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The quality of Cocoa Pod Husk Biochar produced with the "Kon-tiki" kiln technology, and its effect as a soil enhancer on the growth rate of cocoa seedlings.

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International Environmental Studies

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DECLARATION

I, Ernestina Quansah, declare that this thesis is a result of my own research investigations and findings. Sources of information other than my own have been acknowledged and a reference list has been appended. This work has not been previously submitted to any other university for award of any type of academic degree.

Signed: Ernestina Quansah

Date: 11/08/2021

ABSTRACT

A study was conducted to investigate the potential of cocoa pod husk as feedstock for biochar production using the “Kon-tiki” kiln. The effect of cocoa pod husk biochar (CPHB) as a soil enhancer, was tested in particular with respect to the soil’s capacity to retain moisture and nutrients, and their consequences for the growth rate of cocoa seedling on two soil types. The resultant CPHB biochar was applied on two soil types from Ghana, Acherensua (sandy loam and near neutral) soil and Ayinase (clayey loam and acidic) soil at rates of 0%, 5% and 10% (wt./wt.). Cocoa seedlings were grown in polybags in a greenhouse at the Cocoa Research Institute of Ghana (CRIG), adding 100ml of water per pot, at 5 days’ intervals for four months. Soil moisture, soil nutrients and growth parameters were monitored for four months. Soil moisture content and chlorophyll levels of the cocoa leaves were measured weekly 5 days after watering, with time domain reflectometry (TDR) and chlorophyll meter respectively. Data on soil nutrient content were collected after the seedlings were harvested. Plant growth parameters (i.e. stem height, stem diameter, stem dry weight, leaf area, leaf dry weight, root length, root volume, root dry weight, and total dry weight) were determined in the second and fourth month. Using the Kon-tiki kiln, I found that 245.5kg of CPH biomass produced 82.5kg of biochar (CPHB), indicating a 33.4% biochar yield. The cocoa pod husk biochar was alkaline (pH=10.8), total nitrogen (1.06%) and available phosphorus (277μg/kg) were high. This supports earlier results for CPHB using different techniques. The addition of biochar to the soils caused a significant increase in both soil moisture content ($p<.0001$) and soil nutrient content (N, P and K) ($p<0.05$). The 5% CPHB treatment significantly increased almost all growth parameters (except root dry weight, root volume and stem dry weight) at the end of the experiment. However, the growth response to biochar addition was highly non-linear, with 10% CPHB treatments resulting in significant declines ($p<0.05$) in stem height, stem dry weight, leaf dry weight, leaf area index, root volume, root dry weight, and total dry weight relative to the control. The study recommends 5% CPHB application to enhance soil quality and seedling growth. Not only were these positive effects of 5% CPHB seen in the acidic soil, but also in the near neutral soil. The study estimated that about 956.3-1277.5kg CPHB can be produced per ha using the “Kon-tiki” kiln technology.

Keywords: cocoa seedlings, biochar, soil moisture, plant nutrients, seedling growth rate.

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DEDICATION

Dedicated to my supporting husband, Alexander Kali, and my beautiful kids, Kaylen Kali, Alexander Kali Junior and Karzel Kali.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BD	Bulk Density
C	Carbon
Ca	Calcium
CEC	Cation Exchange Capacity
CH_4	Methane
CO_2	Carbon Dioxide
CPH	Cocoa Pod Husk
CPHB	Cocoa Pod Husk Biochar
CRIG	Cocoa Research Institute of Ghana
DW	Dry Weight
D	Diameter
GHG	Greenhouse Gases
H	Stem Height
K	Potassium
LAI	Leaf Area Index
Mg	Magnesium
N	Nitrogen
TN	Total Nitrogen
P	Phosphorus
RL	Root length
RV	Root Volume
SLA	Specific leaf area
SRL	Specific root length

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The cocoa plant (*Theobroma Cacao L.),* an understorey perennial crop which originated from the Amazon basins, is mostly grown in humid tropical condition (Lahive et al., 2019). About 70 % of the world's cocoa is grown in west Africa, and smallholder farmers are the major producers (Lahive et al., 2019). Their farms are low input based, rely on rainfall (Snoeck et al., 2010) and are characterized by low yields, averaging 200-700 kg/ha (Asare & David, 2011). Ghana is the second largest cocoa exporter in the world and cocoa contributes hugely to the country's economy. There is over a million hectares of land under cocoa cultivation in Ghana (Snoeck et al., 2010, Aneani & Ofori-Frimpong, 2013). Like in most west African countries, smallholder farmers in Ghana are the major cocoa producers, and average cocoa yields are low at about 450kg/ha (Nunoo et al., 2014). Low yields have been linked to tree stock (aged trees), sub-optimal farm management and environmental factors (Asare & David, 2011).

Rainfall is a major environmental factor in cocoa production (Lahive et al., 2019). In recent years, erratic rainfall patterns and its associated drought episodes have greatly affected water availability on rain fed agriculture systems (Obia et al., 2020). In west Africa, the areas suitable for cocoa production may be affected by projected long dry seasons due to climate change (Läderach et al., 2013). Climate change is expected to increase average global temperature and to affect spatial and temporal rainfall patterns (Läderach et al.,2013). Generally, suitable cocoa growing regions should have high amounts of rainfall ranging between 1250-3000mm per annum (Asare & David, 2011), rainfall amounts below <1200mm per annum will adversely affect soil water content and may reduce growth and yield (Lahive et al., 2019). Additionally, continuous dry seasons longer than three months with < 100 mm monthly rainfall might negatively affect cocoa growth rate, especially among seedlings (Lahive at al., 2019). On small scale farms, with dependency on rainfall, the ability of the soils to retain the supplied rainfall is critical for seedling development and growth (Bahrun et al., 2018). Most soil functions such as nutrient release for plant use are linked to soil water retention and transmission (Rousseva et al., 2017).

Loss of soil fertility, due to continuous soil nutrient harvesting without adequate fertilization, is a major farm management challenge in West Africa (Snoeck et al., 2010, Munongo et al., 2017). In 1994, agronomic studies conducted across the six agro-ecological zones of Ghana (Guinea savannah, Sudan savannah, coastal savannah, Forest-savannah transition, Semi-deciduous forest and Rain forest) reported that replenishing harvested soil nutrients through fertilization can increase cocoa yields to about 1300 kg/ha (Snoeck et al., 2010). This can contribute to sustainable cocoa production in the future through cocoa intensification, where crop yields per hectare are increased as opposed to increasing the area used for production (Asare & David, 2011). The latter is often associated with deforestation and loss of biodiversity. However, fertilizer use in Ghana is among the lowest in the world, mainly due to the high cost of fertilizers and its limited accessibility for small-scale farmers (Snoeck et al., 2010).

Biochar has been used as a soil enhancer, improving both soil moisture content (Obia et al., 2020, Bahrun et al., 2018), and soil fertility (Pandit et al., 2017, Martinsen et al., 2014), while at the same time increasing crop yields (Pandit al., 2017). Several research projects on annual crops (mostly maize) have reported increases in crop yields in response to biochar application (Haefele et al., 2011; Waqas et al., 2018; Jeffery et al., 2017; Pandit et.al. 2017; Martinsen et al., 2014). Increases in yields have been attributed to increased water retention capacity due to improvement in soil structure (Obia et al., 2020; Obia et al., 2017; Pandit et al., 2017), and to increased soil pH, and nutrient base cations like potassium (K) and Magnesium (Mg) (Jeffery et al., 2017). The efficiency of biochar as soil amendment is dependent on soil type and biochar quality (Obia et al., 2017; Jeffery et al., 2017). Biochar is more effective for soil fertility purposes in tropical soils, which are commonly acidic and characterized by low fertility status. By contrast, temperate soils often are less acidic, and higher in fertility also because of common use of fertilizer (Jeffery et al., 2017). For soil water retention purposes biochar is more effective on sandy soils in areas with prolonged periods of droughts in the growing season (Haefele et al., 2011, Obia et al., 2020).

The type of feedstock used for biochar production affects the quality of biochar (Martinsen et al., 2014). The cocoa pod husk has high K and Ca content and also contains other essential plant nutrients (Phosphorus, Magnesium, Sodium, Iron, and Zinc) (Munongo et al., 2017). Pod husk makes up 70% of the cocoa pod, thus, large quantities of these are left as waste on farms after the beans have been harvested (Munongo et al., 2017). On most small-scale farms, cocoa pod husks are left as large heaps on the farms or applied as mulch or compost which can serve as potential breeding grounds for disease inoculum (Figueira et al., 1993). The charring of cocoa pod husk can aid in waste management while its use as soil amendment can improve soil fertility and structure (Munongo et al., 2017). The pyrolysis process affects the quality of the biochar produced (Pandit et al., 2017, Sun et al., 2017). Traditional production methods such as soil pits are cheap, however, the process is slow and produces low biochar yields 10-20% (Cornelissen et al., 2016). In addition, they also emit high amounts of major greenhouse gases (CH_4, CO_2) contributing to global warming (Pandit et al., 2017). Advanced biochar kilns such as the retort kilns are efficient in producing high yield biochar with little GHGs emissions but are usually very expensive (Pandit et al., 20117). The “Kon-tiki” flame curtain kiln presents a low-cost biochar technology with pyrolysis combustion similar to that of the retort kilns, thus reducing emissions and increasing biochar yields (22-25%) (Cornelissen et al., 2016).

Nevertheless, there is limited research on cost-effective and low gas emissions biochar production technology for the production of cocoa pod husk biochar (CPHB) on local cocoa farms. The purpose of the current research is to investigate the potential of the "Kon-tiki" kiln in producing cocoa pod husk biochar (CPHB) efficiently, and to quantify its effects on soil nutrient content, soil water retention capacity and the growth of cocoa seedlings. We hypothesize that biochar will have a positive effect on soil nutrients and soil moisture content as well as on seedling growth rates. However, the effect will depend on climatic and edaphic conditions. The effect of CPHB on soil fertility and pH are expected to be more pronounced in acid soils than in near-neutral soils, whereas it effects on soil water retention characteristics will be more significant in the sandy soils than in clayey or loamy soil.

1.2 PROBLEM STATEMENT

Cocoa is a major contributor to the economy of West African countries. In Ghana, cocoa is main export crop contributing about $1.87 billion to the economy, and over 2 million (30%) of the Ghanaian working population are employed in the cocoa industry (Sosu, 2014). However, increase in global temperatures and fluctuations in rainfall patterns and distribution due to climate change, has affected suitability of current cocoa growing areas for successful cocoa cultivation (Lahive et al., 2019). In Ghana, the shift in most cocoa farms further south of Brong Ahafo and Western region are clear indications of the influence of climate change on cocoa production (Dzandu, 2016, Vigneri, 2007). Additionally, decline in soil nutrient content due to lack of nutrient recycling on most cocoa farms in the country is a major factor for low crop yields (Snoeck et al., 2010).

Several researches have reported increase in crop yields (mostly among annual crop especially maize) due to improvement of soil properties with biochar application (Obia et al., 2016; Pandit et al., 2018; Jeffery et al., 2017; Lorenz & Lal, 2014). However, there is limited research on biochar application on perennial crops (such as cocoa) (Yeboah et al. 2016). Soil amendments like biochar that can improve soil water and nutrients contents (Obia et al., 2020, Munongo et al., 2017) are essential for sustainable cocoa production as they close the loop by returning nutrients (and carbon) to the cocoa soils. Biochar, a porous material abundant in carbon and other minerals, is produced from the pyrolysis of biomass materials in a closed system under limited oxygen conditions (Cornelissen et al., 2016). Cocoa pod husks are readily available on farms and contain some essential plant nutrients (Munongo et al., 2017). Cocoa pod husks can be transformed into biochar as soil enhancer. Bahrun et al., (2018) showed that cocoa pod husk biochar (produced using the drum kiln) can increase cocoa seedling growth and reduce watering frequency in a greenhouse under sandy loam soils. In this study, CPHB (produced using the "Kon-tiki'' kiln) was applied to two soil types (acidic (clayey loam) and near neutral (sandy loam) soil) in a greenhouse experiment. Data on soil moisture, soil nutrient content, and cocoa seedling growth rate with different CPHB application rates (0, 5 and 10 % wt./wt. CPHB per Kg of soil) were collected over the period of study. Additionally, the study sort to estimate the average amount of CPHB that can be produced per hectare on cocoa farms in Ghana.

AIM AND OBJECTIVES, HYPOTHESIS AND RESEARCH QUESTIONS

The study aimed to investigate the quality and quantity of cocoa pod husk biochar produced by the "Kon- tiki" kiln and the effects of this biochar on the soil water content, soil nutrients and cocoa seedlings growth rate in two different soil types (acidic and one near-neutral).

The objectives of the study are:

- To determine the biochar yield (%) per weight of cocoa pod husk used.

- To determine the quality of cocoa pod husk biochar produce (pH, available P, Total Nitrogen, Exchangeable K^+, Mg^{2+}, Ca^{2+}).
- To explore how biochar addition to soils affects soil nutrient content, soil water content and growth rate of cocoa seedling on two soil types (acidic and one near-neutral).
- To test the effect of biochar on two soil types with widely different characteristics (acidic and near-neutral)
- To estimate the amount of CPHB that can be produced per ha on cocoa farms using the "Kon-tiki" kiln technology.

We hypothesize that:

- "Kon-tiki" kiln will have a positive effect on the quality and quantity of CPHB.
- Biochar will have a positive effect on the soil moisture content, the major soil nutrients (N, P, K) and seedling growth rate.
- Biochar will have a positive effect on the different soil types.

We formulated the following research question from the objectives:

- How does the "Kon-tiki" kilns influence the quality of biochar produced from cocoa pod husk and what is the yield of biochar per weight of feedstock used.
- How does biochar influence the soil moisture and nutrient contents, and cocoa seedlings growth in two different soil types?
- How do different biochar application rates affect soil water content, soil nutrient content, and the growth rate of cocoa seedling in the two soil types?
- How much CPHB can be produced per ha on cocoa farms in Ghana.

1.5 SIGNIFICANCE OF STUDY

Soil water retention is very essential especially during the dry seasons where the recommended 100 mm of monthly rainfall for optimal growth of cocoa seedlings is not attainable (Bahrun et al., 2018). Biochar can serve as an effective soil amendment for nutrient recycling with the added benefit of enhanced soil structure and increased water retention capacity (Obia et al., 2020, Jeffery et al., 2017, Haefele et al., 2011). The major concerns about biochar as a soil amendment are; the availability of feedstock for biochar production and the cost of production of large quantities and quality biochar (Karim, 2020). The "Kon-tiki" kiln presents an innovative method of biochar production with benefits of low-cost, large quantity and standard-quality biochar from a variety of biomass in accordance with all criteria for European Biochar Certification (EBC) and International Biochar Initiation (IBI) (Cornelissen et al., 2016).

In this study, we produced biochar from cocoa pod husk using the "Kon-tiki" kiln and applied it to two different soils (which are common in cocoa growing areas) which served as media for growing cocoa seedlings. The experiment was carried out at the cocoa research institute of Ghana(CRIG) greenhouse with data collected on soil moisture content, soil nutrient content and growth parameters measured over a 120days' period. This study is significant because it fills the knowledge gap on the potential of the low-cost "Kon-tiki" kiln to produce quality and large quantities of biochar from high lignin content biomass (cocoa pod husk). Additionally, the findings from the study will support earlier knowledge on biochar application effect on soil water content, soil nutrient content, and the resultant influence on seedling growth rate. Thus, the study will provide knowledge on how infertile acidic soil and sandy loam soils (nutrient and moisture content) can be improved with biochar application. This opportunity to convert biomass waste on cocoa farms into soil enhancer (biochar) using the "Kon- tiki" kiln has not been exploited in Ghana. The efficient production of CPHB using low-cost technologies may encourage the incorporation of CPHB for the purposes of soil fertility and soil water management by poor small-scale cocoa farmers (Odesola & Owoseni, 2010, Yeboah et al., 2016). Also, the study will provide knowledge about the amount of CPHB that can be produced per ha using the biochar yield (%) per weight of cocoa pod husk used in the experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 THE COCOA PLANT

The cocoa plant is an evergreen perennial crop native to the Amazon and Orinoco river basins, it originated over 2000 years ago among the Aztecs and Mayans in southern and central America. It became widespread in the world in the 16th century after the arrival of the Spaniards (Carr & Lockwood, 2011). The cocoa tree is from the family Malvaceae, it consists of about 200 genera and approximately 2,300 species (Sosu, 2014). The cocoa plant has alternate and smooth edge leaves with no teeth or lobes, leaves are very broad at 10-40cm long and 5-20cm wide (Sosu, 2014). Cocoa seedlings have shallow taproots for anchorage but may grow deeper into the soil depending on weather conditions (soil moisture content) and soil depth. Lateral roots arising from the tap roots are used as feeding roots and can be found just below the soil surface (Sosu, 2014, Lahive et al., 2019). The cocoa plant has chupon (upward) shoots and fan (lateral) branches (Sosu, 2014).

The cocoa plant is mostly grown from seeds but propagation by cuttings is also possible (Carr & Lockwood, 2011). The method of propagation and variety used can affect when the tree will start yielding, for some hybrid species it can occur after 3 years of transplanting. The process starts when the tiny flowers (1-2cm) emerge on the trunks and branches after which the flowers are pollinated by insects. The pods mature 5-6 months after the pollination (Lahive et al., 2019, Sosu, 2014). The pods are oval shaped and filled with 30-60 seeds per pod (Sosu, 2014). The outer layer of the pod (husk) are plump and hard-walled. Matured pods are yellow or orange in color and weigh about 500g (Dzandu, 2016, Sosu, 2014). During processing, the seeds are removed from the pods, fermented and dried. The dried seeds are sold as cocoa beans to the world cocoa market (Lahive et al., 2019, Sosu, 2014).

2.1.1 THE COCOA INDUSTRY

Commercially, the cocoa plant is one of the most lucrative tropical perennial crops in the world (Lahive et al., 2019). Cocoa is used in the food, pharmaceutical and cosmetic industry (Carr & Lockwood, 2011). In the food industry, chocolate producers are the main users of cocoa beans which makes up only 10% of the cocoa pod (Munongo et al., 2017, Sosu, 2014). Chocolate is widely consumed due to its rich nutritional value (protein, cellulose, pentosane, tannin, theobromine, sugar and caffeine) (Sosu, 2014). Approximately 4.73 million tons of cocoa was produced worldwide in 2019/2020 (ICCO, 2021). Globally, cocoa is a source of income (directly or indirectly) to over 40-50 million people (Carr & Lockwood, 201l). Smallholder farmers are the major producers in the world (5-6 million farmers) contributing to about 90% of global production (Carr & Lockwood, 2011). West Africa is the hub of cocoa production, cocoa farming is the primary source of income of over 2 million farmers in the region (Schroth et al., 2016, Snoeck et al., 2010). Ivory Coast and Ghana together produce 53% of the world's cocoa and are the first and second largest world exporters respectively (Aboud & Sahinli, 2019, Zolin & Animah, 2017, Läderach et al., 2013).

2.1.2 COCOA PRODUCTION IN GHANA

The Republic of Ghana, lies within latitude 4^{o}44´N and 11^{o}11`S and 3$^{o}$11`W and 1^{o}11` E. The cocoa plant was first introduced by the Dutch and Swiss missionaries in 1815, but its cultivation was unsuccessful (Zolin & Animah, 2017). The Amelonado cocoa pod was reintroduced in 1879 by Tetteh Quarshie a blacksmith from Akwapim Mampong in the Eastern region of Ghana. Tetteh Quarshie during his travels brought some cocoa seeds from Fernando Po in the northern part of Equatorial Guinea (Zolin & Animah, 2017). Cocoa cultivation spread across the six southern regions of Ghana in the early 1890s after Governor Sir William B. Griffith encouraged Tetteh Quarshie to set up a botanical garden at Mampong to train other farmers interested in cocoa farming (Zolin & Animah, 2017). Ghana has since been a major exporter of cocoa in the world market (Zolin & Animah, 2017, Asamoah et al., 2013). Currently, there are over 1.6 million ha of farm lands used for cocoa cultivation in the country (Sosu, 2014).

In Ghana, 52 % of the working population is employed in the agriculture sector of which 30 % out of the entire working population is employed in the cocoa industry (Aboud & Sahinli, 2019, Zolin & Animah, 2017, Sosu, 2014). The cocoa sector employs over 6 million Ghanaians directly and indirectly (Zolin & Animah, 2017). Cocoa farming is an important part of the country’s economy, complementing the statement “Ghana is cocoa and cocoa is Ghana". Cocoa is the second highest foreign exchange earner for the country second only to Gold. In the year 2004-2008, the cocoa sector constituted 39 % of the total gross domestic product (GDP) of the country (Ofori-Bah & Asafu-Adjaye, 2011). It also contributes to about 30 % of Ghana's total export earnings (Aboud & Sahinli, 2019, Asamoah & Owusu-Ansah, 2017). Ghana’s cocoa is considered the premium quality of the bulk cocoa produced in the world market (Schroth et al., 2016; Jano & Mainville, 2007).

In Ghana, 80 % (265,000) of the cocoa farms in the country are smallholder farms with farm sizes ranging between 1.5-5 ha (Aboud & Sahinli, 2019). Most of the farms are family-owned (Asamoah & Owusu-Ansah, 2017). About 800,000 small-scale cocoa farmers depend on cocoa as their main source of income in the country, with about 70-100 % of their family income dependent on the cocoa farm (Nunoo et al., 2014). However, most cocoa farmers struggle to meet household needs, about 7 % of cocoa farmers in Ghana are extremely poor and usually rely on other forms of income to meet family needs (Asamoah & Owusu-Ansah,2017). The current revenue from cocoa production in Ghana is far less than its potential (Aneani & Ofori-Frimpong, 2013). Currently, Ghana has one of the lowest cocoa yields per ha in the world at an average of 0.45tons / ha as compared to countries in Asia with yields of about 1tons /ha (Nunoo et al., 2014). However, research show that yields can be increased to about 1.3 tons/ha with proper farm management (Snoeck et al., 2010). In recent times, climate change has resulted in changes in hydrologic regimes and air temperatures, and this in turn is expected to negatively affect crop yields in tropical regions (Lahive et al., 2019, Cerri et al., 2007). In Ghana, small-scale cocoa farmers, who already have low incomes due to low yields will become more vulnerable to climate change because of their reliance on rainfall and low-input agriculture systems (Lahive et al., 2019, Läderach et al., 2013, Vigneri, 2007).

2.2 CLIMATE CHANGE AND COCOA PRODUCTION

Climate change results from emissions of greenhouse gases (GHGs) into the atmosphere. The increased concentrations of major GHGs (nitrous oxide (N_2O), methane(CH_4), carbon dioxide (CO_2)) in the atmosphere leads to an increase in average global temperatures termed as global warming (Lahive et al., 2019). Recently, atmospheric CO_2 concentration surpassed 400ppm and is expected to increase to 490-1370 ppm by the end of the century (Lahive teal., 2019). The projected temperature increases are dependent on various emission scenarios called RCPs (Lahive et la, 2019, Van Vuuren et al., 2011). The greater percentage of GHG emitted into the atmosphere originates from anthropogenic activities such as fossil fuel burning, agricultural production and land use change (Lal, 2015, Van Vuuren et al., 2011). Increased land use for agriculture purposes is driven by population growth and change in dietary needs resulting in excess CO_2 emissions beyond what the natural carbon cycle can process (Grace, 2004). Agriculture accounts for 11 % of global greenhouse emissions (IPCC, 2014).

Historical data collected across west Africa over decades clearly shows variability in rainfall amounts and patterns. The situation may worsen as climate change progresses (Lahive et al., 2019, Läderach et al., 2013). Currently, west Africa is experiencing extended periods of drought, and extreme weather events are expected to increase in the future, making present production areas unsuitable for cocoa cultivation (Lahive et al., 2019, Schroth et al. 2016, Medina & Laliberte, 2017). This will significantly impact world cocoa production, national economies and farmers' incomes (Läderach et al.,2013). The cocoa plant can tolerate 1-3 dry months but for optimal growth 100 mm rainfall per month is recommended (Lahive et al., 2019). The optimal temperature for production is 22-25 ^{o}C but temperatures of 20-27 ^{o}C can be tolerated (Lahive et al., 2019, Sosu, 2014, Carr & Lockwood, 2011). The wide leaves of the cocoa plant suggest it easily loses water at high temperatures and its shallow roots decreases it chances of water uptake from deeper soil layers (Lahive et al., 2019, Sosu, 2014, Wicks, 2003). Drought is a growth limiting factor for young cocoa plants as under such conditions seedlings close their stomata to reduce transpiration, which also simultaneously decreases photosynthesis (Bahrun et al., 2018, Carr & Lockwood, 2011). Signs of drought in cocoa seedlings are small leaf size, wilting of leaves, untimely leaf fall and decreased stem growth (Carr & Lockwood, 2011). On the other hand, cocoa seedlings are also sensitive to water logging, this can lead to reduced aeration when soil pores are completely filled with water and roots are irreparably damaged (Bahrun et al., 2018, Sosu, 2014).

In Ghana, sequential data from all six agro- ecological zones in the country 1961 to 2000 revealed continuous increase in temperatures (1 ^{o}C over the last 30 years) and decrease in average annual precipitation (Minia, 2004, Lahive et al., 2019). Temperatures are expected to increase from 0.8 to 5.4 ^{o}C from 2020 to 2080 (Lahive et al., 2019). Continuous increase in annual temperatures, decrease rainfall amounts and variability in precipitation patterns, rising sea levels and frequent occurrence of extreme weather conditions are clear indications of climate change in the country (Lahive et al.,2019, Kolavalli & Vigneri, 2017). The impacts of climate change listed above may negatively affect the start of the planting season and soil moisture content, which might affect production levels and suitability of present production areas for cultivation (Schroth et al., 2016, Lahive et al., 2019, Kolavalli & Vigneri, 2017). Increase in frequency of extreme events such as droughts has resulted in the shifting of the cocoa growing-belt south into the forest zones of the Brong Ahafo and Western regions where climate conditions are still suitable for cocoa production (Vigneri, 2007). The destruction of more forestlands to produce cocoa leads to loss of biodiversity and further global warming (Schroth et al., 2016). Läderach et al. (2013) recommends that small-scale farmers adopt agronomic technologies such labile organic matter (mulch and compost) for soil and water conservation to improve soil structure and water retention capacity. This will serve as both adaptation and mitigation strategies for climate change.

2.3 PROPERTIES OF SOILS SUITABLE FOR COCOA CULTIVATION

A suitable soil for cocoa cultivation is one that can moderate soil moisture content, has a high nutrient level, is well aerated and can firmly support the shallow roots of the cocoa plant (Dzandu, 2016, Sosu, 2014). Optimal cocoa seedling growth and development requires soils with good structure, high water retention capacity and good drainage to prevent waterlogged conditions because, the cocoa plant is sensitive to both drought and flood conditions (Bahrun et al., 2018, Sosu, 2014). The high temperatures in tropical regions results in rapid soil weathering and decomposition of organic matter. In combination with leaching, this increases the risk of soil fertility loss when there is not enough fertilization (Munongo et al., 2017, Jeffery et al. 2011, Snoeck et al., 2010). Cocoa seedlings require major nutrients such as nitrogen (N), phosphorus (P), and potassium (K) for their growth and development (Sosu, 2014). However, fertilizer use in Ghana is among the lowest in the world; only 25 % of coca farmers apply the recommended fertilizers (Nunoo et al., 2014). This is mostly attributed to the low incomes of farmers and the high cost of inorganic fertilizer. With adequate fertilization and soil conditioning, cocoa cultivation can be possible on several soil types (Dzandu, 2016). Integrated Soil Fertility Management (ISFM) is essential because crop yields can be increased with the appropriate soil amendments and techniques (Ofori-Frimpong et al., 2010)

2.4 BIOCHAR

Karim (2020) defines biochar as charcoal that is produced from organic biomass residues at temperatures of 450-700 ^{o}C in a process called pyrolysis with no or limited access to oxygen. Biochar is stabilized carbon, which may be used as a soil enhancer in agriculture. By contrast, charcoal, which is produced from woody biomass, is used primarily for energy purposes (Saravanakumar & Haridasan, 2013). Biochar is largely stable organic carbon (recalcitrant) as opposed to other labile forms of organic matter (compost and mulch), which do not build up the pool of soil organic carbon. Biochar has a high surface area (Sohi et al., 2011), a high content of macro and micro nutrients (except for N) (Munongo et al., 2017, Bahrun et al., 2018), and high pH, due to the elevated content of alkaline ashes (Martinsen et al. 2015). Biochar has variable chemical and physical characteristics depending on pyrolysis temperature, pyrolysis residence time, and type of feedstock (Cornelissen et al., 2016, Jeffery et al., 2017, Fidel et al., 2017, Munongo et al., 2017). The history of charcoal (biochar) production dates back to over thousand years, charcoal mixed with ash or household wastes was used as soil amendment in the Amazon region (Cornelissen et al., 2016, Karim, 2020).

Biochar as soil amendment can be a source of fertilization for soils as nutrients are recycled from farm wastes (Haefele et al., 2011, Martinsen et al., 2013). Several factors affect the efficiency of biochar as a soil amendment. Source of feedstock used, pyrolysis temperature, biochar application rates, soil type to be amended and also crop type (Cornelissen et al., 2016, Lorenz & Lal,2014, Jien & Weng, 2013, Haefele et al., 2011, Sohi et al, 2010). Sandy soils are more improved by biochar application than loamy soil because sandy soils are in low soil organic matter content, this impacts soil moisture and nutrient contents (Lorenz & Lal, 2014, Haefele et al., 2011, Sohi et al, 2010). Biochar with its unique physical properties can alter the texture of sandy soil and soil moisture parameters, offering a mechanism of water storage as well as improving nutrient contents (Li et al., 2020). The type of feedstock used in biochar production also has an effect on various aspects of the soil chemical and physical properties (Cornelissen et al., 2016, Li et al., 2020), while the method of production has an effect on the biochar yield, pH, and C/N ratio (Munongo et al.,2017, Cornelissen et al., 2016). The application rate and method of application affects the release and uptake of nutrients for plant use (Sohi et al. 2010, Zhang et al., 2013).

2.4.1 BIOCHAR EFFECT ON SOIL (WATER AND NUTRIENT CONTENT)

Soil organic matter content influences several soil properties such as soil fertility, and aggregate stability which in turn affects soil structure (Bahrun et al., 2018, Marjenah et al., 2016). Biochar’s effect on soil water retention is more pronounced in dry and sandy soils as opposed to loamy soils (Li et al., 2020). Porosity and hydraulic conductivity also increases in biochar amended soil; this is linked to increased surface area, redistribution from micro aggregates to macro aggregates, and the formation of complexes (Sohi et al., 2010, Jien & Wang, 2013). Increased soil porosity implies high soil water content, as was observed in soil amended with biochar (Ulyett et al., 2014). Obia et al. (2020) noticed that soil water content increased when biochar was added to soil. In addition, increase in soil water retention reduced soil temperature and constant variation in temperatures. Soil water content is a major growth limiting factor among cocoa seedlings (Dzandu, 2016). Studies with maize and mustard reported increased crop yields correlated with increases in soil water retention due to biochar application. For example, 10 % (wt./wt.) biochar application significantly increased soil water retention and maize yields in Nepal (Pandit et al., 2018). As stated earlier, biochar improves the soil structure; this increases the water retention capacity in the root zones. This can result in improved root development and thus, increased crop yields (Marjenah et al.,2016). Tropical areas experiencing continuous droughts episodes due to climate change (Lahive et al., 2019), can benefit from this property of biochar to retain soil moisture (Obia et al., 2020)

Several reports have recorded an increase in soil pH of biochar amended soils. This is attributed to high concentrations of base cations (Ca^{2+}, Mg^{2+}, K^{+}) as carbonates. The increase in ash content results in the reduction of acidity in carboxyl groups (Munongo et al.,2017, Fidel et al., 2017). The increased in potassium(K) availability in biochar amended soils has been attributed to the high K content in biochar ash (Pandit et al., 2018, Martinsen et al., 2014). K can affect osmotic adjustments, enzyme activation, and regulate the opening and closing of stomata, thus, reducing drought stress (Ahmad et al., 2018). Therefore, K can influence major plant physiological and biological activities to improve plant growth (Ahmad et al., 2018). In addition to an increase in soil pH, biochar may improve the CEC of the amended soil. This is due to the high variable charge, pH values and surface area of biochar (Lorenz & lal.,2014, Jien & Wang, 2013). The high CEC in biochar amended soil provides chemically active surfaces for nutrient adsorption thereby making nutrient that would otherwise be lost to leaching available, the high CEC again helps catalyze useful reactions (Schultz et al., 2014, Jien & Wang, 2013, Sohi et al., 2010).

Biochar can increase fertilizer use efficiency by reducing fertilizer application (half of the recommended fertilization rate can be saved) (Yeboah et al., 2016), and can reduce the potential leaching of essential nutrients (NO_3—N, PO_4—P) (Jeffery et al., 2017, Pandit et al., 2018). Nano pores in biochar increase absorption of NO_3^--N (Pandit et al., 2018, Hale et al., 2013). Biochar increases soil pH, which increases the availability of $PO_4^{—}$P associated with increased variable (negative) charge of the soil (Pandit et al., 2018, Dzandu, 2016, Hale et al., 2013). Increase in crop yields on acidic and eroded soils, due to biochar addition, have also been attributed to the decreased concentration of dissolved toxic metals such as Aluminum (Al) and lead (Pb) (Lorenz & Lal.,2014, Cornelissen et al., 2013). The decrease in the concentration of dissolved toxic elements in soil water of amended soils is attributed to increase in pH and exchangeable base cations (K^+, Ca^{2+} and Mg^{2+}) and to formation of stable hydroxide complexes, thus reducing their availability in soil solution (Tsai et al., 2018, Cornelissen et al., 2013). Also, improvement in micro-nutrient availability (Fe and Zn) with biochar incorporation enhances soil fertility and productivity on degraded tropical soils (Munongo et al., 2017, Jeffery et al, 2017). Cornelissen et al., (2018) reported that 5t/ha and 15t/ha cocoa shell biochar when added to soil significantly increased nutrient content of degraded acidic Ultisols.

2.4.2 BIOCHAR EFFECT ON PLANT GROWTH

The cocoa plant can grow to heights of 3 -10 m (Dzandu, 2016). Seedlings bear plagiotropic branches meaning 3 to 5 shoots grow out of the shoot apex (Bahrun et al., 2018, Dzandu, 2016). The cocoa plant comprises of tap and lateral roots systems, the former aids in providing support while the latter is used in water and nutrient uptake (Dzandu, 2016). Vegetative and flowering stages are both influenced by soil water content (Carr & Lockwood, 2011). However, the flowering phase is the most affected by soil water content, drought stress can limit the exchange of gases due to reduced stomatal conductance that causes reduced chlorophyll contents and plant growth rate (Carr & Lockwood, 2011, Bahrun et al., 2018).

Studies on the effect of biochar on plant growth has been carried out on several crops (mostly annual crops) in both greenhouse and field studies all over the world (Pandit et al., 2018, Yeboah et al., 2016, Haefele et ale, 2011, Bahrun et al., 2018, Jeffery et al., 2017). There are contrasting views on the potential of biochar to increase crop yields. Most scientists have attributed the increased in plant growth rate with biochar application to improved soil fertility and increased water retention (Bahrun et al., 2018, Haefele et al., 2011, Waqas et al.,2018, Jeffery et al. 2017). Pandit et al (2018) also found that maize harvest increased by a factor of four even at low application rates such as 2%wt. /wt. biochar per hectare, if biochar was applied locally at planting stations only. The rate of application of biochar is crucial for crop yields, a significant improvement in plant physiological characteristics of rice was reported at 10 % biochar application compared to 2 % biochar treatment (Waqas et al.,2018). However, there have been reports of reduced seedling growth rate and biomass yield with increased biochar application rates (Sun at el., 2019, Bass et al., 2016). In pot experiment in Indonesia, Bahrun (2018) reported reduction in cocoa seedling growth rate at biochar application rates above 9 g biochar of CPHB per 1kg of soil. This can be attributed to reduction in development growth from extreme change in bulk density, high soil moisture and reduced soil aeration (Bahrun et al., 2018). Crops exposed to soil with reduced water permeability and reduced aeration can result in permanent root damage and decreased growth rates (Bahrun et al., 2018).

2.5 COCOA POD HUSK AS FEEDSTOCK FOR BIOCHAR PRODUCTION

In most parts of Africa, crop residues have value as fodder, fuel, soap making or as soil amendments (Yeboah et al., 2016, Opoku-Ameyaw et al., 2010). Thus, the use of crop residues as biochar for soil amendment proposed should outweigh other possible biomass use, especially in drier areas where biomass is scarce (Yeboah et al., 2016). The cocoa pod husk (CPH) constitutes about 70 % (wt./ wt.) of the matured cocoa pod (Munongo et al., 2017).

Figuiera et al., (1993) estimates that about 10 tons of cocoa pod husk is produced from each ton of cocoa beans produced which poses a major problem in waste management for farmers.

In most farms in Ghana, cocoa pod husks are cast in heaps and left on the sides of the cocoa farms (Sosu, 2014). Untreated CPH can serve as a source of inoculant (*Phytophthora spp*.) for the cocoa black pod disease (Figuiera et al., 1993, Munongo at al., 2017, Lu et al., 2018). On small-holder cocoa farms, the black pod disease can reduce annual production yields by 30- 90 % if effective treatment management is not applied (Lu et al., 2018). Munongo et al., (2017) recommends that cocoa pod husk be charred to potentially reduce the spread of *Phytophthora spp*, while that char may be used as soil enhancer (biochar). Charring of cocoa pod husk can be a novel process in residual management on-farm and can also be potentially used as a soil enhancer, with little or no greenhouse gas emissions (Munongo et a, 2017, Yeboah et al., 2016). Cocoa pod husk (CPH) is rich in essential plant nutrients (P, N, K, Ca, Mg, Fe and Na) (Lu et al., 2018, Munongo et al., 2017). As with all biochar, CPHB was found to be alkaline in nature which makes it suitable as a soil amendment especially in acidic tropical soils (Yeboah et al., 2016). CPHB has potential as soil amendment, income generator, waste management system, and long-term carbon storage (Munongo et al., 2017, Yeboah et al., 2016).

2.6 BIOCHAR PRODUCTION TECHNOLOGIES

Most Terra Preta soils in the Amazon region in South America were found to contain large amounts of biochar mixed with various materials, proving that large quantities were produced for agricultural purposes (Wiedner & Glaser,2015). Several methods for biochar production have been developed over the years, all with specific advantages and disadvantages such as low yield, long pyrolysis time, high cost of technology, and high emissions of toxic gases (CH_4, NO, N_2O, CO_2 and smoke particles) into the atmosphere (Cornelissen et al., 2016, Saravanakumar& Haridasan, 2013, Pennise et al., 2001). The adoption of biochar on small-scale farms will be influenced by the accessibility and cost of the biochar technology (Lorenz & lal., 2014). Some methods of biochar production are described below:

2.6.1 PIT KILN

The pit kiln is the simplest method of biochar production. It is made by digging a hole in the ground and starting a fire at the bottom. After which the feedstock is added to burn with oxygen present. The pit can be made into any size or shape. The process converts all biomass into CO_2 and ash. After complete burning of feedstock, soil is added to quench the fire. The biochar yield per biomass is low at 10-20 % (Saravanakumar& Haridasan, 2013). Ash and CO_2 (the dominant GHG which causes global warming) are the main by-product from the burning process (Haefele, 2011). Thus, the process releases high amounts of pyrolysis gases unburnt into the atmosphere (Pennise et al., 2001).

2.6.2 RETORT KILN

The retort kiln was designed to reduce the emission of unburnt pyrolysis gases; this was achieved through the partial afterburning of the unburnt gases. The pyrolysis gases are recirculated into the combustion chamber where it is combusted internally, thus, resulting in 75 % gas emissions reduction (mainly CO, CH_4 and aerosols) (Saravanakumar& Haridasan, 2013). The energy contained in the recirculated carbon and hydrogen rich flue gases is used to sustain the pyrolysis process so that less heat from the endothermic pyrolysis reactions is needed to sustain the process (Sparrevik et al., 2014). The yield of biochar per feedstock is very high at 30-45 % (Saravanakumar& Haridasan, 2013), the recirculation of flue gases results in secondary biochar production from the biomass, thus, increasing biochar yields. The technology has high costs of installation and maintenance, and the cost of production per ton of biochar using this technology ranges between US$600-900 (Cornelissen et al., 2016, Schultz et al., 2014). Biochar production using this method may be limited by these costs in developing countries (Jeffery et al., 2017, Cornelissen et al., 2016).

2.6.3 "KON-TIKI" KILN (FLAME CURTAIN KILN)

A novel type of technology, the "Kon-tiki" flame curtain pyrolysis combines the simplicity of the pit kiln and the partial afterburning of pyrolysis gases in the retort kiln. The "Kon-tiki" flame curtain can be simply constructed to precision into conical soil pit on farms. The pit is dug to precision into a conical shape to limit the presence of oxygen during pyrolysis (Cornelissen et al., 2016, Sparrevik et al, 2014). The feedstock is carefully layered in batches on top of each other while using the flame to char the biomass, thus, the name "flame-curtain kiln". This reduces the production of ash and emission of CO_2. Temperatures above 700 ^{o}C have been recorded with this pyrolysis process, thus, higher than temperatures recorded in the pit kiln (Pennise et al., 2001). In an experiment in Nepal, Cornelissen et al., (2016), reported that biochar derived from various feedstock using the "Kon-tiki" flame curtain complies with international biochar quality standards. The biochar yield (%) from varied biomass was relatively high ranging between 22-30 % of feedstock biomass weight, and elemental nutrient contents (C, P, K, Ca, Mg and Na) were moderate compared to the retort metal kiln (Cornelissen et al., 2016, Sparrevik et al, 2014). However, the residence time for pyrolysis in the "Kon-tiki" flame curtain is longer than that of the retort metal kiln (Sparrevik et al, 2014). Gas and aerosol emissions are relatively low compared with other traditional methods (soil pits) (Sparrevik et al, 2014, Pennise et al., 2001).

CHAPTER 3

MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE

The experiment was conducted in a greenhouse (figure 1) at the Cocoa Research Institute of Ghana (CRIG), located in New Tafo in the Abuakwa North Municipality of the Eastern Region of Ghana. New Tafo is geographically sited within latitude 06^{o} 13’ N, longitude 00^{o} 22’ W, with an altitude of 222 m above sea level. The greenhouse at CRIG used for the study is specifically positioned on latitude 6^{o} 13’ 28” N and longitude 0^{o} 21’ 49” W (figure 1).

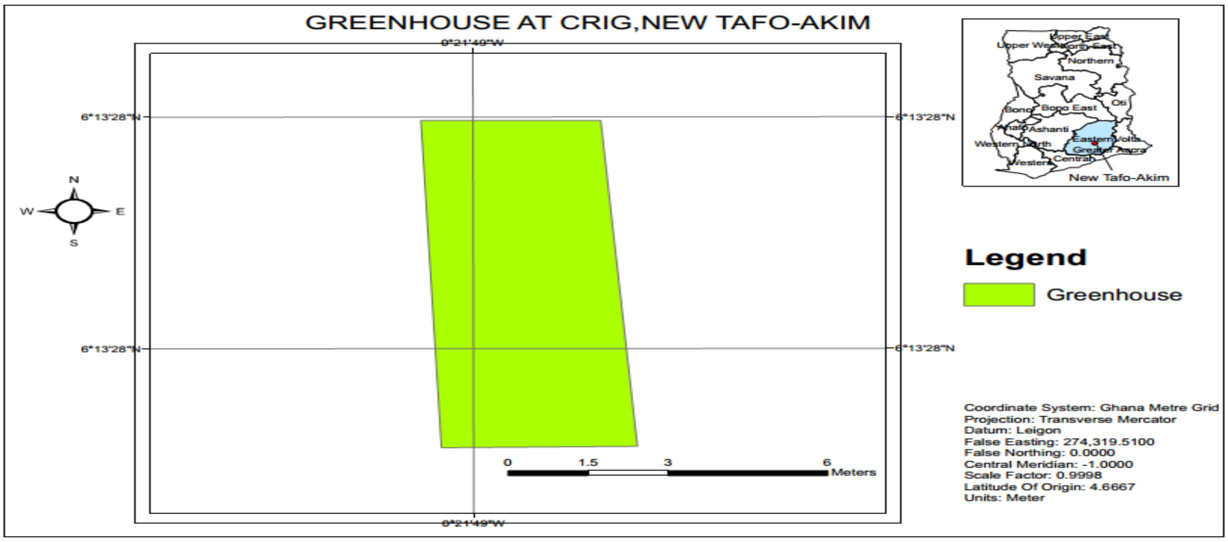

Figure 1 *GPS map of the study site*

3.2 EXPERIMENTAL DESIGN AND TREATMENT APPLICATIONS

The pot experiment was conducted with two soil types Acherensua soil (sandy loam and near neutral) and Ayinase (clayey loam and acidic), and carried out at CRIG greenhouse for four months (figure 2) (April, 2020 to July, 2020). The soils for the experiment were obtained from two cocoa farms, Ayinase was procured from the Western Region and Acherensua was procured from the Ahafo Region. The soil samples were collected from 0-30 cm depth and were well homogenized by repeated shoveling. Samples then were thoroughly mixed to form a composite sample according to treatments. The characteristics of the soil samples are summarized in Table 1. The use of black polybags to nurse cocoa seedlings is the recommended and common practice in Ghana. For this experiment, standard black polybags with volume of 886 cm^3 were used. The bags were perforated at the base and each bag was filled with 730 g and 780 g of sieved dry topsoil for Ayinase and Acherensua soil respectively for the control. In two additional treatments, both soils were mixed with 5 % and 10 % CPHB weight/weight, respectively. Each polybag was packed to a bulk density of 1.23 g cm^{-3} and 1.35 g cm^{-3} for the control, which is typical for the undisturbed topsoil of Acherensua and Ayinase, respectively. The perforations at the base of the polybags was for aeration and drainage of excess water. All the filled poly bags were arranged on trestle tables in the greenhouse. Seeds were obtained from CRIG farms; one seed was sown per polybag.

The experiment was arranged in a completely randomized design (CRD) with three replications. At the start of the experiment, all soils were slowly saturated with tap water until water was seen dripping from the bottom of the polythene bag (assumed indicative of full saturation) and allowed to drain overnight to field capacity before initial soil moisture content measurements were made. A fixed watering regime at 50 % of rainfall at 5 days watering interval was used. There was no net drainage after watering the pots as all the water was absorbed by the soil. No fertilizers were applied to the treatments. The total number of seedlings used in the experiment totaled 270 (2 soils x 3 treatments x 3 replications x 15 seedlings per treatment) seedlings for the study. The biochar produced was characterized by biochar yield (%), pH and nutrient contents.

Figure 2 *Greenhouse for experiment*

3.3 BIOCHAR PRODUCTION

Biochar was produced from pre-dried cocoa pod husk (at 9 % moisture content) (CPH) obtained from the CRIG farms. Two local "Kon-tiki" kilns were constructed on CRIG farms with the aid of a hoe and a digging chisel in four hours (see Appendix A). The Kon-tiki kiln was carefully shaped into a cone shape to maintain the pyrolysis process and aid in limiting oxygen flow. The dimensions were diameter and depth of 2x1.5 m and 1.5x1.5 m for the two kilns respectively. The feedstock was weighed with the help of a hanging scale (Becknell 235-6M hanging scales) and raffia bags before the process was started. The pyrolysis process was started with a few dry woody veins found on the farm to start the fire; after which pre-dried cocoa pod husk was gradually added making use of the flames from the pyrolysis process while avoiding the production of GHGs and emission of aerosols into the atmosphere. The addition of feedstock into the soil pit was slowly repeated layer by layer until the soil pit was filled up (see Appendix A).

The residence time for the completion of the pyrolysis process was between 2-3hours. The pyrolysis process was concluded by quenching the fire with enough water, this was to avoid the possibility of the biochar burning into ash overnight (see Appendix A). The kiln was covered with a polythene sheet and left overnight to cool. The CPHB produced was shoveled out the next day. The yield data for the biochar was measured with a hanging scale (Becknell 235-6M hanging scales) after it was air- dried for a week at temperatures of 35-40 ^{o}C under shelter. Moisture content was 10-15% (the recommended 105 ^{o}C was not followed because of limited resources and time). The values were not corrected for the yield report in Table 2. The uncertainty in moisture content may have led to overestimation in the biochar yield data reported in Table 2. The CPHB was stored in raffia bags for later use; basic properties of the CPHB produced can be found in Table 3.

3.4 SOIL AND BIOCHAR MEDIA PREPARATION

The two-soil series sampled and biochar produced were mixed as a media for growing seedlings in the experiment. The soil samples were air-dried under shelter at 35-40 ^{o}C for one week until they were sufficiently dry and of constant weight. Dried soil samples were sieved to remove debris and particle sizes larger than 2 mm. The biochar was put in bags and crushed by foot into smaller particles without further sieving. The biochar was applied at 0 %, 5 % and 10 % (wt./wt.) for both soil series (see Appendix A), the amount of biochar to be applied to each soil type differed by weight and bulk density.

3.5 SOIL AND BIOCHAR CHEMICAL PROPERTIES ANALYSIS

The pyrolyzed cocoa pod husks were characterized at the CRIG laboratory for pH and nutrient composition. The biochar and soil samples were air dried after sieving with a $\leq$ 2 mm mesh. The samples were then oven dried at 105 ^{o}C overnight before the various laboratory analysis and measurements were collected. The parameters measured were; pH, Total N, Available P, Exchangeable K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, Zn and Fe.

3.5.1 pH MEASUREMENTS

The pH measure for both the soil and biochar were measured using the pH meter. 5 g of each sample was measured into a beaker then mixed with 25 ml of distilled water (1:5) and was mechanically stirred for an hour. The pH meter and electrodes were calibrated with appropriate buffer solutions before use (Rayment & Higginson, 1992).

3.5.2 NUTRIENT CONTENT MEASUREMENTS

Total nitrogen (N) was determined using the Kjeldahl digestion (Bremner, 1965). 1 g of the sample was digested with 50 ml of distilled water and 10ml of sulphuric acid (H_2SO_4) which converts it to ammonium sulphate. Then the volume of ammonium was estimated by distilling with 300 ml of distilled water and 50 ml of caustic soda ($NaOH\text{-}Na_2S_2O_3$.) After which the distillate was mixed with 50 ml of boric acid together with 15 ml sulphuric acid (H_2SO_4) and 10 g anhydrous potassium sulphate into a round Jena flask. Then titration was done with 0.02 M HCl, the titre value is used to calculate the nitrogen content (see calculations below). Available phosphorus was determined using Bray No. I extraction solution, measured by the murphy blue coloration and spectrophotometric determination at 880 nm (Murphy & Riley, 1962). Exchangeable K^+, Ca^{2+} and Mg^{2+} were extracted with a 1M ammonium acetate (adjusted to pH 7) and determined by atomic absorption spectroscopy for Mg^{2+} and Ca^{2+}, while for K^+, flame photometer was used (Jackson, 1973).

$$\%N = \frac{\text{molar mass x titre value x volume of extract x 100}}{\text{Weight of Sample x 1000 x volume of aliquot}}$$

$$\text{Available P} = \frac{\text{meter reading x volume of extract}}{\text{weight of sample x volume of aliquot}}$$

$$K^+(\text{meq}/100\text{g}) = \frac{\text{meter reading}}{\text{atomic weight of cation}}$$

$$Ca^{2+} \text{ and } Mg^{2+} (\text{meq}/100\text{g}) = \frac{\text{AAS meter reading}}{\text{atomic weight of cation}}$$

Total Al, Fe and Zn were determined by catalytic elemental combustion analysis at 103 ^oC after acidification with 50 µL1 M HCl per 15 mg dry sample.

3.6 SOIL MOISTURE CONTENT AND CHLOROPHYLL MEASUREMENTS

The in-situ soil moisture was measured using a hand held time domain reflectometer (TDR) SM150 (Delta-T devices, Cambridge England). The soil moisture content was randomly measured weekly, six days after watering with five replications per treatment. They were done together with chlorophyll measurements.

3.7 PLANT GROWTH MEASUREMENTS

Five cocoa seedlings were randomly selected per treatment in all 3 replications and harvested. The destructive growth analysis was done in the second and fourth months. The selected seedling samples were separated into leaves, shoots and roots. The mean seedling growth rate for the first month (April, 2020) after germination was determined by measurement of the germination of seedlings (%), number of seedlings germinated, leaf area, number of leaves, plant height(cm), plant diameter(mm) and chlorophyll measurements. In the second month (May, 2020), destructive sampling was carried out with 5 plants in each treatment in all 3 replications. The data collected included; leaf area, plant height, leaf number, plant diameter, root length, root volume, fresh weight and dry weight (shoot, root and leaves). Plant height was determined using a centimeter ruler by measuring from the base (soil surface) to the tip of the apical leaf each month. With the aid of a Vernier caliper (Digital Calipers 150 mm, 6”), the girth of the stem was measured 1cm from the surface of the soil each month.

The leaf area was measured in the second and fourth month, the leaf area was determined with the centimeter ruler by measuring length and breadth of leaves on each plant. The root length was measured using the centimeter ruler to the tip of the last root each month. Chlorophyll content was measured with the hand- held CL-01 chlorophyll content System (Chlorophyll content meter, Hansatech Instruments, Norfolk-UK). Measurements were done weekly and randomly with 5 plants of each replication in each treatment five days after watering. The leaf, shoot and root dry weights were determined after drying in the oven at 105 ^{o}C for 72 hours, using an electronic weighing scale (Analytical balance ME54, Mettler Toledo).

3.8 STATISTICAL ANALYSIS

Data collection and data processing: The project seeks to obtain data on the effects of biochar – soil combinations (2 biochar application rates (5% and 10 %) and two soil types) on soil moisture content, soil nutrient content as well as on seedling growth rate. To detect the effect of the treatments on soil moisture content, soil nutrient content and seedlings growth rate, the data collected were analyzed using analysis of variance (ANOVA). Significant differences were assumed at $p \leq 0.05$ (SAS).

CHAPTER 4

RESULTS

4.1 INITIAL SOIL CHEMICAL ANALYSIS OF EXPERIMENT SOILS

The results on soil properties are shown in Table 1. Ayinase was strongly acidic (4.47) while Acherensua was near neutral (7.84). Ayinase was high in N but low in available P as compared to Acherensua. Additionally, Ayinase was low in exchangeable K^+, Mg^{2+} and Ca^{2+} but high in Al content as compared to Acherensua. The soil types had a significant effect on total N, Available P and exchangeable Ca^{2+}, however, it had no significant effect on exchangeable K^+, Mg^{2+} (see Appendix C). The soil types had significant effect soil moisture content, chlorophyll content (see Appendix B). For the growth parameters, soil types had significant effect on leaf area, specific leaf area and total dry weight for both months (see Appendix D).

***Table 1** Properties of soil types used in the experiment*

Properties	Acherensua	Ayinase
pH	7.84	4.47
Total N (%)	0.13	0.32
Avail. P (µg/kg)	77.5	23.3
Exch. K (cmol/kg)	0.27	0.18
Exch. Mg (cmol/kg)	2.01	1.12
Exch. Ca (cmol/kg)	32.14	4.53
Zn (µg/g)	17.21	3.27
Al (cmol/kg)	3.64	4.89
Fe (mg/kg)	3.36	11.7

4.2 BIOCHAR CHARACTERIZATION

4.2.1 BIOCHAR YIELD

From the results shown in Table 2, a mean weight of 82.5 kg of CPHB was produced from 245 kg of CPH (dry weight). Thus, an average yield of 33.4 % of the initial weight of the CPH was retrieved as biochar. The dry weights of the CPHB were recorded after air-drying for a week under shade, however, it is recommended that samples be oven dried at 105 ^{o}C overnight before being measured for accurate results.

Table 2 *Biochar yield from cocoa pod husk using two different kiln sizes in experiment*

Size of kiln	Mass of CPH (kg)	Mass of CPHB (kg)	%Yield
2m x1.5m	255	83	32.5
1.5m x1.5m	234	81	34.6
2m x1.5m	253	84	33.2
1.5m x1.5m	240	80	33.3
Mean	245.5	82.5	33.4

4.2.2 BIOCHAR CHEMICAL ANALYSIS

Table 3 shows the chemical analysis of the cocoa pod husk biochar (CPHB). The CPHB produced is alkaline (pH-10.8) This is in conformity with earlier high pH values reported for CPHB, cocoa shell, and maize cob biochar (Yeboah et al., 2016, Martinsen et al., 2015, Martinsen et al., 2014) (see Table 3). Also, the results show high concentration of Exchangeable K^{+}, Mg^{2+} and Ca^{2+}, the results are in conformity with earlier reports for various biochar types in the literature (see table 3). Additionally, the CPHB used in the experiment was found to be high in total Nitrogen (TN) (1.60 %). The results are in conformity with CPHB reported by Yeboah et al., (2016) and cocoa shell biochar reported by Martinsen et al., (2015). However, the results are in contrast to low TN values earlier reported for maize cob biochar (0.7 %) (Martinsen et al., 2014). The available phosphorus in the experiment was high (277 µg/kg). The result was in conformity with CPHB reported by Yeboah et al., (2016) (see Table 3).

Table 3 *Nutrient content of cocoa pod husk biochar from the experiment and the literature*

Properties	Experiment CPHB	Yeboah et al., 2016(CPHB)	Martinsen et al., 2015 (Cocoa shell)	Martinsen et al., 2014(Maize cob)
pH	10.8	10.4	10.5	9.7
Total N (%)	1.60	1.08	1.37	0.7
Avail. P (µg/kg)	277	263	-	-
Exch. K (cmol/kg)	15.2	13.5	126	56.1
Exch.Mg (cmol/kg)	12.7	17.1	32.8	0.8
Exch. Ca (cmol/kg)	35.5	18.7	37.1	0.9

4.3 BIOCHAR EFFECT ON SOIL MOISTURE CONTENT

Table 4 shows the soil moisture content and the chlorophyll content of cocoa seedlings, measured weekly and cumulated into amounts per month, for the four-month duration of the experiment. The results clearly show that cocoa pod husk biochar (CPHB) addition significantly influenced ($p<.0001$) soil moisture content (see Appendix B). Soil moisture content increased with increase in CPHB application rates. The soil moisture content was significantly different for different months ($p<.0001$) (see Appendix B). Biochar application significantly increased ($p<.0001$) Soil moisture content in the order 10 % wt./wt. > 5 % wt./wt.> 0 % wt./wt. CPHB for the 4 months' duration of the experiment. Also, the soil moisture content had a significant effect (p<.0001) on the soil moisture content. Also, it was noted that the results were significantly increased (p<000.1) in Acherensua (sandy loam) with the increase in biochar application as compared to Ayinase which was (clayey loam). Thus, biochar application and soil types had a significant effect (p<0.0001) on soil moisture content (see Appendix B). The results were as expected since the biochar is expected to increase the soil moisture content in sandy loam soil as compared to clayey loam soil.

Additionally, Table 4 also shows the results for leaf chlorophyll content during the experiment duration. The results show that biochar application significantly influence (p<.0001) chlorophyll content (see Appendix 1b). The results were non-linear as 5 % wt./wt. CPHB was not significantly different (p<.0001) in chlorophyll content as compared to the control. However, 10 % wt./wt. CPHB application significantly decreased (p<.0001) chlorophyll content. Thus, chlorophyll content was decreased in the order 10 % wt./wt. < 5 % wt./wt. ≈ 0 % wt./wt. CPHB for the 4 months' duration of the experiment. The soil type had a significant effect (p<.0001) on chlorophyll content (see Appendix B). The chlorophyll content was highest in the Ayinase as compared to Acherensua. The results are as expected as Ayinase is inherently high in TN (0.32 %) as compared to Acherensua (0.13 %), and it was significantly increased in other major nutrients (P and K) with biochar application (Table 4 and see figure 3). Additionally, the moisture content of Ayinase (clayey loam) soil is higher than Acherensua (sandy loam), drought stress limits the exchange of gases due to reduced stomatal conductance that causes reduced chlorophyll contents in Acherensua as compared to Ayinase. However, as noted 10 % CPHB reduced chlorophyll due to seedlings exposed reduced water permeability and reduced aeration can result in reduced photosynthesis and thus low chlorophyll content.

Table 4 *Effects of cocoa pod husk biochar on soil moisture content and chlorophyll content for Acherensua and Ayinase soils. Means are given with standard deviations for 3 replications measurements.*

Soil types	Acherensua			Ayinase		
Treatment	B0	B5	B10	B0	B5	B10
SMC 1MG(%)	13.9± 1.0c	18.6±0.4b	20.9±0.7a	17.8±0.4c	20.4±1.2b	23.6±1.0a
SMC 2MG(%)	14.1±0.9c	19.5±0.2b	21.7±0.4a	17.5±1.0c	20.8±0.6b	23.2±0.6a
SMC 3MG(%)	14.3± 0.7c	18.0±0.5b	20.0±0.9a	18.4±0.9c	21.0±1.1b	24.8±0.4a
SMC 4MG(%)	14.4±1.2c	18.8±1.0b	20.4±0.3a	17.5±1.1c	21.1±0.6b	23.5±0.9a
Chlorophyll 1MG(SPAD)	4.8±0.3a	5.6±0.4a	1.9±1.0b	7.2±1.8a	9.3±0.4a	3.1±1.0b
Chlorophyll2MG (SPAD)	7.3±1.0a	8.1±0.8a	4.2±0.9b	9.5±1.2a	9.7±0.4a	5.2±0.6b
Chlorophyll 3MG (SPAD)	5.4±0.5a	5.8±1.0a	3.4±0.5b	8.8±0.9a	10.8±0.7a	4.4±1.1b
Chlorophyll 4MG (SPAD)	4.8±0.3a	5.7±0.4a	1.9±0.2b	7.2±1.8a	9.3±1.2a	3.9±1.3b

Means with the same letter are not significantly different.

SMC-Soil moisture content   MG-Months after germination

B0- 0%wt./wt. CPHB   B5-5%wt./wt. CPHB   B10-10%wt./wt. CPHB

4.4 BIOCHAR EFFECT ON SOIL NUTRIENTS

The results of the nutrient analysis are presented in Table 5. Biochar addition had significant influence on soil pH, TN, Available P and K^+ in both soil series. Biochar addition increased pH significantly ($p < 0.05$) for both soil types as compared to the compared. Biochar addition had a significant effect ($p < 0.001$) on TN. The results were expected as CPHB was high in TN (1.6 %), the TN values reported for all biochar treatments were in accordance to the inherent TN content of the CPHB and the inherent TN content of the soil types. Ayinase initially had a higher TN value (0.32 %) as compared to Acherensua (0.13 %).

Additionally, biochar had significant effect ($p < 0.001$) on available phosphorus and there was also significant difference in available P values for biochar application rates. The results were as expected since the CPHB used in the experiment had high available P content (277 µg/kg) and the inherent available P values was high in Acherensua as compared to Ayinase. The Ayinase soil had low available P (23.3 µg/kg) content but with biochar application the available P was significantly increased as compared to the Acherensua soil type which was initially had high available P values (77.5 µg/kg). Also, Biochar addition had a significant effect ($p<0.001$) on Exchangeable K^+. The results are as expected since CPHB reported high exchangeable K^+ values (15.2 cmol/kg). However, biochar addition had no significant effect on exchangeable Ca^{2+} ($p=0.77$) and exchangeable Mg^{2+} ($p=0.15$) for biochar treatments (see Appendix C). Thus, for Ayinase there was significant increase ($p<000.1$) in pH with biochar addition and also significant increase in soil TN, K^+ and available P content as compared to Acherensua. Also, Al concentrations were significantly decreased ($p<0.05$) with biochar application at 10% wt./wt. CPHB application for all soil types (see Table 5 and Appendix C). Thus, biochar and soil type had a significant effect on soil nutrient content (TN, available P and K^+).

***Table 5** Effects of cocoa pod husk biochar treatments on soil nutrient content for Acherensua and Ayinase soils. Means are given with standard deviations for 3 replications measurements.*

Soils	Acherensua			Ayinase		
Treatments	B0	B5	B10	B0	B5	B10
pH	7.82±0.44b	8.28±0.43a	8.78±0.66a	4.78±0.82b	7.35±0.08a	7.50±0.03a
Total N(%)	0.15±0.09b	0.33±0.06a	0.47±0.11a	0.29±0.09b	0.45±0.10a	0.55±0.04a
Available P(µg/g)	78.3±8.83c	120±7.15b	137±3.15a	21.5±0.43c	95.4±7.96b	122±4.02a
K^+(cmol/kg)	0.37± 0.01c	1.74±0.19b	4.48±0.34a	0.11±0.04c	1.20±0.19b	3.74±0.44a
Mg^{2+} (cmol/kg)	2.28± 0.65a	2.64±0.66a	3.83±0.05a	1.61±0.91a	2.72±1.31a	2.92±1.95a
Ca^{2+} (cmol/kg)	28.4±0.67a	28.9±2.75a	32.6±6.01a	6.18±0.11a	8.22±1.82a	10.0±1.10a
Zn (µg/g)	19.2±0.89a	19.90±1.80a	19.46±0.42a	3.27±0.42b	3.98±0.77b	6.08±0.32a
Al^{3+} (cmol/kg)	3.83±0.14a	3.47±0.17a	2.31±0.77b	4.97±0.11a	3.90±0.43a	2.83±0.16b
Fe (mg/kg)	2.80±0.48b	3.57±0.05a	4.02±0.42a	12.22±0.75a	11.21±0.94a	9.03±0.91b

Means with the same letter are not significantly different.

4.5 BIOCHAR EFFECT ON COCOA SEEDLING GROWTH RATE

Table 6 shows the results of biochar application on the seedling growth parameters for the second and fourth months after germination. The results showed clear differences between the two months. In the second month, CPHB application (both 5 % and 10 %) significantly affected ($p<0.05$) stem height, stem diameter, leaf area index (LAI), root volume, leaf dry weight and total dry weight. The effect of biochar application on growth rate was non- linear as 5 % (wt./wt.) CPHB application showed significant increase ($p<0.05$) in LAI, leaf dry weight, root volume, and total dry weight as compared to the control (Table 6). In contrast, the 10 % (wt./wt.) CPHB treatment showed significant decrease ($p< 0.05$) in leaf dry weight, leaf area index, root volume and total dry weight as compared to control (see table 6 and Appendix D). Figure 3 shows the cocoa seedlings two months after germination, the figure clearly shows effects of biochar application rates and soil types on cocoa seedling growth rate.

In the fourth month after germination, CPHB application had a significant effect ($p<0.05$) on all the growth parameters collected. The 5 % CPHB significantly increased ($p<0.05$) stem height, stem diameter, leaf area index, leaf dry weight, root length, and total dry weight as compared to the control (Table 6). However, in the same month the 10 % (wt./wt.) CPHB treatment showed significant decrease ($p< 0.05$) in stem height, stem dry weight, leaf dry weight, leaf area index, root volume, root dry weight, and total dry weight as compared to control (see table 6 and Appendix D). Additionally, the specific leaf area and specific root length significantly increased ($p<0.05$) with the application of 10 % wt./wt. The growth parameters were also significantly affected ($p<0.001$) by the soil type (see Appendix D). The Ayinase soil shown an increased in most growth parameters as compare to Acherensua (Appendix D and figure 3). The results are as expected as Ayinase is inherently high in TN and was significantly increased in other major nutrients (P and K) with biochar application.

Table 6 *Effects of cocoa pod husk biochar on basic yield parameters of cocoa seedlings on Acherensua and Ayinase soils for second and fourth months. Means are given with standard deviations for 3 replications measurements*

Soil type	Acherensua						Ayinase					
Treatments	B0	B0	B5	B5	B10	B10	B0	B0	B5	B5	B10	B10
Month	2MG	4MG	2MG	4MG	2MG	4MG	2MG	4MG	2MG	4MG	2MG	4MG
H(cm)	21.3a	26.7b	22.1a	30.1a	21.4a	21.7c	24.3a	27.3b	23.1a	30.2a	26.4a	21.6c
D(mm)	4.0a	4.9b	4.5a	6.1a	4.0a	4.6b	4.0a	5.5b	4.3a	6.4a	4.1a	4.7b
RL (cm)	16.1a	18.0b	20.2a	26.0a	18.5a	19.3b	18.2a	20.5b	22.0a	28.5a	19.7a	20.2b
LAI(cm)	146b	971b	234.0a	1370a	116c	345c	214b	1290b	253a	1740a	130c	462c
RV (cm^3)	0.9b	2.4a	1.5a	3.9a	0.5c	1.4b	1.0b	3.3a	1.3a	3.4a	0.7c	1.9b
SDW (g)	0.4a	1.1a	0.5a	1.4a	0.4a	0.6b	0.5a	1.3a	0.5a	1.53a	0.5b	0.5b
RDW(g)	0.2a	1.1a	0.3a	1.1a	0.2b	0.3b	0.2a	0.9a	0.4a	1.0a	0.5b	0.4b
LDW(g)	0.7b	1.4b	1.1a	1.9a	0.5c	0.2c	1.9b	2.1b	2.5a	3.0a	0.8c	0.5c
SLA	220a	723b	212a	741b	238a	3500a	264a	615b	250a	580b	267a	1990a

SRL	97.7a	16.8b	84.6a	24.5b	95.4a	91.5a	78.9a	25.7b	88.1a	30.9b	99.7a	115a
TDW	1.2b	3.5b	1.78a	4.4a	1.19c	1.2c	1.5b	4.3b	1.8a	5.6a	1.2c	1.3c

Means with the same letter are not significantly different.

M- Months, MG- months after germination, H- stem height, D-stem diameter, RL-root length, LAI-leaf area index, RV-root volume, SDW-stem dry weight, RDW-Root dry weight, LDW-Leaf dry weight, SLA-Specific Leaf Area, SRL-Specific root length, TDW- Total dry weight.

Figure 3 *Picture of cocoa seedlings on the fourth month after germination.*

S1BO- Acherensua 0 % CPHB   S2BO-Ayinase 0 % CPHB   S1B5-Acherensua 5 % CPHB

S2B5-Ayinase 5 % CPHB   S1B10-Acherensua 10 % CPHB   S2B10-Ayinase 10 % CPHB

CHAPTER 5

DISCUSSION

5.1 THE EFFECT OF BIOCHAR ON SOILS

Soils used for cocoa cultivation need to have medium to high fertility for satisfactory yields (Snoeck et al., 2010). The recommended soil pH for successful cocoa seedling development is 5.0-7.5, with a pH of 6.5 being most suitable (Dzandu, 2016). The study reported that Acherensua soil was near neutral (pH at 7.84), while Ayinase was acidic (pH at 4.47). As expected for high pH value soils, Acherensua had high available P and high exchangeable K, Mg, and Ca content as compared to Ayinase (Sun et al., 2017, Munongo et al., 2017). The application of biochar to the soils resulted in improvement in Ayinase chemical properties as compared to the Acherensua. This is in conformity with findings that that biochar is more effective on low fertility acidic (Jeffery et al., 2017, Cornelissen et al., 2018) and less effective on highly fertile soils (high pH and high CEC) (Cornelissen et al., 2018). Also, the Acherensua soil is sandy loam while Ayinase is clayey loam. Prior to the experiment, the clayey loam soil had a higher water retention capacity before biochar application as compared to the sandy loam soil. For the purpose of soil moisture improvement, biochar application significantly increased the moisture content of the sandy loam as compared to the clayey loam soil (Haefele et al., 2011).

5.2 BIOCHAR CHARACTERIZATION

5.2.1 Biochar yield

The study indicates high biochar yields (33.4 %) for CPH, the results are higher as compared to earlier recorded CPHB yields using other high temperature pyrolysis techniques (Munongo et al., 2017) and also higher than earlier biochar yield (22-25 %) recorded for various feedstock using the “Kon-tiki” kiln (Pandit et al., 2017, Cornelissen et al., 2016). It is recommended that samples be oven dried at 105 ^{o}C overnight before being measured. In our case, measurements for biochar yields were done after it was air- dried for 7 days and this may have led to an overestimation of the biochar yield due the hygroscopic nature of biochar. Generally, the pyrolysis temperature, feedstock and residence time determine the biochar yield (Sun, 2017, Munongo et al., 2017, Lehman, 2007). Duku et al., (2011) reports that biomass with high lignin content such as nut shells and wood produce the highest biochar yield when pyrolyzed. Sun et al., (2017) reports that biochar yield gradually decrease with temperature, however, above 400 ^{o}C less volatile components are decomposed slowly, while the volatile components are released to form aromatic compounds, thus, minimizing yield decrease. At higher temperatures increased residence time changes the inherent structure of the biomass not the yield (Sun et al., 2017).

5.2.2. Biochar chemical analysis

The study shows high pH values for cocoa pod husk biochar (CPHB), this is in line with earlier reports for CPHB (Munongo et al., 2017, Yeboah et al., 2016). High pH values are associated with higher alkalinity of biochar (Munongo et al., 2017). Additionally, the results showed high values for exchangeable Ca^{2+} and Mg^{2+}, this also complies with earlier reports that concentration of trace nutrients (Mg^{2+}, Ca^{2+}, Fe and Zn) are high in biochar derived at high temperatures (Sun et al., 2017, Munongo et al., 2017). The high Total Nitrogen (TN) values (1.6 %) are in conformity with high TN content recorded by researches on cocoa shell biochar and cocoa pod husk biochar (Yeboah et al., 2016, Martinsen et al., 2015). However, the results were in contrast with biochar produced from low lignin and high cellulose biomass such as maize cob, rice straws and wheat straws, which reported low TN values (Cornelissen et al., 2013, Martinsen et al., 2014, Jeffery et al., 2017, Cornelissen et al., 2016). The high TN value recorded in the experiment may be explained by the inherent high N content of the CPH (Munongo et al, 2017, Yeboah et al., 2016). This supports earlier studies that the quality of biochar is influenced by feedstock and pyrolysis conditions (Cornelissen et al., 2013, Cornelissen et al., 2016, Sun et al., 2017, Jeffery et al., 2017, Pandit et al., 2017). The report further supports earlier findings by Pandit et al., (2017) and Cornelissen et al. (2016) that "Kon-tiki" kilns can produce high quality biochar. It also supports earlier findings that cocoa pod husk can be effectively used as feedstock for biochar production (Munongo et al., 2017, Yeboah et al, 2016, Sosu, 2014, Odesola & Owoseni, 2010).

5.3 BIOCHAR EFFECT ON SOIL MOISTURE CONTENT

The study clearly shows an increase in soil moisture with biochar application, this supports earlier findings that biochar application can increase plant available water (Jeffery et al., 2018, Obia et al., 2017, Bahrun et al., 2018). Additionally, the results are in conformity with findings that soil moisture increases with increased biochar application rates (Martinsen et al., 2014, Bahrun et al 2018). Although not measured in the current study, the increase in soil moisture with biochar application is linked to improvement in soil structure resulting in increased water retention capacity (Bahrun et al., 2018, Obia et al., 2017, Jeffery et al., 2018). The biochar application increases soil pore aerations and water availability (Bahrun et al., 2018). Acherensua soil which is sandy loam showed a significant increase in water content with biochar addition, this supports earlier findings that the effect of biochar on sandy soils are more noticeable than that in loamy or clayey soil (Jeffery et al., 2018, Haefele et al., 2011).

5.4 BIOCHAR EFFECT ON SOIL NUTRIENT CONTENT

The addition of biochar increased soil pH which resulted in increased availability of essential nutrients (K^+, Ca^{2+} and Mg^{2+}) for plants use (Jeffery et al., 2017, Munongo et al., 2017, Martinsen et al., 2013). The results showed a significant increase ($p< 0.05$) in pH with biochar application. Initially, Ayinase (acidic low nutrient soil) had high Al content (4.89 mg/g) as compared (3.64 mg/g) after biochar application, this could also be due to the difference in soil pH (Cornelissen et al, 2018). The soils' low mineral nutrient contents illustrate the decline in soil fertility associated with tropical soils under continuous cultivation without replacement of nutrients (Yeboah et al. 2016, Munongo et al., 2017). Ayinase chemical properties were greatly improved and noticeable with biochar addition. Biochar application increased the pH value significantly. The change in pH value resulted in significant increase in essential plant nutrients (P, N, and K^+) and decline in toxic elements (Al^{3+}) (Cornelissen et al, 2018, Jeffery et al., 2017, Martinsen et al., 2013). The high exchangeable K^+, Ca^{2+} and Mg^{2+} content in the biochar amended soil was increased due to increase in base cations because of the alkaline nature of biochar, and the resultant increase in soil pH (Jeffery et al., 2017, Sohi et al., 2010). Thus, the results support earlier findings that biochar has potential as a quality soil amendment in remediating degraded acidic cocoa soils which may be high in toxic elements (Al) (Cornelissen et al, 2018). This can be explained by exchange of toxic elements with plant essential nutrients (Ca^{2+}, Mg^{2+} and K^+) at high base saturation (Munongo et al., 2017, Jeffery et al., 2017, Martinsen et al., 2013). After exchange Al hydrolysis and precipitates as Al-oxide making it inaccessible to plants. Thus, the study supports earlier findings that biochar application for fertility purposes is more effective on low fertility acidic soils (Jeffery et al., 2017, Cornelissen et al., 2018) and less effective on highly fertile soils (high water retention, high pH and high CEC) (Cornelissen et al., 2018). However, it should be noted that not only were these positive effects of 5 % CPHB seen in the acidic soil, but also in the near neutral soil though more pronounced in the former.

5.5 BIOCHAR EFFECT ON COCOA SEEDLINGS GROWTH RATE

The study reported an increase in cocoa seedling growth rate with 5 % wt./wt. CPHB biochar application. Several researchers (Bahrun et al. 2018, Marjenah et al., 2016), have recorded similar results earlier. Generally, increase in crop yield after biochar application is attributed to improvement in soil structure and increase in water retention (Obia et al., 2020, Bahrun et al., 2018, Waqas et al., 2017) as well as improved nutrient availability (Jeffery et al., 2017, Martinsen et al., 2014). In addition, increased crop yields can be attributed to alleviation of soil acidity reducing toxicity, and increased base saturation (Cornelissen et al., 2018, Martinsen et al., 2015). The present study does not allow assessment of the relative importance of the different factors, and the mechanism for increased seedling growth rate with biochar application may result from a combination (Cornelissen et al., 2018). The study is compares the effect of biochar application on cocoa seedling growth rate on two distinct soil types (sandy loam (near neutral) soil and clayey loam (acidic) soil in a greenhouse experiment.

However, at 10 % wt./wt. CPHB application resulted in decline in growth rate. Similar results were recorded for high biochar application for cocoa seedlings, wheat and banana (Bahrun et al., 2018, Sun et al., 2019, Bass et al., 2016). Bahrun et al. (2018) reported decreased cocoa seedling growth rate with increased biochar application. This could be the result of high increase in soil bulk density, high moisture content and limited aeration as most pore spaces become filled with water and limited oxygen is supplied to the root, resulting in potential root damage and decreased growth rate (Bahrun et al., 2018). Nevertheless, more research is needed to find out the threshold for biochar application. Our study clearly shows that biochar application can increase soil nutrient and moisture content and consequently increase seedling growth rate. There however, appears to be a clear upper limit of biochar addition above which seedling growth declines, thus, the rates of biochar application need to be taken into consideration (Bahrun et al., 2018, Bass et al., 2016, Sun et al., 2019). Time was also an important factor as with time the biochar application increase the growth rate for 5 % CPHB (wt./wt.) for more growth parameters, while the 10 % CPHB (wt./wt.) further decreased the growth rate for more growth parameters. Thus, the effect of biochar application on the seedling growth rate was time sensitive.

5.6 COCOA POD HUSK BIOCHAR (DRY WEIGHT) PRODUCED PER HA ON COCOA FARMS IN GHANA.

The cocoa pod constitutes about 70 % of cocoa the cocoa pod (Munongo et al., 2017). Figueira et al. (1993) estimates that for 1 ton of dry cocoa beans produced 10 tons of cocoa pod husk (wet weight) is produced, while Duku et al. (2011) reports that 595 kg of dry cocoa pod husk can be obtained from fresh residue of 700 kg of cocoa pod husk in Ghana. In Ghana, the average dry cocoa beans produced per hectare is 0.45 ton (Nunoo et al., 2014). This study reports the percentage yield of CPHB to CPH as 33.4 %. Thus, an approximation of how much biochar can be produced per farms can be easily calculated from the above information as shown below:

Amount of CPH(weight) per ha; 1ton of cocoa beans =10 tons of CPH

Thus, 0.45 ton (dry weight) cocoa beans per ha = 4.5 tons (fresh weight of CPH) per ha

If 0.70 tons' fresh weight CPH = 0.60 tons' dry weight CPH

Then, 4.5 tons (fresh weight) CPH= 3.83 tons (dry weight) CPH.

Thus, 3.83 tons of CPH of cocoa pod could be produced per ha of cocoa farm in Ghana.

From the study, the biochar yield is 33.4 %. Therefore, the amount of biochar that can be produced per ha at an average biochar yield of 33.4 % from 3.83 tons of CPH will be 1.28 tons CPHB per ha.

From the literature (Pandit et al., 2017, Cornelissen et al., 2016), the average biochar yield from various biomass using “Kon-tiki” kiln is 25 %.

Thus, 25% from 3.83 tons of CPH will be 0.96 tons CPHB per ha.

Therefore, farmers can produce between 0.96-1.28 tons from 3.83 tons of CPH collected from the farms to effectively fertilize their farms if the above assumptions on biochar yield (%) and average CPH produced per ha, using the “Kon-tiki” kiln technology

CONCLUSION AND RECOMMENDATION

In this study, we aimed to investigate the potential of the “Kon-tiki” kiln to produce large quantity and quality biochar from cocoa pod husk. Additionally, the study sort to explore the effect of the resultant cocoa pod husk biochar (CPHB) on soil quality (moisture and nutrient content) and seedling growth rates. The CPHB yield (%) was high (33.4 %) and high in pH, N, P and K^+ which was similar to CPHB produced using different biochar production techniques. Most reports on “Kon-tiki” kiln has been on agricultural biomass with high cellulose and hemicellulose content but low lignin content (i.e. corncobs, wheat and rice straws) which are the easiest to pyrolyzed. In this study, the ability of the “Kon-tiki” kiln to efficiently produce high quantity and quality biochar from cocoa pod husk which has high lignin content biomass will encourage more small-scale cocoa farmers to adopt the technology. In Ghana, it is estimated that 3.83 tons (dry weight) of CPH can be produced per ha of cocoa farm. The above can generate an average of about 0.96-1.28 tons CPHB using the “Kon-tiki” kiln technology.

Additionally, the study supports earlier findings that cocoa pod biochar can be an efficient soil enhancer for the purpose of fertility and moisture content improvement on the two soil types studied. Soil moisture content was improved in both the clayey loam(Ayinase) and sandy loam(Acherensua) soils, but more improved in the sandy loam soil. For the purpose of soil fertility improvement, the study reported an increase in nutrient content (N, P and K) in both the acidic (Ayinase) soil and near neutral (Acherensua) soil but the nutrient content in Ayinase soil more increased. The study recommends that 5% wt./wt. CPHB per kg of soil be used to improve soil quality and seedling growth rate but higher CPHB application rates (10 % wt./wt.) may decrease growth rate. In addition, the study shows that effect of biochar application on plant growth rate is time sensitive. Thus, a long term study will provide relevant knowledge to enable stakeholders make better decisions concerning the long term adaptation of biochar as a soil enhancer for the purpose of improving soil quality and plant growth rate.

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APPENDIX

Appendix A: Production of cocoa pod husk biochar using the "Kon-tiki" kiln

Figure 4 *Constructing the "Kon-tiki" kiln at CRIG farms.*

Figure 5 *Beginning of pyrolysis process*

Figure 6 *Completion of pyrolysis process*

Figure 7 *Quenching of fire after pyrolysis process.*

Figure 8 *Mixing of biochar and soil.*

Appendix B: ANOVA of soil moisture content and chlorophyll content

ANOVA of Monthly soil moisture content (%) of the soil sample

Source	*SS*	*DF*	*MS*	*F-value*	*P-value*
Soil	1204.66	5	240.931	50.2770	<0.0001
Biochar	523.692	3	174.564	36.4276	<0.0001
Soil*Biochar	354.794	15	23.6529	4.93585	<0.0001

ANOVA of monthly chlorophyll content of the leafs

Source	*SS*	*DF*	*MS*	*F-value*	*P-value*
Soil	293.63456	5	58.726913	49.414999	<0.0001
Biochar	37.524116	3	12.508038	10.524727	<0.0001
Soil*Biochar	46.0602	15	3.07068	2.5837838	<0.0001

Appendix C: ANOVA of chemical analysis of treatment soils

ANOVA of pH content of the soil sample

Source	DF	SS	MS	F-value	P-value
Soil	1	7.43208889	79.43208889	234.48	0.014
Biochar	2	7.40043333	23.70021667	56.04	0.038
Soil*Biochar	2	9.14034444	12.57017222	9.77	0.021

ANOVA of the total N of the soil samples

Source	DF	SS	MS	F Value	P-value
Soil	1	7.09137800	7.09137800	382.19	<.0001
Biochar	2	1.76250256	0.88125128	47.49	<.0001
Soil*Biochar	2	0.16276624	0.08138312	4.39	0.0372

ANOVA of the Available P of the soil samples

Source	DF	Type III SS	MS	F-value	P-value
Soil	1	15032.16164	15032.16164	80.93	<.0001
Biochar	2	13209.59059	6604.79529	35.56	<.0001
Soil*Biochar	2	4254.78223	2127.39111	11.45	0.0017

ANOVA of the Exchangeable K of the soil samples

Source	DF	SS	MS	F-value	P-value
Soil	1	0.42775824	0.42775824	0.50	0.4931
Biochar	2	50.36037001	25.18018501	29.42	<0.0001
Soil*Biochar	2	1.50528212	0.75264106	0.88	0.4402

ANOVA of the Exchangeable Ca of the soil samples

Source	DF	SS	MS	F- value	P-value
Soil	1	2597.534201	2597.534201	226.30	<.0001
Biochar	2	6.262716	3.131358	0.27	0.7658
Soil*Biochar	2	79.411485	39.705743	3.46	0.0651

ANOVA of the Exchangeable Mg of the soil samples

Source	DF	SS	MS	F-value	P-value
Soil	1	1.43947355	1.43947355	1.20	0.2949
Biochar	2	5.34619670	2.67309835	2.23	0.1504
Soil*Biochar	2	1.07531144	0.53765572	0.45	0.6491

ANOVA of the Al of the soil samples

Source	DF	SS	MS	F-value	P -value
Soil	1	9.00091837	9.00091837	62.12	<.0001
Biochar	2	3.90142857	1.95071429	13.46	0.0009
Soil*Biochar	2	0.58836735	0.29418367	2.03	0.1740

Appendix D: ANOVA of growth parameters of cocoa seedlings.

ANOVA of Height of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	4.56020000	4.56020000	1.49	0.245
Biochar	2	12.78031111	6.39015556	2.09	0.0166
Soil*Biochar	2	11.72653333	5.86326667	1.91	0.1899

ANOVA of Stem diameter of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.00039200	0.00039200	0.00	0.9502
Biochar	2	0.54276978	0.27138489	2.82	0.0099
Soil*Biochar	2	0.17706133	0.08853067	0.92	0.4248

ANOVA of Leaf Area of cocoa seedlings

Source	DF	SS	MS	F-value	Pr -value
Soil	1	4979.35469	4979.35469	10.31	0.0075
Biochar	2	43706.89953	21853.44977	45.26	<.0001
Soil*Biochar	2	2716.63024	1358.31512	2.81	0.0996

ANOVA of Root length of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.54080000	0.54080000	0.04	0.8476
Biochar	2	61.93693333	30.96846667	2.21	0.1525
Soil*Biochar	2	21.85960000	10.92980000	0.78	0.4806

ANOVA of Root volume of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.00802222	0.00802222	0.12	0.7382
Biochar	2	0.76004444	0.38002222	5.54	0.0197
Soil*Biochar	2	0.06164444	0.03082222	0.45	0.6482

ANOVA of Stem dry weight of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.00330756	0.00330756	0.54	0.4755
Biochar	2	0.00264311	0.00132156	0.22	0.8081
Soil*Biochar	2	0.00544578	0.00272289	0.45	0.6499

ANOVA of Root dry weight of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.00777089	0.00777089	0.95	0.3501
Biochar	2	0.03064711	0.01532356	1.86	0.1973
Soil*Biochar	2	0.01552178	0.00776089	0.94	0.4161

ANOVA of Leaf Dry Weight of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.00619756	0.00619756	0.28	0.6057
Biochar	2	0.94357378	0.47178689	21.39	0.0001
Soil*Biochar	2	0.05555511	0.02777756	1.26	0.3188

ANOVA of Total dry biomass of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.05035022	0.05035022	0.99	0.3396
Biochar	2	1.21194844	0.60597422	11.90	0.0014
Soil*Biochar	2	0.09868978	0.04934489	0.97	0.4072

ANOVA of Leaf ratio of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	6.5701339	6.5701339	0.22	0.6508
Biochar	2	908.7540959	454.3770479	14.90	0.0006
Soil*Biochar	2	60.9601352	30.4800676	1.00	0.3966

ANOVA of Root ratio of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	5.72224701	5.72224701	0.38	0.5500
Biochar	2	52.63464951	26.31732476	1.74	0.2170
Soil*Biochar	2	38.83476761	19.41738381	1.28	0.3125

ANOVA of Stem ratio of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	0.0292771	0.0292771	0.00	0.9732
Biochar	2	606.3944295	303.1972148	12.14	0.0013
Soil*Biochar	2	9.3312233	4.6656116	0.19	0.8319

ANOVA of Specific Leaf Area of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	5460.939503	5460.939503	3.85	0.0733
Biochar	2	1072.521907	536.260954	0.38	0.6930
Soil*Biochar	2	316.376081	158.188040	0.11	0.8954

ANOVA of Specific Root Length of cocoa seedlings

Source	DF	SS	MS	F-value	P-value
Soil	1	110.0335544	110.0335544	0.15	0.7083
Biochar	2	548.2483507	274.1241753	0.37	0.7012
Soil*Biochar	2	447.1553473	223.5776737	0.30	0.7475

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