UNIVERSITY OF CAPE COAST

EFFECT OF PINEAPPLE WASTE BIOCHAR AND COMPOST APPLICATION ON PINEAPPLE YIELD AND QUALITY IN A LOW NUTRIENT COASTAL SAVANNA ACRISOL

EMMANUEL HANYABUI

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BY

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Thesis submitted to the Department of Soil Science, School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Master of Philosophy degree in Land Use and Environmental Science

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's signature: ………………………… Date: ………………………….

Name: Emmanuel Hanyabui

Supervisor's Declaration

I hereby declare that the preparation and presentation of the dissertation were supervised in accordance with the guidelines on supervision of dissertation laid down by the University of Cape Coast.

Supervisor's Signature: ……………………. Date: ………………………….

Name: Prof. Kwame Agyei Frimpong

ABSTRACT

Pineapple production in Ghana is constrained by low soil fertility due to continued cultivation without soil nutrients replenishment. Inorganic fertilizer use in Ghana is limited due to high cost, unreliable supply, and hence poor accessibility to the smallholder farmers. Biochar and compost can be used as alternative or supplemental nutrient sources to inorganic fertilizers. The experiment was conducted to determine the effect of combined application of pineapple waste biochar and compost on pineapple growth, yield, and nutritional composition of three pineapple varieties in a low nutrient coastal savanna Acrisol. Seven treatments were evaluated, sole biochar, sole compost, compost + biochar, sole NPK fertilizer (NPK), compost + NPK fertilizer, Biochar + NPK fertilizer, and control. A split-plot design with three replications was used, with pineapple variety as the main plot and fertilizer application as the sub-plots. The MD2, sugar loaf, and smooth cayenne pineapple varieties were used as a test crop in the study. The study revealed that the soil at the experiment field had low nutrients contents, especially nitrogen, phosphorus, and potassium. Combined application of biochar and compost or inorganic NPK fertilizer increased pineapple plant height and number of leaves compared with unamended soil. Compost applied together with biochar and NPK fertilizer increased pineapple yield in terms of fruit weight, length, and diameter. However, the application of biochar and NPK fertilizer influenced N, P, and K content in pineapple leaf. Total soluble solids, total phenolic content, vitamin C, and pH of pineapple fruit was influenced by compost and biochar application. Therefore, it can be concluded that a combination of biochar and compost can be used as a soil amendment to increase pineapple yield and improve fruit quality.

KEY WORDS

Pineapple waste

Biochar

Compost

Soil fertility

Pineapple

Fruit quality

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DEDICATION

Dedicated to my parents, siblings, and the entire family.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ECEC	Effective cation exchange capacity
FAO	Food and Agriculture Organization
HCL	Hydrochloric acid
MAP	Months after planting
TAA	Total Titratable Acidity
TAC	Total Antioxidant Capacity
TSS	Total Soluble Solids
TF	Total Flavonoids
TPC	Total Phenolic Content
Vit C	Vitamin C

CHAPTER ONE

INTRODUCTION

Background of the study

Pineapple (*Ananas comosus*) is a fresh fruit that is cultivated widely in tropical and subtropical regions of Africa because of its importance, with about 90-150 tons ha^{-1} of biomass generated as waste material after the fruit is being harvested (Liu et al., 2013). In most countries, out of the total quantity of pineapple produced 70 % is consumed as fresh fruit (De La Cruz Medina and García, 2005). Tones of pineapple peel waste are generated in markets and pineapple processing plants. A study by Liu et al. (2013) showed that on average, fresh pineapple residue contains about 678.6 g kg^{-1} organic matter, 10.75 g kg^{-1} total N, 0.83 g kg^{-1} P_2O_5 and 11.4 g kg^{-1} K_2O 65.5 g kg^{-1}.

In some parts of the country, residues of pineapple are burnt in situ. This process often results in gaseous losses of plant nutrients, which could have been returned to improve soil fertility, while the smoke from the burning residues pollutes the environment (Heard et al., 2006). In other places, the pineapple waste is buried directly into the soil. Liu et al. (2013) stated that when pineapple waste is incorporated directly into the soil, it can take about 35 weeks for the pineapple residue to decompose. As a result, composting appears to be a better option for managing the residue of pineapple before incorporating it into the soil. Compost is formed from organic materials that have been decomposed and recycled to be used as fertilizers or soil amendments (Adamtey et al., 2009). Compost application as soil amendment improves soil organic matter, improvement of soil fertility, and increase crop yield (Trupiano et al., 2017). A study conducted by Cogger et al. (2008) indicates that incorporating compost into the top few centimetres of the soil are easily broken down by soil microbes and impacts positively on soil carbon, nitrogen, and bulk density

Biochar has received heightened global attention as a sustainable amendment to improve soil quality. Biochar is a stable, recalcitrant organic carbon (C) compound that is produced by the thermochemical decomposition of biomass (feedstock) in low or no oxygen conditions for use as a soil amendment (Jeffery et al., 2011). Biochar application improves soil physicochemical properties and decrease leaching of nutrient in agronomy, thereby increasing crop production (Ding et al., 2016; Biederman and Harpole, 2013).

Biochar is carbon-rich but N-poor whereas as compost is rich in nutrients. Thus, biochar applied together has the potential to improve soil fertility and soil physicochemical properties to enhance crop growth and increased yield. Biochar application can sequester carbon from the atmosphere directly into the soil. Contrary to compost, the biochar gradually mineralizes in the soil as it contains a high recalcitrant C content in humid tropical soil (Frimpong et al., 2016). Biochar and compost can influence soil cation exchange capacity (CEC). In high CEC compost and biochar amended soils, cations retained on biochar particles surface, humus from compost, and clay soil are readily available for plant uptake rather than being leached below the plant root zone (Ding et al., 2016).

Moderately fertile soils, such as sandy loam soils of neutral to mildly acid pH are mostly used for pineapple cultivation but with good attention to watering and fertilizer application. Pineapple can also grow satisfactorily in sandy and calcareous soils (Crane, 2006). Pineapple should be cultivated in well-drained soils in landscape regions that do not flood because pineapple plants are susceptible to water-logged soils (Ficciagroindia, 2007). In general, a pH range of 5.0 to 6.0 is considered the best for pineapple cultivation but in terms of pineapple flavour and fruit quality, light soils are deemed to be the best to that grown on other soils (Hossain, 2016). However, on humus-rich sandy and loamy soil pineapple can do quite well (Ficciagroindia, 2007).

Biochar application in combination with compost enhanced soil quality, enhanced nutrient use efficiency, soil structure stability, and improved water holding capacity (Mensah and Frimpong, 2018; Trupiano et al., 2017). Under field conditions, the integration of biochar and compost had a positive impact on soil nutrients and water-holding capacity (Trupiono et al., 2017; Liu et al., 2012) as compared with biochar and compost applied singly. According to Naeem et al. (2017) biochar applied also with inorganic NPK fertilizer enhances growth and yield of crops as compared to the individual application. They further explained that the integration of compost and biochar with fertilizer can improve crop physiological development and increase nutrients concentration (nitrogen, phosphorus, and potassium). Biochar and compost application decreased soil pH but increased soil organic carbon, total nitrogen, available phosphorus, and available potassium (Naeem et al., 2017).

Statement of the Problem

Pineapple production in Ghana is limited by low soil fertility as a result of continuous cultivation without soil nutrients replenishment. The use of inorganic NPK fertilizer in Ghana is limited due to high cost, unreliable supply, and hence poor accessibility to the smallholder farmers (Mensah and Frimpong, 2018). Continuous use of inorganic fertilizers may lead to soil acidification, affecting soil biota and biogeochemical processes, hence harming the environment. However, the mineralization of organic matter decreases crop production (Palm et al., 2001). Application of compost enhances soil physicochemical properties but under high temperature and moisture conditions prevailing in Ghana, it loses it's potential leading to rapid mineralization and loss of nutrients due to leaching and gaseous losses (Bernal et al., 1998). However, biochar mineralizes in a biphasic pattern as the labile compounds mineralize rapidly after which the recalcitrant carbon degrades slowly (Cross and Sohi, 2011).

Justification

Production of biochar and compost using pineapple waste helps to minimize environmental pollution, curtail greenhouse gases released into the atmosphere as a result of open burning by most farmers. The application of compost mostly influences the structure of the soil positively by decreasing soil bulk density as a result of the admixture of low-density organic matter into the soil mineral fraction. Compost decomposes very fast under the high temperature and moisture conditions leading to rapid nutrient loss. Biochar does not readily mineralize in soils because of its highly resistant control carbon. Combined application of pineapple waste biochar and compost can make nutrients available for plants and release them slowly through their interactive effect for efficient use by the plant. Also, biochar applied in combination with compost can minimize the emission of greenhouse gases due to the high carbon sequestration by biochar. The mineralization of N from compost can be reduced because of the recalcitrant biochar carbon. Hence, reducing the available N and substrates of varying carbon that influence the production of CO_2, CH_4, and N_2O in soil. Biochar and compost produced from pineapple waste will reduce the production cost, increase crop yield, and ensure sustainable agricultural production. The use of biochar and compost as a soil amendment will improve soil fertility and increase crop yield, and also enhance the livelihoods of small-holder farmers who cannot afford exclusive inorganic fertilizers.

Hypothesis

The hypothesis underlying the research are as follow:

1. Combined pineapple waste biochar and compost application will not affect pineapple growth and fruit yield more than the addition of pineapple waste compost or biochar only.
2. Pineapple waste biochar and compost applied together cannot enhance pineapple fruit quality such as total soluble solids, vitamin C content, titratable acidity better than the sole application of biochar or compost.

Objectives

The study examines the impact of combined application of biochar and compost on soil fertility, pineapple growth and yield, and nutritional composition in a low nutrient soil in the Central Region of Ghana.

Specifically, the study is targeted to;

1. Examine the effect of pineapple waste biochar and / or compost on pineapple growth (height and number of leaves) and fruit yield.
2. Examine the effect of pineapple waste biochar and/or compost on pineapple fruit quality (pH, titratable acidity, total antioxidant content, total flavonoids, total phenolic content, and vitamin C content).

CHAPTER TWO

LITERATURE REVIEW

The review gives information about the production and characteristics of biochar and compost. It covers the impact of biochar and compost on soil fertility improvement and crop yield. The review also covers the application of compost and biochar and their effect on soil physicochemical properties. The effects of inorganic NPK fertilizer, biochar, and/or compost application on soil fertility and the yield of the crop were also reviewed. This chapter further provides information on the cultivation and ecology of pineapple.

Biochar

Biochar is a carbon-rich, stable solid produced when biomass (leaves, wood, manures, etc) is heated under low or no oxygen content. Technically, thermal combustion of feedstocks under oxygen (O_2) limited conditions at temperatures relatively high (< 700 ^{o} C) is how biochar is produced. (Nartey and Zhao, 2014). Chan and Xu (2009) explained that biochar is a carbonated organic by-product as a result of pyrolysis of biomass composed of recalcitrant organic carbon which is not easily mineralized by soil microbes. Yadav et al. (2017) reported that biochar is a substance similar to charcoal, rich in carbon and produced by the thermal breakdown of biomass (organic material or feedstock) under low oxygen conditions with relatively temperatures less than 700°C (< 700°C), the process is called pyrolysis. Yadav et al. (2017) stated that what distinguished biochar from charcoal is its use as a soil amendment. They also reported that within some years, the carbon present in the biomass could be lost in the atmosphere if biomass is allowed to decompose in air large amounts. Nonetheless, about 50 percent of the carbon in the biomass is transformed into biochar during the pyrolysis cycle but only two-thirds of the remaining 50 percent can be released as usable energy (Yadav et al., 2017). Biochar carbon stability is one of the most important environmental characteristics of biochar relative to other sources of organic carbon (Yadav et al., 2017). According to Masiello and Druffel (1998) biochar can persist up to 10,000 years in the soil environment. Yadav et al. (2017) explained that the carbon contained in the biochar can reside for 100 to 2000 years but it depends on soil type, climate, location, and various farm management practices adopted for crop production. Bajiya et al. (2017) concluded that 1 metric ton of dry biochar can sequester carbon (approximately 0.3 metric tons) which is equivalent to 1.2 metric tons of CO_2. Hence, biochar can sequester a considerable amount of carbon in the soil. They further explained that the amendment of biochar to soil acts as a possible carbon sink and thus aims to minimize the amount of carbon dioxide emitted back into the environment.

Biochar feedstocks

Sohi et al. (2009) explained that one important factor in the production of biochar is the type of feedstock, especially if biochar is being applied as a soil conditioner. Gaunt et al. (2008) argued that there is little agreement on what should be included as a material for biochar production. Sohi et al. (2009) reported that presently, feedstocks used in research facilities or commercial-scale includes crop residues (comprising rice husk, corn cob, straw and nut shells), wood chip and wood pellets, switchgrass, litter from the chicken, paper sludge, dairy manure, organic garbages, etc. The most important organic material parameters for large scale production and the value of fuel products include the oxygen ratio, hydrogen, and carbon (Friedl et al., 2005). When feedstocks are pyrolyzed at moderate temperatures (about 500 °C), those with elevated lignin content yield the largest biochar yields. (Fushimi et al., 2003; Demirbas, 2006). As time goes by, the choice of feedstock for the production of biochar may be proposed, according to Sohi et al. (2009) by the required balance between the products (biochar, oil, and gas) produced from Pyrolysis, whether a slow-pyrolysis or rapid-pyrolysis is required. It can also be used for composting and mulching, in addition to using plant residues for biochar preparation. The ongoing harvesting of crop residue from the same cultivated land removes the soil cover and reduces the provision of soil nutrients (Sohi et al., 2009).

Production of biochar

From time immemorial, people have known about the carbonization of wood for biochar production. By using waste resources, advanced biochar technology will contribute to humanity by providing future energy needs as well as increasing the capacity for soil carbon sequestration (Kataki et al., 2015). Different biomass with various physical and chemical properties are used to produced biochar. In the process of thermal conversion, total feedstock biomass properties are important, particularly moisture and ash content, the value of caloric, fractions of fixed carbon, and volatile components; percentage lignin, cellulose, and hemicellulose; inorganic substances percentage and composition, moisture content, particle size, and bulk density (Nartey and Zhao, 2014). They further explained that, in the production of biochar, extensive feedstock biomass, for example, crops containing bio-energy (switchgrass, willows, and miscanthus), residues of the forest (sawdust, grain crops, and nutshells), waste from organic sources (animal manure and green yard waste, sewage sludge, agricultural waste, and kitchen waste. According to Kataki et al. (2015), biochar production involves three widely used technologies, namely fast pyrolysis, slow pyrolysis, carbonization, and gasification.

Pyrolysis is a thermo-chemical breakdown of feedstock under a low or no oxygen environment. Fast, intermediate, and slow pyrolysis are the three main types of pyrolysis depending on the parameters of the process, for instance, temperature, residence time, heating rate, and sweeping gas flow (Kataki et al. (2015).

Slow pyrolysis can be defined as a continuous procedure in which biomass feedstock purged (free oxygen) is transferred to a heated kiln which is external (volatile biochar coming at the end is removed as a result of gas flow) (Nartey and Zhao, 2014). Gaunt and Lehmann (2008) stated that slow pyrolysis can produce more biochar than any other technology used and can maintain about 50 % of the feedstock carbon. The chemical industry uses it to manufacture methanol, charcoal, activated carbon, and other wood-based chemicals, to produce coal coke, to convert ethylene dichloride into vinyl chloride for the production of polyvinyl chloride (PVC), to convert biomass into syngas and biochar, to convert waste into safe disposable substances and to transform medium-weight oil-based hydrocarbons into lighter ones (Kataki et al. (2015).

On the other hand, fast pyrolysis depends on rapid heat transfer, typically too fine particles of biomass with a rapid heating rate of less than 650 ^{o}C (Nartey and Zhao, 2014). Hence, phase transition phenomena and processes of mass and heat transfer, as well as chemical reaction kinetics, play a vital role (Kataki et al., 2015). Therefore, to promote the production of activated charcoal, reducing biomass particulate exposure at intermediate temperatures is necessary (Augustínová et al., 2013).

Gasification is a thermo-chemical breakdown of biomass under a controlled amount of oxygen at high temperatures (> 700 °C) which helps in the production of fuel gasses called producer gas or syngas. The gas consists primarily of carbon monoxide (CO_2), hydrogen (H_2), and methane traces (CH_4) (Kataki et al. (2015). Consequently, because the producer gas can be burned at higher temperatures, its gasification output is more efficient than the original fuel's direct combustion. For gasification, biodegradable waste can also be used. Furthermore, due to high temperatures, corrosive elements such as chloride and potassium are eliminated, resulting in the production of clean gas instead of hazardous fuels (Higman and Burgt, 2008).

Carbonization is a mechanism by which organic materials are transformed into content-rich in carbon. This reflects various pyrolytic processes, close to conventional processes used in coal production. Temperatures range between 280 ^oC and 500 ^oC. The biomass breaks down spontaneously and creates charcoal along with the output of certain combustible and non-combustible gases (Kataki et al., 2015). Biochar can be rendered with either small, simple, or stationary mobile units. This is one of the benefits of its production. Approximately 50 to 1000 kilograms of biomass per hour can be used as inputs in a small unit whereas large industries can function up to 8000 kilograms per hour (Kataki et al., 2015).

Characteristics of biochar

The initial biomass feedstock and its biochar are subject to many studies to demonstrate the fundamental physicochemical characteristics of both raw and pyrolyzed content (Nartey and Zhao, 2014). According to Zhang et al. (2013), chemical features have been shown to differ greatly, spatially as well as temporarily, concerning individual feedstock species and consequently of BC from the feedstock. Biochar output is frequently evaluated through adjustments in the basic values of carbon (C), hydrogen (H), oxygen (O), silicon (S), and nitrogen (N) and the related ratios. The sample particle left after the residue of solid fuel is carbonized and volatility is eliminated is called the fixed carbon. For the estimation of the number of carbonaceous substances, the solid sample contains, the fixed carbon is used. In particular, as often defined in Van Krevelen diagrams, for the determination of aromaticity and maturation degrees the H/C and O/C ratios are used (Nartey and Zhao, 2014).

The basic oxygen carbon, oxygen-hydrogen, and carbon-hydrogen ratios have been established and are relatively straightforward to calculate the degree of pyrolysis as well as the amount of BC oxidative modification in soil and solution systems (Lehmann et al., 2006; Yu et al., 2011).

According to Cohen-Ofri et al. (2007), titration by Boehm be used to operationally determine biochar acid and basic functional groups where the biochar is balanced in the presence of consistently strong bases (HCO_3^-, CO_3^{2-}, OH^-, and ethoxides) or H_2SO_4, HCl, and HNO_3 which are strong acids for the estimation of the fraction of strong acid or base extract reacted. They further explained that in determining their relative amounts of functional groups of the carboxylic, lactonic, phenolic or carboxylic (base balance) functions or basic functions (acidic balance), Variations are used in the number of acids or bases required. Boehm is appropriate for biochar which is hydrophobic but when there is a large number of bio-oils or mineral surfaces, a substantial deficit is evident. (Nartey and Zhao, 2014).

Because of the existence of tube fractures originally from plant cells, different pyrolytic temperatures at which biochar produced have a distinctive structure similar to the honeycombs. Biochar has a large area of BET (Brunauer, Emmett, and Teller) due to these well-developed pores (Gao, Yue, and Gao, 2013; Cantrell et al., 2012). The pyrolytic temperature value indicates that biochar prepared at low temperature pyrolytic can be ideal for influencing fertilizer nutrients release but high temperatures can lead an AC-like content for environmental recovery (Gao, Yue, and Gao, 2013; Cantrell et al., 2012). Also, biochar produced at low temperatures is very stable than biochar produced at high temperatures, it becomes fragile once incorporated into the soil, and pores are abraded into fine fractions (Nartey and Zhao, 2014).

Effect of biochar on soil physical properties

Soil porosity

The porosity of soil is the pore ratio of the average volume of soil. It's a very important attribute of soil which affects plant growth. Base on the size of the pore spaces in the soil, soil porosity can be classified into three main types namely macro, meso, and micropores. These pore spaces in the soil serve as a habitat for microbes in the soil, it is also important for soil aeration, nutrients movement as well as water retention (Aslam, Khalid, and Aon, 2014). Herth et al. (2013) reported that the application of biochar increased the total porosity of soil thus the porosity increase depends on the biochar amount this increase in porosity depends on the amount of biochar added and the soil type. The three main types of soil pores and their contribution to increased pore spaces vary depending on the biochar and form of soil (Githinji, 2013). Biochar's high porous nature increased the porosity of soils (Mukherjee et al., 2013). Some scientists have found that the biochar application would negatively affect the porosity of the soil due to the clogging of soil pore by biochar dust (Aslam, Khalid, and Aon, 2014).

Soil bulk density

The measure of how soil particles are finely compressed is called soil bulk density, it is stated as g cm^{-3} per unit volume. For the properties of the soil and the growth of the plant, bulk density plays a major role e.g. high bulk density soils (> 1.6 Mg cm^{-3}) has low tendency to absorb water and resistance to penetration of plant root into the soil can eventually contribute to soil characteristics and plant growth. (Aslam, Khalid, and Aon, 2014). According to Mukherjee and Lal (2013), bulk density is decreased as a result of the application of biochar because the biochar porosity used is very high and the bulk density in the soil is significantly minimized by increasing the pore volume. Githinji (2013) further explained that bulk density significantly decreased the biochar application rate.

Soil water holding capacity

From crop production and farmers' point of view, it a very significant property of the soil (Aslam, Khalid, and Aon, 2014). Continuous irrigation of crops is decreased when the soil can hold a higher amount of water and also plant grown in that particular soil does well. It has been reported that the application of biochar improves the soil water quality of soil water to 97 % and 56 % of the saturated water content (Aslam, Khalid, and Aon, 2014). According to Laird et al. (2010) stated that soil amended with biochar retained about 15 percent more moisture than managed soil. Applying biochar to soil improved the capacity to hold soil water but depending on the texture. They concluded that sandy soil amended with biochar considerably increased the soil water holding capacity. Herath et al. (2013) experimentally described that biochar application enhances soil water retention due to the adsorption of biochar and improved soil porosity.

Soil aggregation

Colloidal particle adhesion together depends on the attractive net forces that exist between them, it's called soil aggregation. Soil with good aggregate stability has a good structure and thus provides a good medium for the movement of nutrients and water in the soil to take up plants (Aslam, Khalid, and Aon, 2014). They further explain that the adhesion of soil-colloidal particles is improved with different polysaccharides secreted by microorganisms. Biochar application provides shelter for microorganisms and also protect predators and desiccation from attacking microorganisms (Aslam, Khalid, and Aon, 2014).

Effect of biochar on soil chemical properties

In general, biochar has a high pH which can alter the soil pH which is favorable for most crops in various ways when applied to soil (Chan and Xu, 2009). The high pH of biochar which natural and the abundance of basic cations (Ca, Mg, and K) that are retained from the feedstock make biochar a major liming capability. The alteration of the pH of the soil can be attributed to biochar's primary ash content (Beesley and Moreno-Jimenez, 2011; Lehmann et al., 2011). According to Beesley and Moreno-Jimenez (2011), It has also been shown that biochar application increases a cation exchange capacity (CEC), enhancing the sorption ability of many organic and inorganic substances, including essential plant nutrients. In a field experiment in which Anthrosols are mixed with biochar, the mixed biochar soil is found to have a CEC 1.9

times higher than that of unamended soil and was subjected to the charging density and the large biochar surface area (Liang et al., 2006). Chen et al. (2011) also observed the addition of 4.5 Mg ha^{-1} of biochar increased CEC by 24.5 %. Steiner et al. (2008) reported that biochar acts as an absorbent which reduces nitrogen leaching and increases the efficiency of nitrogen usage.

Effect of biochar on soil biological properties

The applied biochar increased alkalinity effect can help to enhance the number of rhizomes when preparing acidic soils, especially if they function optimally at neutral pH (Rondon et al., 2007). According to Van Zwieten et al. (2010), The biochar-modified ferrosol form of soil becomes a very different preference for earthworms compared with power. They further clarified that the increased absorption of CH_4 was beneficial and available immediately upon application newly produced biochar to the soil. The application of biochar enhances soil aeration, thereby reducing the production of CH_4 and increasing oxidation of CH_4. Biochar has been hypothesized to enhance the reduction of N_2O to N_2 (Sohi et al., 2009). According to Van Zwieten et al. (2009), information to support the argument is limited, and this may be because they addressed particular cases where each soil type is influenced differently by the biochar type used and the amount of biochar applied under various climatic conditions.

Effect of biochar on soil fertility

Suliman et al. (2017), explained that biochar can boost the physical, chemical, and biological properties of depleted nutrient soils. They argued that a combination of soil porosity and surface functionality is a gateway for biochar to retain soil water. They further explained that due to the biochar internal porous structure, soil porosity can be increased. Previous studies revealed that applying biochar to soils that are not fertile decreases soil bulk density, increasing overall pore volume, and water holding capacity (Agegnehu et al., 2017). When newly produced biochar is exposed to an environment full of oxygen and there is water in the surroundings of the soil, in biochar, spontaneous surface oxidation reactions result in a net adverse charge increase and thus an enhancement in the cation exchange capacity (CEC). Aged biochar particles are due to high negative charges, which may promote soil aggregation and increase plant access to nutrients (Agegnehu et al., 2017; Lehmann et al., 2003a). Furthermore, biochar application greatly improves the exchange potential of cations and soil anions and enhances their nutrient keeping capabilities (Granatstein et al., 2009; Inyang et al., 2010). Agegnehu et al. (2017) reported that aging biochar produces oxygen-containing functional groups. The particular region of the surface affects water holding capacity of the soil, sorption capacity, and also serves as a habitat for microbes. Naturally, aged biochar's have a high negative charge as compared to biochars which are fresh or aged artificially. Fresh biochar with a pH range of 7.0 – 11.0 is known to have a surface negative charge which is very low but pH below 7.0 has a positive charge and the surface negative charge increases until pH of 3.5 which is following oxidation of biochar artificially (Silber et al., 2010).

Agegnehu et al. (2017) explained that biomass type and pyrolysis conditions influence both biochar structure and composition, resulting in substantial variations in biochar characteristics associated with nutrients content and retention changes. Agegnehu et al. (2017) reported that the mixing of biochar during composting results in higher N retention after composting as well as heavy metal stabilization, quicker volume reductions due to higher carbon mineralization levels, and improvements in the microbial community structure. Agegnehu et al. (2016) found that biochar application to soil has emerged as a method for sequestration of carbon, mitigation of greenhouse gas (GHG) emissions, and improvement of soil quality.

Effect of biochar on crop yields

Various researchers have reported the positive reactions biochar applications had on crop production, fruit yield, and dry matter (Major et al., 2009; Duku et al., 2011). In extremely degraded acids or nutrients soils, the effect of biochar application is often observed. Low additions of charcoal significantly affect several plant species, while increased levels appear to suppress the growth of the plant (Glaser et al., 2001; Ogawa et al., 2006). Tropical soils can be improved if biochar is applied as a soil amendment also to inorganic NPK fertilizer or other types of organic fertilizers (Ogawa et al., 2006; Woolf, 2008; Glaser et al., 2002). According to Hass et al. (2012), a statistical meta-analysis revealed that the biochar application to soil has resulted in a 13 percent increase in plant productivity in soils that have acidic or neutral pH where biochar modification has decreased soil pH value (limiting impact) and increased crop productivity. As soil holds more water, nitrogen (N) and phosphorous (P) is less freely leached from the soil, soils have thinner and more widely rooted crops with increasing biochar use (Bruun et al., 2014; Ventura et al., 2013). In the latest meta-analyses, Jeffrey et al. (2011), and Biederman and Harpole (2013) observed that the use of biochar improves crop yields by 10 and 30% on average, while Thomas and Gale (2015) report an average growth reaction of 41 % for woody crops.

Biochar Application Rate

Biochar application rate is dependent on several factors which include the type and nature of feedstock used, the extent of metal contamination in the feedstock, different proportions and types of nutrients (N, P, etc.) (Nartey and Zhao, 2014). Biochar application rate ranges from 5 to 50 t ha^{-1} (0.5-5 kg / m^2) with appropriate management practices has a positive impact on crop yields, according to Chan et al. (2007). This is a wide range, but the plots with greater biochar application frequency often demonstrate better outcomes when multiple rates are used (Chan et al., 2007; Major et al., 2010b). It is desirable to apply minimum or optimum rate of biochar which can improve soil fertility and increase crop production, as the excessive use of biochar is not economically efficient (Chan et al., 2007). In contrast to tons of bulk biochar material, it is very appropriate to report the rate of application of biochar in tons per hectare because the carbon (C) content of biochar material varies. Biochar materials cannot be used to replace fertilizer in most cases. Given this, it cannot be expected that applying biochar without adding the necessary quantities of nitrogen (N) and other nutrients will improve crop yield. Rondon et al. (2004) noted that the high-rate application of biochar (165 tons per hectare) to poor soil reduces crop yields. Winsly (2007) observed that even small biochar application rates could considerably boost the productivity of crops if the biochar applied contains enough nutrients that the soil lacks. For biochar's produced from piggery and poultry manure can be used as organic fertilizer, also as a soil conditioner with agronomic advantages at a low application rate (10 t ha^{-1}) (Chan et al., 2007). He also explained that applying a high quantity of biochar to soil can increase the benefit of carbon credit; however, in soils that have low nitrogen content, it may fail to support the productivity of crops as a high C/N ratio leads to low N availability. Because of biochar recalcitrance, biochar applications alone can have useful impacts over soil several seasons (Steiner et al., 2007; Major et al., 2010b). Taking into account the required rate of application, the soil management practices, and biochar availability, it is possible to apply incremental biochar amendments. However, useful impacts of applying biochar to soil are expected to enhance from time to time (Steiner et al., 2007).

Challenges associated with the use of biochar

Biochar has various problems with agricultural and grassland soils. These problems include a reduction in net N mineralization, a decrease in crop availability (Anderson et al., 2011). Volatile matter content of biochar which of a large proportion can lead to higher immobilization, therefore decrease the accessibility of N. Lower biochar temperatures would lead to net immobilization owing to the degradation of the remaining functional groups and bio-oils (DaLuca et al. 2006). Sohi et al. (2010) explained that amending soil has important organizational and institutional barriers. Because biochar can be applied in large quantities but once applied, it cannot be and cannot be taken out of the soil, the potential adverse effects on human health, water quality, environmental pollution, and food safety need to be closely assessed.

Compost

Compost is stable humus like product obtained from organic matter after a controlled aerobic biological decomposition. Compost provides a primary nutrient source for the crop in organic cropping systems (Richard et al., 2012). Compost use is a major contributing factor to increase production and sustainable farming. However, compost will address the soil fertility problem faced by farmers (Madeleine et al., 2005). According to Paulin and Peter (2008), compost consists of organic decomposed materials that are relatively stable and that have been accelerated biologically degraded under-regulated, aerobic conditions. Compost produced from plants and animal remains for plant recycling and animal remains for agriculture. The process of decomposition renders organic matter putrescible a stable form that can enhance the soil and improve the growth of the plant (Adugna et al., 2016). Furthermore, the benefits of composted organic products include the transition of waste from waste sites to alternative applications, the elimination of pathogenic inocula and fuel decomposition, residues of pesticides and herbicide, control of soil erosion, and as a fertilizer for the sustainability (Adugna et al., 2016). Compost applications produce healthy green crops and also boost the production of organic food on a large scale (Paulin and Peter, 2008).

Characteristics of compost

The material used to produce compost can be grouped into three categories basically; crop or plant residues such as leaves, clippings, waste from the processing unit; biosolids from municipal waste such include household and industrial wastewater sludge; compost prepared using manure which includes human feces and animal wastes (Alexander, 2001). These three sources contain high organic matter quantities as well as the observable amount of nutrients (macro and micro). The kind of material used to prepare the compost and the method used to produce the compost shows how valuable or stable is the compost (Alexander, 2001). Compost produced from plant materials has low nitrogen (N) compared with biosolids. The content of biosolids compost is generally higher in nitrogen and phosphorus compared with compost prepared using manures and yard trimmings (Alexander, 2001). Cogger (2005) reported that the nitrogen (N) content of compost derived from yard trimmings is typically less than 1 percent from dry mass, but usually more than 1 percent from farm manure, biosolids, and food waste compost. The concentration of phosphorus (P) in compost derived from biosolids is usually between 1 and 2 %, while the concentration of P in compost prepared from farmed manures or plant material is about 0.2 to 0.4 % (Cogger, 2005).

Removal of undesirable physical contaminants such as glass, leather, metals, plastic, and rocks are of great concern when composting municipal solid waste (Alexander, 2001; Cogger, 2005).

Production of compost

Yvette and Holmer (2000) explained that there is a long history of agricultural and municipal solid waste composting which is basically about recycling organic matter into manure and applied as a soil amendment to improve soil fertility. They further observed that currently, the high interest in composting has increased because composting technologies does not pose any negative effect on the environment. One of the environmentally friendly acceptable techniques of waste treatment is composting (Yvette and Holmer, 2000). According to Fauziah et al. (2009), composting is an aerobic method that uses natural microorganisms to convert organically biodegradable matter into humus. Pathogens are eliminated in the process costs and even N converts reactive ammonia into stable organic forms, decreasing the amount of waste and improving its composition. It facilitates waste handling and makes transportation very easy and most often allows application at high levels as a result of the slow and stable release character of N in compost (Fauziah et al., 2009). He also said that factors like the temperatures, supply of oxygen, and the moisture content influence the composting process effectively.

Aerobic composting

It is the mechanism by which organic waste materials break down in which oxygen, carbon dioxide, ammonia, water, and heat are part of the product generated during the composting cycle (Yvette and Holmer, 2000). They further explained that any type of organic wastes can be subjected to composting but considering the effectiveness, there is the need to consider the right ingredients and conditions. Some of these conditions include the range of moisture contents (between 60 - 70 %) and the C/N ratio (should be 30:1). Yvette and Holmer (2000) observed that any variation in the process can inhibit the decomposition. They concluded that food waste and sewage sludge provide nitrogen but wood and paper is an important carbon source.

Anaerobic composting

Under anaerobic composting Yvette and Holmer, (2000) reported that composting is the degradation of organic waste in the absence of oxygen, some of the products which are obtained through the process include carbon dioxide (CO_2), Ammonia (NH_3), Ammonium (NH_4) and a trace amount of organic acids and other gases. Anaerobic composting was used some years ago for composting animal manure and human waste but is only used for some urban solid waste and green waste (Yvette and Holmer, 2000).

Effect of compost on soil physical properties

Bulk density

The application of compost typically significantly affects soil structure by reducing the density of soil as a result of the admixture of low-density organic matter into the proportion of the mineral soil. Organic and inorganic fractions interaction improve soil porosity which has a positive effect on soil structure (Adugna, 2016). According to Brown and Cotton (2011), increased compost rate decreased the density of soil bulk after a predictable trend. Low-density soil means increased pore space and an indicator of improved tilting of the soil (Adugna, 2016). The content of organic matter is much lighter by weight than the proportion of soil minerals (Brown and Cotton, 2011).

Aggregate stability

Adugna (2016) stated that soil structure is determined by particles, aggregates, and pores in soil size and space distribution. The more compact the ground structure, the worse the soil conditions for plant growth. He further explained that compost application increases the overall stability of clay and sandy soils most effectively. Well humidified (fostering micro-aggregate) and fresh low-molecular OMs (fostering macro-aggregate) can be expected to have a positive effect (Amlinger et al., 2007). The type of compost, the amount of compost, the intervals in which compost is applied and the type of soil in which the compost is applied affect the composting effect (Adugna, 2016). Additionally, Both the soil aggregate and the pore properties are linked to the unique surface area of "active" which impacts many processes for soil conservation and exchange. The higher the specific surface area, the stronger the interactions between soil fauna, micro-organisms, and root hair should be under optimal conditions (Adugna, 2016). Hence, a highly specific surface area may provide the conditions required for the ideal form of soil (Amlinger et al., 2007).

Infiltration rate and water holding capacity

According to Adugna (2016), the quality of plant water is dependent on two factors: the volume of water that the soil can maintain and the quantity of water that it can absorb into the soil. In general, the structure of the soil, organic matter content, and particle size is influenced by water holding capacity and filed capacity. Brown and Cotton, (2011) reported that compost application has a major impact on the water holding capacity of coarse-textured soils but with finer-textured soils, water holding capacity is less or no improvement. They further explained that adding compost to all soils increased the rate of water infiltration compared with the regulation. Soil texture has a major impact on the infiltration rate to preserve the soil's capacity to retain water (Adugna, 2016). From the study conducted by Brown and Cotton (2011), they found out that the major water holding capacity improvements were observed in sandy and coarse-textured soils, although the enhancement of water absorption rates was noticed in finer textured soils.

Effect of compost on soil chemical properties

Cation Exchange Capacity (CEC)

When assessing soil fertility, cation exchange capacity is one of the main indicators to consider especially when it comes to nutrients and leaching of nutrients into groundwater (Adugna, 2016). Agegnehu et al. (2014) and Gamal (2009) observed that due to the stability of organic matter being rich in functional groups into the soil, compost amended soils increased in CEC. Data from the second phase showed that, as a significant soil quality index, soil CEC was increased as a result of compost application, which also showed a considerable increase in the ability of soils treated with organic matter (Mohammad et al., 2004). Organic matter contributes about 20 to 70 percent to CEC in most soils (Amilinger et al., 2007).

Soil pH

Soil pH is the index of soil acidity or alkalinity and is defined to be the negative logarithm for soil suspension hydrogen activity. Soil pH is a significant indicator of crop production because most organisms living in plants and soils prefer slightly alkaline or acidic conditions which boost their vitality (Adugna, 2016). The pH of soil influences the distribution of soil nutrients (Agegnehu et al., 2014; Daniel and Bruno, 2012). According to Gamel (2009), continuous application of compost enhances or maintain soil pH.

Nutrients level

Compost provides a wide useful nutrients variety including nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur including many other trace elements (Agegnehu et al., 2014). The nutrient content and other important chemical properties such as pH, carbon-nitrogen ratio, and electrical conductivity (EC) depend on the organic feedstock used and the compost processing conditions (Adugna, 2016). Inorganic NPK fertilizer can be substituted by compost generated from an acceptable organic material input mixture of organic and compost substrate rich in nutrients (Amlinger et al., 2007). Soheil et al. (2012) stated that compost application improved the volume and availability of the primary nutrients (N, P, and K) and the micronutrient contents in the soil. Researchers also found that the volume of compost in dry matter greatly influenced the concentrations of macro and micronutrients, and also had a major impact on heavy metals concentration. Soils amended with compost have a similar level of plant nutrients available compared with soil fertilized traditionally and high macro- and micronutrient concentrations compared to control soils (Soheil et al., 2012; Brown and Cotton, 2011). In a field experiment conduct by Gamel (2009), where he applied compost at 0 ton, 5 ton, and 10 ton ha^{-1}. The nutrients content of the compost is not fully available at once. The presence and the varying strength of different binding mechanisms within the organic matrix can be attributed to this, resulting in partial stagnation of nutrients but as a result of the slow and gradual release of plant nutrient, the fertilization effect will last longer (Tayebeh et al., 2010; Adugna, 2016). As a result, the protection against leaching with compost is far better than soluble mineral fertilizers (Tayebeh et al., 2010).

Effect of compost on soil biological properties

According to Adugna (2016), promoting soil biology is a major key factor for a compost application. A broad variety of species can be seen in the soil only on a strong microscope, from huge visible organs to species. The soil living organisms perform a variety of functions, which make important contributions to the normal and healthy soil we find. Compost has a stimulating effect on the compost substrate of both the microbial population and soil micro-biota (Adugna, 2016). Compost application has increased microbial activities in compost amended soils compared with unamended soils (Brown and Cotton, 2011). They further explained that because microorganisms get food from the organic matter present in compost, the microbial activity in compost amended soils was 2.23 times greater as compared to soils without compost amendment. Generally, there are two types of organic matter fractions that are responsible for microbial activity in soils namely; easily degradable organic compounds may increase the activities of microbes and biomass in a short period (Adugna, 2016).

Effect of compost on soil fertility

Adugna, (2016) reported that due to the significant role that compost play by providing nutrients to the soil and the role of influencing soil physical properties, the addition of compost to soil has been accepted to maintain the quality of the soil. For soils that are not cultivated, it is clear that more than 95 % of nitrogen and sulfur are present for organic soils, but 25 % of phosphorus is also possible (Amlinger et al., 2007). One successful way of growing soil organic matter (SOM) in the soil is to add compost generated from biomass waste. Soil organic matter (SOM) enhancement's most important influence factors include efficiency, compost humification degree, soil properties (including soil type, particularly clay content), and management. Because of the high level of stable carbon in fresh and unripe composts, mature composts raise SOM far more than both (Bouajila and Sanaa, 2011; Daniel and Bruno, 2012). Soheil et al. (2012) explained that compost with a high quantity of organic matter (OM) increased organic carbon (OC) in soil and the quantity of OC in uncultivated soil was higher than soil cultivated due to the impact of plant cultivation and increased degradation of organic matter in crop soil. Compost application often positively affects the structure of the soil by reducing soil bulk density (Amlinger et al., 2007 in Adugna, 2016). Brown and Cotton (2011) observed that Soil bulk density is reduced concerning compost rate increases. Soils with low bulk density mean that there is more porous space and this is why soil tilth is improved. Liu et al. (2013) explained that once compost was added, soil meso and macropores increased due to enhanced soil aggregation and stabilization, which was primarily initiated by diverse soil species.

Effect of compost on crop yield

Compost application adds up to the stabilization and enhancement of crop production and quality of crop because of its various beneficial effects on the physical, chemical, and biological features of soil (Tayebeh et al., 2010; Amlinger et al., 2007). They further argued that in comparison with pure mineral fertilization, greater yield safety can be anticipated. Better crop outcomes were often achieved by applying a greater quantity of compost every 2nd to 3rd year during the first years than implementing compost in reduced amounts of < 10 Mg ha^{-1} annually. Nevertheless, crop yields are mostly lower after the application of pure compost compared to mineral fertilization during the first growing seasons. Mohammad et al. (2004) explained that the application of compost does not only improve crop development and productivity in terms of amount but also improves the quality of agricultural products. Adugna (2016) explained that organic manures such as compost discharge nutrients to crops very slowly and plants do not absorb these nutrients immediately. Therefore, in the critical yield-forming era, crops are unable to access the necessary quantity of nutrients. Liu et al. (2013) reported that application compost increases the production of pine concerning the growth parameters of plant height, leaf length, leaf width, etc. In addition, previous trials have shown an improved use of other parameters such as nutrient absorption and root vigor. (Ribeiro et al., 2007; Caballero et al., 2009). Liu et al. (2013) observed that compost application also fostered development, increased pineapple fruit weight, and yield.

Combined effect of biochar, compost, and inorganic NPK fertilizer on soil fertility

According to Lui et al. (2012), the integration of biochar and compost under field conditions had a positive synergistic effect on the nutrient content of soil and the capacity to hold water. They further clarified that compost and biochar applied together minimizes fertilizer inputs, stabilizes the structure of the soil, and improves the capability of water retention and nutrients content. Compost applied in addition to biochar has many benefits compared with single biochar and compost application (Mensah and Frimpong, 2018). Trupino et al. (2017) stated that the integration of compost and biochar improves the properties of compost, which helps in the sequestration of carbon and great value addition as a result of biochar long-term stability. It has been reported that biochar and compost applied together enhance soil quality, reduced the use of fertilizer input synergistically, increased crop production improved nutrient performance, improved structure of the soil, and increased water retention ability. (Mensah and Frimpong, 2018). Lui et al. (2012) observed that compost applied in addition to biochar can sequester carbon (C) when stable biochar/compost complexes are established. They found out that it also supplies available plant nutrients through biological N fixation, a combined supply of nutrients, and decreases the rate at which nutrients are leached. In addition, stabilization of organo-mineral improves soil structure and water balance, and favorable structure soil pores are established. Consequently, the application of compost in addition to biochar has a positive impact on water supply, particularly when dealing with water retention as compared with compost applied solely (Lui et al., 2012). In most cases, the sole application of biochar does not provide an adequate amount of nutrients to plant (Glaser and Birk, 2012; Glaser et al., 2002).

The combined effect of biochar, compost, and inorganic NPK fertilizer on crop yield

Mensah and Frimpong (2018) observed that the use of biochar alone or the combination of biochar and compost improves soil quality and thus increases crop yields. According to Naeem et al. (2017), the combined application of biochar and compost with inorganic fertilizer enhances the growth and yield of crops as compared to the individual application. They further explained that a combination of compost and biochar with fertilizer increased the concentration of physiological attributes and nutrients (nitrogen, phosphorus, and potassium). The application of compost and biochar decreased soil pH but increased soil organic carbon, total nitrogen, available phosphorus, and available potassium (Naeem et al., 2017). Wu et al. (2019) explained that compost application, in addition, to have a synergistic impact on the nutrients of the soil and also on the structure of the microbial community. Generally, both biochar and compost play an important role in the productivity of crops, particularly through enhancement of N uptake by crops (Bass et al., 2016). Compost and inorganic fertilizer applied together increased nitrous oxide (N_2O) emissions by improving the concentration of nitrate (NO_3^-) compared to unamended soil (Wu et al., 2019; Rodriguez et al., 2011). According to Oladele et al. (2019), low rate (3 to 6 t ha^{-1}) application of biochar small dose of nitrogen fertilizer rate (30 kg ha^{-1}) the efficiency of nitrogen fertilizer, grain, and biomass yield, and physicochemical properties of crops and soil compared with inorganic fertilization with nitrogen fertilizer only.

Cultivation of Pineapple

Origin and Distribution of Pineapple

Pineapple originated from southern Brazil and Paraguay, where its wild families are located (Morton, 1987). He said pineapples were domesticated by the Indians and transported to Mexico and western India very long time before the Central Americans came from Europe. According to Morton, the Caribbean Indians began placing pineapple crowns outside their dwelling gates as symbols of friendship and hospitality (Morton, 1987).

According to Morton (1987), the pineapple was introduced into the Philippines by the Spaniards and in the 16^{th} Century, they took it to Hawaii and Guam. In 1885, the first sizeable plantation which was about five (5) acres was established in Oahu. He further stated that. He further stated that the Portuguese traders took seeds from Molucccas to India in 1548 and also brought pineapples to Africa in the east and west. In 1650, the pineapple plant goes to Europe and in 1686 the fruits of the pineapple plant were produced in Holland but in England, trials were not successful until 1712. In the late 1700s in England and France, greenhouse culture flourished (Morton, 1987).

Ecology of pineapple

Soil

Pineapple is cultivated in various types of soil, including soils that are deficient in nutrients. Moderately fertile soils, sandy loam soils of neutral to mildly acid pH are good for the cultivation of pineapple but can also grow well in sandy and calcareous soils with good agronomic practices and fertilizer application (Crane, 2006). Pineapple plant should be cultivated soils which are well-drained in landscape regions that do not flood because, however, pineapple plants are susceptible to water-logged soils (Ficciagroindia, 2007). In general, a pH range of 5.0 to 6.0 is considered the best for pineapple cultivation but in terms of pineapple flavor and fruit quality, light soils are deemed to be the best to that grown on other soils. However, on humus-rich sandy and loamy soil pineapple can be grown quite good (Ficciagroindia, 2007).

Temperature

Pineapple plant requires different temperature ranges for different stages of growth. Temperature range between 18.33 to 45 °C (65 °F - 95 °F) is considered the most favorable for pineapple growth although cool nights can be tolerated by the plant for short periods (Morton, 1987). He said that cold over a long period delay growth and maturity, and can also cause acidity in the fruit (Nakasone and Paull, 1998). According to Nakasone and Paull (1998) a range of desired temperatures, both at maximum and minimum, would be between 15 - 20 °C and between 25 to 32 °C respectively, with optimal temperatures of around 30 °C and at night 20 °C.

Sunlight

The fruit weight and intensity of solar radiation are directly related. The condition is that with every 20 percent reduction in solar radiation, output declines by about 10 percent (Nakasone and Paull, 1998). The shading of higher plant densities therefore reduces fruit weight linearly and reduces yield curvilinear (Nakasone and Paull, 1998). Strong sunlight can lead to fruit springing, particularly during ripening. Several methods are applied to prevent this, including using newspaper and weeds as to provide shade.

Rainfall

Variability of rainfall is considerable at the locations where pineapples are planted. Annual rainfall for the manufacturing of pineapples ranges between 600 mm to over 3500 mm, with an optimal range of 1000 - 1500 mm for excellent commercial manufacturing (Nakasone and Paull, 1998). Despite the xerophytic properties of pineapple, extended dry periods may have a negative influence on development. According to Nakasone and Paull (1998) pineapple has a potential 4.5 mm evapotranspiration rate per day and with soil water holding capacity of rarely more than 100 mm, the supply of water to crop could be utilized without rain for three to four weeks, but plants can't achieve the floral induction sizes when exposed to extended water stress.

Nutrients Use Efficiency of Pineapple

Application of nutrients to pineapple plants in their right proportion and balanced form is one of the key elements of increased yield, fruit quality, and fruit weight (Amorim et al., 2011). Moreover, it is of prime significance to determine pineapple plant nutrient requirements in the different plant development stages for an effective supply of plant nutrients. Grangeiro et al. (2007) indicated that one of the instruments for balanced fertilization is the rate of nutrient uptake, expressed as nutrient uptake curves depending on the era of the plant. According to Teixeira et al. (2011), pineapple plant nutrients requirement is high compared to other plants and depends, among other variables, on the cultivar, fruit weight, and planting density.

Pineapple plant nutrient absorption is associated with its phenological cycle and can be described as an original vegetative development and slow absorption of nutrients from plantlet transplantation up to the first 6 months of development, followed by a second stage after 6 months of development. Pineapple fruit nutrients translocation and photoassimilates start by increasing the nutrient uptake and output of biomass to induced pineapple flowering (Pegoraro et al., 2014). The demand for nitrogen (N) and potassium (K) by pineapple plant is very low in the first three months after planting, but when it reaches the flowering stage, demand increases (Malézieux and Bartholomew, 2003). Razzaquea and Hanafi (2001) reported that potassium (K) is the most needed nutrient in the cultivation of pineapples. They said the absence of K leads to poor growth and decreases output and quality of fruits. On the other side, excessive soil application of K leads to low NH_4^+, $Ca^{2+,}$ and Mg^{2+} uptake.

Table 1: Summary of findings from other biochar and compost research works.

Authors (Year)	Country	Method	Findings	Source of data
Fu et al. (2016)	China	Sorption Experiments	Biochar produced from pineapple peel is environmentally friendly and capable of removing organic contaminants due to its effective adsorbent nature. Pineapple waste biochar and compost application influenced Cation Exchange Capacity (CEC). Both biochars had pH levels significantly higher than pineapple peel.	Article
Ahmed et al. (2004)	Malaysia	Laboratory Experiments	K-rich fulvic and K-rich HA acids can be used for crop production due to the high amount of humic and fulvic acids and a K released from the decomposition of pineapple leaves.	Journal Article
Liu et al. (2013)	China	Field Experiment	Pineapple composted residue (CPRR) decreased soil bulk density and improved organic matter content, available in N, P, and K. CPRR has also promoted growth in pineapples and increased fruit yields.	Journal

Agegnehu et al. (2017)	Australia	Field Experiment	Application of biochar and biochar-compost directly affected native or applied nutrient quality. Compost significantly improved plant production, soil nutrient status, and plant nutrient quality with fertilizer application.	Journal
Ch'ng et al. (2016).	England	Field Experiment	The application of biochar and compost improves crop productivity in acid soils by reducing phosphorus fixation.	Journal Article
Eyles et al. (2015)	Australia	Field Experiment	The positive impact of biochar on crop response can positively be increased by organic fertilizer addition in the form of compost.	Article
Ahmed et al. (2001)	Malaysia	Field Experiment	Burning, piling pineapple residues in rows, or allowing pineapple residues to decompose in situ does not increase both the absorption of K and P and the yield.	Journal Article
Ch'ng et al. (2016)	Malaysia	Pot Experiment	Biochar and compost applied in addition to rock phosphate help to fixed Al and Fe instead of P, thus making P	Article

			more available to plant for a longer period compared with the application of rook phosphate without organic amendments.	
Hossain, et al. (2019	Bangladesh	Fieldwork	Soil amended with biochar affected plant height, the number of leaves, above and below-ground biomass positively Application of inorganic NPK fertilizer together with biochar supported the best plant growth.	Research Article
Mensah and Frimpong, (2018)	Ghana	Field and Pot Experiment	Biochar and compost applied singly or their integration influenced soil pH, available phosphorus, mineral nitrogen, reduced exchangeable acidity, and increased effective cation exchange capacity.	Mensah and Frimpong, (2018)

CHAPTER THREE

MATERIALS AND METHODS

This chapter presents the materials and methods that were used in this study. The detailed descriptions of the materials and methods used in the experiment are presented in the sections below.

Experimental site

The experiment was conducted at the Asuansi Farm Institute, located at Asuansi between latitude 5°05'N and 5°25N and longitude 1°5W, and 1°20W in the Abura-Asebu-Kwamankese District of the Central Region of Ghana. The area lies within the southern fringes of the semi-deciduous rainforest with two wet seasons in a year. The rainfall pattern follows the double maxima (bimodal) rainfall distribution experienced in most parts of southern Ghana with an annual mean rainfall of about 980 mm. The major season rain starts in March and ends in July whilst minor season rain commences from September to mid-November. The topography of the area consists of low hills and small knolls. The soil type described as Acrisols (FAO-UNESCO, 1980) belongs to the locally classified Asuansi series of the Asuansi-Kumasi/Nta-Ofin compound association. The soils at the experimental site were developed from granite, which gives rise to highly porous gravelly sandy loams over gritty sandy clay soils that are often rich in minerals especially potassium if they are not over-cropped or severely leached.

Soil sampling

Soil samples were collected at a depth of 0 - 20 cm in a Z pattern before planting and before the amendments were incorporated to determine the initial soil physicochemical properties. The experimental field had a gentle slope. The samples were bulked, air-dried, sieved through a 2 mm mesh sieve, and kept in a dark room at a temperature of about 25 ^oC before the physicochemical analyses. Soil samples that were not disturbed were also collected with core samplers for soil bulk density and soil moisture determination.

Experimental design and layout

The study was conducted using the split-plot design with four replications, with pineapple variety as the main plot and treatments as the sub-plots. The sub-plot size was 2.5 m by 0.6 m and four (4) soil samples were taken per plot during the soil sampling. There were seven (7) treatments involving sole compost, sole biochar, combined biochar and compost, inorganic fertilizer (NPK), combined compost and inorganic NPK fertilizer, combined biochar, and inorganic NPK fertilizer, and the control. Three varieties of pineapple (*Ananas comosus)* namely; MD2, sugar loaf, and smooth cayenne were used as test crops for the study because they are widely grown in Ghana. These together make a total of 84 sub-plots. The amendments and application rates are summarized in Table 2.

Table 2: Treatment used in the experiment

Treatment	Biochar (tons ha^{-1})	Compost (tons ha^{-1})	Inorganic NPK fertilizer (kg ha^{-1})
Control	0	0	0
Compost only (C)	0	10	0
Biochar only (B)	10	0	0
NPK	0	0	90:60:60
Compost + Biochar (C+B)	10	10	0
Compost + NPK	0	10	90:60:60
Biochar + NPK	10	0	90:60:60

Figure 1: Amendments addition and laying of the plastic mulch

Field preparation and Planting of pineapple suckers

The experimental field was cleared with a cutlass and de-stumped with a disc plow. Subsequently, the plot was harrowed to a depth of 20 cm to break soil clods before ridges measuring 2.5 m × 0.6 m in length and breadth, respectively, were formed. The ridges were then covered with plastic mulch purchased from Dizengoff Ghana Limited. The pineapple suckers used for the study, weighing between 291 g and 355 g, were obtained from Blue Skies (Ghana) Company Limited. The suckers were planted on 16th November 2018 in double rows, with 8 suckers per row at a spacing of 40 cm × 25 cm as shown in Figure 2.

Figure 2: Grouping of sorted pineapple suckers for planting

Fertilizer Application

Fertilizer was applied at the rate of 100: 60: 60; N: P_2O5: K_2O kg ha^{-1}, respectively, as recommended by the Ministry of Food and Agriculture (MoFA) for the Central Region (FAO, 2005). The split method of fertilizer application was adopted to optimize nutrient utilization by pineapple plants and to minimize nutrient, especially nitrogen losses due to leaching and volatilization (FAO, 2006). Thus, inorganic NPK 15: 15: 15 was used for the basal application and supplemented with urea (46 % N), Triple Superphosphate (TSP) (46 % P_2O_5), and Muriate of Potash (MOP) (60 % K_2O). The basal application was done at 4th and 8th week after planting while the top-up was done on 16^{th}, 24^{th}, $32^{nd,}$ and 42^{nd} weeks after planting. On each date, fertilizer was applied at an equal rate.

Biochar

The biochar used in the study was produced from pineapple waste including leaves and peels, collected from farmers' fields at Akwanda and Nsadwir and markets (Kingsway and Kotokoraba) within the Cape Coast municipality. The pineapple waste was chopped and sun-dried for a week to reduce the moisture content before they were used for biochar production. The ELSA barrel (Steiner et al., 2018) was used to prepare the pineapple waste biochar at a temperature of approximately 550 ^oC. The Elsa barrel had a small, 1 mm holes at the bottom to allow airflow into the barrel as wells as larger L – shaped, 6 cm x 6 cm inward-bent on the top sidewalls of the barrel facilitate the flow of secondary air (Steiner et al., 2018). After pyrolysis, the biochar produced was ground and sieved through a 2 mm mesh sieve and stored at 4 ^oC prior to field application.

Figure 3: Drying of pineapple waste biochar and the Elsa barrel used to produce the biochar

Table 3: Post carbonization characteristics of the pineapple waste biochar

Feedstock	**Carbonization Characteristics**				
	Time (min)	Weight (FSt (kg)	Weight BC (kg)	Eff. W W (%)	Temp (^oC)
Pineapple waste	30	9	4.9	54	550

FSt, feedstock; BC, biochar; Eff. WW, efficiency per weight; Temp, temperature

Compost

The Windrow method of composting (Yvette and Holmer, 2000) was adopted to produce the compost used in the study. The feedstock used for preparing the compost included chopped pineapple leaves collected from farmers' fields at (Akwanda and Nsadwir), two-month-old poultry manure, and chopped corn stover collected from the University of Cape Coast Teaching and Research Farm in a proportion of 60:20:20, respectively. The total C and N were analyzed for the pineapple leaves, poultry manure, and corn stover, then the C/N ratio was calculated by dividing the C/N before using them for composting. The pineapple waste, poultry manure, and corn stover were combined in such a ratio that the overall C/N ratio of the compost will be within the range of 20-30: 1. During the composting process, the mixture of materials was turned every three days during the first four (4) weeks and weekly afterward till the compost matured, the compost matured at one month two weeks. Due to the quantity of composting materials used, three compost heaps were formed. The temperature of each heap was recorded every time it was turned. The graph showing the average temperature of the compost at each turning time is presented in Figure 5. After six (6) weeks, the matured compost was air-dried for two weeks and a sample was then taken to the laboratory for analysis. Figure 4 shows how pineapple waste was composted.

Figure 4: Compost preparation

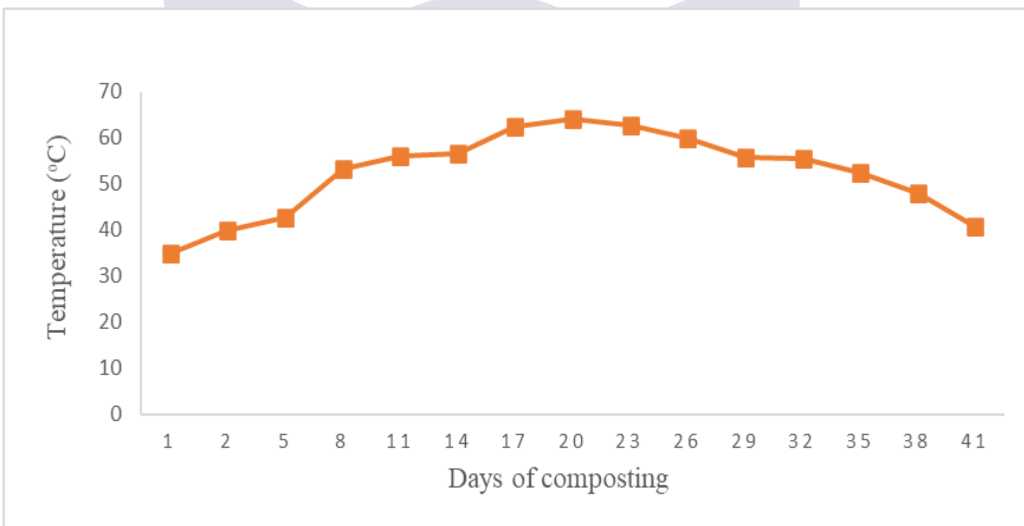

Figure 5: The average temperature dynamics during the pineapple waste compost production process.

Table 4 gives details of the C, N, and C/N ratio values of each feedstock before composting and the quantity of each feedstock composted are shown in Table 5.

Different types of feedstocks were used for the compost preparation. The respective quantities of various feedstocks used and their C, N, and C/N ratio values before composting are presented in Table 4 and 5.

Table 4: Quantities of feedstock used for composting.

Type of feedstock	**The quantity used (kg)**
Pineapple waste (peels and leaves)	100
Poultry manure	50
Corn stover	50

Table 5: The C, N, and C/N ratio values of feedstock before composting.

Type of feedstock	**% OC**	**% N**	**C/N ratio**
Poultry manure	36.44	2.49	1:15
Corn stover	58.7	1.20	1:49
Pineapple peels	45.2	1.76	1:26
Pineapple leaves	49.5	1.55	1:32

Data collection

On each sub-plot, five (5) randomly selected plants were tagged as described by Rebolledo-Martinez et al. (2005). The tagged plants were randomly chosen from the inner 8 plants and data were taken on them to determine the growth and yield responses of pineapple in the different treatments. Pineapple 'D' leaf, which is the youngest physiologically matured leaf on the plant, was used to determine the growth parameters of the pineapple except for the number of leaves. Data on 'D' leaf length, 'D' leaf width, and 'D' leaf weight was taken prior to artificial flower induction treatment (8MAP). Regarding the growth parameters, data collection on plant height and number of leaves per plant began from two months after planting (2MAP) and was repeated every two months afterward until the eighth month after planting (8MAP). Plant height was measured from the surface of the soil to the tip of the leaf using a meter rule as shown in Figure 6. The length and width of the 'D' leaf were also determined with a meter rule. The mean height and width of the five plants tagged on each experimental plot were calculated and recorded.

Data was also collected on yield parameters such as fresh fruit weight, fruit diameter, and length at the physiological maturity (14MAP) stage of the pineapple. Fresh fruit weight was determined using an electronic scale. At the physiological maturity stage (14 MAP), fruits from the five (5) tagged plants were harvested and weighed. Samples of the fresh pineapple (300 g) were dried at 60 ^oC for 4 days to determine the dry weights of the fruits. Additional weighed (100 g) samples of the fresh fruits were used to determine the quality of the pineapple.

Figure 6: Measurement of growth parameters

Laboratory analyses carried out during the study are described below

Soil Analysis

Pre-treatment soil samples

Samples of soil collected from the pineapple field before any amendment was added were air-dried, ground and sieved through a 2 mm mesh and stored in well-labeled polythene bags. The soil samples were sent to Agricultural Science and Technology laboratory in Kenyatta University, Kenya for laboratory analysis. The physicochemical properties of the soil that were determined included the textural class, pH, bulk density, organic matter content, total nitrogen content, available phosphorus, exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), exchangeable acidity (H^{+} and Al^{3+}). Effective Cation Exchange Capacity (ECEC) of the soils was calculated as the sum of the exchangeable bases and the exchange acidity.

Soil pH

The soil pH was measured in a 1: 2.5 soil-water solution using a glass electrode of a pH meter (AD 1000, Addwa, Romania) following the method of Okalebo, Gathua, and Wommer (2002). Approximately 20 g of air-dry soil sample was weighed into a plastic bottle with a screw cap. Deionized water (50 ml) was added and the mixture shaken for 30 minutes on SCILOGEX Pro Linear Digital Shaker. The pH of the soil solution was measured by inserting the electrode of the pH meter into the soil solution.

For electrical conductivity, the suspension soil was left to settle for an hour after taking the pH reading. After 2 hours, the conductivity of the supernatant liquid was measured using the electrode.

Total Nitrogen (TN)

The block digester procedure was used to determine total nitrogen in the soil samples as described by Okalebo et al. (2002). About 0.3 g of soil sample was weighed into a labeled digestion tube and 2.5 ml of digestion mixture made up of salicylic acid and sulphuric acid-selenium was added to each tube including the blank. The mixture was digested at 110 ^{o}C for an hour. The sample was removed and allowed to cool before three successive 1 ml portions of hydrogen peroxide were added. The temperature was increased to 330 ^{o}C for the healing process to begin. After the tube has cooled down, 25 ml of distilled water was added to the mixture while thoroughly stirring until no more sediment could dissolve. The mixture was allowed to cool again and then topped with water up to 50 ml. The solution was allowed to settle and the clear solution was filtered for analysis.

A 10 ml aliquot of sodium hydroxide was pipetted and added to the reaction chamber of the steam distillation equipment. Immediately, the distillation steamed up into 5 ml 1% boric acid with 4 drops of mixed indicator. The distillation was continued for 2 more minutes after the solution turned orange. The distillate was then titrated against M/140 HCl from green to wine red.

The equation below was used to determine total nitrogen

$$\% N = \frac{(a-b) \times 0.1 \times v \times 100}{1000 \times w \times al} \quad [1]$$

Where:

a = Titre volume of HCl used to titrate the blank.

b = Volume of the titre HCl for the soil

v = Titre volume of the digestion

w = Weight of the soil used

al = aliquot of the solution taken for analysis.

Soil Particle Size Distribution

Particle size distribution in the soil used for the study was determined using the hydrometer method described by Okalebo et al. (2002). A 50 g air-dry soil sample was weighed into a 400 ml beaker and 10 ml of Calgon solution was added and allowed to stand for 10 minutes. A dispersing cup was used to collect the suspension and mixed for 2 minutes. The suspension was transferred into a dispersing cup and mixed for 2 minutes. The solution was shaken at 180 revolutions per hour on a SCILOGEX Pro Linear Digital Shaker for 2 hours and subsequently, transferred into a graduated cylinder. The soil remaining in the cup was rinsed with distilled water into the graduated cylinder to reach the 1000 ml mark. A hydrometer was immersed in the solution. The cylinder was tightly sealed, and the solution was mixed by turning the cylinder upside down and shaken vigorously for ten (10) minutes. To avoid any froth being formed at the top of the suspension, 2-3 drops of amyl alcohol were immediately added to the soil suspension and, after 20 seconds, the hydrometer was gently inserted into the cylinder. After 40 seconds, the hydrometer reading was taken as well as the temperature of the solution for clay and silt.

To determine the amount of clay, the suspension was stirred for 10 minutes and allowed to stand for 2 hours undisturbed. Both the hydrometer and temperature readings were taken after 2 hours. The proportions of sand, silt, and clay in the soil were determined by the equations below: After the percentage of each particle size in the sample has been calculated, soil textural class was determined using the textural triangle.

Equations showing how the proportions of sand, silt, and clay in the soil were determined.

$$Sand\ \% = \frac{\text{MS} - \text{HR}}{\text{MS}} \times 100 \qquad [2]$$

$$Clay\ \% = \frac{\text{HR}}{\text{MS}} \times 100 \qquad [3]$$

$$Silt\ \% = 100\ \% - (\%\ clay + \%\ sand) \qquad [4]$$

Where:

MS = Mass of sand

HR = Hydrometer reading

Bulk Density

Bulk density is a measure of the weight of the soil per unit volume expressed in g cm^{-3}. Hammer was used to striking the core samplers into the soil. Soils at both ends of the core sampler were trimmed with a straight-edged knife. The core samplers with their contents were then dried in the oven at 105 ^{o}C to a constant weight. The core sampler volume was calculated by measuring the height and radius of the core sampler.

Bulk density was determined using the equation below:

$$pb = \frac{W2 - W1}{V} \quad [5]$$

Where

Pb = *Dry Bulk Density*

$W2$ = *Weight of core cylinder + oven – dried soil*

$W1$ = *Weight of empty core cylinder*

V = *Volume of core cylinder* ($\pi\, r^2\, h$), *where*:

π = 3.142

r = *radius of the core cylinder*

h = *height of the core cylinder*

Organic Carbon

Soil organic carbon content was determined using the Walkley - Black method (Rowell, 1994). This involves wet combustion with potassium dichromate and sulphuric acid mixture. The excess dichromate was titrated against ferrous sulfate after the reaction (FAO, 2008). Approximately 0.5 g of soil samples were weighed in duplicates and transferred into 500 mL Erlenmeyer flask, a blank was also included and the weights were recorded. Using a pipette, 10 mL of 0.167 M potassium dichromate ($K_2Cr_2O_7$) was added to the soil and was gently swirled. A 20 mL of concentrated H_2SO_4 was also added and the flask was undisturbed for 30 minutes. After the 30 minutes, the content was diluted with 200 mL of distilled water, swirling was repeated to ensure thorough mixing. To complex Fe^{3+} which would otherwise interfere in the endpoint, 10 mL and 0.2

g of H_3PO_4, NaF respectively was added before the addition of diphenylamine green endpoint.

The calculation of organic carbon is shown below:

$$\%\ organic\ carbon = \frac{(B-S)\times Molarity\ of\ F^{2+}\times 0.300}{weight\ of\ soil} \times \frac{100}{77} \times 100 \qquad [6]$$

Where:

B= Blank titre value

S = Sample titre value

0.300 = 12/4000= milli-equivalent weight of carbon

$\frac{100}{77}$ *= the factor converting the carbon oxidized to total carbon*

100 = the factor to change from decimal to a percentage

Available Phosphorus (P)

The Bray P2 method as described by Okalebo, Gathua, and Wommer (2002) was the method used to determine soil available phosphorus. Approximately 2.50 g of air-dried soil was weighed into a 250 ml plastic bottle. Then, 50 ml of the Bray 2 extracting solution was added and shaken for 5 minutes. A linear shaker was used to shake the contents for 5 minutes and filtered through Whatman No. 5 filter. From there, 10 ml of each P standard series solution, soil extract, and blanks were pipetted into 50 ml volumetric flasks. Approximately 20 ml of distilled water was added followed with the addition of 5 ml of 0.8 M H_3BO_3. Initially, 10 ml of ascorbic acid was added to each flask and topped to the 50 ml level with distilled water, it was then stopped and the substance was very well shaken. After an hour, a spectrophotometer was used to measure the intensity of the blue colour at 880 nm.

The content of available phosphorus was calculated following the equation below

$$P\ mg\ kg^{-1} = \frac{(a-b)\times v\times f\times 100}{1000\times w} \qquad [7]$$

Where:

a = Concentration of P mg 1^{-1} in extract solution

b = Concentration of P mg 1^{-1} in the blank sample

v = Extract volume

w = Weight of the air-dried sample

f = Additional dilution factor (optional)

Exchangeable Acidity

KCl solution was used to extract the acidic cations H^+ and Al^{3+}. Approximately, 5 g of air-dry soil was weighed into a 50 ml centrifuge tube, KCl solution of 30 ml of 1N was added. The centrifuge tube was closed tightly with a stopper then shaken on an electric mechanical shaker for an hour. The content was centrifuge for 15 minutes at 2000 r.p.m. The clear supernatant liquid was decanted carefully into a 100 ml volumetric flask. Another 30 ml of 1N KCl was added to the same soil samples and shaken for 30 minutes. For the titration of H and Al, 25 ml of 1N KCl extract was pipetted into 250 ml conical flask and 100 ml of distilled water was added. Approximately, 5 drops of phenolphthalein indicator were also added then the solution was titrated with 0.05 N NaOH to a permanent endpoint of pink colour. After 1 drop of 0.05 N HCl was added to the same conical flask to bring the solution back to the colourless state then 10 ml of NaF solution was added. The solution was titrated with 0.05 N HCl until the solution colour changed. Immediately, 2 drops of the indicator were added.

The exchangeable acidity was calculated as:

Exchangeable acidity (cmol (+) Kg^{-1}) = (ml NaOH sample - ml NaOH blank) × 10 [8]

Exchangeable cations

Exchangeable cations (bases) are those which are substituted from the soil with other cations. Those found mostly in soils include Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}; all of these are extracted and determined in 1 M NH_4OAc soil extract (FAO, 2008). Five grams of soil samples was into a 100 ml bottle of extraction to which 20 ml of ammonium acetate solution was added and stirred. The solution could stand overnight. The suspension was filtered using a funnel lined with filter paper; the soil was successively leached into a 100 ml volumetric flask with 20 ml of ammonium acetate, which allowed the funnel to drain with each addition. The filtrate was made with ammonium acetate up to the 100 ml limit. Extract aliquots were used to evaluate Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}.

Exchangeable potassium and sodium were determined using the flame analysis method by using the flame photometer. Working standards of 0, 2, 4, 6, 8, and 10 ug ml^{-1} of both K^{+} and Na^{+} were prepared in ammonium acetate, aspirated into the flame photometer to record the readings (emissions). Soil extracts were then aspirated and their emissions were also recorded. The standard and emission were plotted using the calibration curve. The concentration of K^{+} and Na^{+} concentration was read from the curve.

Exchangeable Ca^{2+} and Mg^{2+} were determined by titration. This method involved chelation of the cations with ethylene diaminetetra-acetic acid (EDTA). The usual procedure involved the determination of Ca^{2+} and Mg^{2+} together, using solochrome black indicator. A 25 ml aliquot of the extract was put in a 250 ml conical flask for the calcium, and the solution was diluted with distilled water to 150 ml. Added 10 drops of KCN, $NH_2OH.HCl$ and triethanolamine (TEA) each; added enough NaOH to lift the pH to 12 or slightly higher. Five drops of Calcon indicator were introduced, and EDTA titrated the solution from red to a blue endpoint.

The exchangeable magnesium was calculated by putting a 25 ml sample extract aliquot in 250 ml and adding distilled water to create a complete 100 ml amount. 20 ml of 20 percent tungstate solution and adequate buffer solution to get a pH of 10 was applied. The solution was heated and filtered the material through filter paper. A solution containing 50 ml of buffer per litre washed over the paper and precipitate. 10 drops of each KCN, $NH_2OH.HCl$, $K_4Fe\ (CN)_6$, and TEA were added and allowed for a few minutes to stand for a reaction. Thereafter 10 drops of the EBT indicator were applied and the solution was titrated with EDTA from red to a permanent blue endpoint.

KCl solution was used for removing the acid cations Al^{3+} and H^+. Ten grams of soil samples were weighed into a beaker; 30 ml of 1 M KCl was added and allowed to stand overnight. The soil was leached successively into a 100 ml volumetric flask with 10 ml of KCl, and the solution was made to the limit. Fifty milliliters of KCl extract were pipetted into a conical flask of 250 ml and five drops of an indicator of phenolphthalein were added. The solution with NaOH was titrated to a pink endpoint.

Exchangeable cations were calculated following the equations below:

$$cmol_c\ K^+ kg^{-1} = \frac{C \times 10}{wt \times 39.1} \quad [9]$$

$$cmol_c\ Na^+ kg^{-1} = \frac{C \times 10}{wt \times 22.99} \quad [10]$$

$$cmol_c\ Ca^{2+} kg^{-1} = \frac{4 \times T}{wt} \quad [11]$$

$$cmol_c\ Mg^{2+} kg^{-1} = \frac{4 \times T}{wt} \quad [12]$$

$$cmol_c\ H^+\ Al^{3+} kg^{-1} = \frac{2 \times T}{wt} \quad [13]$$

Where:

C = concentration of extract from the standard curve

T = Sample titre value.

The effective cation exchange capacity (ECEC) of the soil was calculated by the summation of the basic cations.

$ECEC = Ca^{2+} + Mg^{2+} + K^+ + Al^{3+} + H^+$

Organic Matter and Ash Content

Okalebo, Gathua, and Wommer's (2002) method of organic matter determination was used to determine the organic matter and ash content of pineapple waste biochar and compost. Approximately, 10 g of well-mixed air-dry biochar and compost samples of known moisture content was weighed into a dry nickel crucible. The crucible with the sample was heated slowly in a furnace at a temperature of 550 °C for eight hours. The crucible was allowed to cool in a desiccator immediately it was removed from the furnace then the wight was taken.

The equation below was used in calculating ash and organic matter content

$$\%\ Ash = \frac{W3-W1}{W2-W1} \times 100 \qquad [14]$$

% Organic matter = 100 – ash % [15]

Where:

W1 = The weight of the empty, dry crucible

W2 = The weight of the dry crucible containing biochar and compost

W3 = The weight of the dry crucible containing biochar and compost following ignition.

Plant analyses

The pineapple plant was analysed for N, P, and K contents as influenced by different treatments of biochar and/ or compost, and inorganic NPK fertilizer. The leaves and fruit of the pineapple plant were analysed separately. Each plant sample was milled to a very fine powder and stored in transparent zip-lock bags for further analysis (Galicia et al., 2009). The samples were prepared into a solution for the determination of nitrogen, phosphorus, and potassium. The sample solutions were therefore prepared to necessitate the oxidation process.

Sulphuric Acid-Hydrogen peroxide digestion

The digestion mixture comprised 350 ml of hydrogen peroxide, 0.42 g of selenium powder, 14 g of lithium sulphate, and 420 ml sulphuric acid. The digestion procedure as outlined by Stewarts et al. (1974) was followed. A 0.2 g of the sample milled was weighed into a 100 ml Kjeldahl flask, and a mixed digestion reagent of 4.5 ml was added and digested for two hours at 360 ^{o}C. The same method was used to prepare the blank digestions, thus digestion of mixture without sample. Upon digestion, the digests were quantitatively transferred into 100 ml volumetric flasks.

Determination of total nitrogen

Steam distillation was installed, steam was passed through for 20 minutes. A 100 ml conical flask containing 5 ml of the boric acid indicator was placed under the apparatus condenser after flushing the apparatus. Using a pipette, 20 ml aliquot of the sample digest was transferred to the reaction chamber through the trap funnel and10 ml of alkali mixture was added commencing the distillation to collect 50 ml of the distillate. The distillate was then titrated against M/140 HCl from green to wine red. The total nitrogen content of the pineapple leaf was calculated using the equation below:

$$\% N = (B - S)\ X\ Solution\ Volume/100\ X\ Aliqout\ X\ sample\ weight \qquad [16]$$

$Where$

$S = Sample\ titre\ value$

$B = Blank\ titre\ value$

Determination of phosphorous

Plant samples available phosphorus were determined using the Spectrophotometric method (Rowell, 1994). A millilitre of the sample aliquot digest was pipetted into a 25 ml volumetric flask. About 100 ml of 5 µg P/ml was prepared from a stock solution of P. From of 5 µg P/ml solution, a set of working standards of P containing 0, 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 µg P/ml were prepared in 25 ml volumetric flask. Both blank and P standards contained the same 40 volume of extracting solution as the plant samples. A 10 ml of distilled water was added to each flask and 4 ml of reagent (12 g ammonium molybdate in 250 ml water + 2908 g of potassium antimony tartrate in 100 ml distilled water + 2.5 M H_2SO_4 1L distilled water and made up to 2 L, to every 200 ml of this solution 1.156 g of ascorbic acid was dissolved) also added before topping up to the volume with distilled water. The colour was allowed to develop for 15 minutes before determining the absorbance on the spectrophotometer at 882 nm. Excel was used to plot a calibration curve using the concentrations and absorbance of the standard solutions; samples concentration was extrapolated from the curve.

The calculation for phosphorus content in pineapple leaf:

$$\mu g\ P/g\ soil = C \times Dilution\ factor \qquad [17]$$

C is the concentration obtained from the curve

Fruit quality analyses

pH

The pH of juice samples was recorded at ambient temperature conditions using a digital pH meter (PHT- 01 ATC). A beaker of 100 ml volume was used to store the pineapple juice samples, thoroughly stirred, and the electrodes of pH meter immersed in the juice samples. The pH values were read from the screen of the pH meter.

Total Soluble Solids (TSS)

Pineapple In determining the total soluble solids of the pineapple juice, a digital refractometer (Palm Abbe Digital Refractometer) was used. The obtained values were expressed in % Brix.

Titratable Acidity (TA)

Titratable acidity of the pineapple juice was obtained using a modified method of (Crisosto and Garner, 2001). This was done by pipetting 10 ml of the juice into a conical flask. A 200 ml of 0.1N NaOH was poured into a burette and was titrated against the sample in the flask with three drops of phenolphthalein as an indicator. The obtained TA values were expressed as a percentage of citric acid (mole equivalent = 0.064). The formula used to calculate the titratable acidity is as follows:

% Titratable acidity = (0.1 x 0.064 ml of 0.1 N NaOH) x100/ g of sample [18]

Vitamin C Determination

In determining Vitamin C, a modified titration method as described by (Helmenstine, 2019) was used. 10 ml of pineapple juice was pipetted and diluted to 100 ml. 25 ml of the homogenized solution was pipetted into a 250 ml Erlenmeyer flask. 10 ml of 0.5M H_2SO_4 and 0.5g $NaHCO_3$ was added. The solution was then titrated against the standard, KIO_3 until a deep blue I.starch complex was obtained. Moles of iodine reacting were calculated using the equation below:

Ascorbic acid + $I_2 \longrightarrow 2\ I^-$ + dehydroascorbic acid.

The concentration in mol/L of ascorbic acid in the solution obtained was calculated and then the concentration in mg/100ml was also calculated.

Total Phenolic Content (TPC)

In determining the total phenol content of pineapple juice, a modified spectrophotometric method as described by Lu et al. (2011) was used. 10 ml of fruit juice was diluted to 100 ml with distilled water and filtered. 250 µl of the filtrate was pipetted into a colorimetric tube in triplicate. 750 µl of distilled water was added followed by 1 ml of 10-fold diluted Folin Ciocalteau phenol reagent. After 5 minutes, 1.5 ml of 10% Na_2CO_3 was added to the mixture. They were allowed to react for about 30 min in the dark after which the absorbance of the solution was read at 765 nm using

UV mini 1240 (Shimazu Cooperation). A graph of standard calibration and unstandard calibration curve was plotted using Gallic acid equivalents in mg/100ml juice.

Total Antioxidant Capacity (TAC)

Ethyl acetate, methanol, and pineapple water extracts were assessed using the Prieto et al. (1999) method in determining total antioxidant ability. A sample solution aliquot of 0.1 ml (100 µg / ml) was mixed with 1 ml of reagent solution (0.6 mm sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate). The tubes had been sealed and incubated for 90 minutes in a boiling water bath at 95 °C. Once the samples had cooled to room temperature, the absorption of each of the aqueous solution was measured against a blank at 695 nm. A standard blank solution contained 1 mL of the reagent solution and the amount of the same solvent used for the sample was sufficient. This was incubated in the same conditions as the sample remaining. The water-soluble antioxidant potential was expressed as equivalents of ascorbic acid (µmol / g) from extract for samples of unknown composition.

Total Flavonoid Content (TFC)

The total flavonoid content was estimated using the colorimetric assay developed by Zhishen et al. (1999) with some modifications. 250 µl of the juice extract was pipetted into colorimetric tubes and mixed with 750 µl distilled water. 1 ml of 5 % w/v $NaNO_2$ was added. 1 ml of 10 % $AlCl_3$ was added after 10 minutes incubation time followed by 2.5 ml of 1 M NaOH after 5 minutes. The final volume was made up to 6 ml with distilled water. The absorbance was read at 510 nm. The standard solution of quercetin was used to plot the calibration curve. The outcomes were expressed as mg quercetin per L of juice.

Nutritional Content Determination

Protein Determination

Protein was determined by pipetting 2 ml of the juice into a numbered Kjeldahl digestion flask. About 4.5 ml of digestion mixture was added, and the sample was digested at 360 ºC for two hours (AOAC, 1995). The digest was allowed to cool down and diluted with distilled water to 100 ml. Upon adding 10 ml of alkali mixture using 5 ml of boric acid as an indicator, 20 milliliters (20 ml) of the digested was immediately distilled. Approximately 50 ml of the distillate was collected and titrated against 0.00712 M HCl until it turned to a pink colour which determined the endpoint. The remaining diluted digest was reserved for the mineral determination as described by the Food and Agriculture Organisation (FAO, 2008). Percentage protein was calculated using the formula;

N (mg/L) = T (ml) x100/aliquot x Dilution factor [19]

% N = N (mg/L)/10000

% Protein = % N x 6.25 [20]

Calcium Determination

An aliquot of 10 ml of the reserved digest was pipetted into a 250 ml conical flask, and 150 ml of distilled water was added. One ml each of potassium cyanide, hydroxylamine hydrochloride, potassium ferrocyanide, and triethanolamine were added. 20 ml of 10% sodium hydroxide was added to raise the pH, and then ten drops of calcon indicator were added to the solution and titrated against 0.005 M EDTA solution (AOAC, 1995).

$$Calcium\left(\frac{mg}{l}\right) = T \times M \times \frac{1000}{volume} \times Molar\ mass \times 10 \quad [21]$$

Magnesium Determination

An aliquot of 10 ml of the reserved digest solution was pipette into a 250 ml conical flask. One hundred and fifty millilitres (150 ml) of distilled water were added. Fifteen millilitres (15 ml) of buffer solution were added and allowed to stand for a few minutes. One millilitre (1 ml) of each of potassium, cyanide, hydroxylamine hydrochloride, potassium ferrocyanide, and triethanolamine were added. Ten (10) drops of erichrome Black T indicator was added and titrated against 0.005 m EDTA solution (Keeney and Nelson, 1982).

$$Magnesium\left(\frac{mg}{l}\right) = T \times M \times \frac{1000}{volume} \times Molar\ mass \times 10 \qquad [22]$$

Phosphorus Determination

In determining the phosphorous of the samples, two millilitres of an aliquot of the digested sample solutions was pipette into a 25 ml volumetric flask. 2 ml of the blank digest was also added to the 2 ml of standard phosphorus solution to give it the same background as the digest. Ten millilitres of distilled water was added to the standards as well as the sample solutions. Four millilitres of reagent B are made up of ascorbic acid and reagent (Keeney and Nelson, 1982). A reagent was added to the standard and sample solutions. To make up to 25 ml volume, distilled water was added to the volumetric flask and allowed the colour to develop for about 15 minutes. Using a spectrophotometer with a wavelength of 882 mn, the absorbances of the normal and sample solutions were determined after colour. Using their concentration against absorbance a typical calibration curve was plotted.

The equation used for the calculation is as follow;

If C = P mg/ml obtained from the graph then

$$\text{P (mg/L)} = \frac{Cmg\ x\ diluted\ factor}{aliquot} \qquad [23]$$

Sodium and Potassium Determination

Potassium and sodium concentrations in the digested samples were determined using the flame photometer. The following standard concentrations of both potassium and sodium were prepared 0, 2, 4, 6, 8, and 10 ug/ml (Keeney and Nelson, 1982). The work standards as well as the sample solutions were individually aspired into the flame photometer and recorded their emissions. Standard working emissions and the concentration was used to plot the calibration curve. The concentration of potassium and sodium in the sample solution were extrapolated using their emissions from the curve.

$$\text{K or Na (mg/L)} = \frac{C(ppm)\ x\ solution\ volume}{aliquot} \qquad [24]$$

Data analyses

The data collected were analysed using GenStat Statistical Software version 12 (VSN International) software. Differences between the variables were established using correlations. Analysis of variance was performed among treatments and their interaction effects for the significant difference at 95 % confidence level using Fisher's Unprotected LSD. Two-way ANOVA in randomized blocks was used to determine the effect of treatments on pineapple growth, fruit quality, and yield. The value of the F probability indicates the strength of significance at $P \leq 0.05$. The least significant difference (l.s.d) test was used for means comparison.

CHAPTER FOUR

RESULTS

This chapter highlights the physicochemical properties of the soil before the experiment was set up. It also explains the physicochemical properties of biochar and compost applied and presents the effect of pineapple waste biochar and / or compost, and inorganic fertilizer application on some growth parameters of pineapple. Furthermore, the effect of pineapple waste biochar and/or compost on leaf N, P, and K contents at the fruiting time, pineapple yield, and fruit quality are presented.

Table 6: Physicochemical properties of the soil, biochar, and compost used in the study.

Parameter	Soil	Biochar	Compost
Bulk density (g cm^{-3})	1.5		
pH	6.8	9.8	8.5
Organic carbon (%)	1.09	68.3	36.1
Total nitrogen (%)	0.11	0.68	1.6
Available / Total phosphorus (mg kg^{-1})	15	280	260
Exchangeable bases (c mol kg^{-1})			
Ca^{2+}	0.60	10.2	2.60
Mg^{2+}	0.93	3.26	8.61
K^{+}	0.38	18.80	18.60
Na^{+}	0.08	0.75	4.60
Exchangeable acidity (c mol kg^{-1})	0.1	0.3	0.7
ECEC (c mol $_c$ kg^{-1})	2.09	33.31	35.11
Electrical conductivity (mS cm^{-1})		9.59	3.59
Ash content (%)		39.43	62.14
Sand (%)	74		
Silt (%)	12		
Clay (%)	14		
Textural class	Sandy loam		

The soil used for the experiment was sandy loam with particle size distribution of 74 % sand, 12 % silt, and 14 % clay, a bulk density of 1.5 g cm^{-3} and is slightly acidic soil (Table 6). The total nitrogen (N) and organic carbon contents in the soil were 0.11 and

1.09 respectively. The available phosphorus content in the soil was 15 mg kg^{-1}. Exchangeable calcium (Ca^{2+}), potassium (K^{+}), magnesium (Mg^{2+}), and sodium (Na^{+}) concentrations in the soil were 0.60, 0.38, 0.93 and 0.08 c mol kg^{-1} respectively (Table 6). The exchangeable acidity in the soil was 0.1 c mol kg^{-1} whereas the Effective Cation Exchange Capacity (ECEC) was 2.09 c mol kg^{-1}.

The pH of the biochar and compost used in the study were 9.8 and 8.5 respectively (Table 6). The total nitrogen (N) contents in the biochar and compost were 0.68 and 1.60 %, respectively while the total organic carbon (TOC) concentrations in the biochar and compost were 68.3 and 36.1 %, respectively. The total P contents in the biochar and compost were 280 and 260 mg kg^{-1}, respectively. Exchangeable calcium (Ca^{2+}), potassium (K^{+}), magnesium (Mg^{2+}), and sodium (Na^{+}) concentrations in the biochar were 10.2, 18.80, 3.26 and 0.75 c mol kg^{-1} respectively while exchangeable calcium (Ca^{2+}), potassium (K^{+}), magnesium (Mg^{2+}), and sodium (Na^{+}) concentrations in the compost were 2.60, 18.60, 8.61 and 4.60 c mol kg^{-1} respectively. The exchangeable acidity in the biochar was 0.3 c mol kg^{-1} but for compost, it was 0.7 c mol kg^{-1}. Effective Cation Exchange Capacity in the biochar and compost were 33.31 and 35.11 c mol kg^{-1} respectively.

Electrical conductivity for biochar and compost was 9.59 mS cm^{-1} and 3.59 mS cm^{-1}, respectively. Pineapple biochar had an ash content of 39.43 % while compost had ash content at 62.14 %.

Effects of biochar and /or compost and inorganic NPK fertilizer application on growth of pineapple prior to flower induction.

Number of leaves

The effect of NPK, biochar, and/ or compost and on plant height is shown in Figure 7.

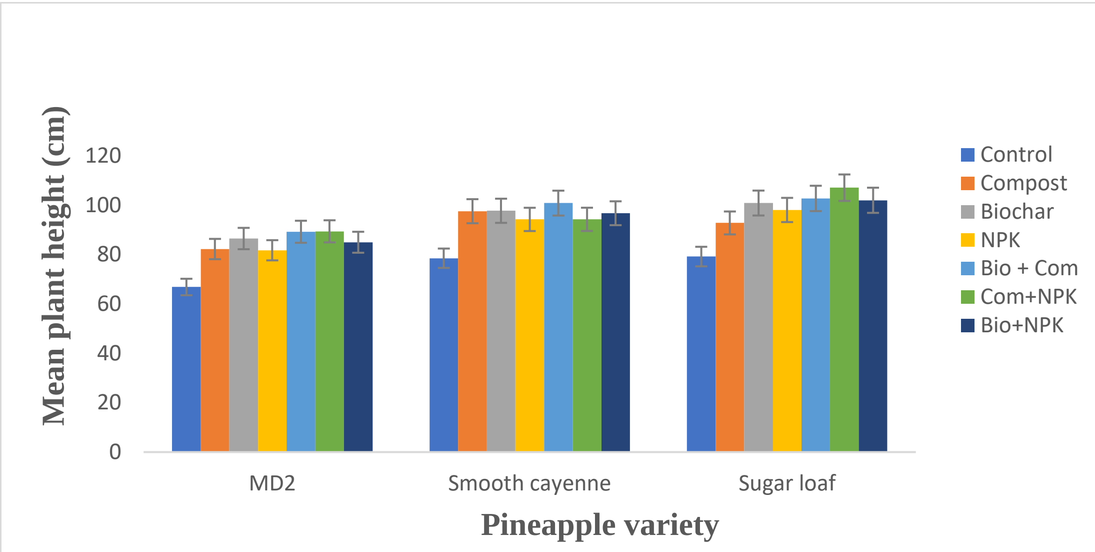

Figure 7: Effect of biochar and / or compost and inorganic NPK fertilizer application on pineapple plant height prior to flower induction treatment (8MAP).

Plant height was taken on all the three varieties of pineapple. Plant height varied significantly ($P < 0.05$) among the varieties and across the treatments (Figure 7). Compost applied in combination with NPK fertilizer recorded the highest plant height for sugar loaf variety, however, this was not significantly higher from biochar + compost, and biochar across all the varieties. The control recorded the lowest value of plant height among all the varieties.

Number of leaves

The effect of NPK fertilizer, compost, and/or biochar on the mean number of leaves per plant is shown in Figure 8

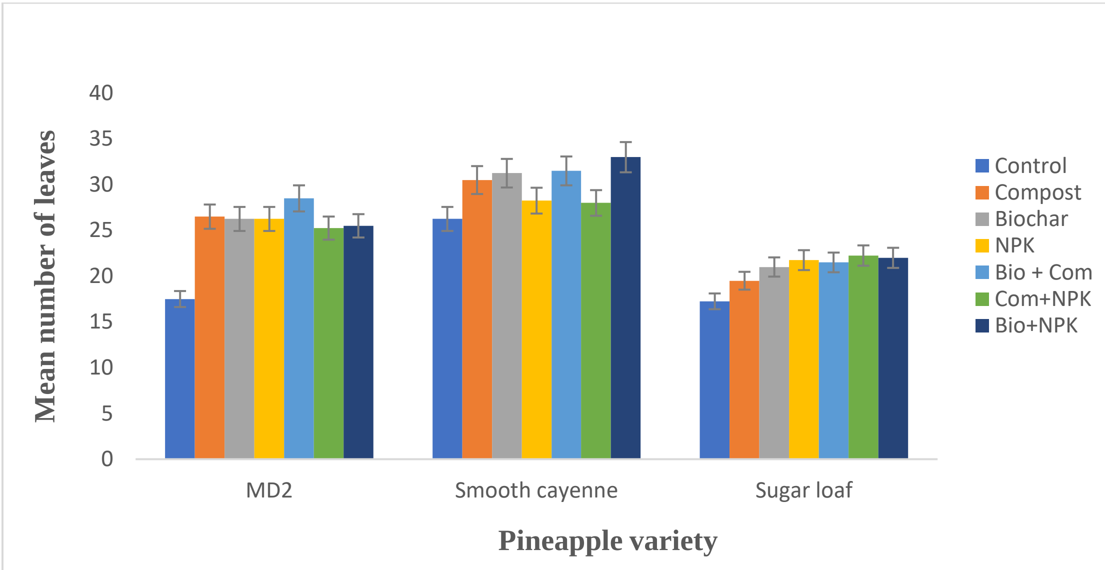

Figure 8: Effect of biochar and/or compost and inorganic NPK fertilizer application on the number of leaves of pineapple prior to flower induction treatment (8MAP).

The number of leaves varied significantly among the different varieties and across all the treatments (Figure 8). Combined application of biochar and compost recorded the maximum number of leaves but was not significantly ($P < 0.05$) higher from biochar + NPK fertilizer across the varieties. The control recorded the minimum number of leaves among the three varieties of pineapple (Figure 8).

Table 7: Interactive effect of pineapple variety and fertilizer application on growth parameters of pineapple prior to flower induction.

Variety × fertilizer interaction	Plant height (cm)	Number of leaves
V1F1	66.87	18
V1F2	82.25	27
V1F3	86.50	26
V1F4	81.75	26
V1F5	89.25	29
V1F6	89.42	25
V1F7	85.00	26
V2F1	79.20	17
V2F2	92.82	20
V2F3	100.88	21
V2F4	98.07	22
V2F5	102.75	22
V2F6	107.10	22
V2F7	102.00	22
V3F1	78.52	26
V3F2	97.57	31
V3F3	97.75	31
V3F4	94.25	28
V3F5	100.85	32
V3F6	94.27	28
V3F7	96.75	33
l.s.d	4.470	2.132
F pr.	0.002**	<.001***

*NS= not significant (P > 0.05), *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P < 0.001*

V1= MD2, V2= Sugar loaf, V3= Smooth cayenne.

F1 (Control), F2 (Compost 10 t/h), F3 (Biochar 10 t/ha), F4 (NPK), F5 (Comp 10 t/ha + Bio 10t/ha), F6 (Comp 10/ha + NPK) and F7 (Bio 10 t/ha + NPK).

A significant (P < 0.05) variation was observed among pineapple variety and fertilizer interaction in respect of plant height prior to flower induction (Table 7). *Sugar loaf* variety which received F5 (Biochar + Compost), F6 (Compost + NPK) and F7 (Biochar + NPK) resulted in significantly (P < 0.05) higher plant height than their counterparts under *MD2* and *smooth cayenne* variety. The highest plant height (107.10 cm) was recorded by the pineapple plant in V2F6 and the lowest pineapple plant height was recorded in V1F1. Although, F5 (Compost + Biochar) and F6 (Compost + NPK) recorded the highest plant height for *MD2* variety, and F5 (Compost + Biochar) recorded the highest plant height for *smooth cayenne* variety.

Significantly ($P < 0.001$) variation was found among the pineapple varieties and fertilizer application in respect of the number of leaves of the pineapple plant (Table 7). Combined application of compost and biochar recorded the maximum number of leaves and control recorded the minimum number of leaves under MD2 variety. The ridges under *sugar loaf* which received F4 (NPK), F5 (compost + Biochar), F6 (Compost + NPK) and F7 (Biochar + NPK) resulted in significantly ($P < 0.001$) higher number of leaves (22) with the same value (Table 7). Similarly, the control recorded the significantly ($P < 0.001$) lower number of leaves for the sugar loaf variety. Under *smooth cayenne*, the plots which were amended with F7 (biochar + NPK), F5 (compost + Biochar), F3 (biochar), and F2 (compost) recorded significantly ($P < 0.001$) higher number of leaves than their counterparts under MD2 and *Sugar loaf variety*. The maximum number of leaves (33) was recorded by the pineapple plant in V3F7 whereas the lowest number of leaves (17) was recorded in V2F1 (Table 7).

The 'D' leaf analyses before floral induction are presented in Table 8.

Table 8: Effect of pineapple waste biochar and compost on 'D' leaf prior to floral induction.

Treatment	Mean length (cm)	Mean width (cm)	Mean weight (g)
Control	80.30	4.68	55.00
Compost	83.85	5.40	57.50
Biochar	82.97	5.92	63.50
NPK	84.53	5.88	62.50
Bio+Com	83.90	6.08	64.17
Com+NPK	84.67	5.95	61.50
Bio+NPK	85.67	5.62	66.83
l.s.d	5.421	0.4714	5.766
F pr.	0.562 NS	<.001***	0.014**
Variety			
MD2	80.53	5.586	69.21
Sugar loaf	91.24	5.650	56.71
Smooth cayenne	79.32	5.707	59.64
l.s.d	3.549	0.3086	3.775
F pr.	<.001***	0.730 NS	<.001***

*NS= not significant (P > 0.05), *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P < 0.001*

V1= MD2, V2= Sugar loaf, V3= Smooth cayenne

F1 (Control), F2 (Compost 10 t/h), F3 (Biochar 10 t/ha), F4 (NPK), F5 (Comp 10 t/ha + Bio 10t/ha), F6 (Comp 10/ha + NPK) and F7 (Bio 10 t/ha + NPK).

The effect of organic and inorganic fertilizer application on the length, width, and weight of pineapple 'D' leaf are presented in Table 8. From the Table, there was no significant (P > 0.05) difference among the treatments applied though biochar applied in combination with inorganic fertilizer (NPK) recorded the highest 'D' leaf length to be 85.67 cm. The control plot had the least 'D' leaf length but was not significantly (P > 0.05) different from the other treatment (Table 8).

At eight months after planting (8MAP), there was a highly significant (P < 0.001) difference for the mean width of 'D' leaf among the treatment's application (Table 8).

It was also observed that plots amended with biochar in combination with compost had the highest 'D' leaf width which was significantly ($P < 0.001$) different from the others. The 'D' leaf width from the sole application of compost, biochar, and inorganic fertilizer, the combined application of compost and NPK, and biochar and NPK also recorded higher 'D' leaf width which was significantly different from the control. However, the control treatment had the lowest 'D' leaf width. There was a significant ($P < 0.05$) difference between the mean 'D' leaf weight (Table 8). Biochar applied together with NPK recorded the maximum 'D' leaf weight (66.83 g) prior to flower induction. This was followed by the combined application of biochar and compost, sole application of biochar, and NPK. The minimum 'D' leaf weight was observed in the control plot though was not significantly ($P > 0.05$) different from compost applied singly (Table 8).

Pineapple 'D' leaf length varied significantly ($P < 0.001$) among different pineapple varieties (Table 8). *Sugar loaf* pineapple variety recorded longer 'D' leaf length followed by *MD2* and *Smooth cayenne* variety. When it comes to the mean 'D' leaf width, there was no significant ($P > 0.05$) difference observed among the three varieties though Smooth cayenne variety obtained the highest mean 'D' leaf width followed by *Sugar loaf* and *MD2* variety. The highest mean 'D' leaf weight was recorded under *MD2* pineapple variety followed by *Smooth cayenne* and *Sugar loaf* variety with values 69.21 g, 59.64 g, and 56.71 g respectively (Table 8).

Table 9: Interactive effect of fertilizer application and pineapple variety on 'D' leaf of pineapple.

Variety × treatment interaction	Mean length (cm)	Mean width (cm)	Mean weight (g)
V1F1	79.00	4.65	71.50
V1F2	81.10	5.70	68.50
V1F3	83.15	5.85	77.50
V1F4	80.50	5.65	64.00
V1F5	78.10	6.05	64.50
V1F6	69.40	5.15	52.50
V1F7	92.45	6.05	86.00
V2F1	91.95	4.35	37.00
V2F2	88.45	5.40	51.50
V2F3	92.25	6.15	61.00
V2F4	93.60	5.70	57.00
V2F5	91.45	5.75	58.50
V2F6	94.50	6.50	72.50
V2F7	86.50	5.70	59.50
V3F1	83.05	5.05	62.50
V3F2	82.00	5.10	52.50
V3F3	73.50	5.75	52.00
V3F4	79.50	6.30	66.50
V3F5	82.15	6.45	69.50
V3F6	77.00	6.20	59.50
V3F7	78.05	5.10	55.00
l.s.d	9.389	0.8165	9.986
F pr.	0.010 **	0.015**	<.001***

*NS= not significant (P > 0.05), *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P < 0.001*

V1= MD2, V2= Sugar loaf, V3= Smooth cayenne

F1 (Control), F2 (Compost 10 t/h), F3 (Biochar 10 t/ha), F4 (NPK), F5 (Comp 10 t/ha + Bio 10t/ha), F6 (Comp 10/ha + NPK) and F7 (Bio 10 t/ha + NPK).

The variety and fertilizer interaction had a significant effect on pineapple mean ‘D’ leaf length throughout the vegetative growth of the plant (Table 9). The mean ‘D’ leaf length varied significantly (P < 0.05) among different pineapple varieties and fertilizer interaction (Table 9). The highest ‘D’ leaf length was recorded under V2F6 with a value of 94.50 cm. Aside from this variety and fertilizer interaction; V1F7, V2F1, V2F3, V2F4, and V2F5 are the interactions which recorded higher mean 'D' leaf among the others. The interaction under V1F6 recorded the lowest length of 'D' leaf. Looking at the result (Table 9), treatment F6 (Compost + NPK) under *MD2* variety recorded the lowest mean 'D' leaf length but the same treatment F6 (Compost + NPK) under Sugar loaf variety recorded the highest mean 'D' leaf length. The mean 'D' leaf width had no significant variation among the pineapple varieties and fertilizer interaction (Table 9).

The study shows *Sugar loaf* pineapple variety planted on soil amended with compost and inorganic NPK fertilizer (V2F6) had the highest mean 'D' leaf width (6.50 cm) before floral induction. The same interaction was observed to be one that recorded the highest mean 'D' leaf length from Table 9. *Sugar loaf* pineapple variety planted on unamended soil (V2F1) had the lowest mean 'D' leaf width which was significantly ($P < 0.05$) different from the other treatment interaction. Plots amended with combined biochar and compost under the treatment interaction V3F5 recorded the second-highest mean 'D' leaf width prior to induction of pineapple flower.

The interaction between pineapple variety and fertilizer application had a significant effect on pineapple mean 'D' leaf weight (Table 9). F7, F3, and F1 under the *MD2* variety pineapple variety gave a significantly ($P < 0.001$) higher mean 'D' leaf weight than their counterpart under the *MD2* variety, and the treatment interaction V1F3 had the highest 'D' leaf weight of 86.00 g among all the varieties. Even though the treatment variety interactions V1F6, V2F2, V3F2, and V3F3 gave significantly ($P < 0.05$) lower mean 'D' leaf weight per plant than the others, the lowest mean 'D' leaf weight of 37.00 g was recorded in V2F1 (Table 9).

Table 10: Yield component of pineapple as affected by pineapple variety and fertilizer application.

Treatments	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)
Control	825.90	6.14	13.63
Compost	864.80	6.15	13.22
Biochar	915.70	6.56	13.63
NPK	1058.10	6.95	14.16
Bio+Com	979.30	6.76	13.68
Com+NPK	1148.10	7.27	14.38
Bio+NPK	1032.10	6.78	13.96
l.s.d	109.0	0.4121	0.4631
F pr.	<.001 ***	<.001 ***	<.001***
Variety			
MD2	896.90	5.67	13.99
Sugar loaf	856.30	7.32	12.97
Smooth cayenne	1171.30	6.99	14.46
l.s.d	71.3	0.2698	0.3032
F pr.	<.001 ***	<.001 ***	<.001 ***

*NS= not significant (P > 0.05), *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P < 0.001*

V1= MD2, V2= Sugar loaf, V3= Smooth cayenne.

F1 (Control), F2 (Compost 10 t/h), F3 (Biochar 10 t/ha), F4 (NPK), F5 (Comp 10 t/ha + Bio 10t/ha), F6 (Comp 10/ha + NPK) and F7 (Bio 10 t/ha + NPK).

The results of the yield component of pineapple as affected by fertilizer application are presented in Table 10. A highly significant difference (P < 0.001) was observed among the treatments in respect of pineapple fruit weight. The NPK fertilizer applied with compost recorded the highest fruit weight among all the treatments whereas the lowest fruit weight (825.90 g) was recorded by the control plot. The highest pineapple fruit length (7.27 cm) was observed under the combined application of compost and NPK which was significantly (P < 0.001) different from the rest of the treatments. The control plot recorded the lowest fruit length (6.14 cm)

There was a significant (P < 0.001) difference observed among all the treatments under fruit diameter (Table 10). The application of compost together with inorganic NPK fertilizer recorded the highest fruit diameter (14.38 cm). The sole application of compost recorded the lowest fruit diameter (13.2 cm) but was not significantly different from the control and sole application of biochar (Table 10).

Table 10 also shows the yield component of pineapple as affected by pineapple varieties. From the Table, there was a significant (P < 0.001) difference among the pineapple varieties under fruit weight. *Smooth cayenne* pineapple variety had the highest fruit weight (1171.3 g) which was significantly higher than the *MD2* variety (896.9 g) and *Sugar loaf* variety (856.3 g) variety. Under the fruit length from the same table, the *Sugar loaf* variety recorded the highest fruit length to be 7.32 cm but was significantly higher than *MD2* and smooth cayenne variety. From the results, the smooth cayenne variety recorded the highest fruit diameter to be 14.46 cm which was significantly (P < 0.001) higher than the fruit diameter recorded by sugar loaf and *MD2* pineapple variety.

Table 11: Interactive effect of pineapple variety and fertilizer application on pineapple yield.

Variety × treatment interaction	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)
V1F1	708.80	5.38	14.05
V1F2	899.80	5.44	13.68
V1F3	877.10	5.60	13.89
V1F4	976.00	5.87	14.33
V1F5	906.90	5.50	13.63
V1F6	1040.10	6.17	14.71
V1F7	869.90	5.74	13.67
V2F1	670.30	6.28	12.49
V2F2	743.60	6.89	12.65
V2F3	866.80	7.47	12.99
V2F4	849.50	7.32	12.93
V2F5	891.50	7.77	12.87
V2F6	1029.70	7.84	13.40
V2F7	942.80	7.70	13.46
V3F1	950.90	6.77	14.35
V3F2	1098.50	6.14	13.32
V3F3	1003.30	6.62	14.00
V3F4	1348.80	7.68	15.21
V3F5	1139.50	7.01	14.54
V3F6	1374.50	7.80	15.04
V3F7	1283.50	6.91	14.74
l.s.d	188.7	0.7139	0.8021
F pr.	0.125 NS	0.069 NS	0.114 NS

*NS= not significant ($P > 0.05$), *= significant at $P < 0.05$**= significant at $P < 0.01$, ***= significant at $P < 0.001$*

V1= MD2, V2= Sugar loaf, V3= Smooth cayenne.

F1 (Control), F2 (Compost 10 t/h), F3 (Biochar 10 t/ha), F4 (NPK), F5 (Comp 10 t/ha + Bio 10t/ha), F6 (Comp 10/ha + NPK) and F7 (Bio 10 t/ha + NPK).

The interaction between pineapple variety and fertilizer application had no significant effect on the pineapple fruit weight, fruit length, and fruit diameter (Table 11). F4, F5, and F6 under *MD2* pineapple variety gave a significant ($P < 0.05$) higher fruit weight than the rest of the treatment under the same variety. The plot which did not receive fertilizer under the *MD2* variety gave a fruit weight of 708.80 g, which was significantly lower than that produced by F2 and F3 by *MD2* variety. Under the *Sugar loaf* pineapple variety, F6 recorded the highest fruit weight but was not significantly different from the rest of the treatments. F1 which is the plot with no treatment recorded the lowest fruit weight under the *Sugar loaf* pineapple variety. F6 which is the combination of compost and inorganic fertilizer (NPK) had the highest fruit weight under the smooth cayenne variety which was not significantly different from F4, F5, F2, and F3. The lowest fruit weight under smooth cayenne variety was recorded by the F1. V3F6 gave a higher fruit weight than V2F6 and V1F6, even though the difference was not significant. The lowest fruit weight 670 g was recorded in V2F1 while the highest of 1374.50 g was recorded in V3F6 (Table 11).

The highest fruit length of 7.84 cm was produced on sugar loaf variety where compost was applied together with NPK (V2F6). This was not significantly ($P < 0.05$) higher than F4, F3, F5, F7, under sugar loaf variety; F4, F5 under *smooth cayenne* variety, and F6 under *MD2* variety (Table 11). The lowest fruit length was recorded by the *MD2* pineapple variety planted on unamended soil (V1F1). The variety and fertilizer application interaction did not significant ($P < 0.05$) affect pineapple fruit diameter (Table 12). The highest fruit diameter of 15.21 cm was produced by smooth cayenne on the plot which NPK was applied (V3F4), sugar loaf pineapple variety grown on unamended soil (V2F1) had the lowest fruit diameter of 12.49 cm.

Effect of NPK, compost, and/or biochar application on N, P, and K contents of pineapple leaves at fruiting.

The percentage nitrogen, phosphorus, and potassium contents of pineapple leaves are presented in Tables 12 and 13.

Table 12: Effect of variety and fertilizer application on N, P, and K contents of pineapple leaves at fruiting.

Treatment	Nitrogen in leaf (%)	Phosphorus in leaf (%)	Potassium in leaf (%)
Control	0.79	0.20	1.05
Compost	0.85	0.22	1.11
Biochar	0.89	0.21	1.14
NPK	0.86	0.26	1.06
Bio+Com	0.89	0.23	1.10
Com+NPK	0.89	0.21	1.07
Bio+NPK	0.94	0.22	1.07
l.s.d	0.037	0.006	0.024
F pr.	<.001	<.001	<.001
Variety			
MD2	0.85	0.25	1.12
Sugar loaf	0.99	0.19	1.08
Smooth cayenne	0.82	0.24	1.05
l.s.d	0.023	0.004	0.016
F pr.	<.001	<.001	<.001

*NS= not significant (P > 0.05), *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P < 0.001*

V1= *MD2*, V2= *Sugar loaf*, V3= *Smooth cayenne*, F1 (Control), F2 (Compost 10 t/h), F3 (Biochar 10 t/ha), F4 (NPK), F5 (Comp 10 t/ha + Bio 10t/ha), F6 (Comp 10/ha + NPK) and F7 (Bio 10 t/ha + NPK).

Significant differences (P < 0.001) were observed in pineapple leaf nutrient (N, P, and K) content among all the treatments (Table 12). Pineapple leaf harvest from the plot amended with biochar and NPK fertilizer recorded the highest (0.94 %) nitrogen (N) content. It was also noticed that the sole application of biochar, combined application of biochar and compost, and application NPK in combination with compost had the same N content (0.89 %). The control treatment recorded the lowest N content in pineapple leaf. The plot amended with inorganic fertilizer (NPK) recorded the highest (0.26 %) phosphorus (P) content which was significantly ($P < 0.001$) different from the rest of the treatments. The control plot recorded the least (0.2 %) P content (Table 12). Biochar amended soil recorded the highest K content (1.14 %) in the pineapple leaf whilst the control had the lowest content of K in pineapple leaf though was not significantly ($P > 0.05$) different from plots amended with NPK, Compost + Biochar, and Biochar + NPK.

Nitrogen, phosphorus, and potassium content in pineapple leaf varied significantly among the varieties (Table 12). *The sugar loaf* pineapple variety recorded the highest N content of 0.99 % followed by the *MD2* variety. The lowest percentage N content was recorded by the *Smooth cayenne* variety. For the percentage P content, the *MD2* pineapple variety recorded the highest (0.25 %) while the *Sugar loaf* variety had the least (0.19 %). *MD2* variety had the highest K content and *Smooth cayenne* with the lowest K content recording 1.12 % and 1.05 % respectively.

Table 13: Interactive effect of pineapple variety and fertilizer application on N, P, and K contents of pineapple leaves at fruiting.

Variety × treatment interaction	**Nitrogen in leaf (%)**	**Phosphorus in leaf (%)**	**Potassium in leaf (%)**
V1F1	0.68	0.27	1.13
V1F2	0.82	0.26	1.14
V1F3	0.88	0.22	1.18
V1F4	0.84	0.32	1.04
V1F5	0.87	0.27	1.11
V1F6	0.88	0.20	1.08
V1F7	0.73	0.21	1.17
V2F1	0.80	0.25	1.10
V2F2	0.97	0.16	1.13
V2F3	0.97	0.17	1.13
V2F4	0.96	0.18	1.10
V2F5	1.06	0.19	1.12
V2F6	1.01	0.18	1.01
V2F7	1.02	0.19	0.99
V3F1	0.71	0.26	0.97
V3F2	0.76	0.24	1.07
V3F3	0.83	0.25	1.12
V3F4	0.79	0.24	1.05
V3F5	0.73	0.23	1.08
V3F6	0.78	0.23	1.05
V3F7	0.96	0.26	1.00
l.s.d	0.063	0.010	0.041
F pr.	<.001	<.001	<.001

NS= not significant (P > 0.05), *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P < 0.001.

V1= MD2, V2= Sugar loaf, V3= Smooth cayenne, F1 (Control), F2 (Compost 10 t/h), F3 (Biochar 10 t/ha), F4 (NPK), F5 (Comp 10 t/ha + Bio 10t/ha), F6 (Comp 10/ha + NPK) and F7 (Bio 10 t/ha + NPK).

From Table 13, the interaction between pineapple variety and treatment exhibited significant (P < 0.001) differences in this experiment for pineapple leaf N, P, and K content where the control had the lowest N concentration of 0.68 % in V1F1, 0.80 %

in V2F1 and 0.71 % in V3F1 with 1.06 % the highest obtained in V2F5. The phosphorus (P) content in pineapple leaves was observed to be higher in V1F4 recording 0.32 % which was significantly different from the rest. The least P content was obtained in V2F2. The highest leaf K content of 1.18 % was obtained in V1F3 which was significantly different from the other fertilizer treatment. The lowest leaf potassium content of 0.97 % was obtained in V3F1 (Table 13).

Effect of inorganic NPK fertilizer, biochar, and/ or compost application on protein and mineral content of pineapple juice

Table 14: Effect of fertilizer application and pineapple varieties on protein and mineral content of pineapple juice

Treatment	Protein (%)	Phosphorus	Potassium	Sodium	Calcium	Magnesium
		(mg l^{-1})				
Control	6.61	362.30	133.40	62.86	113.10	16.16
Compost	6.92	258.90	140.60	60.22	109.40	11.11
Biochar	6.65	261.00	144.10	51.70	106.50	13.94
NPK	7.20	268.40	146.20	54.85	112.20	13.67
Bio+Com	7.61	295.10	136.00	52.33	116.80	13.81
Com+NPK	7.08	272.00	134.60	52.00	112.20	14.23
Bio+NPK	7.04	314.20	135.20	51.73	110.60	14.93
l.s.d	0.152	3.037	0.639	2.047	4.672	1.070
F pr.	<.001	<.001	<.001	<.001	0.003	<.001
Variety						
MD2	6.69	282.40	151.60	54.58	114.30	15.69
Sugar loaf	8.85	299.90	144.10	76.98	109.60	12.75
Smooth cayenne	5.51	288.50	120.00	33.73	110.70	13.49
l.s.d	0.099	1.988	0.418	1.340	3.058	0.700
F pr.	<.001	<.001	<.001	<.001	0.008	<.001

*NS= not significant (P > 0.05), *= significant at P < 0.05**= significant at P < 0.01, ***= significant at P < 0.001*

The protein content of pineapple juice samples is presented in Table 14 and the percentage mean protein content ranges from 6.61 % to 7.61 %. Juice from pineapple planted with biochar in combination with compost was significantly ($P < 0.001$) higher in protein content than pineapple juice from other fertilizer. The control treatment recorded the lowest percentage protein in pineapple juice. The mineral contents of pineapple juice samples are presented in Table 14. The result showed that the phosphorus (362.30 mg l^{-1}), sodium (62.86 mg l^{-1}), and magnesium (16.16 mg l^{-1}) content in the juice from pineapple planted on unamended soil were significantly ($P < 0.001$) higher than juice from pineapple treated with compost only, biochar only, NPK only, biochar + compost, compost + NPK fertilizer and biochar + NPK fertilizer.

Pineapple treated with NPK fertilizer had the highest potassium content of 146.20 mg l^{-1} whereas pineapple planted on unamended soil recorded the lowest potassium content (133.40 mg l^{-1}). Similarly, biochar applied in combination with compost recorded the highest juice calcium content (116.80 mg l^{-1}), while juice obtained from pineapple treated with biochar had the lowest calcium content of 106.50 mg l^{-1}.

From Table 14, there was a significant difference in juice mineral content among the pineapple varieties planted. The juice from the *Sugar loaf* pineapple variety recorded the highest percentage protein (8.85 %), phosphorus (299.90 mg l^{-1}), and sodium (76.98 mg l^{-1}). The least percentage protein and sodium content were recorded by the juice from smooth cayenne with values of 5.51 % and 33.73 mg l^{-1} respectively. Also, the least phosphorus content was recorded by *MD2* (282.40 mg l^{-1}). However, the juice from *MD2* variety had the highest potassium (151.60 mg l^{-1}), calcium (114.30 mg l^{-1}), and magnesium (15.69 mg l^{-1}) contents. The juice from the *Sugar loaf* pineapple variety had the lowest calcium and magnesium content (Table 14).

Table 15: Interactive effect of pineapple variety and fertilizer application on protein and mineral content of pineapple juice

Variety × treatment interaction	Protein	Phosphorus	Potassium	Sodium	Calcium	Magnesium
	(%)			(mg l^{-1})		
V1F1	6.62	309.9	148.5	55.26	111.4	16.91
V1F2	6.41	220.1	143.5	55.10	107.8	12.75
V1F3	6.13	282.1	151.6	53.44	107.2	13.83
V1F4	6.41	249.6	147.7	53.01	113.3	12.98
V1F5	8.09	335.5	152.0	55.66	139.3	17.73
V1F6	7.03	281.7	158.2	55.42	110.2	18.51
V1F7	6.13	297.9	159.6	54.19	111.3	17.12
V2F1	7.34	368.5	132.8	97.71	112.3	18.78
V2F2	9.00	267.6	141.8	97.55	110.3	8.19
V2F3	9.41	261.2	142.8	66.46	111.7	16.18
V2F4	9.58	277.0	169.5	77.14	109.1	10.95
V2F5	9.14	289.8	140.8	67.33	110.3	12.40
V2F6	8.36	264.6	144.1	67.09	115.0	11.47
V2F7	9.14	271.0	137.2	65.62	98.4	11.29
V3F1	5.87	308.6	118.9	35.60	115.6	12.78
V3F2	5.35	288.9	136.4	28.01	110.0	12.40
V3F3	4.41	239.8	137.9	35.21	100.7	11.81
V3F4	5.63	278.7	121.3	34.41	114.4	17.07
V3F5	5.63	259.9	115.1	34.02	100.8	11.30
V3F6	5.84	269.7	101.6	33.50	111.5	12.70
V3F7	5.86	373.6	108.7	35.36	122.0	16.38
l.s.d	0.263	5.260	1.1068	3.546	8.091	1.853
F pr.	<.001	<.001	<.001	<.001	<.001	<.001

The interaction between pineapple variety and fertilizer application had a significant effect on the pineapple fruit juice mineral content (Table 15). The highest juice percentage protein (9.58 %) was recorded in V2F4 where *Sugar loaf* was treated with NPK fertilizer. Though V1F5 recorded the highest percentage protein under *MD2* pineapple variety, and V3F1 had the highest percentage protein under smooth cayenne. The juice from *Smooth cayenne* treated with biochar only recorded the least (4.41 %) protein content. Smooth cayenne variety treated with biochar and NPK fertilizer recorded the highest (373.6 mg l^{-1}) phosphorus concentration in pineapple juice, while *MD2* treated with compost only had the lowest (220.1 mg l^{-1}) phosphorus content in pineapple juice. Potassium content in pineapple juice was higher in V2F4 but biochar application in combination with NPK fertilizer had the lowest potassium content under the smooth cayenne variety. Similarly, the highest (97.55 mg l^{-1}) sodium content was recorded under V2F2, whereas the lowest (28.01 mg l^{-1}) was recorded under V3F2. The result also showed that the calcium was higher (139.3 mg l^{-1}) in samples treated with biochar and compost under *MD2* variety but magnesium was higher (18.78 mg l^{-1}) in ordinary soil without any treatment under the same variety (MD2). The lowest calcium and magnesium content in pineapple juice was obtained in V2F7 and V2F2 recorded values of 98.4 mg l^{-1} and 8.19 mg l^{-1} respectively (Table 15).

Effect of inorganic NPK fertilizer, biochar, and /or compost on pineapple fruit quality

The fruit quality of pineapple as affected by inorganic NPK fertilizer, biochar, and/or compost is presented in Table 16 and 17.

Table 16: Effect of fertilizer application and pineapple varieties on pineapple fruit quality

Treatment	**pH**	**TSS**	**TA**	**TAC**	**TF**	**TPC**	**Vit C**
		°Brix	**(g kg^{-1})**		**(mg 100 ml^{-1})**		
Control	3.96	13.17	7.28	24.63	24.99	13.88	8.57
Compost	3.96	14.04	6.95	21.12	19.07	15.75	17.39
Biochar	3.94	12.60	7.19	16.39	12.94	19.18	16.50
NPK	3.97	13.47	6.60	16.01	13.90	13.99	9.05
Bio+Com	4.00	14.29	6.38	16.60	18.04	14.88	12.99
Com+NPK	4.03	12.86	6.61	19.52	16.90	16.39	11.32
Bio+NPK	3.98	12.88	6.03	22.92	17.39	20.18	11.30
l.s.d	0.067	1.213	0.449	5.385	10.07	4.823	4.903
F pr.	0.148	0.055	<.001	0.008	0.307	0.065	0.001
Variety							
MD2	3.99	13.22	6.52	15.94	8.08	9.97	13.49
Sugar loaf	4.14	15.47	7.16	26.95	22.68	13.36	9.24
Smooth cayenne	3.80	11.30	6.50	15.92	22.06	25.64	13.39
l.s.d	0.044	0.794	0.294	3.525	6.590	3.158	3.210
F pr.	<.001	<.001	<.001	<.001	<.001	<.001	0.013

TSS= Total Soluble solids, TA = Titratable acidity, TAC= Total Antioxidant Capacity, TF= Total Flavonoids, TPC= Total Phenolic content, Vit C= Vitamin C.

The fertilizer application on pineapple fruit quality is presented in Table 16. There was no significant difference ($P > 0.05$) between the pH of the pineapple fruit juice among all the treatments. Pineapple plant grown on soil amended with compost and NPK fertilizer recorded the highest pH value of 4.03, whereas pineapple treated with biochar had the lowest pH value of 3.94. The highest total soluble solids (TSS) of 14.29 % was obtained in pineapple planted on soil amended with biochar and compost though was not significantly different from the rest of the treatment. Sole application of biochar recorded the least TSS (12.60 %). Titratable acidity (7.28 g kg^{-1}), total antioxidant capacity (24.63 mg 100 ml^{-1}), and total flavonoid (24.99 mg 100 ml^{-1}) were high in the juice from plant on control plots. Biochar in combination with NPK fertilizer had the lowest titratable acidity (6.03 g kg^{-1}), NPK fertilizer only had the least total antioxidant content (16.01 mg 100 ml^{-1}), and the plot which received biochar only recorded the lowest (12.94 mg 100 ml^{-1}) total flavonoid from Table 16. Pineapple plant treated with biochar and NPK fertilizer recorded the highest (20.18 mg 100 ml^{-1}) total phenolic content (TPC). The highest (17.70 mg l^{-1}) vitamin C level was recorded in plant harvested from soil amended with compost solely. However, fruits harvest from the unamended soil without any amended recorded the lowest TPC (13.88 mg 100 ml^{-1}) and vitamin C content (8.57 mg 100 ml^{-1}).

Table 16 gives information about the fruit quality of pineapple as affected by pineapple varieties. Significant ($P < 0.001$) difference was observed among pineapple varieties and fruit quality. The highest pH (4.14), TSS (15.47 %), TA (7.16 g kg^{-1}), TAC (26.95 mg 100 ml^{-1}) and TF (22.68 mg 100 ml^{-1}) was recorded by *sugar loaf* variety. The lowest pH (3.80), TSS (11.30 %), TA (6.50 g kg^{-1}), and TAC (15.94 mg 100 ml^{-1}) was recorded by *Smooth cayenne* pineapple variety. However, the *MD2* had the least (8.08 mg 100 ml^{-1}) total flavonoid (TF). Subsequently, smooth cayenne obtained the highest total phenolic content (TPC) (25.64 mg 100 ml^{-1}) while the *MD2* variety obtained the least total phenolic content (9.97 mg 100 ml^{-1}). Moreover, the highest (13.49 mg 100 ml^{-1}) vitamin C content was obtained by *MD2* variety whereas the lowest vitamin C content (9.24 mg 100 ml^{-1}) was recorded by *Sugar loaf* pineapple variety (Table 16).

Table 17: Interactive effect of pineapple variety and fertilizer on pineapple fruit quality

Variety × treatment interaction	**pH**	**TSS (ºBrix)**	**TA (g kg^{-1})**	**TAC (mg 100 ml^{-1})**	**TF (mg 100 ml^{-1})**	**TPC (mg 100 ml^{-1})**	**Vit C (mg 100 ml^{-1})**
V1F1	3.96	13.35	7.17	19.93	10.99	10.56	19.22
V1F2	3.96	12.83	6.69	15.40	7.07	9.70	12.38
V1F3	3.91	13.15	6.97	12.95	4.93	9.67	8.84
V1F4	4.01	12.40	6.38	13.02	6.06	10.81	9.68
V1F5	4.05	14.35	6.10	12.60	6.20	10.28	10.05
V1F6	4.04	14.20	6.36	15.73	10.71	8.52	12.52
V1F7	3.95	12.27	5.84	21.84	10.61	10.23	21.73
V2F1	4.11	14.45	7.51	34.03	36.74	15.23	7.80
V2F2	4.19	17.54	7.45	32.56	29.90	13.77	9.41
V2F3	4.11	13.38	7.63	23.27	14.42	12.44	8.04
V2F4	4.15	16.28	7.05	21.99	15.85	12.50	11.05
V2F5	4.15	16.68	6.95	24.60	26.58	14.24	9.87
V2F6	4.13	14.95	7.13	27.12	17.29	12.47	8.86
V2F7	4.14	15.05	6.44	25.09	17.96	12.86	9.63
V3F1	3.81	10.43	7.17	17.84	27.26	31.75	19.22
V3F2	3.78	11.75	6.49	16.41	20.25	23.76	12.38
V3F3	3.80	11.28	6.67	13.05	19.48	19.53	8.84
V3F4	3.74	11.75	6.28	12.02	19.78	18.65	9.68
V3F5	3.79	11.85	6.10	14.60	21.34	20.13	10.05
V3F6	3.86	11.70	6.54	15.73	22.69	28.18	12.52
V3F7	3.84	11.33	5.84	20.92	23.61	37.45	21.73
l.s.d	0.116	2.102	0.777	9.327	17.44	8.354	8.492
F pr.	0.754	0.039	1.000	0.851	0.892	0.047	0.748

TSS= Total Soluble solids, TA = Titratable acidity, TAC= Total Antioxidant Capacity, TF= Total Flavonoid, TPC= Total Phenolic content, Vit C= Vitamin C.

Pineapple variety and fertilizer interaction significantly ($P < 0.05$) affected total soluble solids (TSS) of pineapple juice (Table 17). The highest (TSS) of 17.54 % was produced by Sugar loaf pineapple planted on plots on which compost was applied (V2F2), and the least total soluble solid of 10.43 % was obtained on the plot where Smooth cayenne pineapple was grown and unamended (V3F1).

Interaction of pineapple variety and fertilizer also significantly ($P < 0.05$) affected the total phenolic content of pineapple juice (Table 17). The highest total phenolic content of 37.45 mg 100 ml^{-1} was obtained by *Smooth cayenne* pineapple variety planted on a plot on which biochar and NPK fertilizer were applied (V3F7), whereas the least total phenolic content (TPC) of 8.52 mg 100 ml^{-1} was recorded on the plot where *MD2* pineapple variety was planted and amended with compost and NPK fertilizer (V1F6).

Interaction between pineapple variety and fertilizer application did not significantly ($p < 0.05$) affect pineapple juice pH, titratable acidity (TA), total antioxidant content (TAC), total flavonoid (TF), and vitamin C (Table 17). V2F2 had the highest (4.19) pH but was not significantly different from V2F5 and the lowest (3.74) was recorded in V3F4. Also, titratable acidity was higher in V2F3 and lower in V3F7. The highest total antioxidant content (34.03 mg 100 ml^{-1}) was recorded on unamended soil where *Sugar loaf* pineapple variety was grown (V2F1), and the lowest (12.02 mg 100 ml^{-1}) was recorded on a plot where Smooth cayenne was grown and fertilized with NPK fertilizer. Similarly, V2F1 recorded the highest (36.74 mg 100 ml^{-1}) total flavonoid content and the lowest (4.93) obtained in V1F3. Pineapple juice produced from MD2 and Smooth cayenne variety planted on plots amended with biochar and NPK fertilizer had the highest vitamin C content of the same value (21.73 mg 100 ml^{-1}), whereas the lowest (7.80 mg 100 ml^{-1}) was obtained in V2F1.

CHAPTER FIVE

DISCUSSION

Soil physicochemical properties

The soil pH of 6.8 is considered to be optimal for plant growth. Parikh and James (2012). stated that soil pH ranging from 6 to 7.5 is optimal for plant growth but some plant species can tolerate more basic or acidic conditions. The soil bulk density of 1.55 g cm^{-3} is fair. Soil bulk density less than or equal to 1.3 g cm^{-3} is considered to be good; between 1.3 g cm^{-3} and 1.55 g cm^{-3} is fair; and greater than 1.8 g cm^{-3} is extremely bad (Mukhopadhyay et al., 2019). Mukhopadhyay et al. (2019) explained that soil bulk density directly influences soil structure, compaction, and water holding capacity. Soil bulk density can be affected by soil particle size distribution, soil structure and organic matter content, and the management practices are done on the soil (Mukhopadhyay et al., 2019).

Total nitrogen (TN), available phosphorus (P), exchangeable calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), and sodium (Na^+) contents, and soil organic carbon content were all low. This finding is in agreement with Laekemariam, Kibret, and Mamo, (2017)'s report. Landon (2014) reported that soil TN values ranging from 0.1 – 0.2 % are low. The total nitrogen content of the soil was low (Table 6) (total N < 0.13 %) as per the standards of the Ministry of Food and Agriculture (2012).

Nitrogen is a very important plant nutrient because plants need it in large amounts but it is easily lost from the soil through leaching, erosion, volatilization, and runoff. The available phosphorus content of the soil was low (Table 6) (available P < 0.20 mg kg^{-1}) according to the standards of the Ministry of Food and Agriculture (2012). The low level of soil total N and available P of the experimental field in this study is in agreement with the report of the Ministry of Food and Agriculture (2015) who explained that the extent of nutrient depletion is widespread in all the agro-ecological zones of Ghana, with nitrogen and phosphorus being the most deficient nutrients. Soil organic carbon is one of the most important constituents of the soil due to its capacity as both a source of energy and nutrients for soil microorganisms and a trigger for nutrient availability through mineralization. A low soil organic carbon is reduced microbial biomass, activity, and nutrient mineralization due to shortage of energy sources. This may reduce the effect of mineral fertilizers on crop yield in such soils. Also, soil erosion as well as practices like burning, crop, and residue removal can further exacerbate the low soil organic carbon content of the area of study (MoFA, 2015).

The pH for biochar (9.8) and compost (8.5) were both strongly alkaline (Table 6). Prasad et al. (2019) have explained that the high pH of biochars can be attributed to the higher temperature at which they are pyrolysed. According to Mohd Hasan et al. (2019), pyrolysis temperature from 400 ^{o}C and above leads to the high pH of the biochar produced. They further explained that a 25 % increase in pyrolysis temperature from 400 to 500 ^{o}C can produce biochar with pH around 10. The pyrolysis process leads to a by-product (biochar), which has a high concentration of basic ions. The total phosphorus (P) contents of the biochar and compost were high (Trupiano et al., 2017). Pineapple biochar contained a higher organic carbon content compared to the composted pineapple waste. The relatively higher total organic C (TOC) in the pineapple biochar than the composted pineapple feedstock may be due to the presence of higher fractions of stable and total carbon as the high pyrolysis temperature caused an increase in the amounts of volatiles released leading to a concentration of C forms in the biochar (Crombie et al., 2012; Bird, 2015).

Growth performance of pineapple following pineapple waste compost and / or biochar application

Plant height

Pineapple plants were relatively taller in the combined biochar and compost, and combined compost and with NPK treatments for the *MD2, Sugar loaf, and Smooth cayenne* pineapple varieties compared to the other treatments (Figure 7). The results are in accordance with Hossain et al. (2019) who reported that the sole application of biochar without inorganic fertilizer resulted in a lower plant height compared to the combined application of biochar and inorganic fertilizer. The increased plant height following the integration of biochar and compost can be attributed to the potential synergistic effect between the combined application of biochar and compost on soil physicochemical properties such as soil pH, available phosphorus, total organic carbon, exchangeable basis and acidity, effective cation exchange capacity, and greater soil nutrients, especially N availability, which would have improved cell division, plant growth and physiological performance (Seehausen et al., 2017; Mensah and Frimpong, 2018). The relatively greater height of pineapples grown in the Compost + NPK amended soil may be as a result of increased nutrients release from the readily soluble inorganic NPK fertilizer, (Chen, 2008). According to Zhou et al. (2002) plants grown in soil amended with inorganic fertilizer in combination with organic manure grew quite rapidly due to enhanced N and P mineralization and release from the organic inputs. Schulz and Glaser (2012) also confirmed the inorganic NPK fertilizer application in addition to biochar increased plant height in tropical soils.

Number of leaves

Pineapple leaves varied significantly among varieties across the treatments (Figure 8). The maximum number of leaves obtained in soil amended with biochar and inorganic NPK fertilizer could be attributed to high nutrients supply from the amendment (Fischer and Glaser, 2012). Several researchers have reported that inorganic NPK fertilizer application in addition to biochar nutrient supply capacity is higher than the sole application of biochar (Fischer and Glaser, 2012; Schulz and Glaser, 2012). According to Lehmann et al. (2003) and Oladele et al. (2019), biochar and inorganic fertilizer applied together have synergistic effect, due to increasing plant nutrient uptake, lower nutrient loss, and increased cationic element availability and this may be another mechanism responsible for the increased number of leaves. The comparatively higher number of leaves and leaf development recorded in Figure 8 may be due to N, P, and K content in the soil as reported in other studies (Madon et al., 1995; Ayoola and Makinde, 2009; Adekiya, et al. 2012).

Interactive effect of pineapple variety and fertilizer application on growth parameters of pineapple.

Pineapple varieties and fertilizer interaction had a significant variation on pineapple height (Table 7). This result is similar to that obtained by (Schulz and Glaser, 2012). The highest plant height recorded by Sugar loaf pineapple variety planted on soil amended with compost and NPK fertilizer (V2F6) could be attributed to the fact that nutrients were released at different times from organic (compost) and NPK fertilizers

(Islam et al., 2017). Pineapple variety and fertilizer interaction had a significant effect on pineapple number of leaves (Table 7). V3F7 recorded the maximum number of leaves compared to the other interaction as presented in Table 7. According to (Khan et al., 2008; Arif et al., 2012) the beneficial effect of inorganic fertilizer (NPK) on number of leaves of pineapple growth could be attributed to the positive impact of nitrogen (N) and probably the phosphorus (P) and potassium (K) content in the fertilizer on vigorous vegetative plant growth. The lower number of leaves of the pineapple plant observed in the control could be attributed to less available N and other nutrients required for optimum plant growth (Khan et al., 2008). The result of the study is in agreement with the findings of Fagbenro et al. (2018).

Pineapple 'D' leaf as affected by inorganic NPK fertilizer, biochar, and/or compost application prior to floral

The 'D' leaf is defined as the utmost physiological matured leaf. It's the longest leaf you can see after the upper blades are being gathered in both hands (Sinha et al., 2018). As shown in Table 8, biochar and NPK fertilizer applied together increased pineapple 'D' leaf length and width. This indicates a strong positive synergistic effect of the combined application of biochar and NPK fertilizer (Mete et al., 2015). This can also be explained on the basis that the inorganic fertilizer (NPK) applied together with the biochar released enough nitrogen into the soil for pineapple plant uptake. This confirms findings of Tei et al. (2000). From Table 8, the *Sugar loaf* pineapple variety had the longest 'D' leaf length, the highest 'D' leaf width was recorded by smooth cayenne variety whereas the maximum 'D' leaf weight was obtained by *MD2* variety. This result can be attributed to the total number of leaves on the suckers of the various varieties before it was planted.

Interactive effect of fertilizer application and pineapple variety on 'D' leaf of pineapple.

Pineapple ‘D’ leaf length and width varied significantly among the different pineapple varieties cross the treatments (Table 9). The results indicated that Sugar loaf pineapple variety grown on plots amended with compost and NPK fertilizer (V2F6) recorded the highest mean ‘D’ leaf length and width compared to the other treatments. This observation can be explained that nitrogen released from the compost and NPK fertilizer was utilized by the Sugar loaf pineapple variety as compared to MD2 and Smooth cayenne pineapple varieties. Apart from organic fertilizers releasing nutrients into the soil to enhance soil physicochemical properties, which improve the growth of plant and development (Idem et al., 2012). As shown in Table 9, pineapple ‘D’ leaf weight varied significantly among pineapple varieties across the treatments. V1F7 produced the highest ‘D’ leaf weight. The result obtained for the ‘D’ leaf weight concurs with earlier findings of Tei et al. (2000) who reported that an increase in nitrogen (N) fertilizer application increase the fresh leaf weight of crops. According to Makinde et al. (2007) and Uko et al. (2009), the response of crops to fertilizer application is affected by soil nutrient reserved.

Yield component of pineapple as affected by pineapple variety and fertilizer application.

Compost + NPK treated pineapple had the highest fruit weight among the treatments (Table 10) due to the presence of N and P following the addition of inorganic fertilizer which makes nutrients soluble and readily available for plant growth (Chen, 2008). This result agrees with the findings of Ogundare et al (2015) and Khan et al (2017) who stated that maximum nutrient availability due to the combined application of organic and inorganic fertilizers improved plant nutrient absorption, which in turn contributed to dry matter production and fruit yield.

Similarly, compost applied in addition to NPK fertilizer recorded the highest pineapple fruit length and diameter. This result is in agreement with the observation made by Tewodros et al. (2018) who reported that the function of cell division, multiplication, and photosynthesis that led to an increase in the size and length of the leaves, fruits, and stems. Furthermore, both N and P are necessary for root formation, elongation, and increase in fruit length, diameter, and fruit yield.

Pineapple fruit weight, length, and diameter varied significantly across different pineapple varieties. *Smooth cayenne* pineapple variety had the highest (1171.3 g) fruit weight (Table 10). The highest pineapple fruit length was obtained by Sugar loaf pineapple variety. But Smooth cayenne pineapple variety had the highest fruit diameter. The inconsistency between the findings could be explained by the variation in soil fertility and the environmental conditions under which the plant was grown (Tewodros et al., 2018).

Interactive effect of pineapple variety and fertilizer application on pineapple yield.

As presented in Table 11, pineapple variety and fertilizer interaction had no significant variation on pineapple fruit weight, length, and diameter. The highest pineapple fruit weight was recorded by the Smooth cayenne variety planted on soil amended with compost and NPK fertilizer (V3F6). This finding is in line with the view of Khan et al. (2017) who reported that that maximum nutrient availability due to the combined application of organic and inorganic fertilizers improved plant nutrient absorption, which in turn contributed to dry matter production and fruit yield. Ademar, et al. (2004) also reported that the application of N, P, and K has significant differences in the fruit yield of pineapple. Pineapple fruit length did not vary significantly ($P > 0.05$) among pineapple variety across the treatments (Table 11). The highest fruit length of 7.84 cm was produced by *Sugar loaf* pineapple variety planted on the plot fertilized with compost and NPK fertilizer (V2F6). The result is in agreement with Ogundare et al. (2015) and Khan et al. (2017) who stated that maximum nutrient availability due to the combined application of organic and inorganic fertilizers improved plant nutrient absorption, which in turn contributed to dry matter production and fruit yield. V3F4 recorded the highest pineapple fruit diameter.

Effect of variety and fertilizer application on N, P, and K contents of pineapple leaves at fruiting.

The higher nitrogen content of pineapple leaf in the Biochar + NPK treatment was probably as a result of a reduction in N leaching due to biochar addition (Table 12). Similar results were obtained by Zheng et al. (2013), who reported that biochar supplement reduced demand for N fertilizer in crop production as a result of a decrease in N leaching, therefore, increase N use efficiency for crops. Biochar addition influences the bioavailability of N and also alters other nutrients bioavailability for plant uptake (Taghizadeh-Toshi et al., 2012; Basri et al., 2013). Bashir et al. (2012) also reported that nitrogen content in leaves significantly increased with the application of urea. Increased P contents of NPK treated pineapple leaf explains the fact that inorganic fertilizer has a positive effect on plant biomass because mineral fertilizer easily soluble for plant uptake and utilization (Chen, 2008).

The findings contradict the observation made by Darnaudery et al. (2016) who noted increased P content of leaf on soil amended with organic fertilizer. Biochar treated soil had the highest potassium content (1.14 %) in pineapple leaf (Table 12). This finding was consistent with those of Hossain et al. (2019) who reported a significant increase in K content for plant leaf for biochar amended soil as compared to NPK fertilizer application. According to Biederman and Harpole (2013) the application of biochar could increase K content in plant tissue effectively.

Interactive effect of pineapple variety and fertilizer application on N, P, and K contents of pineapple leaves at fruiting

Sugar loaf pineapple variety planted on soil amended with biochar and compost had the highest pineapple leaf N content (V2F5) (Table 13). The integration of biochar and compost may have resulted in the N released from compost decomposition being absorbed onto the porous biochar surface to minimize leaching. Besides, the high pH of the amended soil contributed to the release of nitrogen and other available nutrients in the soil (Dadhawal et al., 2011). According to Cross and Sohi (2011), adsorbed N would subsequently be slowly released for plant uptake. Increase in P content following NPK application under *MD2* pineapple variety indicate that inorganic fertilizer has a positive effect on plant biomass because it is soluble for plant uptake and utilization (Chen, 2008). The higher K content recorded by *MD2* pineapple variety on soil amended with biochar only in Table 13 is in agreement with those of Hossain et al. (2019) who reported a significant increase in K content for plant leaf for biochar amended soil as compared to NPK application. According to Biederman and Harpole (2013) application of biochar can increase K content in plant tissue effectively.

Pineapple juice protein and mineral contents as affected by biochar and/or compost and NPK fertilizer application.

Protein helps in providing essential body component, maintain fluid balance, hormones, and enzymes formation, and also contribute to the functioning of the immune system of the body (Tortoe et al., 2014). Pineapple juice from pineapple planted on soil amended with biochar and compost was significantly ($P < 0.001$) higher in protein than the rest of the pineapple juice samples (Table 14). The current findings conform with those of Worthington (2001) who reported that nitrogen from all fertilizer types enhances the amount and quality of the plant-produced protein. As presented in Table 14, the phosphorus (362.30 mg l^{-1}), sodium (62.86 mg l^{-1}), and magnesium (16.16 mg l^{-1}) content of pineapple juice produced from pineapple grown on unamended soil were significantly ($P < 0.001$) higher than pineapple juice produced from pineapple treated with any fertilizer. The result agreed with those of Abiose and Ikujenlola (2014) who experimented on the comparison of the mineral content of quality protein crops and chemical composition. Potassium content in pineapple juice increased significantly in soils amended with inorganic fertilizer (NPK). This attests to the fact that the application of inorganic fertilizer easily makes nutrients available for plant use and this supports a work done by Stefano et al. (2004). Also, the combination of compost and biochar (CB) increased calcium content in pineapple juice to an appreciable amount as compared to the rest of the treatments (Table 14). This can be attributed to the adsorbing property of biochar. Biochar is known to absorb nutrients and release it gradually for plant use (Trupiano et al., 2017).

The differences can also be attributed to the concentration of exchangeable cation (such as Ca, Mg, and K) on the treated soil, thus affecting the final mineral content of the pineapple juice (Ogunyemi et al., 2018).

Protein, phosphorus, potassium, magnesium, sodium, and calcium content varied significantly among different pineapple varieties (Table 14). The *sugar loaf* pineapple variety had the highest percentage protein, phosphorus, and sodium contents. From the findings, it can be concluded that mature sugar loaf variety is a good source of protein (Kader et al., 2010). The increase in phosphorus and sodium content observed in the *Sugar loaf* pineapple variety can be attributed to the utilization of fertilizers applied. However, the *MD2* pineapple variety had the highest potassium, calcium, and magnesium contents (Table 14). The findings are in partial agreement with Kader et al. (2014) who reported a significant increase in Mg, Ca, and K for the *MD2* pineapple variety.

Interaction of pineapple variety and fertilizer application on protein and mineral content of pineapple juice

The highest percentage protein (9.58 %) was recorded in V2F4 where *sugar loaf* pineapple variety was treated with NPK fertilizer (Table 15). Worthington (2001) reported that nitrogen from NPK fertilizer types enhances the amount and quality of the plant-produced protein. *Smooth cayenne* pineapple variety planted on soil amended with biochar and NPK fertilizer (V3F7) recorded the highest phosphorus concentration in pineapple juice, while the *MD2* pineapple variety grown on soil treated with compost only had the lowest phosphorus content in pineapple juice. This can be attributed to the adsorbing characteristic property of biochar. Biochar is known to absorb nutrients and release it gradually for plant use (Trupiano et al., 2017). V2F4 recorded the highest potassium content in pineapple juice (Table 15). Calcium content was higher in samples treated with biochar and compost under the *MD2* pineapple variety but magnesium content was higher in *MD2* pineapple variety grown on unamended soil.

Effect of biochar and/ or compost and NPK fertilizer on pineapple fruit quality

As shown in Table 16, pineapple juice pH recorded for the treatments were highly acidic. Plot fertilized with compost and NPK fertilizer had the highest pH value of 4.03, whereas the pineapple plant treated with biochar had the lowest pH value of 3.94. These findings correspond to those of Ashraf et al. (2010) who reported that the application of K with N and P increased the pH of juice and acid contents. They further explained that the application of potash in combination with N and P adds some level of sourness of the juice. The increased total soluble solids (TSS) found in pineapple samples treated with biochar and compost contradict with those of Sánchez-Monedero et al. (2019) who reported a decrease in TSS content and acidity for biochar and compost amended soil. The TSS of pineapple juice increased with the application of nitrogen (N) and phosphorus (K) fertilizer but the addition of K was more effective in enhancing it (Ashraf et al., 2010).

Titratable acidity (7.28 g kg^{-1}), total antioxidant content (24.63 mg 100 ml^{-1}), and total flavonoid (24.99 mg l^{-1}) was high in the samples from the control plots. NPK fertilizer applied in addition with biochar had the lowest titratable acidity (6.03 g kg^{-1}), NPK fertilizer treated plot had the least (16.01 mg 100 ml^{-1}) total antioxidant content, and the plot which received biochar only recorded the lowest (12.94 mg 100 ml^{-1}) total flavonoid from Table 16. An increase in titratable acidity contents is not desirable (He et al., 2003) because it leads to a decrease in sugar and acid ratio (He et al., 2003; Ashraf et al., 2010). Several studies have reported that the application of SOP enhanced the quality of juice by decreasing the contents of citric acid (Mustafah and Saleh, 2006). The integration of biochar and compost had the highest (20.18 mg 100 ml^{-1}) total phenolic content (TPC). This finding is in agreement with those of Saha et al. (2019) who reported increased total phenolic and antioxidant content in crops treated with biochar and mineral fertilizer. Concomitantly, fruits harvest from the plot amended with compost only had the highest (17.70 mg 100 ml^{-1}) vitamin C. According to Antonio et al. (2007), the levels of vitamin C are dependent on many factors which include production practice, cultivar, plant nutrition, and maturity. The results from the current study agree with those of Aminifard et al. (2013) who determined that the application of compost at different rates improved vitamin C of fruit. According to Dumas et al. (2003), the application of organic fertilizer resulted in low yield tomatoes with a high content of ascorbic acid, whereas inorganic fertilizer application with organic fertilizer gave a high yield of fruit with a lower content of ascorbic acid. Hence, the findings from this experiment confirmed previous results that vitamin C level in pineapple grown organically was consistently higher than those grown conventionally.

As shown in Table 16, the fruit quality of pineapple varied significantly among different pineapple varieties. The highest pH (4.14), total soluble solids (15.47 %), titratable acidity (7.16 g kg^{-1}), total antioxidant content (26.95 mg 100 ml^{-1}), and total flavonoid (22.68 mg 100 ml^{-1}) was recorded by *Sugar loaf* pineapple variety. These findings were consistent with those of Wardy et al. (2009). According to Wardy et al. (2009), a high pH of *Sugar loaf* pineapple variety may not be suitable for producing jam as compared to Smooth cayenne and *MD2* pineapple varieties because linkages of glycoside would remain relatively less stable at low acidity. The microbial stability of pineapple varieties reflects the pH values obtained. Smooth cayenne and *MD2* pineapple varieties with lower pHs' keep better as compared to *Sugar loaf*. Wardy et al. (2009) explained that to enhance *Sugar loaf* products keeping properties, acidifiers may be needed to do that. Bartholomew et al. (2003) stated that total soluble solids influence the sweetness index than total sugars. Total soluble solids can be used to determine fruit maturity and quality of pineapples, it ranges from 10.8 to 17.5 % with a few variations between the varieties (Wardy et al., 2009). The titratable acidity recorded can be attributed to the stage of maturity, the cultivar, storage conditions, and the fruit part (Wardy et al., 2009). Moreover, the highest (13.49 mg 100 ml^{-1}) vitamin C content was obtained by *MD2* pineapple variety (Table 16). The quality of *MD2*, *Smooth cayenne*, *and Sugarloaf* pineapple fruit juice vitamin C content is compatible with all varieties meeting the dietary requirements of vitamin C but the *MD2* pineapple variety has the best potential because of its very high weight-for-weight ratios relative to other varieties (Wardy et al., 2009). Therefore, the level of vitamin C in the pineapple fruit juice can be attributed to the internal browning related to post-harvest chilling injury (Wardy et al., 2009).

Interaction effect of pineapple variety and fertilizer on pineapple fruit quality

Pineapple fruit quality varied significantly among pineapple varieties across the treatments (Table 17). *Sugar loaf* pineapple variety planted on the plot amended with compost only (V2F2) had the highest pH (4.19). This finding is in the same trend as those of Aminifard et al. (2013) and Giovanni et al. (2011), who reported higher pH of pepper harvest from soil amended with compost only. Wang and Lin (2002) explained that fruit's pH is associated with acidity and citric acid is the main organic acid present in most fruits. They further explained that low pH-value fruits (planted in soils amended with organic fertilizers) have more citric acid, which is advantageous for human consumption. In addition, low pH fruit is more appropriate for maturing while also improving shelf life (HernandezPerez, et al., 2005). Similarly, *Sugar loaf* pineapple variety planted on soil amended with compost only produced the maximum total soluble solids (17.54 ^{o}Brix). Similar results were reported by Aminifard et al. (2013) who obtained higher total soluble solids (TSS) from fruit harvested from the plot that received compost as compared to fruits harvested from the inorganic fertilizer plot. Rajbir et al. (2008) also opined that improved fruit quality could be due to better plant growth at a different dose of organic fertilizer, which could have enhanced better quality fruit production. Plot amended with biochar only under *Sugar loaf* pineapple variety obtained the highest titratable acidity (TA) in the pineapple juice from Table 17. According to Petruccelli et al. (2015) and Caliman et al. (2010), tomato fruits planted on soil treated with biochar obtained high fruit quality values in terms of titratable acidity (TA). Petruccelli et al. (2015) explained that the application of biochar can maintain the tomato variety properties, hence suitable for the production of tomato.

The highest total antioxidant capacity (TAC) (34.03 mg 100 ml^{-1}), total flavonoids (TF) (36.74 mg 100 ml^{-1}) was recorded by *Sugar loaf* pineapple variety planted on unamended soil (V2F1). The differences observed may be attributed to the stages of fruit maturity because maturity is an important factor in the assessment of the antioxidant capacity of fruit (Gruz et al., 2011). The study showed that total phenol content (TPC) varied significantly ($P < 0.05$) among pineapple variety and fertilizer application interaction at maturity. This conforms to a study conducted by (Tlili et al., 2014). The highest total phenolic content was obtained by Smooth cayenne pineapple variety grown on soil amended with biochar and NPK fertilizer. This could be attributed to treatments synergistic effect inducing ripening. As presented in Table 17, vitamin C level was higher (21.73 mg 100 ml^{-1}) in MD2 and smooth cayenne pineapple fruit harvest from the plot amended with biochar and NPK fertilizer. *Sugar loaf* pineapple variety planted on unamended soil obtained the least vitamin C content recording a value of 7.80 mg 100 ml^{-1} (Table 17). Similar results were observed by Owureku-Asare et al. (2015) who reported high vitamin C content in pineapple fruit planted on soil amended with inorganic fertilizers (NPK). In this regard, Teisson et al. (1973) reported that increasing the amount of K increases fruit pulp ascorbic acid content which may lead to a decrease in internal fruit darkening (Teisson et al., 1973).

CHAPTER SIX

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Smallholder pineapple farmers are unable to apply the required amounts of inorganic fertilizer due to its high cost and the farmers' limited technical knowledge in fertilizer use. Continuous and/or excessive application of inorganic fertilizer affects the physicochemical properties of soil and negatively affects the environment through air and water pollution. Organic nutrient inputs such as compost and biochar have received global research attention but the potential synergistic effect of the two amendments has to be adequately researched.

The study examined how biochar applied together with compost will impact pineapple growth, yield, and nutritional composition of three pineapple varieties in a low nutrient coastal savanna Acrisol in the central region of Ghana. The findings from this study are expected to help in decision-making on the appropriate fertilizer and amendment to increase pineapple yield and enhance fruit quality whereas improving soil fertility for sustainable commercial pineapple production.

Conclusions

The physicochemical properties such as exchangeable cation, organic carbon, total nitrogen, and available phosphorus of the soil from the experimental field were low and did not meet the optimum nutrients requirement of pineapple. The study showed that pineapple plants were relatively taller in combined biochar and compost, and the combined compost and inorganic NPK fertilizer treatments regardless of the pineapple variety compared to the other treatments. Inorganic NPK fertilizer in addition to pineapple waste biochar resulted in a higher number of leaves indicating a strong positive synergistic effect of combined application of biochar and inorganic NPK fertilizer.

Integration of biochar and compost increased pineapple 'D' leaf weight. Biochar applied together with NPK fertilizer increased pineapple fruit weight but was not significantly different from pineapple waste biochar and compost applied together. NPK fertilizer applied in addition to pineapple waste compost increased pineapple fruit weight, length, and diameter compared to the sole application of biochar, compost, and NPK fertilizer. Both N and P from the compost and inorganic NPK fertilizer are necessary for root formation, elongation, and increase in fruit length, diameter, and fruit yield. Between the three pineapple varieties, *Smooth cayenne* variety outperformed *MD2* and *Sugar loaf* in terms of fruit weight.

The addition of biochar and NPK fertilizer resulted in higher N content in pineapple leaf. Biochar supplement reduced demand for N fertilizer in crop production as a result of a decrease in N leaching, therefore, increase N use efficiency for crops. Sole application of NPK fertilizer increased P content in pineapple leaf compared to the combined application of biochar and compost. Pineapple plant treated with pineapple waste biochar increased K content in pineapple leaf. Application of biochar enhances K availability for pineapple uptake which led to increased K content in plant tissue effectively. Among the three varieties of pineapple, N content was higher in *Sugar loaf* leaf. Also, P and K content in pineapple leaf was higher in the *MD2* pineapple variety.

Pineapple juice produced from pineapple grown on soil amended with biochar in and compost was significantly ($P < 0.001$) higher in protein than the rest of the pineapple juice samples. Nitrogen from all fertilizer types enhances the amount and quality of the plant-produced protein. Phosphorus, sodium, and magnesium contents of pineapple planted on unamended soil were significantly ($P < 0.001$) higher than pineapple juice produced from pineapple treated with any type of fertilizer. Mineral content (calcium and potassium) varied significantly among treatments. The differences can be attributed to the concentration of exchangeable cation (such as Ca, Mg, and K) on the treated soil, thus affecting the final mineral content of the pineapple juice. *Sugar loaf* pineapple variety had the highest percentage protein, phosphorus, and sodium but the *MD2* pineapple variety had the highest potassium, calcium, and magnesium. The increase in phosphorus and sodium content observed in *Sugar loaf* may be attributed to the utilization of fertilizers applied.

Pineapple grown on soil amended with compost and NPK fertilizer recorded the highest pH value, whereas the pineapple treated with biochar had the lowest pH value. The application of K with N and P increased the pH of juice and acid contents. The increased total soluble solid found in the pineapple sample produced from pineapple treated with biochar and compost was a result of the application of nitrogen (N) and phosphorus (K) fertilizer but the addition of K was more effective in enhancing it. Titratable acidity, total antioxidant capacity, and total flavonoids were high in the samples produced from pineapple from the control plots. Integration of biochar and compost increased total phenolic content. Additionally, pineapple fruits harvested from the plot amended with compost only increased vitamin C content in pineapple juice, probably due to the production practice, cultivar, plant nutrition, and maturity. The fruit quality of pineapple varied significantly among different pineapple varieties. The results also illustrated that *Sugar loaf* pineapple variety had the highest pH, total soluble solids (TSS), titratable acidity (TA), total antioxidant capacity (TAC), and total flavonoids (TF). The highest vitamin C content found in pineapple juice produced from the *MD2* pineapple variety could be internal browning related to post-harvest chilling injury.

Recommendation

The following recommendations were proposed from the study:

1. Future studies should include a cost-benefit analysis to determine the profitability of combined biochar and compost use compared to the exclusive use of inorganic fertilizer for pineapple production.
2. Studies should be carried out to investigate the effect of biochar and/or compost and NPK fertilizer application on pineapple sucker and slip production.
3. Future studies should be carried out to explain the residual effect of compost and/or biochar and NPK fertilizer on pineapple fruit quality.

REFERENCES

Abiose, S., & Ikujenlola, A. (2014). Comparison of chemical composition, functional properties, and amino acids composition of quality protein maize and common maize (Zea may L). *African Journal of Food Science and Technology*, 5(3), 81–89.

Adamtey, N., Cofie, O., Ofosu-Budu, G. K., Danso, S. K. A., & Forster, D. (2009). Production and storage of N-enriched co-compost. *Waste Management*, 29(9), 2429-2436.

Adekiya, A.O., Ojeniyi, S.O., & Agbede, M.T. (2012). Poultry manure effects on soil properties, leaf nutrient status, growth, and yield of cocoyam in a tropical Alfisol. *Nigerian Journal of Soil Science*. 22(2), 30 – 39.

Ademar, S., Jose A. Q., Teixelra L.A., & Sigrist J.M.M. (2014). Pineapple yield and fruit quality affected by NPK fertilization in tropical Soil. 38: 263-274.

Adugna, G. (2016). A review of the impact of compost on soil properties, water use , and crop productivity. *Academic Research Journal of Agricultural Science and Research*, 4(1), 93 – 104.

Agegnehu, G., Nelson, P. N., & Bird, M. I. (2016). Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on nitisols. *Soil and Tillage Research* 160(1), 1-13.

Agegnehu, G., vanBeek, C., & Bird, M. (2014). Influence of integrated soil fertility management in wheat productivity and soil chemical properties in the highland tropical environment. *Journal of Soil Science and Plant Nutrition*, 14(2), 24 – 43.

Agegnehu, G., Srivastavab, A. K., & Birda, M. (2017). The role of biochar and biochar- compost in improving soil quality and crop performance: A review. *Applied Soil Ecology* 119(3), 156 - 170.

Ahmed, O. H., Husni, M. H. A., Anuar, A. R., Hanafi, M. M., & Angela, E. D. S (2004). A modified way of producing humic acid from composted pineapple leaves. *J Sustain Agri*, 25(1), 129 - 139.

Ahmed, O.H., Husni, M.H.A., Anuar, A.R., Hanafi, M.M., & Syed Omar, S.R. (2001). Pineapple Residue Management Practices and Fertilizer Regimes: Effects on P and K Uptake, Yield and Some Economic Implications. *PertanikaJ. Trop. Agric. Sci*. 24(2): 123 – 129.

Alexander, R. (2001). Compost utilization in landscapes. In: Stoffella, P.J. & B.A. Kahn, editors. Compost utilization in horticultural cropping systems. *CRC Press LLC. Boca Raton*, FL, 8(1), 151-176.

Aminifard, H. M., Aroiee, H., Azizi, M., Nemati, H., & Jaafar, H.Z.E. (2013). Effect of compost on antioxidant components and fruit quality of sweet pepper (capsicum annuum L.). *Journal of Central European Agriculture,* 14(2), 47-56.

Amlinger, F., Peyr, S., Geszti, J., Dreher, P., Karlheinz, W., & Nortcliff, S. (2007). Beneficial effects of compost application on fertility and productivity of soils. Literature Study, Federal Ministry for Agriculture and Forestry, *Envi. and Water Management,* Austria.

Amorim, A. V., Lacerda, C. F., Moura, C.F.H., & Gomes Filho, E. (2011). Fruit size and quality of pineapples cv. Vitória in response to micronutrient doses and way of application and to soil covers. *R. Bras. Frutic.*, 33(2), 505-510.

Anderson, C. R., Condron, L. M., Clough, T. J., Fiers, M., Stewart, A., Hill, R. A., & Sherlock, R. R. (2011) 'Biochar induced soil microbial community change: Implications for biogeochemical cycling of carbon, nitrogen and phosphorus', *Pedobiologia,* 54(1), 309 – 320.

Antonio, J.P., Francisco, M.A., Ana, S.M., Marıa, I.F., & Estrella, D., (2007). Influence of agricultural practices on the quality of sweet pepper fruits as affected by the maturity stage. *Journal of the Science of Food and Agriculture*, 87(2), 2075 – 2080.

Arif, M., Ali, A., Umair, M., Munsif, F., Saleem, M., & Ayub, G. (2012). Effect of biochar, FYM and mineral nitrogen alone and in combination on yield components of maize. *Sarhad J. Agriculture* 289 (2), 191-195.

Ashraf, M. Y., Gul, A., Ashraf, M., Hussain, F., & Ebert, G. (2010). Improvement in yield and quality of kinnow (citrus deliciosaxcitrus nobilis) by potassium fertilization. *Journal of Plant Nutrition*, 33(11), 1625–1637.

Aslam, Z., Khalid, M., & Aon, M. (2014). Impact of Biochar on Soil Physical Properties, *Scholarly Journal of Agricultural Science*, 4(5), 280 – 284.

Augustínová, J., Cvengrošová, Z., Mikulec, J., Vasilkovová, B., & Cvengroš, J. (2013). Upgrading of bio-oil from fast pyrolysis. 46th International Conference on Petroleum Processing, June 7, 2013, Bratislava, Slovak Republic.

Ayoola, O. T., & Makinde, E. A. (2009). Nutrition and Development, *African Journal of Food, Agriculture*, 9(2), 580 – 592.

Bajiya, R., Lakhran, H., Kumar S., & Seema. (2017). Biochar for enhancing agricultural sustainability under climate change. *International Journal of Current Microbiology and Applied Sciences.* 6(2), 1876-1883.

Bartholomew, D.P., & Malézieux, E. (1994). Pineapple. In: Schaffer, B. and Anderson, P. (eds) *Handbook of Environmental Physiology of Fruit Crops*, Vol. II. CRC Press, Boca Raton, Florida, 12(2), 243 – 291.

Bartholomew, D.P., Paull R.E., & Rohrbach, K.G. (2003). The Pineapple Botany, Production and Uses. CABI Publishing, UK, 8(1), 253-274.

Bashir, N., Malik, S.A., Mahmood, S., Hassan, M., Althar, H.R., & Arthar, M. (2012). Influence of urea application on growth, yield, and mineral uptake in two corn (Zea mays L.) cultivars. *African Journal of Biotechnology*, 11(46), 10494-10503.

Basri, A.H.M., Abdu, A., Jusop, S., Ahmed, H.O., Abdul-Hamid, H., Mohd-Ashadie, K., Zainal, B., Senin L.A., & Junejo, N. (2013). Effects of mixed organic and inorganic fertilizers application on soil properties and the growth of kenaf *(Hibiscus cannabinus* l.) cultivated on bris soils. *American Journal of Applied Sciences*, 10 (12), 1586-1597.

Bass, A. M., Bird, M, I., Kay, G., & Muirhead, B. (2016). Soil properties, greenhouse gas emissions and crop yield under compost, biochar and co-composted biochar in two tropical agronomic systems. *Sci Total Environ.* 550(2) 459 - 470.

Beesley, L., Moreno-Jimenez, E., Gomez-Eyles J.L., Harris E., Robinson, B., & Sizmur T. A (2011). Review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. Environ Pollut, 159(1): 474-480.

Bernal, M. P., Sanchez-Monedero, M. A., Paredes, C., & Roig, A. (1998). Carbon mineralization from organic wastes at different composting stages during them incubation with soil. *Agriculture, Ecosystems & Environment*, 69(3), 175-189

Biederman, L.A., & Harpole, W.S. (2013). Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. *GCB Bioenergy*. 5(2), 202 – 214.

Bird, M.I. (2015). Test procedures for biochar analysis in soils. In: Lehmann, J., Joseph, S. (Eds.), Biochar for Environmental Management: Science, Technology and Implementation, 2nd ed. Routledge, London, pp. 677–714.

Bouajila, K., & Sanaa, M. (2011). Effects of organic amendments on soil physico-chemical and biological properties. *J. Mater. Environ. Sci.* 2 (S1), 485 – 490.

Brown, S., & Cotton, M. (2011). Changes in Soil Properties and Carbon Content Following Compost Application: Results of On-farm Sampling. *Compost Science and Utilization*, 19(1), 88 - 97.

Bruun, E.W., Petersen, C.T., Hansen, E., Holm, J.K., & Hauggaard-Nielsen, H. (2014). Biochar amendment to coarse sandy subsoil improves root growth and increases water retention. *Soil Use Manage*. 30(1), 109 - 118.

Caballero, R., Pajuelo, P., Ordovás, J., Carmona, E., & Delgado, A. (2009). Evaluation and correction of nutrient availability to Gerbera jamesonii H. Bolus in various compost-based growing media. *Scientia Horticulturae.* 122(1), 244 – 250.

Caliman, F.R.B., da Silva, D.J.H., Stringheta, P.C., Fontes, P.C.R., Moreira, G.R., & Mantovani, E.C. (2010). Quality of tomatoes grown under a protected environment and field conditions. Idesia (Chile) 28(2), 75–82.

Cantrell, K. B., Hunt, P. G., Uchimiya, M., Novak, J. M., & Ro, K. S. (2012). Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar, *Bioresource Technology*, vol. 107(1), 419 - 428.

Ch'ng, H. Y., Ahmed, O. H., Majid, N. M. A., & Jalloh, M. B. (2016). Reducing Soil Phosphorus Fixation to Improve Yield of Maize on a Tropical Acid Soil Using Compost and Biochar Derived from Agro-Industrial Wastes. *Compost Science & Utilization*, 25(2), 82 - 94.

Chan, K.Y., & Xu, Z. (2009). Biochar: nutrient properties and their enhancement. In: Lehmann, J. & Joseph, S. (Eds.), *Biochar for Environmental Management – Science and Technology*, Earthscan, London, U.K., pp. 67 – 84.

Chan, K.Y., Van Zwieten E, L., & Meszaros, I. (2007). Agronomic values of green waste biochar as a soil amendment. *Australian Journal of Soil Research,* 45(1), 629 – 634.

Chen, H., Du, Z., Guo, W., & Zhang, Q. (2011). Effects of biochar amendment on cropland soil bulk density, cation exchange capacity, and particulate organic matter content in the North China Plain. Ying yong sheng tai xue bao= *The journal of applied ecology*/Zhongguo sheng tai xue xue hui, Zhongguo ke xue yuan Shenyang ying yong sheng tai yan jiu suo zhu ban 22(2), 2930 - 2934.

Chen, J. H. (2008). Department of Soil and Environmental Sciences, National

Chung Hsing University 250 Kuo-Kuang Road, Taichung. Taiwan ROC.

Cogger, C. G. (2005). Potential compost benefits for restoration of soils disturbed by urban development. *Compost Science & Utilization*, 13(4), 243 - 251.

Cogger, C., Hummel, R., Hart, J., & Bary, A. (2008). Soil and redosier dogwood response to incorporated and surface-applied compost. *HortScience*, 43(7), 2143-2150.

Cohen-Ofri, I., Popovitz-Biro, R., & Weiner, S. (2007). Structural characterization of modern and fossilized charcoal produced in natural fires as determined by using electron energy loss spectroscopy, *Chemistry—A European Journal*, 13(8), 2306 - 2310.

Crane, J. H. (2006). USAID-RED. Oficina FHIA, La Lima, Cortes, Honduras.

Crisosto, C.H., & Garner, D. (2001). Controlled delayed cooling extends peach market life. HortTechnology, 14(2), 99 – 104.

Crombie, K., Mašek, O., Sohi, S. P., Brownsort, P., & Cross, A. (2012). The effect of pyrolysis conditions on biochar stability as determined by three methods. *GCB Bioenergy*, 5(2), 122–131.

Cross, A., & Sohi, S. P. (2011). The priming potential of biochar products in relation to labile carbon contents and soil organic matter status. *Soil biology and biochemistry*, 43(10), 2127-2134.

Dadhawal, K. S., Mandal, D., & Shrimali, S. S. (2011). Soil quality index for different land use systems in Northwestern Hilly Region of India. Journal of the Indian Society of Soil Science, 59(2), 169–176.

Daniel, F., & Bruno, G. (2012). Synergisms between Compost and Biochar for Sustainable Soil Amelioration, Management of Organic Waste, Dr. *Sunil Kumar (Ed.)*, ISBN: 978-953-307-925-7.

Darnaudery, M., Fournier, P., & Léchaudel, M. (2016). Low-input pineapple crops with high quality fruit: promising impacts of locally integrated and organic fertilization compared to chemical fertilizers.

De La Cruz Medina, J., & H.S. Garcia, 2005. Pineapple: Post-harvest operations. Food and Agriculture Organization of the United Nations, pp: 1-38.

DeLuca, T. H., MacKenzie, M. D., Gundale, M. J., & Holben, W. E. (2006). Wildfire-produced charcoal directly influences nitrogen cycling in forest ecosystems, *Soil Science Society America Journal*, vol 70, pp, 448 – 453.

Demirbas, A. (2006). Production and characterization of bio-chars from biomass via pyrolysis. *Energy Sources*, Part A 28, 413-422.

Ding, N., Melloni, L., Zhang, H., Tian, X., & Poeppel, D. (2016). Cortical tracking of hierarchical linguistic structures in connected speech. Nature Neuroscience, 19(1), 158 – 164.

Duku, M. H., Gu, Sai., & Hagan, E. B. (2011). Biochar production potential in Ghana- A review. Renewable and Sustainable Energy Reviews 15(1), 3539 – 3551.

Dumas, Y., adomo, M., Lucca, G., Grolier, P., & Lucca, G., (2003). Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. Journal of the Science of Food and Agriculture, 83(2), 369 - 382.

Eyles, A., Bound, S. A., Oliver, G., Corkrey, R., Hardie, M., Green, S., & Close, D.C. (2015). Impact of biochar amendment on the growth, physiology and fruit of a young commercial apple orchard. Trees 29(2), 1817–1826.

Fagbenro, J.A., Oshunsanya, S. O., Oyeleye, B., & Aduayi, E.A. (2018). Effect of two biochar types and inorganic fertilizer on soil chemical properties and growth of maize (Zea mays l.), *International educational scientific research journal.*

Fauziah S.H., Khairunnisa A.K., Siti Zubaidah B., & Agamuthu P. (2009). Public Perception on Solid Waste and Public Cleansing Management Bill 2007 Towards Sustainable Waste Management in Malaysia. Proceedings of ISWA Congress, Lisbon, Portugal. 12-14 October 2009.

Food and Agriculture Organization. (2008*). Guide for fertilizer and plant nutrients* *analysis.* Rome, Italy: FAO Communication Division.

Food and Agriculture Organization. (2005). Current world fertilizer trends and outlook to 2009/2010. Rome. (in press).

Food and Agriculture Organization. (2006). Fertilizer and Plant Nutrition. Rome. (in press).

FAO-UNESCO. 1980. Soil Map of the World. Paris, UNESCO

Fauziah, S.H., & Agamuthu, P. (2009). Sustainable Household Organic Waste Management via Vermicomposting.

Ficciagroindia, (2007). Pineapple production Guidelines (India).

Fischer, D., & Glaser, B. (2012). Synergisms between compost and biochar for sustainable soil amelioration. In: Kumar, S.E. (Ed.), Management of Organic Waste. *In Tech,Shanghai,* China, pp. 167 – 198.

Friedl, A., Padouvas, E., Rotter, H., & Varmuza, K. (2005). Prediction of heating values of biomass fuel from elemental composition. *Analytica Chimica Acta,* 544, 191-198.

Frimpong, K.A., Amoakwah, E., Osei, B.A., & E. Arthur, E (2016). "Changes in soil chemical properties and lettuce yield response following incorporation of biochar and cow dung to highly weathered acidic soils," Journal of Organic Agriculture and Environment, 4(1), 28 – 39.

Fu, B., Ge, C., Yue, L., Luo, J., Feng, D., Deng, H., & Yu, H. (2016). Characterization of biochar derived from pineapple peel waste and its application for sorption of oxytetracycline from aqueous solution, *BioRes.* 11(4), 9017 - 9035.

Fushimi, C., Araki, K., Yamaguchi, Y., & Tsutsumi, A. (2003). Effect of heating rate on steam gasification of biomass 2. Thermogravimetric-mass spectrometric (TG-MS) analysis of gas evolution. *Industrial & Engineering Chemistry Research,* 42(2), 3929 - 3936.

Gallicia, L., Nurit, E., Rosales, A., & Palacios-Rojas, N. (2009). Laboratory

Protocols 2008: Maize Nutrition Quality and Plant Tissue Analysis Laboratory (No. 56177). CIMMYT: International Maize and Wheat Improvement Center

Gamel, A. (2009). Impacts of Compost on Soil Properties and Crop Productivity in the Sahel North Burkina Faso. *American- Eurasian J. Agric. and Envi. Sci,* 6(2), 220 - 226.

Gao, Y., Yue, Q., & Gao B. (2013). Preparation of high surface area activated carbon from lignin of papermaking black liquor by KOH activation for Ni (II) adsorption, *Chemical Engineering Journal*, 217(1), 345 - 353.

Gaunt, J. L., & Lehmann, J. (2008). Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production. *Environmental Science & Technology* 42(1), 4152- 4158.

Giovanni, M., Angela Maria, G.L., & Antonino, L.M., (2011). The effect of organic supplementation of solarized soil on the quality of tomato fruit. *Scientia Horticulturae*, 129(1),189 -196.

Githinji. L. (2013). Effect of biochar application rate on soil physical properties of a sandy loam. *J. Agriculture and Environmental Sciences.*

Glaser, B., & Birk, J. (2012). State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de ´ındio), *Geochimica et Cosmochimica Acta*, 82(1)39 - 51.

Glaser, B., Haumaier, L., Guggenberger, G., & Zech, W. (2001). The terra preta phenomenon: a model for sustainable agriculture in the humid tropics. *Naturwissenschaften,* 88(2), 37 - 41.

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - a review," *Biology and Fertility of Soils*, vol. 35(4), 219 - 230.

Granatstein, D., Kruger, C. E., Collins, H., Galinato, S., Garcia-Perez, M., & J. Yoder, J. (2009). Use of biochar from pyrolysis of waste organic material as a soil amendment. *Final Project Rep. Ctr. for Sustaining Agric. and Nat. Resour.*, Washington State Univ., Wenatchee.

Grangeiro, L. C., Negreiros, M. D., Souza, D. B., Azevedo, P. D., Oliveira, S. D., & Medeiros, M. D. (2007). Acúmulo e exportação de nutrientes em beterraba. Ci. Agrotéc., 31(3), 267 - 273.

Gruz, J., Ayaz, F. A., Torun, H., & Strnad, M. (2011). Phenolic acid content and radical scavenging activity of extracts from medlar (Mespilus germanica L.) fruit at different stages of ripening. Food Chemistry, 124(1), 271-277.

Hass, A., Gonzalez, J. M., Lima, I.M., Godwin, H.W., Halvorson, J.J. & Boyer, D.G. (2012). Chicken manure biochar as liming and nutrient source for acid Appalachian soil. *J. Environ. Qual*. 41(1), 1096–1106.

He, Z. L., Calvert, D. V., Alva, A. K., Banks, D. J., & Li, Y. C. (2003). Threshold of leaf nitrogen for optimum fruit production and quality in grapefruits. *Soil Science Society of American Journal*, 67(3), 583–588.

Heard, J. W., Francis, S. A., & Doyle, P. T. (2006). Nutritive characteristics of annual species in irrigated pasture in northern Victoria. *Aust. J. Exp. Agric*., 46 (8), 1015-1022.

Herth, H.M.S.K., Arbestain, M.C., & Hedley, M. (2013). Effect of biochar on soil physical properties in two contrasting soils: *An Alfisol and an Andisol. J. Geoderma 209-210*. pp.188 – 197.

Hernandez-Perez, T., Carrillo-Lopez, A., Guevara-Lara, F., Cruz- Hernandez, A., & Paredes-Lopez, O. (2005). Biochemical and nutritional characterization of three prickly pear species with different ripening behavior. *Plant Food*, 8(19), 4953 – 4957.

Higman, C., & Gurgt, M. (2008). Gasification. U.S: Elsevier 391pp.

Hossain Md. F., Piash, I.M., & Perveen, Z. (2019). Effect of Biochar and Fertilizer Application on the Growth and Nutrient Accumulation of Rice and Vegetable in Two Contrast Soils. *Acta Scientific Agriculture*, 3(3),74 - 83.

Hossain, M.F. (2016). World pineapple production: An Overview. *African Journal of Food, Agriculture, Nutrition, and Development*, 16(4).

Idem, N. U. A., Ikeh, A. O., Asikpo, N. S., & Udoh, E. I. (2012). Effect of organic and inorganic fertilizer on growth and yield of fluted pumpkin (Telfaria occidentialis, hook f.) in uyo, akwa ibom state, Nigeria. *Journal of Agriculture and Social Research (JASR*), 12(2).

Inyang, M., Gao, B., Pullammanappallil, P., Ding, W., & Zimmerman, A.R. (2010). Biochar from anaerobically digested sugarcane bagasse. *Bioresour. Technol*. 101 (22), 8868 - 8872.

Islam, M., Islam, S., Akter, A., Rahman, M., & Nandwani, D. (2017). Effect of Organic and Inorganic Fertilizers on Soil Properties and the Growth, Yield and Quality of Tomato in Mymensingh, Bangladesh. *Agriculture*, 7(3), 18.

Jeffery, S., Verheijen, F.G.A., van der Velde, M., & Bastos, A.C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agric. Ecosyst. Environ*. 144(2), 175 - 187.

Kader, A., Hossain, J.M.F., Islam, M. M., Kabir, G., Sarkar, K. S., & Absar, N. (2010). A comparative analysis on the nutritional contents of two varieties of pineapple of chittagong region. *J. B. Sci*., 5(2), 105-112.

Kataki, R., Narzari, R., Bordoloi, N., Chutia, S.R., Borkotoki, B., Nirmali Gogoi, N., & Ajitabh Bora, A. (2015). Biochar: An Overview on its Production, Properties and Potential Benefits. Biology, Biotechnology and Sustainable Development.

Keeney, D. R., & Nelson, D. W. (1982). Nitrogen-Inorganic Forms 1. Alliance of Crop, Soil, and Environmental Sciences Societies (methods of soil), 643-698.

Khan H. Z., Malik, M. A., & Saleem, M. F. (2008). Effect of rate and source of inorganic material on the production potential of spring maize (Zea mays L.). *Pak. J. Agric. Sci*. 45 (1), 40-43.

Khan, A. A., Bibi, H., Ali, Z., Muhammad Sharif, M., Shah, S. A., Ibadullah, H., Khan, K., Azeem, I., & Ali, S. (2017). Effect of compost and inorganic fertilizers on yield and quality of tomato. *Academia Journal of Agricultural Research* 5(10), 287-293.

Laekemariam, F., Kibret, K., & Mamo, T. (2017). Farmers' soil knowledge, fertility management logic and its linkage with scientifically analyzed soil properties in southern Ethiopia. Agriculture & Food Security, 6(1).

Laird, D.A., Fleming, P., Wang, B., Horton, R., & Karlen, D. (2010). Biochar impact on nutrient leaching from a midwestern agricultural soil. *J. Geoderma*. pp. 43 - 442.

Landon, J. R. (2014). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Abingdon: Routledge.

Lehmann, J. et al. (2003a). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: Fertilizer, manure and charcoal amendments, Plant Soil, 249(1), 343–357.

Lehmann, J., da Silva, J. P., Steiner, C., Nehls, T., Zech, W., & Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant Soil* 249(2), 343 – 357.

Lehmann, J., Gaunt, J., & Rondon, M. (2006). Bio-char sequestration in terrestrial ecosystems - a review, Mitigation *and Adaptation Strategies for Global Change*, vol. 11 (2), 403 - 427.

Lehmann, J., Rillig, M., Thies, J., Masiello, C., Hockaday, W., & Crowley, D. (2011). Biochar effects on soil biota – A review. *Soil biology & biochemistry* 43(1), 1812- 1836.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., & O'Neill, B. (2006). Black Carbon increases cation exchange capacity in soils. *Soil*

Science Society of America Journal, 70(1), 1719 - 1730.

Liu, C. H., Liu, Y., Fan, C., & Kuang, S. Z. (2013). The effects of composted pineapple residue returns on soil properties and the growth and yield of pineapple. *Journal of Soil Science and Plant Nutrition*, 13 (2), 433-444.

Liu, J., Schulz, H., Brandl, S., Miehtke, H., Huwe, B., & Glaser, B. (2012). Short-term effect of biochar and compost on soil fertility and water status of a Dystric Cambisol in NE Germany under field conditions, *Journal of Plant Nutrition and Soil Science*, vol. 175 (5), 698 - 707.

Lu, X., Wang, J., Al-Qadiri, H. M., Ross, C. F., Powers, J. R., Tang, J., & Rasco, B. A. (2011). Determination of total phenolic content and antioxidant capacity of onion (Allium cepa) and shallot (Allium oschaninii) using infrared spectroscopy. *Food chemistry*, 129(2), 637-644.

Madeleine, I., Peter, S., Tim, T., & Tom, V. (2005). Agrodok no. 8: The preparation and use of compost. Agromisa Foundation, Wagenningen.

Major, J., Rondon, M., Molina, D., Riha, S. J., & Lehmann, J. (2010b). Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil*, 333(1), 117-128.

Major, J., Steiner, C., Downie, A., & Lehmann, J. (2009). Biochar effects on nutrient leaching. In Lehmann J, Joseph S, editors. Biochar for environmental management: *science and technology*, p. 271 - 87.

Makinde, E. A., Ayoola, O. T., & Akande, M. O. (2007). Effects of organic-mineral fertilizer application on the growth and yield of “egusi” melon (Citrullus vulgaris L.). *Australian Journal of Basic and applied sciences*, 1(1): 15 – 19.

Malézieux, E., & Bartholomew, D.P. (2003). Plant nutrition. In: BARTHOLOMEW, D.P.; PAUL, R.E. & ROHRBACH, K.G., eds. The Pineapple: Botany, production and uses. *Honolulu, CAB*, 2003. p.143-165.

Masiello, C.A. & Druffel, E.R.M. (1998). Black carbon in deep-sea sediments. Sci., 280(5371): 1911-1913.

Mensah, K. A., & Frimpong, A. K. (2018). Biochar and/or compost applications improve soil properties, growth, and yield of maize grown in acidic rainforest and coastal savannah soils in Ghana. *International Journal of Agronomy*, Pp, 1 – 8.

Mete, F. Z., Mia, S., Dijkstra, F. A., Abuyusuf, M., & Hossain, A. S. M. I. (2015). Synergistic Effects of Biochar and NPK Fertilizer on Soybean Yield in an Alkaline Soil. *Pedosphere*, 25(5), 713–719.

Ministry of Food and Agriculture (2012). *Soil Testing Guide* (1st ed.). Accra, Ghana: Statistics, Council for Scientific and Industrial Research (CSIR).

Ministry of Food and Agriculture (2015). *Towards a sustainable soil fertility strategy in Ghana.* Accra: MoFA.

Mohammad, H. G, Denney, M. J., & Iyekar, C. (2004). Use f Composted Organic Wastes as Alternative to Synthetic Fertilizers for Enhancing Crop Productivity and Agricultural Sustainability on the Tropical Island of Guam. *13th International Soil Conservation Organization Conference* – Brisbane, July 2004.

Mohd Hasan, M., Bachmann, R., Loh, S., Manroshan, S., & Ong, S. (2019). Effect of Pyrolysis Temperature and Time on Properties of Palm Kernel Shell-Based Biochar. IOP Conference Series: Materials Science and Engineering, 548, 012020.

Morton, J. (1987). Pineapple. Julia F. Morton, Miami, In: *Fruits of warm climates* FL. p. 18–28.

Mukherjee, A., & Lal. R. (2013). Biochar impacts on soil physical properties and greenhouse gas emissions. *J. Agronomy*. pp. 313 - 339.

Mukherjee, A., Venkataraman, V., Liu, B., & Glance, N. (2013). Fake Review Detection: Classification and Analysis of Real and Pseudo Reviews. UIC-CS-03-2013. Technical Report.

Mukhopadhyay, S., Masto, R. E., Tripathi, R. C., & Srivastava, N. K. (2019). Application of Soil Quality Indicators for the Phytorestoration of Mine Spoil Dumps.

Mustafah, E. A. M., & Saleh, M. M. (2006). Response of balady mandrine tree to girdling and potassium spray under sandy soil conditions. *Research Journal of Agriculture and Biological Sciences*, 2(1), 137–141.

Naeem, M. A., Khalid, M., Aon, M., Abbas, G., Amjad, M., Murtaza, B., & Ahmad, N. (2017). Combined application of biochar with compost and fertilizer improves soil properties and grain yield of maize. *Journal of Plant Nutrition*, 41(1), 112 - 122.

Nakasone, H. Y., & Paulle, R. E. (1998). Tropical Fruits.pp.292-326

Nartey, O. D., & Zhao, B. (2014). Biochar preparation, characterization, and adsorptive capacity and its effect on bioavailability of contaminants: An overview. *Advances in Materials Science and Engineering*. Hindawi Publishing Corporation.

Ogawa, M., Okimori, Y., & Takashi, F. (2006). Carbon sequestration by carbonization of biomass and forestation: three case studies. *Mitigation and Adaptation Strategies for Global Change*, 11(2), 421 – 36.

Ogunyemi, A. M., Otegbayo, B. O., & Fagbenro, J. A. (2018). Effects of NPK and biochar fertilized soil on the proximate composition and mineral evaluation of maize flour. *Food Science & Nutrition.*

Ogundare, S.K. Babatunde, I.J., & Etukudo, O.O. (2015). Responds of tomato variety (Roman F.) Yield to Different Mulch Material and Staking in Kabba, Kogi state *Journal of Agricultural Study*, 3(2) 61-70.

Okalebo, J. R., Gathua, W. K., and Woomer L. P. (2002). Laboratory Methods Of Soil and Plant Analysis: A Working Manual (2nd ed.). Nairobi, Kenya.

Oladele, S., Adeyemo, A., Awodun, M., Ajayi, A., & Fasina, A. (2019). Effects of biochar and nitrogen fertilizer on soil physicochemical properties, nitrogen use efficiency and upland rice (Oryza sativa) yield grown on an Alfisol in Southwestern Nigeria, *International Journal of Recycling of Organic Waste in Agriculture*, 8(1), 295 - 308.

Owureku-Asare, M., Agyei-Amponsah, J., Agbemavor S.W.K., Apatey, J, Sarfo, A.K., Okyere, A.A., Twum L.A., & Dodobi, M.T. (2015). Effect of organic fertilizers on physical and chemical quality of sugar loaf pineapple (Ananas comosus l) grown in two ecological sites in Ghana. *African journal of food, agriculture, nutrition and development*, 15(1).

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G., & Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems & Environment*, 83(1-2), 27-42

Parikh, S. J., & James B R (2012), Soil: The Foundation of Agriculture, Nature Education Knowledge, 3 (2).

Paulin, B., & Peter, O. M. (2008). Compost Production and Use in Horticulture. Western Australian Agri. Authority, Bulletin 4746.

Pegoraro, R. F., Souza, B. A. M. de., Maia, V. M., Amaral, U. do., & Pereira, M. C. T. (2014). Growth and production of irrigated Vitória pineapple grown in semiarid conditions. *Revista Brasileira de Fruticultura*, 36 (1), 693-703.

Petruccelli, R., Bonetti, A., Traversi, M. L., Faraloni, C., Valagussa, M., & Pozzi, A. (2015). Influence of biochar application on nutritional quality of tomato (Lycopersicon esculentum). *Crop and Pasture Science*, 66(7), 747.

Prasad, M., Chrysargyris, A., McDaniel, N., Kavanagh, A., Gruda, N. S., & Tzortzakis, N. (2019). Plant Nutrient Availability and pH of Biochars and Their Fractions, with the Possible Use as a Component in a Growing Media. *Agronomy*, 10(1), 10.

Prieto, P., Pineda, M., & Aguilar, M. (1999). Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E. *Analytical biochemistry*, 269(2), 337-341.

Rajbir, S., Sharma, R.R., Satyendra, K., Gupta, R.K., & Patil, R.T. (2008). Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (Fragaria × ananassa.). *Bioresource Technology*, 99(1), 8507- 8511.

Razzaque, A. H.M., & Hanafi, M. M. (2001). Effect of potassium on growth, yield and quality of pineapple in tropical peat, *PertanikaJ. Trop. Agri*, 56(01):45 – 49.

Rebolledo-Martinez, A., Angel-Perez, A. L. D., Becerril-Roman, A. E., & RebolloMartinez, L. (2005). Growth analysis for three pineapple cultivars grown on plastic mulch and bare soil. *Interciencia, diciembreano*, 30: 012

Ribeiro, H.M., Romero, A. M., Pereira, H., Borges, P., Cabral, F., & Vasconcelos, E. (2007). Evaluation of a compost obtained from forestry wastes and solid phase of pig slurry as a substrate for seedlings production. *Bioresource Technology*. 98(1), 3294 - 3297.

Richard, T. L., Hamelers, H. V. M., Veeken, A., & Silva, T. (2002). Moisture relationships in composting processes. *Compost Science & Utilization*, 10(4), 286 - 302.

Rodriguez, V., de los Angeles Valdez-Perez, M., Luna-Guido, M., Ceballos-Ramirez, J. M., Franco-Hern´andez, O., van Cleemput, O., Marsch, R., Thalasso, F., & Dendooven, L. (2011). Emission of nitrous oxide and carbon dioxide and dynamics of mineral N in wastewater sludge, vermicompost or inorganic fertilizer amended soil at different water contents: A laboratory study. *Appl Soil Ecol.* 49(2), 263 - 267.

Rondon, M., Ramirez, A., & Hurtado, M., (2004). Charcoal additions to high fertility ditches enhance yields and quality of cash crops in Andean hillsides of Colombia. CIAT Annual Report 2004, Cali, Colombia.

Rondon, M.A., Lehmann, J., Ramirez, J., & Hurtado, M. (2007). Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with biochar additions. *Biology and Fertility of Soil*, 43(2), 699 - 708.

Rowel, D. L. (1994). Analysis Methods and Applications In: Soil Science: Springer-Verlag, Berlin, New York.

Saha, A., Basak, B.B., Gajbhiye, N.A., Kalariya, K.A., & Manivel, P. (2019). Sustainable fertilization through co-application of biochar and chemical fertilizers improve yield, quality of Andrographis paniculata and soil health. *Ind. Crops Prod*. 140, 111607.

Sánchez-Monedero, M. A., Cayuela, M. L., Sánchez-García, M., Vandecasteele, B., D'Hose, T., López, G., & Mondini, C. (2019). Agronomic Evaluation of Biochar, Compost and Biochar-Blended Compost across Different Cropping Systems: Perspective from the European Project FERTIPLUS. *Agronomy*, 9(5), 225.

Schulz, H., & Glaser, B. (2012). Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. *Journal of Plant Nutrition and Soil Science* 175 (3), 410 - 422.

Seehausen, M., Gale, N., Dranga, S., Hudson, V., Liu, N., Michener, J., & Thomas, S. (2017). Is There a Positive Synergistic Effect of Biochar and Compost Soil Amendments on Plant Growth and Physiological Performance? *Agronomy*, 7(1), 13.

Silber, A., Levkovitch, I., & Graber, E.R. (2010). PH-dependent mineral release and surface properties of cornstrawdbiochar: agronomic implications. *Environ Sci Technol*, 44:9318–9323.

Soheil, R., Hossien, M. H., Gholamreza, S., Leila, H., Mozhdeh, J., & Hassan, E. (2012). Effects of Composted municipal waste and its Leachate on Some Soil Chemical Properties and Corn Plant Responses. *Int. Journal of Agriculture:* Research and Review. 2 (6), 801 - 814.

Sohi, S. P., Krull, E., Lopez-Capel, E., & Bol, R. (2010). A Review of Biochar and Its Use and Function in Soil. *Advances in Agronomy*, pp, 47 – 82.

Sohi, S., Lopez-Capel, E., Evelyn Krull, E., & Bol, R. (2009). Biochar, climate change and soil: A review to guide future research. CSIRO Land and Water Science Report 05/09, 64 pp.

Stewarts, E., Allen,H., Grimshaw, M., Parkinson,J.A., & Quarmby,C (1974). Chemical Analysis of Ecological Materials. Britain, London: Blackwell Scientific Publications.

Steiner, C., Bellwood-Howard, I., Häring, V., Tonkudor, K., Addai, F., Atiah, K., & Buerkert, A. (2018). Participatory trials of on-farm biochar production and use in Tamale, Ghana. *Agronomy for Sustainable Development*, 38(1).

Steiner, C., Glaser, B., Teixera, W.G., Lehmann, J., Blum, W.E.H., & Zech, W. (2008). Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. *Journal of Plant Nutrition and Soil Science*, 171(2), 893 – 899.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., Macêdo, J. L. V., Blum, W. E. H., & Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and Soil*, 291(3), 275 - 290.

Suliman, W., Harsh, J.B., Abu-Lail, N.I., Fortuna, A.M., Dallmeyer, I., & Garcia-Pérez, M. (2017). The role of biochar porosity and surface functionality in augmenting hydrologic properties of a sandy soil. *Sci. Total Environ*. 574 (5) 139 - 147.

Taghizadeh-Toshi, A., Clough, T.J., Sherlock, R.R., & Condron, L.M. (2012). Biochar adsorbed ammonia is bioavailable. *Plant Soil*, 350(1), 57 - 69.

Tayebeh, A., Abass, A., & Seyed, A. K. (2010). Effect of organic and inorganic fertilizers on grain yield and protein banding pattern of wheat. *Australian Journal of Crop Science* (AJCS) 4(6), 384 - 389.

Tei, F., Benincasa, P., & Guiducci, M. (2000). Effect of nitrogen availability on growth and nitrogen uptake in lettuce, *Acta Hort*.

Teisson, C., Lacoeuilhe, J.K., & Combres, J.C. (1973). Le brunisement interne de l'ananas. V. Recherches des moyens de lutte. Fruits, Paris, 34(1), 399 – 415.

Teixeira, L. A. J., Quaggio, J. A., Cantarella, H. & Mellis, E.V. (2011). Potassium fertilization for pineapple: effects on plant growth and fruit yield. *Rev Bras Frutic*, 33(2), 618-626.

Tewodros, M., Mesfin, S., Getachew, W., Ashenafi, A., & Neim, S. (2018). Effect of Inorganic N and P Fertilizers on Fruit Yield and Yield Components of Pineapple (Annanas comosus MERR L. Var. Smooth cayanne) at Jimma, Southwest Ethiopia. *Agrotechnology* 7: 178.

Thomas, S.C., & Gale, N., (2015). Biochar and forest restoration: a review and meta-analysis of tree growth responses. *New Forests* 46(5):931–946.

Tlili, N., Mejri, H., Yahia, Y., Saadaoui, E., Rejeb, S., Khaldi, A., & Nasri, N. (2014). Phytochemicals and antioxidant activities of Rhus tropartitum (Ucria) fruits depending on locality and different stages of maturity. *Food Chemistry* 160(2), 98 - 103.

Tortoe, C., Johnson, P.N.T., Slaghek, T., Oduro-Yeboah, C., Addo, P., Nyarko, A., & Tamakloe, I. (2014). Physicochemical, Proximate and Sensory Properties of Organic Side-stream Pineapple (Ananas sp.) Flour. *International Journal of Food Science and Nutrition Engineering*, 4(1), 1-8.

Trupiano, D., Cocozza, C., Baronti, S., Amendola, C., Vaccari, P. F., Lustrato, G., Lonardo, S., Fantasma, F., Tognetti, R., & Scippa, S. G. (2017). The effects of biochar and its combination with compost on Lettuce (Lactuca sativa L.) Growth, soil properties, and soil microbial activity and abundance. *International Journal of Agronomy*, Pp, 1-12.

Uko, A. E., Udo, I. A., & Shiyam, J. O. (2009) Optimizing poultry manure rates for two okra (Abelmoschhus esculentus) varieties in a warm wet climate.

Journal of Agriculture Biotechnology and Ecology, 2(3) 273 – 285.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S., & Cowie, A., (2010). Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil*, 327(2), 235 - 246.

Van Zwieten, L.; Singh, B.; Joseph, S. D.; Kimber, S.; Cowie, A.; Chan, K. Y. 2009. Biochar and the emissions of non-CO2 greenhouse gases from soil, in J. Lehmann, S. Joseph (Eds.). Biochar for environmental management, science and technology. London: Earthscan

Ventura, F., Salvatorelli, F., Piana, S., Pieri, L., & Pisa, P.R. (2013). The effects of biochar on the physical properties of bare soil. *Earth Environ. Sci. Trans. R. Soc*. Edinburgh, 103(1): 5 – 11.

Wang, SY., & Lin, S., (2002). Compost as soil supplement enhanced plant growth and fruit quality of strawberry. *Journal of Plant Nutrition*, 25(1), 2243 – 2259.

Wardy, W., Saalia, K.F., Steiner-Asiedu, M., Budu, S.A., & Sefa-Dedeh, S. (2009). A comparison of some physical, chemical and sensory attributes of three pineapple (Ananas comosus) varieties grown in Ghana. *African Journal of Food Science*, 3(1), 022-025.

Winsley, P. (2007). Biochar and bioenergy production for climate change mitigation. *Science Review*, 64 (1), 5 - 10.

Woolf, D. (2008). Biochar as a soil amendment – a review of the environmental implications, Swansea University. International Rice Research Institute, Black Soil, Green Rice, Rice Today; April–June 2007.

Worthington, V. (2001). Nutritional quality of organic versus conventional fruits, vegetables, and grains. *The Journal of Alternative and Complementary Medicine*, 7(2), 161–173.

Wu, D., Feng, Y., Xue, L., Liu, M., Yang, B., Hu, F., & Yang, L. (2019). Biochar Combined with Vermicompost Increases Crop Production While Reducing

Ammonia and Nitrous Oxide Emissions from a Paddy Soil. *Pedosphere*, 29(1), 82 - 94.

Yadav, R.K., Yadav, M.R., Rakesh Kumar, C.M. Parihar, N. Yadav, R. Bajiya, H. Ram, R.K. Meena, Yadav, D.K., & Yadav, B. (2017). Role of Biochar in Mitigation of Climate Change Through Carbon Sequestration. *Int.J.Curr.Microbiol.*App.Sci. 6(4): 859 - 866.

Yu, J. T., Dehkhoda, A. M., & Ellis, N. (2011). Development of biochar-based catalyst for transesterification of canola oil, *Energy and Fuels*, 25(1), 337 – 344.

Yvette, B. G., & Holmer, R. J. (2000). Composting of Organic Wastes: A Main Component for Successful Integrated Solid Waste Management in Philippine Cities.

Zhang, M., Gao, B., Varnoosfaderani, S., Hebard, A., Yao, Y., & Inyang, M. (2013). Preparation and characterization of a novel magnetic biochar for arsenic removal, *Bioresource Technology*, 130 (1), 457 - 462.

Zheng, H., Wang, Z., Deng, X., Herbert, S., & Xing, B. (2013). Impacts of adding biochar on nitrogen retention and bioavailability in agricultural soil. *Geoderma*, 206(1), 32-39.

Zhishen, J., Mengcheng, T., & Jianming, W. (1999). Research on antioxidant activity of flavonoids from natural materials. *Food Chemistry*, 64(1), 555-559.

Zhou, W. J., Wang, K.R., Zhang, G.Y., & Xie, X. L. (2002). Effects of inorganic-organic fertilizer incorporation on productivity and soil fertility of rice cropping system in red soil area of China. *Sci. Agric. Sinica*, 35(1), 1109-1113.

APPENDICES

Appendix 1: ANOVA of the Effects of biochar and/or compost and NPK fertilizer on growth parameters.

A. Plant Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	16.008	5.336	0.53	
Reps.*Units* stratum					
Treatment	6	4391.586	731.931	73.27	<.001
Variety	2	3258.939	1629.469	163.12	<.001
Treatment.Variety	12	358.583	29.882	2.99	0.002
Residual	60	599.372	9.990		
Total	83	8624.488			

B. Number of leaves

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	4.417	1.472	0.65	
Reps.*Units* stratum					
Treatment	6	375.452	62.575	27.54	<.001
Variety	2	1152.667	576.333	253.64	<.001
Treatment.Variety	12	133.833	11.153	4.91	<.001
Residual	60	136.333	2.272		
Total	83	1802.702			

Appendix 2: ANOVA of the Effects of biochar and/or compost, and NPK fertilizer on N, P and K content of pineapple leaf.

A. Nitrogen

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.013610	0.004537	2.25	
Reps.*Units* stratum					
Treatment	6	0.058294	0.009716	4.82	<.001
Variety	2	0.510760	0.255380	126.77	<.001
Treatment.Variety	12	0.218168	0.018181	9.03	<.001
Residual	60	0.120868	0.002014		
Total	83	0.921700			

B. Phosphorus

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.0111322	0.0037107	4.21	
Reps.*Units* stratum					
Treatment	6	0.0904500	0.0150750	17.10	<.001
Variety	2	0.0735608	0.0367804	41.73	<.001
Treatment.Variety	12	0.1056687	0.0088057	9.99	<.001
Residual	60	0.0528843	0.0008814		
Total	83	0.3336960			

C. Potassium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.00017958	0.00005986	1.18	
Reps.*Units* stratum					
Treatment	6	0.02435639	0.00405940	80.33	<.001
Variety	2	0.06679529	0.03339765	660.93	<.001
Treatment.Variety	12	0.03589777	0.00299148	59.20	<.001
Residual	60	0.00303189	0.00005053		
Total	83	0.13026093			

Appendix 3: ANOVA of the Effects of biochar and/or compost, and NPK fertilizer on pineapple fruit quality

A. TSS ºBrix

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	11.691	3.897	1.77	
Reps.*Units* stratum					
Treatment	6	29.198	4.866	2.20	0.055
Variety	2	244.734	122.367	55.42	<.001
Treatment.Variety	12	53.300	4.442	2.01	0.039
Residual	60	132.469	2.208		
Total	83	471.392			

B. Titratable acidity (g/kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.9108	0.9703	3.21	
Reps.*Units* stratum					
Treatment	6	14.3062	2.3844	7.88	<.001
Variety	2	8.2126	4.1063	13.58	<.001
Treatment.Variety	12	0.4407	0.0367	0.12	1.000
Residual	60	18.1487	0.3025		
Total	83	44.0190			

C. Total antioxidant capacity (mg/100ml)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	193.34	64.45	1.48	
Reps.*Units* stratum					
Treatment	6	850.34	141.72	3.26	0.008
Variety	2	2270.37	1135.19	26.11	<.001
Treatment.Variety	12	301.88	25.16	0.58	0.851
Residual	60	2608.97	43.48		
Total	83	6224.90			

D. Total flavonoids (mg/100ml)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1441.7	480.6	3.16	
Reps.*Units* stratum					
Treatment	6	1116.1	186.0	1.22	0.307
Variety	2	3815.8	1907.9	12.55	<.001
Treatment.Variety	12	952.3	79.4	0.52	0.892
Residual	60	9119.4	152.0		
Total	83	16445.4			

E. Total phenol content (mg/100ml)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	28.58	9.53	0.27	
Reps.*Units* stratum					
Treatment	6	442.65	73.77	2.11	0.065
Variety	2	3804.87	1902.43	54.53	<.001
Treatment.Variety	12	813.03	67.75	1.94	0.047
Residual	60	2093.24	34.89		
Total	83	7182.36			

F. Vitamin C (mg/100ml)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	121.26	40.42	1.12	
Reps.*Units* stratum					
Treatment	6	935.80	155.97	4.33	0.001
Variety	2	337.40	168.70	4.68	0.013
Treatment.Variety	12	301.39	25.12	0.70	0.748
Residual	60	2162.55	36.04		
Total	83	3858.39			

G. pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.009600	0.003200	0.48	
Reps.*Units* stratum					
Treatment	6	0.066806	0.011134	1.65	0.148
Variety	2	1.590545	0.795272	118.15	<.001
Treatment.Variety	12	0.055805	0.004650	0.69	0.754
Residual	60	0.403852	0.006731		
Total		83	2.126608		