yellow and then brown from the bottom up; plant loses vigor.	Root knot nematode is a microscopic eelworm that attacks feeder roots.				2015	
V74	8. Leaves appear scorched, yellowed, curled, and wilted.	Leafhoppers are green, brown, or yellow bugs up to ⅓-inch long with wedge-shaped wings. They jump sideways and suck the juices from plants.				2015	
V75	9. Inner leaves yellowed; outer leaves reddish-purple; roots stunted and bitter.	Aster yellows is a mycoplasma disease spread by leafhoppers.				2015	
V76	10. Mottled light and dark green pattern on leaves; leaves are distorted and may become brittle and easily broken; plants are stunted.	Mosaic virus is spread from plant to plant by aphids and leafhoppers.				2015	

Problem		Explanation and cause of problem	No. of times observed	Date it last happened			Knowledge of prevention and management of identified constraint (Score 5 or 0 per attached scheme)
				Day	Month	Year	
V77	11. Round white powdery spots and coating on leaves.	Powdery mildew is a fungal disease. Fungal spores germinate on dry leaf surfaces when the humidity is high; spores do not germinate on wet leaves. Common in late dry season but does not result in loss of plant.				2015	
V78	12. Grayish-white mold growth on soil surface and clinging to roots.	Southern blight or white mold is a fungal disease that favors wet conditions.				2015	
V79	13. Brown spots appear on leaves or roots.	Leaf blight is a fungal disease–Cercospora leaf spot–spread by heavy rainfall and warm temperatures.				2015	
V80	14. Root tops are green.	When Roots tops are exposed to sunlight, green chlorophyll develops.				2015	
V81	15. Roots are thin and spindly.	This results from weed competition for water and nutrients.				2015	
V82	16. Longitudinal cracks in roots.	Soil water is inconsistent, wet then dry, wet then dry.				2015	

Problem		Explanation and cause of problem	No. of times observed	Date it last happened			Knowledge of prevention and management of identified constraint (Score 5 or 0 per attached scheme)
				Day	Month	Year	
V83	17. Roots rot or have enlarged white eyes.	Overwatering; water less often. Plant in well-drained soil.				2015	
V84	18. Roots are pale orange.	Air temperatures too cool, below 18°c.				2015	
V85	19. Roots are hairy.	Plants are over fertilized–too much nitrogen–or roots are in contact with fresh manure.				2015	
V86	20. Roots twist around each, forked or deformed.	Plants are too close. Growing roots will split or grow sideways if they encounter obstacles in the soil.				2015	
V87	21. Root forked or twisted.	Root-knot nematodes feed in the roots and stunt plant growth; they are most common in sandy soils.				2015	
V88	22. Roots have small black holes.	Wireworms are the soil-dwelling larvae of click beetles; they look like wirey-jointed worms.				2015	
V89	23. Roots and stems are chewed.	Carrot weevils are dark brown to coppery, hard-shelled weevils to 1/5-inch long. The larvae are white legless grubs				2015	

Problem		Explanation and cause of problem	No. of times observed	Date it last happened			Knowledge of prevention and management of identified constraint (Score 5 or 0 per attached scheme)
				Day	Month	Year	
		with brown heads. The grubs mine into carrot tops and roots.					
V90	24. Roots are tunneled; rusty mush oozes from tunnels.	Carrot rust fly maggot is yellow to white, about ⅓-inch long. The carrot rust fly is black and green, about 1/5-inch long. Fly lays eggs in crown of carrot plants.				2015	
V91	25. Roots are discolored and decayed.	Root rot or cavity spot is a fungal disease that favors warm soil. Older roots are susceptible to root rot.				2015	
V92	26. Carrots are bitter flavored.	This is caused by exposure to hot, dry weather.				2015	
V93	27. Roots are difficult to lift.	Side-roots will sometimes make carrots difficult to lift.				2015	
Total Score out of 135 marks							a. V94……/135
							b. V95……..%

B2. How many acres do you cultivate carrots? V96 ………………..

B3. How many bags of carrots to you obtain per acre? V97......................

- How many of these are big tubers? V98 …………………
- How many are small tubers? V99 …………………..

B4. How much do you normally spend on your inputs per production period?

- Fertilizer v100 …………………..
- Herbicides v101………………..
- Labour v102……………………
- Seeds v103…………………....
- Other v104…………………….

B5. How much do you sell a bag of carrot?

- Rainy season small tubers v105……………..
- Dry season small tubers v106………………..
- Rainy season big tubers v107…………..
- Dry season big tubers v108………………..

Section C: Socio-demographic characteristics

C1. What is your marital status? V109

Never married	1		Divorced/Separated	5
Married with children	2		Widowed	6
Married without children	3		Single parenting	7
Cohabiting	4		Other	

C2. Household size

		Number
A	Could you please tell me how many adult men; that is 18years and above, live in your household? V110	
B	How many are adult women v111	
C	Could you tell me how many children under 18 years there are? V112	
D	Lastly, how many of the household members are carrot producers? v113	

C3. Income

Would you indicate to me under which of these categories you estimate that your total monthly income of your household falls? If respondent asks what total monthly income is, say the following…. The income we require are the gross cash monthly income before deductions and excluding the value of fringe benefits. Income include profit from trading, wages and salaries. V114

NEW GHC	
Up to 100	01
100-500	02
500-1500	03
1500-2000	04
2000-3000	05
3000-4000	06
4000-5000	07
5000+	08

C4. What is the highest level of formal education you completed? V115

No formal education	1
Some primary education	2
Completed primary education	3

Technical/Vocational	6
University/Polytechnic	7
Post Graduate	8

Some secondary education (JHS/MSLC)	4		Do not know	9
Completed secondary education (SHS)	5		Refused	10

Section D: Climate Change Mitigation and Adaptation

V116-120. Using a weight in the range from 0 to 10 where 0 is the least and 10 is the most, how would you rate your agreement with the following?

116	The climate has changed and it is affecting carrot production	
117	I wish to do something about it but I don't know how	
118	Humans cannot do anything about the climate	
119	Climate Change is natural	
120	The sun is the main cause of climate change	

Given your experience in carrot production, to what extent to you agree or disagree that the following interventions were used during the last growing season

Read out statements in grid below one at a time. Circle appropriate code for each statement. Circle one code only per statement. Rotate order of asking first statement, ticking where you started.

Tick	Code		SD	D	A	SA	DK
	V121	Slash and burn	1	2	3	4	5
	V122	Ploughing	1	2	3	4	5
	V123	Soil amendment with biochar	1	2	3	4	5
	V124	Use of inorganic fertilizers	1	2	3	4	5
	V125	Green Manure	1	2	3	4	5
	v126	Farm Yard Manure	1	2	3	4	5
	V127	Compost	1	2	3	4	5