UNIVERSITY OF EDUCATION, WINNEBA

EFFECT OF DIFFERENT GROWTH MEDIA ON GROWTH, SURVIVAL RATE AND SEEDLING VIGOUR OF COCOA (*Theobroma cacao*)

SAMUEL ADDAE

(M.ED IN CROP SCIENCE)

2022

UNIVERSITY OF EDUCATION, WINNEBA

EFFECT OF DIFFERENT GROWTH MEDIA ON GROWTH, SURVIVAL RATE AND SEEDLING VIGOUR OF COCOA (*Theobroma cacao*)

SAMUEL ADDAE

(7191910009)

A DISSERTATION IN THE DEPARTMENT OF CROP AND SOIL SCIENCES EDUCATION, FACULTY OF AGRICULTURE EDUCATION, SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF EDUCATION IN AGRICULTURE

CROP SCIENCE

IN THE UNIVERSITY OF EDUCATION, WINNEBA

AUGUST, 2022

DECLARATION

STUDENT'S DECLARATION

I hereby declare this work is the result of my own research, except for references from other people's works have been cited and acknowledged accordingly, and that it has not been presented either in whole or part, for the award of a degree in this university.

-------------------------------------- --------------------------------------

SAMUEL ADDAE **DATE**

SUPERVISOR'S DECLARATION

I hereby declare that this work was supervised in accordance with the guidelines for the supervision of project work laid down by University of Education, Winneba.

-------------------------------------- --------------------------------------

PROF. MARGARET ESI ESSILFIE **DATE**

ACKNOWLEDGEMENT

A project of this magnitude requires the efforts of many people. I owe special gratitude to the Almighty God for His gracious love, care, protection and direction throughout my entire education. My profound gratitude goes to Prof. Margaret Esi Essilfie, my Supervisor, for her excellent direction, guidance, concise criticisms, meticulous proof-reading, suggestions and corrections on this write up that enable me to produce this project effectively.

Special gratitude again goes to Mrs. Josephine Gyan, Agricultural Science Tutor at the College of Education, Sefwi Wiawso for her immense support and assistance during my field activities.

I also extend my heart felt gratitude to my lovely wife (Mrs. Victoria Owusu Fuachie) and kids for their unforgettable love, assistance and support throughout my entire education.

Finally, I wish to express my profound gratitude to all friends (mostly Mr. Emmanuel Kwadwo Appiah) who in one way or the other contributed to the success of my study. God richly bless you all.

DEDICATION

This dissertation is dedicated to the Almighty God and to my lovely wife Mrs. Victoria Owusu Fauchie, for all the support, sacrifices and contributions towards my education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The study was carried out to investigate the effect of different growth media on growth, survival rate and seedling vigour of cocoa (*Theobroma cacao*) at the nursery stage. The cocoa seedlings were nursed at Sefwi Wiawso College of Education in the Western North Region of Ghana. The experimental design was Randomized Complete Block Design (RCBD) with three replicates. The treatments were top soil (T1), Sawdust (T2), Cocoa pod husk (T3), Top soil+Sawdust (T4), Top soil+Cocoa podhusk (T5) and Sawdust+Cocoa pod husk (T6). Sixteen (16) poly bags size of 17.5 cm base × 25 cm height was filled with the respective media. Seeds were sown two seeds per poly bag at the depth of 2 cm. The parameters measured were subjected to Analysis of Variance (ANOVA). The means were separated by Least Significant Difference (LSD; $P<0.05$). The results from the study showed that, Top soil+Sawdust growth media supported best growth of cocoa seedlings in all the parameters than the other treatments. However, Cocoa pod husk media responded poorly to all the growth parameters of the cocoa seedlings at nursery stage. It is recommended that the use of sawdust to amend growth medium could be a promising alternative for raising cocoa seedlings at the nursery stage.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Cocoa (*Theobroma Cacao* L.) is one of the most important tropical crops in the world Ploetz, 2016). It is grown mainly in the tropical evergreen and semi-evergreen rainforest and it's the third most important beverage crop next to tea and coffee. Africa contributes 75% of the world's cocoa production and production is centered in West Africa with Ivory Coast, Ghana, Nigeria, and Cameroon being the first, second, fifth, and sixth respectively in the world rankings of producers (Arthur *et al.,* 1991). In Ghana, it is the highest export crop, accounting for 8.2% of the country's GDP, 30% of total export earnings in 2010 (Killick, 2010), and employing over 30% of the population (Bermudez-Lugo *et al.,* 2005). Annual production of cocoa increased from 450,000 metric tonnes in 2000 to 1,004,000 metric tonnes in 2011.

Ghana continues to maintain its position as the world's second-largest producer of cocoa with current production of 800,000 metric tonnes in 2013 (COCOBOD, 2013). Cocoa is the most important cash crop cultivated in Ghana and established on about 1,600,000 hectares. It is a major raw material used in the production of cocoa powder (for beverage drinks, chocolate, and various chocolate-based products, biscuits, and confectionaries). The processed cocoa bean is also used to make sweets, sweetening products, cocoa butter, cosmetics and is used in pharmaceuticals. The cocoa pod husk is used in making soap locally (Gyedu-Akoto *et al.,* 2015). The production of cocoa in Ghana has witnessed a downward trend after attaining 1,000,000 metric tonnes in 2010/2011. Cocoa production declined from one million metric tonnes to 835,000 metric tonnes in 2013 due to numerous factors such as aging trees, unproductive trees, and deficiencies in micro and macronutrients in the soils (COCOBOD, 2013). Adejobi *et al*. (2011) and Adejobi, *et al.* (2014) reported that the use of organic residues has been found capable of increasing and balancing soil nutrients with a consequential increase in crop performance and yield. Recent studies had revealed the use of agricultural wastes such as cocoa pod husk and sawdust as soil amendments and potting media for raising seedlings and vegetables (Anda *et al*., 2010 and Adejobi *et al*., 2013).

1.2 Problem Statement and Justification

In Ghana, plantations of cocoa have been established through seedlings raised in the nursery with only topsoil as the growth media and these soils are suitable or moderately suitable (Sosu 2014). As a result of the new emphasis on cocoa rehabilitation in the country, there will be the need to increase cocoa seedlings production and this will require large quantities of soil for nursery work. However, assessing large quantities of suitable soil for nursery work will pose a serious challenge since suitable land is limited and the majority of the remaining land is not suitable for raising cocoa seedlings. The practice of winning soil is not an environmentally sustainable option as it depletes and destroys the area from which it is collected and its use requires the addition of inorganic fertilizer to supplement the seedling nutrients requirement. There is, therefore, growing interest in the search for alternate growth media for raising seedlings. Current studies are focusing on the use of potting media that are organic-based, less expensive, and suitable for plant growth. Additionally, Cocoa seedlings are raised in polybags and kept at the nursery for 3-6 months or more before transplanting to the field. The common problem faced after 5 months is that the roots usually penetrate through the polybags and grow into the ground or curl at the bottom when not transplanted early. Consequently, such seedlings either take a longer time for establishment in the field after transplanting or die resulting in high mortality of transplanted seedlings. Healthy seedlings with strong undisturbed root systems are required since they establish quickly in the field and their subsequent growth is fast. Currently, the use of different media in nursery practices has been increased considerably due to its many advantages such as providing nutrients, water, and air to support the growing plants. A growing media must provide the necessary conditions that will enhance seedling growth for successful transplanting to the field. A good quality growing media must enhance the development of healthy, fibrous root system to provide support as well as supply nutrients to the plant for the plants growth and development. The over-reliance on forest topsoil for raising cocoa seedlings is a major constraint to the large production of cocoa seedlings, hence, there is, therefore, the need to find suitable alternate growth media or dilutants for the raising of cocoa seedlings. The use of agricultural waste such as cocoa pod husk, sawdust, and rice husk could be investigated.

1.3 Study objectives

1.3.1 Main objective

The main objective of the study is to examine cocoa seedlings growth, survival rate and vigour as affected by different growth media.

1.3.2 Specific objectives

1.3.2.1 The specific objectives were to:

i. Compare the effectiveness of different soil media (topsoil, sawdust and cocoa pod husk) on the growth of cocoa seedlings at nursery stage.

ii. Determine the effect of different soil media on survival rate of cocoa seedlings.

iii. Assess the effect of different soil media on seedling vigour of cocoa at the nursery stage.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution

Cocoa (*Theobroma cacao* L.) is a tropical humid forest native to the Andes' lower eastern equatorial slopes in South America. Cocoa is now farmed all over the world, primarily in the tropical rainforests of Africa, Asia, and Latin America (De Beenhouwer *et al.*, 2013). Cocoa is farmed in Ghana's forest areas (Ashanti, Brong, Ahafo, Eastern, Western, Western north, Central, and Volta) regions, where annual rainfall ranges from 1000 to 1500 mm. It was first brought to the Gold Coast's southern region in the mid-nineteenth (Abbam *et al*., 2018). Cocoa grows best on moist, nutrient-rich, well-drained, and aerated soils. Cocoa cultivation necessitates a well-drained, well-aerated soil with a healthy crumb structure and ample water and fertilizer supply. Cocoa seedlings need nitrogen, phosphorus, potassium, and other nutrients, as well as metabolites (proteins, lipids, and carbs) to grow and develop (Mensah, 2021).

2.2 History of Cocoa and its Production in Ghana

Before 1943, almost all of Ghana's cocoa came from a few seeds introduced by Tetteh Quarshie from Fernando Po in 1879 (Muller, 2016). Governor Griffiths introduced the Aburi cocoa from Sao Tome in around 1890, and the seed was dispersed from it (Danquah *et al.,* 1991). However, before Ghana's independence, these early introductions provided the majority of the country's cocoa. Around 95 percent of Ghana's cocoa trees were of the 'introduced' Lower Amazon Forastero species, now known as West African Amelonado, in the early 1940s (Padi *et al*., 2013). Côte d'Ivoire is the world's biggest cocoa exporter, accounting for 37% of global production. Ghana (22 percent) and Indonesia (11 percent) came in second and third, respectively, in worldwide net exports (15 percent). Consolidated, with the top five nations accounting for 87 percent of global net exports and over 98 percent coming from the top ten countries (ICCO, 2012). After reaching 1,000,000 metric tonnes in 2010/2011, Ghana's cocoa production has been on the decline. Due to a variety of problems including old trees, unproductive plants, and soil shortages in macro and micronutrients, cocoa production fell from one million metric tonnes to 835,000 metric tonnes in 2013 (COCOBOD, 2013).

2.3 Introduction of Cocoa to Ghana

Cocoa (*Theobroma cacao* L.) is native to Central and Southern America's damp tropical forests, from Mexico to Bolivia and Brazil, and has been introduced to the rest of the world in the last 400 years (Nair, 2021). Cocoa breeding and selection programs in Ghana and other West African countries have mostly relied on existing cultivated populations of a few wild cocoa collections (Smith *et al*., 2018). Cocoa in Ghana previously originated from a few seeds delivered by Tetteh Quarshi in 1943 from Fernando Po in 1879. Tetteh Quarshie's tree plantings totaled about 300 healthy and fruitful trees. Governor Griffiths introduced the Aburi cocoa from Sao Tome in around 1890, and the seed was dispersed from it (Abdul-Karimu *et al*., 2017).

The Basle Mission introduced some cocoa into the country between 1857 and 1868, however, these introductions had no substantial impact on cocoa cultivation in the country. Between 1879 and 1892, the West African Amelonado was introduced from islands in the Gulf of Guinea (Abdul-Karimu *et al*., 2017). The Portuguese had earlier introduced them to these islands from Brazil. Governor Griffiths introduced the Amelonado to the Aburi Botanical Gardens in the late 1880s and early 1890s, and it is now widely used throughout Ghana (Amanor *et al*., 2020). Posnette gathered non-Amelonado cocoa in Ghana in the late 1930s and early 1940s, resulting in the 'local-Trinitario hybrids.' Governor Griffiths made four tiny introductions of different types of cocoa to the Aburi Botanical Gardens in 1901, 1905, 1906, and 1909, respectively: 'Pentagona,' 'Ocumare,' 'Cundeamor,' and 'Criollo' (Amanor *et al*., 2020). Some of the seeds planted at Aburi were also delivered to other Divisions of Agriculture stations and farmers.

2.4 Cocoa Production in Ghana

Ghana's economy is mostly based on cocoa cultivation. Cocoa beans are the main element in the cocoa business, as well as chocolate and derivatives, cosmetics, and medications (Purba *et al*., 2019). The country has a long history of cocoa production and was formerly the world's leading producer. Cocoa production in Ghana has experienced a succession of large booms and contractions since its debut in the late 1800s (Odijie, 2020). According to Odijie (2019), cocoa output is impacted by environmental factors such as forest land availability, ecological factors such as deforestation, disease outbreaks, and spatial shifts in production, and economic and social factors such as migration. In terms of cocoa output in Ghana, four major phases may be identified: introduction and exponential growth; standstill followed by a brief but rapid rise following independence; near collapse; and recovery and expansion (Obuobisa-Darko, 2015). Africa produced approximately 3.5 million tons of cocoa beans in 2017/2018. Côte d'Ivoire and Ghana are the top two cocoa bean producers on a country level, with Côte d'Ivoire producing more than double the volume of cocoa beans as Ghana. Ghana is thought to have produced over 800 thousand tonnes of cocoa beans this year, down from around 812 thousand tonnes in 2018/2019 (Akwetey, 2020).

2.5 Cocoa Varieties

Within the *Theobroma cacao* species, there are three varietal types of cocoa: Forastero, Criollo, and Trinitario. The Forastero variants originated in the Amazon basin, and while the Criollo variety is delicate and difficult to produce, the Forastero variety, which is easier and tougher to cultivate, spread throughout Spanish, Dutch, and Portuguese possessions in West Africa, South Africa, and Southeast Asia. Until farmers on the islands planted Forastero to boost what remained, disease and tragedy wiped out practically all Criollo cocoa plants. Trinitario is the name given to this hybrid strain (Anon, 2012).

2.5.1 Forastero Cocoa

Small, purple beans distinguish Forastero types, the bulk of which are cultivated in West Africa. In the realm of chocolate manufacture, the Forastero variety still reigns supreme. Growers preferred forastero because of its high yielding plants, and until the mid-twentieth century, growers substituted the Criollo crop with the low-quality forastero for this reason. Forastero, also known as bulk cocoa (Chery, 2015).

2.5.2 Criollo Cocoa

Criollo plants presently account for less than 1 to 5% of global crop production because of their frail nature, sensitivity to disease, and low yield. Criollo beans are classified as superfine cocoa, and several heirloom types are sought after by craft chocolate makers, partly due to their scarcity and definitely due to their unique, nuanced flavour. There are porcelana, chuao, and ocumare beans within the Criollo variety, each referring to a different terroir of the Criollo bean. Criollo cocoa is frequently fruity, aromatic, and has a low bitterness level (Motilal and Sreenivasan, 2012).

2.5.3 Trinitario Cocoa

While not as rare as criollo beans, trinitario beans account for less than 10% of overall chocolate production. In the 19th and 20th centuries, this hybrid strain migrated from the Caribbean islands to South America. Because it is the least pure, the Trinitario has a wider diversity of tastes and characteristics than any other kind. The criollo to forastero ratios, as well as terroir, have a significant impact on the complex flavours found in this bean (Acierno *et al*., 2016).

2.6 Botany of cocoa

Cocoa (*Theobroma cacao* L.) is a member of the *Malvaceae* family, which is recognized for having entomophilous and bisexual flowering plants. It is made up of roughly 200 genera and close to 2,300 species that are found all over the world, with the tropics being the most abundant (Narayanapur *et al.,* 2018). *Theobroma cacao* L. is an evergreen tree that reaches a height of 4 to 8 meters. Fruit and blooms sprout from the tree's trunk. Cocoa trees are tropical evergreen trees that thrive best in fertile, organically rich, continuously moist but well-drained soils (Handley, 2016). The leaves are alternating, whole, and unlobed, with a length of 10 to 40 cm and a width of 5 to 20 cm. Flowers bloom in groups on the trunk and older branches. Insects, particularly aphids, pollinate the flowers, which are small (1–2 cm in diameter) and have a pink calyx. The cocoa pod is an oval fruit that is 15–30 cm long and 8–10 cm wide, ripens yellow to orange, and weighs around 500 g when fully ripe. The cocoa bean is made up of 20 to 60 seeds that are normally organized in five rows along a central axis and are surrounded by a white sugary pulp (Thompson *et al*., 2012).

2.6.1 The Roots

A dimorphous root, orthotropic taproot, and plagiotropic lateral root characterize cocoa. The cocoa tree's taproot, which develops primarily downward with only a few branches, serves as an anchorage. When the soil is deep and the weather is favourable, the taproot develops quite deep. The major feeding roots, which start from the taproot and extend laterally, are concentrated just below the soil surface up to a depth of 15 - 20 cm (Sosu, 2014).

2.6.2 The Stem

The cocoa plant is divided into tiers. Chupon refers to the upward growth of the seedling's shoot. After the chupon reaches a height of 1–1.5 m, it stops growing and three to five lateral branches emerge. Fans are the term for these lateral branches (Handley, 2016). The emergence of fans is known as jorquette, and the act of forming fans from jorquette is known as jorquetting. As a result, a layer of fans is referred to as a tier. New chupon buds appear on the main stem below the first jorquette and grow up to jorquette again when the cocoa plant is allowed to grow unchecked (Nair, 2021). The difference between a chupon and a fan is that chupon leaves have longer petioles, and fan growth is primarily to the sides, whereas chupon growth is vertically up. Furthermore, the chupons' leaf arrangement is spiral, with a phyllotaxy of three to eight, but the fans' leaves are placed in one plane and alternate (Akesse-Ransford, 2016).

2.6.3 The flowers

Small cushions on the tree's trunk or older branches sprout cocoa flowers. The stems that bear the flowers have thickened leaf axils. Five sepals and five petals make up the cocoa flower. The male flower has five double stamens, each of which can hold up to four anthers (Claus *et al.*, 2018). The female flowers have five joined carpels, each with four to twelve locules (cavities).

Five of the outer whorls of the ten stamens are sterile, whereas five of the inner whorls, which are located opposite the petals, are fertile. The fertile stamens are hidden in the pouched parts of the petals. The ovary is five-lobed and simple, with 40 to 60 ovules per flower (Claus *et al*., 2018). There are five stigmatic lobes on the style. The pollen is discharged from the anthers immediately before daybreak as the flowers open at dawn. Only from dawn until sunset on the day the flower blooms is the stigma open to pollination. Cocoa blossoms are abundant, but only a small percentage of them mature into fruits, and those that are not fertilized fall off within 24 hours. Only 10% of 500 flowers are successfully pollinated, and only 2% ripen into mature fruits. Insects pollinate the blooms, but hand pollination can achieve better rates of pollination. Cherelle wilt makes it impossible to achieve much higher rates of fruit set. Cherelle wilt is a natural thinning mechanism in which the young cherelle fruit stops developing, becomes black, and shrivels but does not fall from the tree. Cherelle wilt is thus not a disease (Bridgemohan and Mohammed, 2019). Boron has been proven to increase pod set and minimize cherelle wilt. As a result, boron is sprayed on trees as an annual foliar spray in some areas.

2.6.4 The fruits

The cocoa fruit is a drupe, which is also known as a pod. A thick husk surrounds the mature pod, which contains 30-50 seeds. With the help of a placenta, the seeds are maintained in place. When young, the pods might be green or reddish. When the green pods develop, they turn yellow, while the reddish pods turn orange or yellow. The husk is thick and fleshy (Akesse-Ransford, 2016).

2.6.5 The Seeds

The crop's commercial component is the seeds, which are known as beans. Each seed has two twisted cotyledons, a little embryo, a thin membrane, the remains of the endosperm, and a leathery testa; the number of beans per pod ranges from 30-60 seeds (shell). The pulp is used to make juices, smoothies, and jellies, while the seeds contain a substantial quantity of fat (40-50%) as cocoa butter and are the major ingredient in chocolate (Grumiller *et al*., 2018). The pulp that surrounds the seed contains about 10-15% sugar and has a sweet, tangy, mango-like flavour. During the fermentation of cocoa beans, yeast thrives on the sweet pulp and transforms sugar into alcohol, which is why the pulp is so important. Bacteria oxidize the alcohol, which results in the production of carbon dioxide, water, and heat. To stop fermentation, reduce water content in the bean, and drive out acetic acid created during fermentation, the cocoa beans must be dried after fermentation. Cocoa beans are dried in the sun for one to two weeks, with the beans being stirred four times a day, and if not properly dried, they will grow mouldy. After fermentation and drying, the cocoa beans are placed in bags and transferred to a central site for grading. The cocoa beans are graded and then put into 60kg sacks for storage (Ganeswari *et al*., 2015).

2.7 Economic Importance of cocoa in Ghana

Cocoa has played and continues to play a significant role in Ghana's economy, and cocoa is a major source of government revenue. Although Ghana has found alternative sources of wealth, the country's economy has become even more reliant on natural resources since oil was discovered on its coasts (Vigneri and Kolavalli, 2017). Cameroon and the Ivory Coast rely heavily on cocoa as a source of revenue. It also helps many African countries thrive by generating foreign exchange earnings, government revenues, and household incomes. Cocoa revenues amounted to 30% of total government revenues on average, and are still the principal economic activity of smallholders, as well as one of Ghana's greatest income-generating cash crops (Achterbosch *et al*., 2014). Cocoa is expected to contribute 2.25 billion Ghanaian cedis (GHS), or roughly 390 million US dollars, to Ghana's Gross Domestic Product in 2021. In 2019, the value was estimated to be 2.11 billion GHS, approximately 366 million USD (Gyamfi, 2017). After Côte d'Ivoire, Ghana is the world's second-largest cocoa producer. Along its supply chain, the cocoa industry employs around 3.2 million people and generates 25% of foreign exchange revenues. In Ghana, it is estimated that 800,000 smallholder cocoa farmers earn between 70% and 100% of their annual income from cocoa cultivation (Gyamfi, 2017).

Cocoa's nutritional importance to man in terms of constituent elements include protein (11%), cellulose (9%), pentosan (7.5%), tannin (6%), butter (54%), water (5%), theobromine (1.3%), sugar (11%) and caffeine (0.2%). This has made it a more dependable income crop that is encouraged globally (Figueroa *et al*., 2020). Chocolate is consumed by millions of people throughout the world as a snack, drink, or dessert due to its nutritional content. Copper, magnesium, potassium, and calcium are minerals found in cocoa that may support a healthy cardiovascular system. Cocoa can help calm hyperactive people or enhance digestion and kidney function by stimulating the neurological system. It also lowers the risk of cardiovascular disease and stroke. Cocoa butter contains stearic, palmitic, and oleic acids, which are utilized in the production of chocolate, chocolate goods, cosmetics, and medications (Verna, 2013).

2.8 Climatic and Soil Requirements

2.8.1 Climatic Requirements

Cocoa is a tropical perennial crop whose optimal development and productivity are influenced by temperature and rainfall. Cocoa can be grown at altitudes of up to 1150 meters above sea level, with an average annual rainfall of 1000 to 2500 millimeters and relative humidity of 80 to 85 percent (Idris *et al*., 2013). 34°C and 14°C are the maximum and minimum temperatures required for its cultivation, respectively. Ghana's economy is strongly reliant on climate-sensitive industries such as agriculture, energy, and forestry, and climate change forecasts for the country foresee more severe and frequent drought, pest, and flood occurrences (Ibe and Amikuzuno, 2019). To reach optimum productivity, cocoa (*Theobroma cacao* L.) requires high temperatures, precipitation, and humidity, therefore cultivation is limited to the "cocoa belt" (20º N and 20º S of the Equator). To produce the highest yield, cocoa trees require temperatures of 21–23°C and yearly rainfall of 1000 to 2500 mm (Ameyaw *et al*., 2018).

Cocoa output is susceptible to precipitation; a 2°C increase in temperature and a 1% reduction in precipitation can result in a reduction in cocoa cultivation, especially in locations bordering the cocoa-growing suitability area to the north and south, respectively (Ameyaw *et al*., 2018). Cocoa trees require a hot, humid environment to grow to their full potential. The relative humidity in cocoa-producing countries is typically high, reaching 100 percent during the day and 70-80 percent at night (Thakran, 2017). Variations in the yield of cocoa trees from year to year are affected more by rainfall than by any other climatic factor. Cocoa is very sensitive to soil water deficiency. Rainfall should be plentiful and well distributed throughout the year. Low temperatures limit the intensity of cocoa flowers, fruit formation, fruit development, and cocoa flour composition, while high winds harm cocoa leaves and have an impact on production. Fungus illnesses such as black pod and vascular streak dieback are more prone to occur when annual rainfall exceeds 2,500 mm (Delgado-Ospina *et al*., 2021).

2.8.2 Soil Requirements

Cocoa may be grown in a variety of soil types. Red laterite soils are commonly used to grow cocoa. It does, however, prefer well-drained sandy loam soil with a pH range of 6.5 to 7.0, as well as water-retaining soils for optimal development and yield (Lahive *et al*., 2019). To allow for the establishment of a good root system, cocoa requires soil with coarse particles and a decent amount of nutrients, dug to a depth of 1.5 meters (Afoakwa E. O. 2016). Cocoa may be grown in a variety of soils. Cocoa grows best in sandy loam soil with good water retention and drainage and a pH range of 5.0-7.5. Cocoa plants have a dense taproot that can reach a depth of 1.5 meters or more, necessitating deep soils (Kochhar, 2016). The organic matter level in the top 15 cm of the soil should be at least 3.5 percent. The ideal ratio of total nitrogen to total phosphorus is roughly 1:5. Cocoa grows best on moist, nutrient-rich, well-drained, and aerated soils. Cocoa cultivation necessitates a well-drained, well-aerated soil with a healthy crumb structure and ample water and fertilizer supply. Cocoa seedlings need nitrogen, phosphorus, potassium, and other nutrients, as well as metabolites (proteins, lipids, and carbs) to grow and develop (Mensah, 2021).

2.9 Cocoa propagation

Seedlings are generally used for planting. The stage of maturity is visible from the change of pod clolour from green to yellow (*Forestero)* and red to yellow (*Criollo*) (Arenga and Cruz 2017). They are raised in nurseries where shade, wind protection, nutrition and irrigation are provided.

Hybrid seeds are often sourced commercially but even with these the plant raised can be highly variable in growth and performance (Nair, 2021). Seed are collected from ripe pods and, if the fresh beans are planted immediately at least 90% should germinate within two weeks. Seeds should be planted in a fiber basket or plastic nursery bag filled with clean soil and placed in a shaded place protected from the sun to prevent scorching (Komlaga *et al.*, 2019). Seedlings grow quickly and are ready to be transplanted after 4–6 months. Planting of seed direct to the field is not practiced due to irrigation and problems with weeds and pest management. Vegetative propagation is used where selected characteristics are desired. The tree raised are much more uniform in growth and performance than those raised from seed. Various techniques including, rooted cuttings, budding and grafting are used (Anjarwalla *et al.*, 2017).

Planting should be done at the beginning of the wet season. This would give the plants enough time to establish themselves before having to cope with the limited water supply during the following dry season (Kongor *et al.*, 2018). Dig holes approximately 0.4 m x 0.4 m x 0.24 m (1½ ft. x 1½ ft. x 10 inches) deep. Cocoa seedlings should be planted 3–4 m (10–13 ft) apart and 3–6 m (10–20 ft) from the shade trees (Komlaga *et al.*, 2019). Refill the hole with the mixture when planting. When transplanting from bags, water the plants thoroughly before moving them into the field. Make sure that the soil around the plant roots is not shaken loose during the transplanting process (Kongor *et al.*, 2018). For seedling plants, the tap root should not be bent or twisted at the time of planting. If this is allowed to happen the mature plant would be physically weak.

2.10 Agronomic Practices

Cocoa cultivation covers a total area of about 5.9 million ha worldwide with around 73% of this area found in the four large cocoa-producing countries in West Africa namely; Ghana, Cameroon, Côte d'Ivoire, and Nigeria. The adoption of good agronomic practices is crucial for the sustainability of cocoa cultivation (Asare *et al.*, 2018).

2.10.1 Disease Control

Phytophthora pod rot (black pod) and cocoa swollen shoot virus (CSSV) are the two diseases considered most important and have received great attention in Ghana. Phytophthora pod rot caused by *P. palmivora* and *P. megakarya* is currently the most important yield-limiting factor in the Ghanaian cocoa industry, with total annual losses estimated at up to 30 to 35% of the nation's crop (Ofori *et al*., 2020).

2.10.1.1 Black Pod Disease (Phytophthora palmivora)

P. palmivora causes cankers on the bark, flowers, and trees of cocoa. These cankers often emit reddish gum, shortening the tree's life and, as a result, lowering the plant's production. The disease damages the flowers the most because it is in these blooms that the cocoa fruit will set (Ofori *et al*., 2020). Infected flowers produce infected fruit, which turns black and is unusable for harvesting and processing. The disease can be controlled by using recommended spacing and Trinidad Selected Hybrids (TSH) with high yielding characteristics and known tolerance to the disease. Remove and burn all infected pods since these encourage the spread of the fungus, control weeds, and manage shade improve airflow, and reduce humidity. The application of fungicides should be timed to coincide with the start of the disease in the field (Nair, 2021).

2.10.1.2 Cocoa Swollen Shoot Virus Disease (CSSVD)

Cocoa Swollen Shoot Virus Disease is a major impediment to cocoa production in West Africa, particularly in Ghana. The disease was originally identified in 1936 in Ghana's Eastern Region. The virus has several distinct strains that can cause defoliation, plant dieback, and substantial yield losses. The most severe strains of the virus can destroy the plant in 2-3 years in sensitive cultivars like West African Amelonado cocoa (Andres *et al*., 2017). Cocoa swollen shoot disease (CSSD) is caused by Cocoa swollen shoot virus (Badnavirus). The disease is one of the most terrible scourges of cocoa, and it nearly wiped off Ghana's cocoa industry in the 1940s (Abrokwah *et al*., 2016). The disease is one of the most important cocoa viruses in West Africa because of its catastrophic effect on yield and the potential to kill cocoa trees, especially when severe strains are involved.

The virus affects all sections of the cocoa plant, with severe strains causing a variety of leaf symptoms as well as stem and root swellings (Marelli *et al*., 2019). Red vein banding of juvenile "flush" leaves, chlorotic vein flecking, or banding that may appear in angular flecks are some of the leaf symptoms. Swellings of the stem occur at the nodes, internodes, and tips. Infected pods can also change shape, becoming rounder, smaller, and smoother as a result of some strains. Cocoa swollen shoot virus belongs to the badnaviridae family of plant-infecting pararetroviruses, which have non-enveloped bacilliform particles that enclose a circular double-stranded DNA genome. Cocoa swollen shoot virus particles have lengths ranging from 121 to 130 nm and a width of 28 nm. Depending on the strain, the genome size ranges from 7.4 to 8.0 kilobase pairs (Ameyaw *et al*., 2014).

In Ghana, Cocoa Swollen Shoot Virus Disease has been managed in an integrated manner for many years, incorporating the use of several tactics such as the cutting out approach, mealybug control, alternative host removal, and the use of tolerant planting materials (Ameyaw, 2019).

2.10.2 Pest Control

Cocoa production has also been hampered by a variety of pests, mainly insects, in several locations. Some insects, such as the pod borer Carmenta theobromae, can be found in the cocoa tree's native habitat. Other insects, such as the cocoa tree mirids in Africa, have adapted to the cocoa tree (Graziosi *et al*., 2017).

2.10.2.1 Mirids

Mirids are the most common insects that attack cocoa in the world. Cocoa mirids have been regarded as a severe pest in Ghana since 1908, owing to their catastrophic impact. Distantiella theobroma (cocoa capsid) and Sahlbergella singularis (mirids) are the most frequent species in Ghana and West Africa. If left neglected for three years, mirid damage alone can cut yields by up to 75%. Cocoa mirids pierce the surface of cocoa stems, branches, and pods, destroying the invaded host cells and leaving unattractive necrotic lesions behind (Muniappan R. *et al.,* 2012). Mirids feed on shoots and frequently cause dieback by killing terminal branches and leaves. Female mirids lay up to 60 eggs under the bark of stems or inside the pod husk after mating. The bug is drawn to trees that are exposed to sunlight, and once they have found their food source, they seek shelter in shaded regions of trees. Some indigenous plants that are planted alongside cocoa have been discovered as alternative hosts for mirids (Akesse-Ransford, 2016). In Ghana, organochlorine insecticides are effective. Imidacloprid, Actellic/Talstar, and Promecarb are currently recommended pesticides that are sprayed as foliar spray four times per year at monthly intervals utilizing motorized mist-blowing equipment. Reduced insecticide use also permits natural enemy populations to grow, creating a better setting for biological control (Van-Lenteren, 2012). The application of Integrated Pest Management (IPM) is a key tool in controlling mirids. The black ant (*Dolichoderus thoracicus*) has been used in some farms as a control measure. Another ant (*Oecophylla smaragdina*) has also been used although this one can be aggressive. The use of conventional insecticides has proved to be the most effective method of control in West African countries, including Ghana (Anderson *et al*., 2019).

2.10.2.2 Cocoa Pod Borer (CPB)

Conopomorpha cramerella, often known as the Cocoa Moth, is the insect that causes the Cocoa Pod Borer (CPB). It was initially identified as a severe threat in 1841, and it caused massive losses in Ghana's cocoa sector during the 1890s and 1900s. Almost all cocoa agricultural areas in Ghana are currently affected by the Cocoa Pod Borer (Anderson *et al*., 2019). Cocoa Pod Borer has infested 60,000 acres by 2000, causing annual losses of US$ 40 million. Both immature and mature cocoa pods are attacked by the Cocoa Pod Borer. Unevenness and early ripening are two prominent symptoms of contaminated pods. Infestation of early pods causes significant losses since the bean's quantity and quality are severely harmed (Kyei-Baffour, 2019). Complete harvesting of ripe or damaged pods, burying of pod husk, placenta, rotten pods, and other harvest remnants are suggested sanitation methods. Pruning the cocoa canopy to less than 4 m in height regularly is also an excellent idea. Cocoa Pod Borer attacks are also reduced by sleeving pods with plastic bags. When pods are about 8-10 cm long, they should be sleeved, and the sleeves should be left on during the pod maturity period (Cork, 2016).

2.10.3 Application of Fertilizer

Cocoa yields are poor under traditional farming approaches, with an average of ten pods per cocoa tree, which is extremely low for a crop that can produce more than 100 pods per tree. Fertilizer utilization is a crucial component to consider in modern cocoa growing to maximize cocoa production (Snoeck *et al*., 2016). Fertilizer application increased yields from 250 kg per hectare to 1,500 kg per hectare after the fourth year of fertilizer application. This indicates that fertilizer application is unavoidable in agricultural production, as proper fertilizer application increases agricultural output. Fertilisers are either broadcast or placed in a circle around the stem once the cocoa has matured. Broadcasting appears ideal because mature cocoa generates a dense layer of lateral roots in the topsoil (Vanhove *et al*., 2016). However, if the cocoa is still young and the roots haven't spread across the trees, applying it in a circle around the stem may result in greater recovery. Because the roots of mature trees come to the surface under the litter, forking the fertilisers into the topsoil is not recommended (Van-Vliet and Giller, 2017).

To prevent ammonia volatilization, it was recommended to apply ammonium or urea forms of nitrogen and cover with litter, however today, Nitrogen is applied in the form of nitrate. Foliar application is considered an efficient approach to apply minor elements that are required in small amounts and may become unavailable if applied to the soil for most crops (Zulfiqar *et al*., 2019). Macronutrients, in general, are not suited for foliar treatment because the amounts to be applied are too large. Foliar treatment of nitrogen in the form of urea is an exception, which is occasionally paired with foliar spraying of insecticides or fungicides in specific crops to save money on application expenses (Manjunatha *et al*., 2016). Although fungicide and insecticide foliar spraying is suggested in cocoa, the use of foliar urea fertilizer may be limited because most fruit crop leaves do not withstand high urea concentrations. Urea sprays can help to overcome transitory nitrogen shortages in the leaves, but they can't take the place of regular nitrogen fertilizer applications in the soil. Micronutrients applied foliarly may be suitable for cocoa production (Bitew and Alemayehu, 2017).

2.10.4 Weed Control

Weed control is mostly a concern during the establishment phase. Young cocoa is traditionally weeded by hand slashing along tree rows or around young plants. Herbicides have also been employed recently. Weed growth is inhibited by considerable shade and leaf mulch when cocoa is mature and has created a complete canopy. Weeds will grow where the canopy allows light to pass through. Weeds compete with immature cocoa plants for nutrition, slowing their growth (Doungous *et al*., 2018).

2.10.5 Pruning

A 70 percent shade is ideal for the young cocoa plant's early growth and development. For trees above the age of five to seven years, this should be gradually reduced to twenty-five percent. Pruning involves thinning branches and eliminating old or dead stems and branches (Wessel and Quist-Wessel, 2015). Most farm management requires this to allow the crop to develop well by allowing direct sunshine. Pruning should be done twice a year in cocoa production. Pruning is done to enhance a tree's structure or to limit the amount of sunlight it receives. Pruning should be done after the main harvest just before the monsoon (Niether *et al*., 2018). The second pruning should be done 6 months after the first one. Any lower branches and dead branches should be removed. Limited the branches to 4 to 5 for better sunlight. Burn any diseased branches after they are removed (Alcorn *et al*., 2013).

2.11 Adoption of Different Growth Media

Plant performance in bare roots and container nursery production is influenced by the growing media. Crop production is determined by the nutrients present in the soil as well as other factors. The emergence and growth of seedlings are mostly influenced by nursery media. As a result, proper media that can boost seedling vigour provides nutrients, water, and air as well as support for growing plants to ensure continuous cocoa output (Anthonio *et al*., 2018). Cocoa nurseries face many challenges in cocoa-growing areas, including a lack of suitable growth media for propagating hybrid cocoa seedlings. In addition, topsoil for nurseries is typically transported from long distances to nursery sites, and its scarcity impedes the government's and COCOBOD's goals of raising healthy hybrid cocoa seedlings for effective and efficient distribution to farmers. One of the most significant parts of cocoa seedling production is the quality of the growth media (Anthonio *et al*., 2018). To assist appropriate shoot and root growth, the growing media must perform four basic functions: delivering water, supplying nutrients, allowing gas exchange to and from the roots, and providing support for the plant. The use of agro-industrial waste materials including sawdust, rice husk, and coconut fiber as potting media has been suggested as a superior alternative to topsoil (Bhuyan *et al*., 2020).

2.11.1 Cocoa Pod Husk

Cocoa pod husk is a major by-product of Ghana's cocoa industry, accounting for more than 70% of the matured fruit. It's really fibrous and contains a lot of cell wall components. Cocoa pod husk is usually gathered in a mound in the field and is seen as a waste. This can be utilized to amend soils to reduce waste, so efforts must be made to utilise the husk by putting it into potting media for the development of cocoa seedlings (Figueroa *et al*., 2020). Cocoa pod husk is a natural fertilizer that is frequently used as a soil additive. Plant derived ash has been demonstrated to improve soil pH and crop yield when used as a liming material. Several studies in Africa found that plant-derived ash, such as that from wood and cocoa pod husk, boosted N, P, K, Ca, Mg, soil status, soil pH, and vegetable, rice, millet, and maize yields (Lucchini *et al*., 2014). According to research from Nigeria and Ghana, Cocoa pod husk has high mineral concentration, particularly in K, Ca, and P, allows it to partially replace traditional fertilizers. When compared to NPK fertiliser (combination of $(NH_4)2SO_4$, P_2O_5, and K_2O), a study in Nigeria found that mixing CPH powder with basal phosphorus fertiliser may achieve equal plant quality, seed production, and harvest index of black benniseed farming (Figueroa *et al*., 2020). Other research has focused on the use of Cocoa pod husk ash as a fertilizer, with results showing that replacing up to 50% of traditional NPK fertiliser with Cocoa pod husk ash improved grain yield and nutrient uptake in maize production (Ouattara *et al*., 2021) as well as fruit growth, yield, and soil fertility in tomato production. Due to limited distribution and marketing for fertiliser procurement in poor countries like Ghana, such eco-friendly applications could potentially replenish the shortfall of pricey NPK fertiliser (Figueroa *et al*., 2020).

2.11.2 Sawdust

Sawdust is created when wood is milled, chopped, ground, or drilled with a saw or other machine. Woods including white and black odum, ofram, mahogany, wawa, and oyina are utilized in Ghana's manufacturing process (Krottenthaler *et al*., 2015). Sawdust has been examined and used as a mulch and soil supplement for growing seedlings and vegetables in many nations. Sawdust is made up of around 40% lignin and 60% cellulose, with minor amounts of waxes, resins, and oils (Stoffel *et al*., 2014). It has a poor nutrient density, with only 0.048percent nitrogen, 0.007 percent phosphorus, 0.017 percent potassium, and 0.106 percent calcium, which fluctuates depending on the type of wood used to make the sawdust. After breaking down, sawdust becomes humus, which improves soil structure, aeration, and water holding capacity while also enhancing microbial activity. Agricultural scientists have been reluctant to accept sawdust as a desirable form of organic matter to use as a mulch or soil amendment because of the problems when added to the soil (its slow rate of decomposition and its temporary depression of nitrates) (Flynn and Idowu, 2017). Regardless of these drawbacks, the benefits acquired from the usage of these wood wastes in improving the physical qualities of the soil cannot be underestimated. Depending on the type of crop to be cultivated.

2.11.3 Coconut Husk

Coconut husks, which are by-products of the coconut processing, are used to make cocopeat. It's a binding material derived from the coconut husk's fibre portion. Cocopeat is a natural alternative to mined peat moss that helps to slow the extraction of peat from environmentally sensitive marshes across the world (Danley-Thomson *et al*., 2016). Due of its unique physical qualities, including as high total pore space, high water content, low shrinkage, low bulk density, and delayed biodegradation, it is utilized as a growth media and a soil addictive. Cocopeat, applied alone or as part of a soil media, has been found to be good for a wide range of potted plants (Bhardwaj, 2014). It may also store and distribute nutrients to plants, as well as offer adequate aeration and oxygenation, all of which are necessary for healthy root development.

2.11.4 Rice Husk

Rice husks, also known as rice hulls, are the paddy grain rice's outermost coating that is separated from the brown rice during milling. It's one of the world's most readily available agricultural wastes. Approximately 600 million tonnes of rice paddy are produced globally.

Every year, paddy rice husk accounts for 20% of total paddy rice production. Rice husk is made up of 75-90 percent rice (Chabannes *et al*., 2018). The remaining is made up of mineral components like silica and organic materials like cellulose and lignin trace elements and alkalis. Rice husk is high in potassium, phosphorus, calcium, and other micronutrients that are essential for plant growth. Rice husk is an important organic fertilizer because it helps to improve soil physical qualities, nutrition, and water usage efficiency (Oladele, 2019). Rice husk is an organic substance that can be used as a mulch, compost, or a soil amendment to improve aeration and water holding capacity. It is efficient in loosening heavy soil and adding organic matter to the soil, which allows the soil to retain water and nutrients, allowing plants to thrive and flourish. Rice husk does not decompose or deplete nitrogen, hence it is best utilized in conjunction with compost or soil as a soil addition (Oladele, 2019).

2.12 Effect of Different Growth Media on Cocoa Seedling Production

There are two types of growing media: soilless media, which refers to a potting medium that contains peat, usually perlite or vermiculite, and/or any organic material without soil, and soil media, which refers to a potting medium that contains peat, usually perlite or vermiculite, and/or any organic material without soil (Zhang *et al*., 2012). The term "sterile mix" is sometimes used to describe this. The second type is a soil-based media mix, which is a potting medium that includes a percentage of soil. To enable proper shoot and root growth, the media must meet all of the basic plant requirements. The growing medium must provide support, good drainage, nutrients, appropriate air circulation, and water to the plants (Vijayaraghavan, 2016). Agricultural and agro-industrial residues, if managed properly, can be beneficial to agriculture, since these contain important plant nutrients such as nitrogen, phosphorus, potassium, magnesium, and other nutrients. Cocoa pod husk manure is reported to contain Ca, P, K, and also has a sizeable amount of useful organic constituents (Doungous *et al*., 2018). Propagating media is any medium in which a plant grows and must be porous enough for root aeration, drainage and capable of retaining water and nutrients to support developing seedlings. It may consist of a mixture of organic and inorganic components that have different but complementary properties. There are two types of propagating media namely; the soilless mix and the soil-based mix. The organic components used include peat, soft and hardwood barks, or sphagnum moss. Recent studies have shown that leaf mulch, rice husk as well as other agricultural wastes such as cocopeat, cocoa pod husk, and kola pod husk has been used as a media for supporting seedling growth (Doungous *et al*., 2018). Organic matter either fresh or composted plays a critical role in maintaining nutrient availability. It also supplies plants with essential nutrients and soil organisms with energy.

2.13 Effect of different soil media on growth of cocoa seedlings

A growing media is any substance (ie. peat, sand, cocopeat, vermiculite or other material) that provides nutrients, water, and air as well as provides support for the growing plants. A potting/growing media must provide the necessary conditions that will enhance seedling growth for successful transplanting to the field (Singh *et al.,* 2021). The most important aspect of seedling production is the quality of the growing media which is determined by the growth rate of the plants grown in them. The quality of a potting media is based on its physical and chemical properties. Singh (2021), stated that a good quality potting media must have physical and chemical properties that can result in increasing plant growth rates, improving yields and enhancing tremendous plant quality. In seedling production, one of the most important aspects is the quality of the growth media (Jara-Samaniego *et al.,* 2017). The growing media must serve four main functions in order to facilitate proper shoot and root growth and these includes, providing water, supplying nutrients, permitting gas exchange to and from the roots and providing support for the plant (Dickens, 2013). Propagation media influence the emergence and growth of seedlings thus, a good quality growing media must have acceptable physical and chemical properties to perform these functions to enhance seedling growth and development (Dickens, 2013). According to Dickens (2013), application of organic amendments has a significant effect on germination of Okra seed. Ofori-Frimpong *et al.,* (2010), reported better cocoa seedlings growth with the use of compost developed from cocoa pod husk as potting medium

2.14 Effect of soil media on survival rate of cocoa seedlings

The substrates (i.e., the propagation media in which plants grow), which provide anchorage for the plant roots, air spaces to enhance aeration and retain sufficient available water are known as the growth media (Anthonio *et al.*, 2018). Growing media affect plant performance in bare roots and container nursery production. The inherent nutrients and soil factor determine the productivity of crops. Mostly, nursery or propagation media influence the emergence and growth of seedlings. Thus, suitable media that could enhance the vigour of seedlings is crucial for continual cocoa production (Anthonio *et al.,* 2018). The medium from which seedlings are transplanted influences seedling growth and survival on the field. The survival of seedlings at transplanting is partly dependent on the medium from which seedlings are transplanted. Poor-quality seedlings at the juvenile stage may result in the poor establishment of seedlings on the field, slow growth, and reduced survival percentage (Akpalu *et al.,* 2021). In Ghana, cocoa seedlings are mainly transplanted in June, when the rainfall is frequent and peaks in October, leaf development may be intense due to high rainfall. However, shortly after the dry season sets in November, decrease in soil moisture at this period of growth results in high seedling mortality since plants are very sensitive to moisture stress at this stage (Akpalu *et al.,* 2022). Rapid root growth and the ability to tap water during this phase of growth are vital to seedling survival and early establishment. Mulcahy *et al.* (2013) demonstrated that in sandy substrates 30% (v/v) biochar – concentrated in the root zone of tomato seedlings significantly increased seedling resistance to wilting for over 4,000 tomato seedlings each year. Similarly, Akpalu *et al*. (2021), conducted an experiment on field performance and survival of cocoa seedlings raised in different growing media. According to them, cocoa seedling survival at the onset and end of the dry season significantly increased for seedlings transplanted from soilless media compared to those from the top soil.

2.15 Effect of different soil media on seedling vigour of cocoa at nursery stage

The use of agricultural wastes as potting media can support seedlings growth in the nursery and field performance after transplanting (Raviv, 2011). The positive impacts of media types and their combinations with compost on the growth and nutrient uptake of cocoa seedlings positively influence seedling vigour. Soil mixes are considered to be important and necessary for the growth and development of seedlings as it provides the basic necessities required by the plant throughout its life. The quality of a potting media is based on its physical and chemical properties. Singh (2021), stated that a good quality potting media must have physical and chemical properties that can result in increasing plant growth rates, improving yields and enhancing tremendous plant quality. Gruda (2019), also, reported that a good quality potting media must enhance the development of healthy, fibrous root system to provide support as well as supply nutrients to the plant for the plants growth and development.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site and Location

The nursery experiment was conducted at the nursery site of the Sefwi Wiawso College of Education located in the Western North Region of Ghana. The Sefwi Wiawso municipal is one of the largest municipalities in the Western North region, lying in the north-east part of the region and bordered to the north by Ashanti Region. Juaboso, Bodi, and Sefwi Akotombra District to the West. It is also bordered by Bibiani-Anhwiaso-Bekwai to the East and Wassa Amenfi to the south-east. The main occupation in the area is farming. The study area is located within the semi-deciduous humid forest zone of Ghana with an altitude of 247.6 above sea level. The area is characterized by a bimodal rainfall pattern with an annual rainfall of 1500 mm (MoFA Sefwi Wiawso, 2012). River Tano (perennial water source) flows through the whole municipality together with other smaller rivers, which makes it possible for irrigation, especially for dry season cultivation of vegetables. Agriculture being the major economic activity, the people grow crops such as yam, cassava, groundnut, cowpea, maize, palm oil, plantain, mango, cocoa, rice, coffee and vegetables (MoFA, 2012). Rearing of animals such as goats, sheep, pigs, cattle and poultry are also their major economic activity. However, these are done mostly on subsistence base.

3.2 Soil type and vegetation

The soils in Sefwi Wiawso in contrast were acidic with the pH values ranging from 4.6 ± 0.2 to 5.5 ± 0.3. The acidity increased with increasing soil depth. The soils in Sefwi Wiawso municipality are Alfisols and ultisols of the semi-deciduous forest zone of Ghana and have a bleached E horizon, but do have clays that accumulate in the subsoil. They are very common in the Midwestern region, and are the most fertile type of the forest soil. (Nyle and Ray, 2014) Alfisol contain the subsurface layer of loamy materials (a mixture of mostly clay and sand with little silt) that has a relatively high water holding capacity (Nyle and Ray, 2014). Ultisols are intensely weathered soil of warm and humid climates retention capacity greater than that of oxisol, but less than Alfisol. Some of the crops grown are cocoa, oil palm, rice, cassava, yam, maize, groundnut, mango, coffee, banana, papaya and pineapple (MoFA Sefwi Wiawso, 2012).

3.3 Climate

The total annual rainfall in Sefwi Wiawso ranges between 1200 mm and 1600 mm, averaging 1400 mm according to the meteorological service, Sefwi Wiawso (2019). The rainfall pattern is bimodal with two different rainy seasons. The major rainny season is between March to July and the minor rainny season is also between Septembers to November each year.

3.4 Experimental Design, Treatments, and Field layout

The experimental design used was Randomized Complete Block Design (RCBD). There were six small treatments namely; Topsoil (T1), Sawdust (T2), Cocoa pod husk (T3), Topsoil + Sawdust (T4), Topsoil +cocoa pod husk (T5), and Sawdust + cocoa pod husk (T6) with three replicates were employed. The six (6) treatments were assigned to each plot measuring 60 cm in length by 60 cm long in each replicate. There was 30 cm left between each plot and 40 cm left between each replication. Each plot contains sixteen (16) polythene pots. The total field size was 5.4 m × 2.6 m (14.04 m^2).

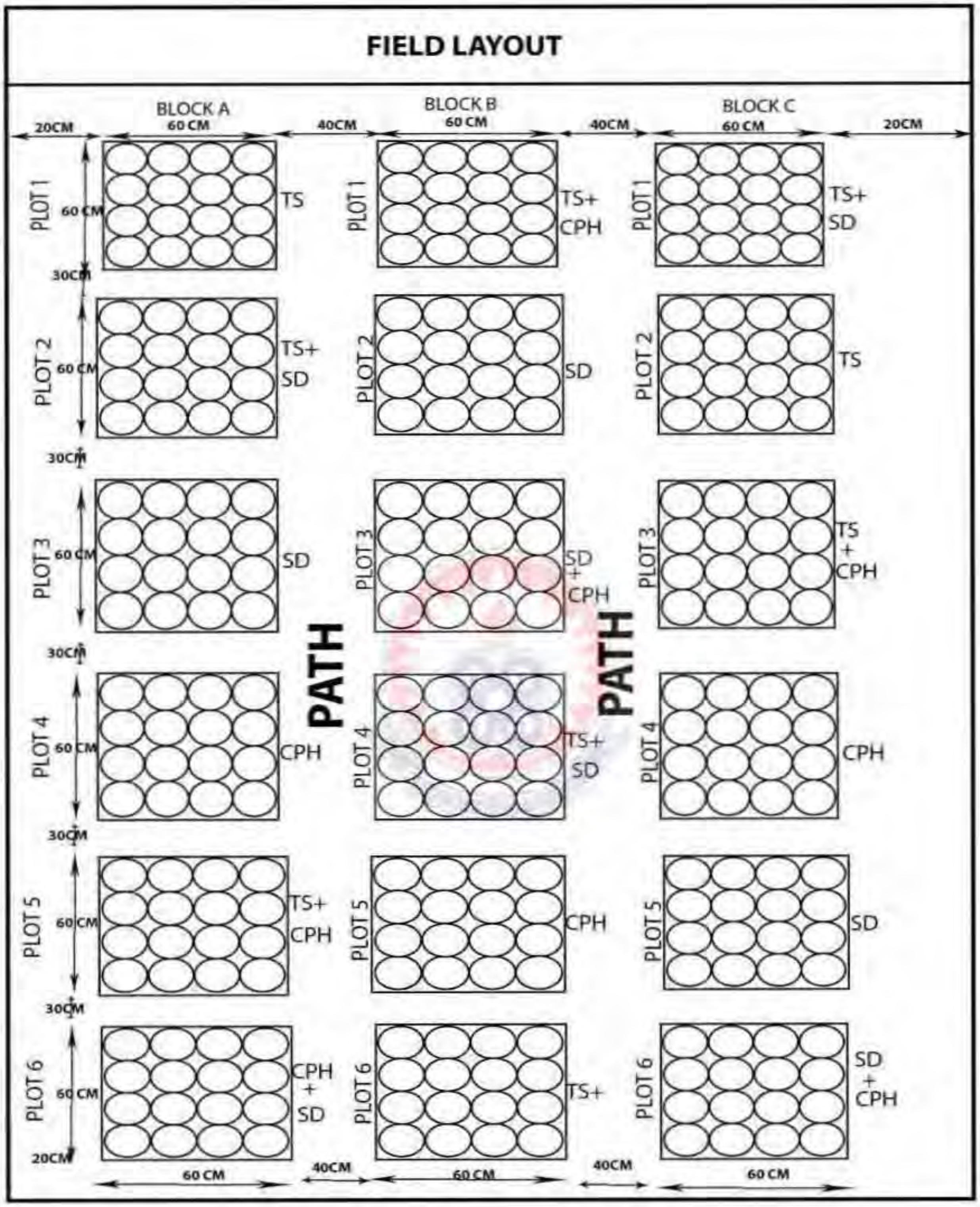

Figure 3.1: Field layout not drawn to scale

3.5 Nursery site preparation

The land was cleared manually and leveled using rake. The land was demarcated into six plots, and three replications. Each plot measured 60 cm in length × 60 cm in width. The field size area was 14.04 m^2. A shade net, which allowed about 40% sunlight through it was employed in this study. It was raised about 2 meters high using bamboo and palm fronds. The entire experimental site was fenced with a net and secured with a gate to prevent sheep, goats, and other animals from entering the nursery site.

3.6 Growth media and poly pot preparation and planting

Topsoil was collected from Sefwi Wiawso newtown old dumping site from a depth of 0-15 cm. The cocoa pod husk was obtained from Mr. Affum cocoa farm at Domeabra in Sefwi Wiawso district and sun dried for 48 hours. The sawdust was obtained from Buadac Sawmill Company Limited at Nsawora. The cocoa pod husk was pounded in the mortar with pestle and sieved to fine texture. The sawdust which was obtained from Wawa tree was composted for six weeks. Wawa tree was selected because it had soft texture and can decompose faster. Nursery poly bags were initially perforated at the base with a perforator creating a 0.25 mm hole to facilitate drainage. Poly bags size of 17.5 cm × 25 cm, base and height respectively were used. Each poly bag was filled with 5 g of Top soil, 5 g of cocoa pod husk and 5 g of sawdust according to treatment. The poly bags were filled with the growth media and their mixtures namely; Top soil+sawdust, Top soil+cocoa pod husk and Sawdust+cocoa pod husk in a ratio 1:1 by volume. Hybrid cocoa seeds were obtained from Sefwi Akurafu Seed Production Unit of Ghana COCOBOD-Sefwi Wiawso. The hydrid cocoa used as the planting materials was C75 (Clone 75). Fresh cocoa beans were removed from the pods and left for two days for the mucilage on the beans to be removed when wash. The washed beans were left open in a cool environment for three days to determine the viability. The seeds were sown two seeds per poly bag at the depth of 2 cm. Sowing was done on 16th march, 2021, and thinning was carried out two weeks after seedling emergence. For each treatment, 16 poly bags were filled with respective medium.

3.7 Agronomic Practices

A supplement irrigation two times was done every day that is morning and evening except days that it rains. Each received the same quantity of water. Two seeds sown per poly bag were thinned to one seedling per stand two weeks after planting. Weed control was done using hand picking and hoeing two weeks after planting and when weeds appear during the experimental period. Insecticide treatment (60 ml Akate master 200sL in 4.5L of water) was carried out on the third week using a hand sprayer so as to minimize of insect pest attack on cocoa seedlings

3.8 Data Collection

Three plants from the middle of each plot were randomly selected and tagged for vegetative growth data measurements.

3.8.1 Vegetative Growth Data

3.8.2 Plant Height

The height of the three tagged seedlings was measured with a meter rule from the base to the apical leaf of the plant at 30 days after sowing. This was done every two weeks until the seedlings were 86 days after planting.

3.8.3 Canopy width

Using the meter rule, the canopy width of three tagged seedlings per plot was measured. The meter rule was used to take measurements from one leaf edge to the widest spread of the leaf, and the mean was calculated. Every two weeks, the process was repeated. Data collection began in the fourth week (30 days) following sowing.

3.8.4 Stem diameter

The stem diameter of the three seedlings per plot was measured with a vernier caliper, from the base of the shoot about 4 cm above the soil surface, marked with a permanent marker. The vernier caliper was opened and screwed to fix the marked part of the shoot and the measurement was read from the vernier scale. Starting 30 days after sowing, this was repeated every two weeks. The average stem diameter was computed.

3.8.5 Number of Leaves per plant

The total number of leaves per plant was counted on the three tagged plant per plot recorded at 30 days after sowing, this was repeated every two weeks, and the mean computed and recorded.

3.8.6 Leaf Length

A meter rule was used to measure the length of leaf for each of the three tagged seedlings on each plot. It was accomplished by maintaining the leaves flat and measuring the length of each leaf from the pointing section (apex) on one end to the point where the leaf joins the stalk (base) on the other end with a ruler. This began 30 days after planting and continued every two weeks until 86 days had passed. The measurement was collected from the seedling's 3rd and 4th leaves from the base.

3.8.7 Leaf width

The leaf width was measured using the same format as the leaf length. Each tagged seedling leaf from each plot was measured by flattening the leaf and measuring the breadth of each leaf from one end to the other with a ruler. The data was gathered and recorded. This was done 30 days after sowing and repeated every two weeks until the seedlings were 86 days old. The measurements were taken from the plant's third and fourth leaves at the base (seedling).

3.8.8 Root Length

Three tagged seedlings were destructively sampled uprooted from each plot and separated into root and shoot. This was done after watering the seedlings so that the root could be easily separated from the media without damaging the root system. The measurements of the uprooted and separated root system were taken from the base to the tip of the root using a meter rule. This was done from 30 days of sowing until at 86 days after sowing.

3.8.9 Seedlings root and shoot fresh weight

From each plot three tagged seedlings were chosen and separated into root and shoot. This was done after watering to avoid leaving any root systems in the medium and to make uprooting easier. The root and shoot were separated and chopped into pieces before being weighed using an electronic weighing scale and the mean computed. This measurement was taken 86 days after the seedlings were sowed.

3.10 Statistical Analysis

Data on seedling vegetative growth was subjected to Analysis of variance (ANOVA) and Fisher's Least Significant Difference (LSD) was used to separate means from treatment at 5% level of probability using statistical package Genstat (2016).

CHAPTER FOUR

4.0 RESULTS

4.1 Vegetative Growth

4.1.1 Number of leaves per plant

There were no significant differences (p>0.05) between treatments in number of leaves per plant (Fig. 4.1). Top soil+Sawdust recorded the greatest number of leaves per plant (2.70 cm) at 4 weeks after planting and Top soil+Cocoa pod husk recorded the least (1.30 cm) compared to cocoa pod husk (1.50 cm) at the same period. There were no significant differences (p>0.05) between treatments [i.e., Sawdust, Cocoa pod husk and Sawdust+Cocoa pod husk] except for Top soil, Top soil+Cocoa pod husk and Top soil+Sawdust, at 6 and 8 WAP in number of leaves per plant although greatest was Top soil+Sawdust (4.30 cm and 5.70 cm respectively) and Cocoa pod husk recorded the least mean value of 2.10 cm and 3.00 cm respectively. At 10 WAP, Top soil+Sawdust recorded the greatest mean value (6.43 cm) in number of leaves per plant and Cocoa pod husk recorded the lowest mean value (3.70 cm). Top soil, Sawdust, Top soil+Cocoa pod husk and Sawdust+Cocoa pod husk recorded no significant differences (p>0.05) at 12 WAP except for Top soil, Top soil+Sawdust and Cocoa pod husk which recorded significant difference (p<0.05). Top soil+Sawdust recorded the greatest number of leaves per plant (6.90 cm) and Cocoa pod husk recorded the least (4.10 cm) (Fig. 4.1).

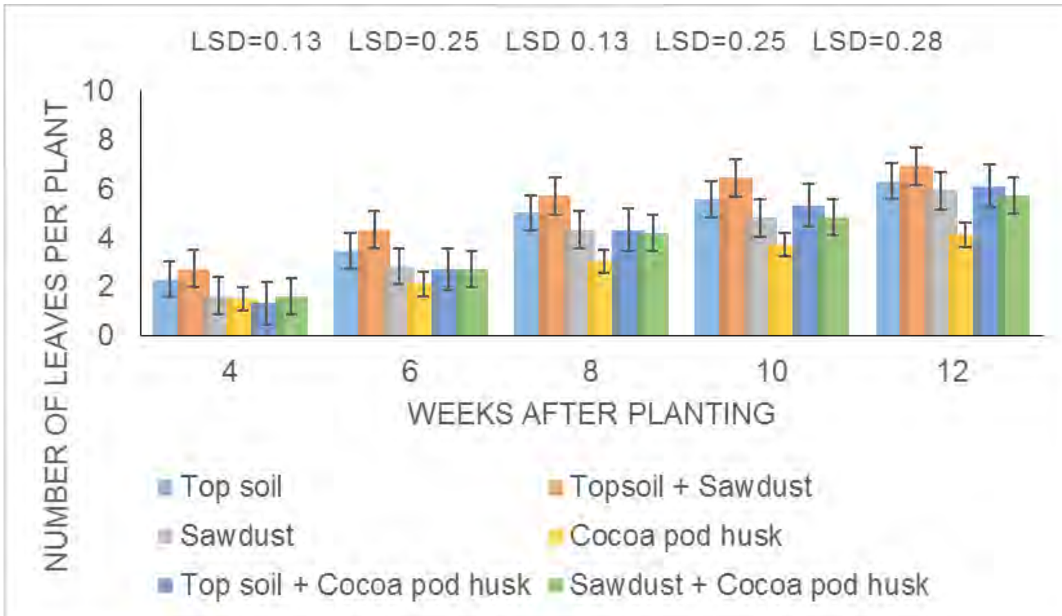

Figure 4.1 Effect of topsoil, sawdust and cocoa pod mixtures on number of leaves per plant of cocoa seedlings

4.1.2 Leaf Length

Significant differences ($p<0.05$) were observed in leaf length between treatments across the weeks with Top soil + Sawdust producing the longest leaf and Cocoa pod husk recording the least leaf length (Table 4.1). Plants grown on top soil followed with longer leaf length then Sawdust, Top soil + Cocoa pod husk respectively across the week (Table 4.1).

Table 4:1 Effect of topsoil, sawdust and cocoa pod mixtures on leaf length of cocoa seedlings

Treatment	Leaf Length (cm)				
	4WAP	6WAP	8WAP	10WAP	12WAP
Top soil	8.23d	8.53e	8.66d	8.63e	8.83e
Topsoil + Sawdust	8.70e	8.93f	9.20e	9.30f	9.63f
Sawdust	7.56c	7.86d	8.06c	7.83d	8.06d
Cocoa pod husk	6.60a	6.83a	7.00a	5.80a	6.03a
Top soil + Cocoa pod husk	7.10b	7.30b	7.50b	6.10b	6.40b
Sawdust + Cocoa pod husk	7.50c	7.70c	8.00c	7.56c	7.80c
LSD (0.05)	0.08	0.07	0.06	0.06	0.30
CV (%)	0.6	0.6	0.4	0.5	0.7

Values followed by similar letters under the same column are not significantly different at p=0.05

4.1.3 Canopy Width

At 4 and 6 WAP showed a similar growth trend with significant difference (P<0.05) occurring between treatments except for Top soil+Cocoa pod husk and Sawdust+ Cocoa pod husk which were statistically the same (Fig 4.2). However, Top soil and sawdust mixture recorded the widest canopy width at 4 and 6 WAP while Cocoa pod husk recorded the least compared to Top soil+ Cocoa pod husk, Sawdust, Sawdust+Cocoa pod husk, and Top soil. Significant differences (p<0.05) were also observed between treatments at 8 and 10 WAP. There was no significant differences (p>0.05) between treatments in canopy at 12 WAP. Top soil, however, recorded the widest canopy width (8.90 cm) while Cocoa pod husk recorded the least canopy width (6.30 cm) compared to Top soil + Cocoa pod husk, Sawdust, Sawdust + Cocoa pod husk, and Top soil at 12 WAP (Fig. 4.2).

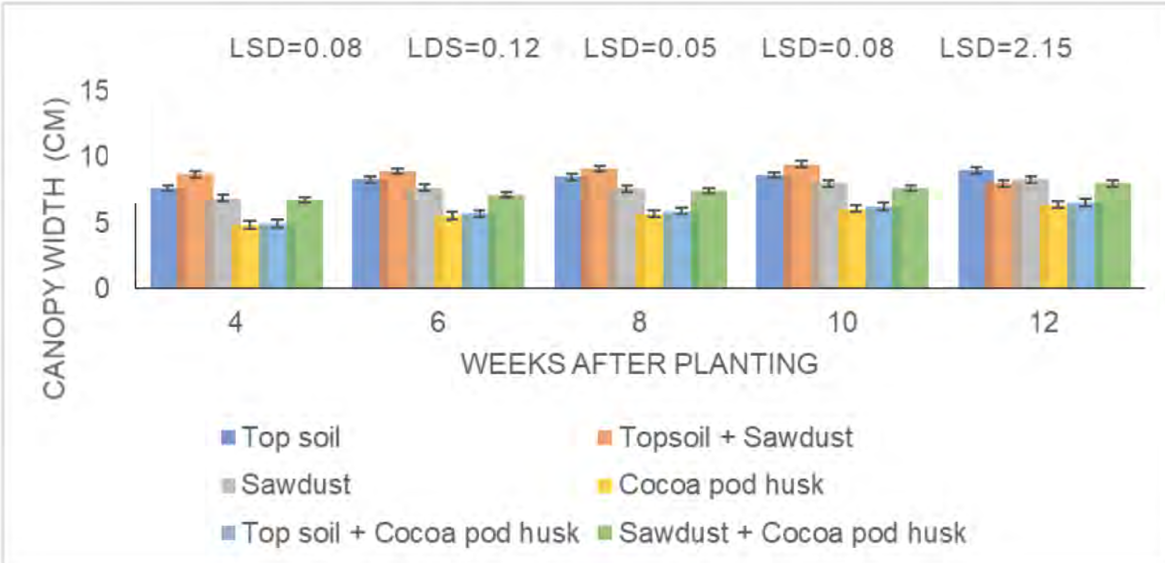

Figure 4.2 Effect of topsoil, sawdust and cocoa pod mixtures on canopy width of cocoa seedlings

4.1.4 Leaf Width

There were no significant difference ($p>0.05$) between topsoil, Top soil + Cocoa pod husk, and Sawdust + Cocoa pod husk in leaf width at 4 WAP (Table 4.2). Top soil+ Sawdust recorded a significantly ($p<0.05$) widest leaf width (5.90 cm) than Sawdust (4.50 cm) and Cocoa pod husk which recorded the least leaf width (3.83 cm). There were significant difference ($p<0.05$) between treatments in leaf width at 6, 8, and 10 WAP. Top soil+Sawdust recorded the greatest leaf width and Cocoa pod husk recorded the least at the same periods (Table 4.2). There was a significant difference ($p<0.05$) between treatment at 12 WAP. However, Top soil and Top soil+Cocoa pod husk were statistically similar ($p>0.05$). Top soil+Sawdust mixture recorded the widest mean value at 12 WAP in leaf width (6.56 cm) and Cocoa pod husk recorded the least mean value (4.33 cm) at the same period (Table 4.2).

Table 4.2 Effect of topsoil, sawdust and cocoa pod mixtures on leaf width of cocoa seedlings

Treatment	Leaf Width (cm)				
	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Top soil	4.66cd	4.83c	5.03c	5.13c	5.33c
Topsoil + Sawdust	5.90f	6.20f	6.30f	6.46f	6.56e
Sawdust	4.50b	4.60b	4.80b	4.90b	5.20b
Cocoa pod husk	3.83a	4.00a	4.13a	4.30a	4.33a
Top soil + Cocoa pod husk	4.76de	5.00d	5.20d	5.30d	5.40c
Sawdust + Cocoa pod husk	4.96e	5.16e	5.30e	5.40e	5.53d
LSD (0.05)	0.06	0.09	0.05	0.06	0.07
CV (%)	0.7	1.1	0.6	0.7	0.8

Values followed by similar letters under the same column are not significantly different at p=0.05

4.1.5 Plant Height

Top soil+Sawdust produced significantly ($p<0.05$) taller plant for the entire growing period at WAP 4 (Table 4.3). The difference were not significant ($p>0.05$) for Top soil and Top soil+Cocoa pod husk from 6 to 10 WAP. However, significant difference ($p<0.05$) existed between Sawdust, Cocoa pod husk, and Sawdust+Cocoa pod husk at the same period (Table 4.3). At 12 WAP there were no significant differences ($p>0.05$) between Sawdust and Top soil+ Cocoa pod husk and then, Cocoa pod husk and Sawdust+Cocoa pod husk with the exception of Top soil and Top soil+Sawdust where significant ($p<0.05$) difference exist. Top soil+Sawdust mixture produced the tallest Plant height (22.36 cm) whiles Sawdust+Cocoa pod husk recorded the least (18.56 cm) at 12 WAP (Table 4.3).

Table 4.3 Effect of topsoil, sawdust and cocoa pod mixtures on plant height of cocoa seedlings

Treatment	Plant height (cm)				
	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Top soil	16.90de	17.70d	17.96d	18.13d	20.96c
Topsoil + Sawdust	17.13e	18.20e	18.46e	18.80e	22.36d
Sawdust	15.93c	16.80c	16.96c	17.23c	20.10b
Cocoa pod husk	14.73a	15.60a	15.80a	16.03a	18.86a
Top soil + Cocoa pod husk	16.80d	17.63d	17.96d	18.23d	20.33b
Sawdust + Cocoa pod husk	15.46b	16.33b	16.60b	16.80b	18.56a
LSD (0.05)	0.18	0.11	0.06	0.05	0.17
CV (%)	0.6	0.4	0.2	0.2	0.5

Values followed by similar letters under the same column are not significantly different at p=0.05

4.1.6 Stem Diameter

Cocoa seedlings planted on Top soil+Sawdust produced significantly ($p<0.05$) widest stem diameter whiles cocoa seedlings planted in cocoa pod husk produced the least for the entire growing period (Fig.4.3). At 6 and 10 WAP, cocoa seedlings planted on Top soil+ Sawdust produced wider stem diameter compared to the Top soil, Sawdust+Cocoa pod husk, Sawdust, Top soil+Cocoa pod husk and Cocoa pod husk. Top soil+Sawdust recorded the widest stem diameter at 8 and 12 WAP whiles Cocoa pod husk recorded the least mean value for the same period (Fig. 4.3).

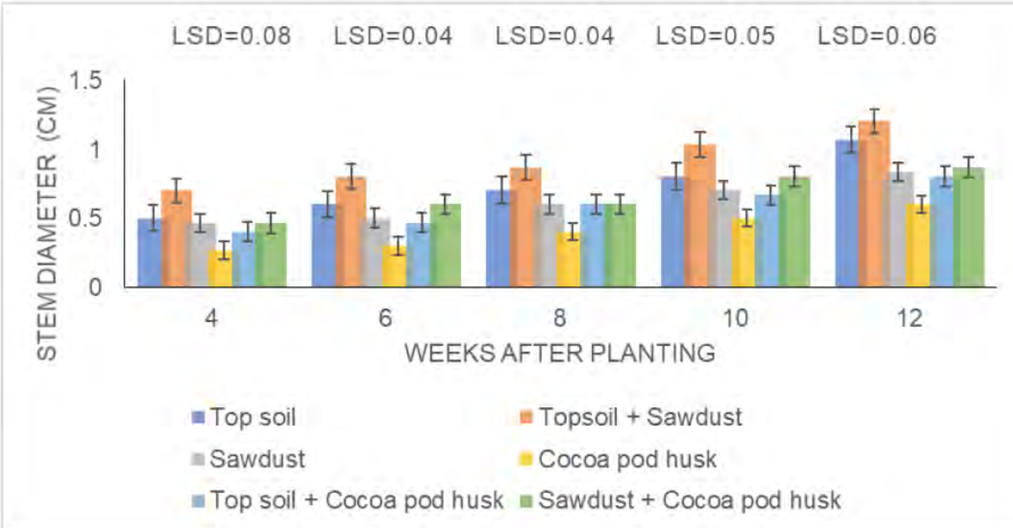

Figure 4.3 Effect of topsoil, sawdust and cocoa pod mixtures on stem diameter of cocoa seedlings

4.1.7 Shoot Root ıresh weight, and Root length

4.1.7.1 Shoot fresh weight

Seedlings grown in Sawdust and Sawdust+cocoa pod husk was not significantly different ($p>0.05$) in shoot fresh weight (Table 4.4). However, significant differences ($p<0.05$) exist between topsoil, topsoil+sawdust, cocoa pod husk and top soil+cocoa pod husk in shoot fresh weight. Top soil+sawdust produced significantly ($p<0.05$) higher shoot fresh weight compared to other treatments while cocoa pod husk recorded the least mean value (0.47 g) in shoot fresh weight (Table 4.4).

4.1.7.2 Root fresh weight

Seedlings grown in cocoa pod husk, Top soil+cocoa pod husk and Sawdust+cocoa pod husk did not show any significant differences ($p>0.05$) in root fresh weight (Table 4.4). However, significant differences ($p<0.05$) exist between top soil, top soil+sawdust and sawdust in root fresh weight. Seedlings grown in Top soil+sawdust produced significantly higher root fresh weight followed by topsoil. However, Top soil+cocoa pod husk and cocoa pod husk recorded similar mean value of (0.30 g) in root fresh weight (Table 4.4).

4.1.7.3 Root length

Seedlings grown in Top soil+Sawdust, sawdust and Sawdust+Cocoa pod husk showed no significant differences ($p>0.05$) in root length (Table 4.4). However, Top soil+Cocoa pod husk, Topsoil and Cocoa pod husk recorded significant differences ($p<0.05$) in root length. Seedlings grown in Top soil+Sawdust gave significantly ($p<0.05$) higher root length (8.23 cm) than Cocoa pod husk, Top soil+Cocoa pod husk, and Top soil (Table 4.4). Cocoa pod husk however, recorded the least mean value of (3.90 cm) in root length (Table 4.4)

Table 4.4 Effect of topsoil, sawdust and cocoa pod mixtures on Shoot fresh weight, Root fresh weight and Root length of cocoa seedlings

Treatment	Shoot fresh weight (g)	Root fresh weight (g)	Root length (cm)
Top soil	1.40c	0.50c	5.50b
Top soil + Sawdust	1.70e	0.70d	8.23d
Sawdust	0.90b	0.40b	8.17d
Cocoa pod husk	0.47a	0.30a	3.90a
Top soil + soil cocoa pod husk	1.47d	0.30a	7.63c
Sawdust + Cocoa pod husk	0.90b	0.33a	8.20d
LSD (0.05)	0.063	0.043	0.079
CV (%)	3.1	5.6	0.6

Values followed by similar letters under the same column are not significantly different at p=0.05

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of different soil media on vegetative growth of cocoa

Number of leaves generally depends on the nutrients absorbed from the substrate. The greatest number of leaves was recorded in Top soil+Sawdust and was significantly different from all treatments seedlings for the entire growing period (Fig. 4.1). The least mean value for Cocoa pod husk could be attributed to the differences in the properties of the media in terms of its water holding capacity which may facilitate the plant nutrient uptake. More number of leaves on plants has positive correlation with the plant's vigour, which aids photosynthetic activities. The observations made in this current study confirm earlier findings on seedlings of cocoa (Sosu, 2014), oil palm (Ofosu, 2014), *Terminalia Ivorensis* (Omokhua *et al.,* 2015) and plantain (Kumah, 2012).

In the present study, the results show that seedlings grown in Top soil+Sawdust media recorded the longest leaf length as compared to the cocoa seedlings grown in Cocoa pod husk media which recorded the least (Table 4.1). This can be attributed to the fact that, Sawdust that were added to the Topsoil reduced the bulk density of the soil which loosened the soil and thereby increasing the air space of the media mix. This is in agreement with the observation of Kennedy *et al.* (2015) that organic matter such as sawdust loosens the soil and increases the amount of pore space to support leaf growth. In the present study, the canopy width of Top soil+Sawdust media mix was the widest at 4 and 6 WAP compared to the other growth media. The observation in this study is similar to that of Adejobi *et al.* (2013) who reported that the addition of organic materials such as sawdust and kola pod husk as nutrient sources produced a positive effect on cocoa seedlings. Similarly¸ Ayanlaja (2002), reported that the use of organic residues helps in increasing and balancing soil nutrients with consequential increase in crop performance. Thus adding sawdust to the soil will improve soil structure which will provide favourable environment for better plant growth. This is in agreement with El Sharkawi *et al.* (2006), who reported that the application of sawdust as media alters the physical properties of the soil such as increasing soil aggregation, aeration and water holding capacity. The results show that cocoa seedlings leaf width increased in Top soil+Sawdust across the growing period. This emphasizes the importance of Top soil+Sawdust in providing nutrient for the growth of the cocoa seedlings (Sosu, 2014).

Gungula and Tame (2016) reported that media consisting 50% top soil to which different amount of sawdust and organic material were added showed the best results for growth of citrus rootstock seedlings. The current findings of the study is in consonance with Ofori-Frimpong *et al.* (2010), who reported better cocoa seedlings growth with the use of compost developed from Sawdust as potting medium. Top soil+Sawdust treated medium recorded the greatest mean value across the weeks than other treatments except Top soil at 4 WAP (Table 4.3). This could be attributed to the availability of plant nutrients released from the sawdust serving as organic matter as well as the good aeration of the medium, aiding good water retention capacity. Einert (2013), opined that better plant height is attained in mixed amended media than in sole media. According to Nasir *et al.* (2011), a suitable growth medium plays four vital functions: Serving as a reservoir for plant nutrient, supplying available water to plants, providing gases to enhance aeration, which enable root to respire and retaining sufficient available water all together and acting as plant support anchorage for the plants roots. This current study conforms to Marinou *et al.* (2013) that tomato planted in sawdust increased the vegetative growth of tomato plant compared to the control (i.e., without sawdust). Yusuf *et al.* (2014), opine that greater plant height growth observed on organic amendment treated media could be ascribed to the fact that the materials release considerable amount of nutrients for plant use since their decomposition could enrich soil properties, which agrees with the present study. Least mean plant height observed for cocoa seedlings on Cocoa pod husk could also be due to low nutritional status leading to poor seedling growth. Composition of growth medium influences the quality of seedling and might have been responsible for the poor observation under Cocoa pod husk. Growth medium could influence the quality of seedling emergence and growth. Top soil+Sawdust recorded the greatest seedling stem diameter across the weeks.

This may be attributed to the excellent water holding capacity of the medium, good aeration property and availability of plant nutrients in the medium, which facilitated photosynthetic activity that is, more reserved food and, thus, increased seedling diameter. This finding conforms to that of Mhango *et al.* (2011), which found Uapaca kirkiana planted on forest soil amended with sawdust produced the greatest root collar diameter. Oviasogie *et al.* (2011) suggested that an ideal medium should provide porosity to enhance good aeration, which offers better growth to plants. Top soil+Sawdust offered these conditions necessary for efficient growth of cocoa seedlings. Top soil+Sawdust media produced the greatest mean **s**hoot fresh weight, root fresh weight and longest root length of cocoa seedlings compared to other medium used in this study. The observation in this study is similar to that of El Sharkawi *et al*. (2016), who reported that the application of sawdust to soil alters the physical properties of the soil such as increasing soil aggregation, aeration and water holding capacity thus enhances root development due to its oxygenation properties. This is in consistent with the findings of Hsieh (2014) who reported that oxygen is needed to stimulate root length, weight and shoot development of plants in both soilless and soil based medium.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

1. From the experiment conducted, Top soil+Sawdust media significantly supported best growth of cocoa seedlings in all the parameters used for the study than the other treatments. However, cocoa pod husk responded poorly to all the growth parameters of the cocoa seedling at nursery. This may be attributed to its low bulk density, water holding capacity, cation exchange capacity (CEC), high porosity, low organic matter content, and other relevant minerals which could have supported the growth of cocoa seedlings at the nursery stage. Therefore, the cause of the difference in growth parameters may be due to the differences in the properties of the media. The use of sawdust to amend growth medium could be a promising alternative for raising cocoa seedlings at the nursery stage.

6.2 Recommendations

Based on the performance of the cocoa seedlings at nursery in this experiment, nursery operators could add sawdust to the top soil for the raising of cocoa seedlings.

REFERENCES

Abbam, T., Johnson, F. A., Dash, J., and Padmadas, S. S. (2018). Spatiotemporal variations in rainfall and temperature in Ghana over the twentieth century, 1900–2014. *Earth and Space Science*, *5*(4), 120-132.

Abdul-Karimu, A., Adomako, B., and Adu-Ampomah, Y. (2017). Cocoa introductions into Ghana. *Ghana Journal of Agricultural Science*, *39*(2), 227-xx.

Abrokwah, F., Dzahini-Obiatey, H., Galyuon, I., Osae-Awuku, F., and Muller, E. (2016). Geographical distribution of cacao swollen shoot virus molecular variability in Ghana. *Plant disease*, *100*(10), 2011-2017.

Achterbosch, T. J., van Berkum, S., Meijerink, G. W., Asbreuk, H., and Oudendag, D. A. (2014). *Cash crops and food security: Contributions to income, livelihood risk and agricultural innovation* (No. 2014-15). LEI Wageningen UR.

Acierno, V., Yener, S., Alewijn, M., Biasioli, F., and Van Ruth, S. (2016). Factors contributing to the variation in the volatile composition of chocolate: Botanical and geographical origins of the cocoa beans, and brand-related formulation and processing. *Food Research International*, *84*, 86-95.

Adejobi, K. B., Famaye, A. O., Adeniyi, D. O., Akanbi, O. S. and Orisajo, S. B. (2011). Comparative Effect of Organo Mineral Fertilizer and Cocoa Pod Husk Ash on the Soil, Leaf and Chemical Composition and Growth Performance of Cocoa (Theobroma cacao) *in Southwest Nigeria. Obeche Journal* 29 (1): 212-217.

Adejobi, K. B,, Akanbi, 0. S,, Ugioro, 0., Adeosun, S. A., Mohammed, I., Nduka, B. A., & Adeniyi, D. 0. (2014). Comparative effects of NPK fertilizer, cowpea pod husk and some tree crops wastes on soil, leaf chemical properties and growth performance of cocoa (Theobroma cacao L.). *African Journal of Plant Science,* 8(2), 103-107.

Afoakwa, E. 0. (2016). *Chocolate science and technology*. John Wiley & Sons.

Akesse-Ransford, Geoffrey. (2016). Insect Diversity Of Cocoa Under Different Management Systems In Central And Eastern Regions Of Ghana (Doctoral dissertation, University of Ghana).

Akpalu, M. M., Ofosu-Budu, G. K., Kumaga, F. K., Ofori, K., and Mintah, L. (2021). Field performance and survival of cocoa seedlings raised in different growing media. *Acta Universitatis Sapientiae, Agriculture and Environment*, *13*(1), 100-112.

Akpalu, M. M., Ofosu-Budu, G. K., Kumaga, F. K., Ofori, K., and Mintah, L. (2021). Field performance and survival of cocoa seedling raised in different growing media. ACTA Universitatis Sapientiae *Agriculture and Environment, 13* (2021) 100–112

Akwetey, G. A. (2020). Prevalence of Mycotoxigenic Fungi and Mycotoxins (Ochratoxin A) in Dried Cocoa Beans (Doctoral dissertation, University of Ghana).

Alcorn, P. J., Forrester, D. I., Smith, R. G. B., Thomas, D. S., James, R., Nicotra, A. B., and Bauhus, J. (2013). The influence of site quality on timing of pruning in Eucalyptus pilularis and Eucalyptus cloeziana plantations. *Australian Forestry*, *76*(1), 25-36.

Amanor, K., Yaro, J., and Teye, J. (2020). Long-Term Change and Agricultural Commercialisation In Ghanaian Cocoa.

Ameyaw, G. A. (2019). Management of the Cacao Swollen Shoot Virus (CSSV) Menace in Ghana: The past, present and the future. *Plant Dis-Curr Threats Manag Trends*.

Ameyaw, G. A., Dzahini-Obiatey, H. K., and Domfeh, O. (2014). Perspectives on cocoa swollen shoot virus disease (CSSVD) management in Ghana. *Crop Protection*, *65*, 64-70.

Ameyaw, L. K., Ettl, G. J., Leissle, K., and Anim-Kwapong, G. J. (2018). Cocoa and climate change: insights from smallholder cocoa producers in Ghana regarding challenges in implementing climate change mitigation strategies. *Forests*, *9*(12), 742.

Anda, M., Shamshuddin, J., Fauziah, C. I. and Syed-Omar, S. R. (2010). Increasing the Organic

Anderson, J., Ellsworth, P. C., Faria, J. C., Head, G. P., Owen, M. D., Pilcher, C. D., and Meissle, M. (2019). Genetically engineered crops: importance of diversified integrated pest management for agricultural sustainability. *Frontiers in bioengineering and biotechnology*, *7*, 24.

Andres, C., Gattinger, A., Dzahini-Obiatey, H. K., Blaser, W. J., Offei, S. K., and Six, J. (2017). Combatting cocoa swollen shoot virus disease: what do we know? *Crop protection*, *98*, 76-84.

Anjarwalla, P., Ofori, D., Owino, A., Matuku, D., Adika, W., Njogu, K., and Kehlenbeck, K. (2017). Testing different grafting methods for vegetative propagation of baobab (Adansonia digitata L.) in Kenya to assist its domestication and promote cultivation. *Forests, Trees and Livelihoods*, *26*(2), 85-95.

Anon. (2012) WACRI cocoa varieties: Explanatory notes. Mimeographed. Cocoa Research Institute of Ghana, Tafo

Anthonio, M. M., Boampong, E. Y., Coleman, F. N., and Anthonio, F. A. (2018). The impact of different growth media on cocoa (Theobroma cacao L.) seedling. *Journal of Energy and Natural Resource Management*, *5*(1).

Arenga, D. Z. H., and Cruz, J. C. D. (2017). Ripeness classification of cocoa through acoustic sensing and machine learning. In 2017IEEE 9th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM) (pp. 1-6). IEEE.

Arthur, J. A. (1991). International labor migration patterns in West Africa. *African Studies Review,* 34(3), 65-87.

Asare, R., Muilerman, S., and Anim-Kwapong, G. J. (2018). Good agronomic practices in cocoa cultivation: rehabilitating cocoa farms. In *achieving sustainable cultivation of cocoa* (pp. 197-224). Burleigh Dodds Science Publishing Limited.

Ayanlaja, S. A. (2002). Soil Nutrient Management Research on the Humid Forest Zone of Nigeria for Cocoa Production between 1940 and 2000 missing gaps.17th WCSS. Thailand Symposium No.16 paper, No.1503.

Bhardwaj, R. L. (2014). Effect of growing media on seed germination and seedling growth of papaya cv. Red lady. *African journal of plant science*, *8*(4), 178-184.

Bhuyan, N., Narzari, R., Gogoi, L., Bordoloi, N., Hiloidhari, M., Palsaniya, D. R., and Kataki, R. (2020). Valorization of agricultural wastes for multidimensional use. In *Current Developments in Biotechnology and Bioengineering* (pp. 41-78). Elsevier.

Bitew, Y., and Alemayehu, M. (2017). Impact of crop production inputs on soil health: a review. *Asian Journal Plant Science*, *16*(3), 109-131.

Bridgemohan, P., and Mohammed, M. (2019). The ecophysiology of abiotic and biotic stress on the pollination and fertilization of cacao (Theobroma cacao L.; formerly Sterculiaceae family). *Abiotic and Biotic Stress in Plants*, *524*, 141-157.

Chabannes, M., Garcia-Diaz, E., Clerc, L., Bénézet, J. C., and Becquart, F. (2018). *Lime hemp and rice husk-based concretes for building envelopes*. Springer International Publishing.

Chery, W. (2015). Factors Influencing Sustainable Cocoa Production in Northern Haiti.

Claus, G., Vanhove, W., Van Damme, P., and Smagghe, G. (2018). Challenges in cocoa pollination: the case of Côte d'Ivoire. *Pollination in plants*, *39*.

COCOBOD, (2013) Socio-economic study. Final report (MASDAR).Ghana Cocoa Board

Cork, A. (2016). 23. Pheromones as Management Tools: Mass Trapping and Lure-and-Kill. In *Pheromone Communication in Moths* (pp. 349-364). University of California Press.

Danley-Thomson, A. A., Gardner, C. M., Gwin, C. A., and Gunsch, C. K. (2016). Cocopeat for wastewater treatment in the developing world. I: Comparison to traditional packing media in lab scale biofiltration columns. *Journal of Environmental Engineering*, *142*(2), 04015069.

Danquah, F. K. (1991). *The capsid, black pod and swollen shoot cacao diseases in Ghana: 1910-1966.* Iowa State University.

De Beenhouwer, M., Aerts, R., and Honnay, O. (2013). A global meta-analysis of the biodiversity and ecosystem service benefits of coffee and cacao agroforestry. *Agriculture, ecosystems & environment*, *175*, 1-7.

Delgado-Ospina, J., Molina-Hernández, J. B., Chaves-López, C., Romanazzi, G., and Paparella, A. (2021). The Role of Fungi in the Cocoa Production Chain and the Challenge of Climate Change. *Journal of Fungi*, *7*(3), 202.

Dickens, E. D. (2013). Propagation of Treculia africana as influenced by seed storage and propagation media. *Agricultura tropica et subtropica*, *46*(2), 52-57.

Doungous, O., Minyaka, E., Longue, E. A. M., and Nkengafac, N. J. (2018). Potentials of cocoa pod husk-based compost on Phytophthora pod rot disease suppression, soil fertility, and Theobroma cacao L. growth. *Environmental Science and Pollution Research*, *25*(25), 25327-25335.

Einert, A. E. (2013). Performance of Rice Hulls Media for Pot Easter Lilies Under Three Forcing System. *Journals of the American Society for Horticultural Science*, 7(1), 60- 63.

El Sharkawi, H., Yamamoto, S. and Honna, T. (2016). Rice Yield and Nutrient Uptake as Affected by Cyanobacteria and Soil Amendments-A Pot Experiment. *Journal of Plant Nutrition and Soil Science* 169: 809–815.

Figueroa, K. H. N., García, N. V. M., and Vega, R. C. (2020). Cocoa By-products. *Food Wastes and By products: Nutraceutical and Health Potential*, 373-411.

Flynn, R., and Idowu, J. (2017). Managing Organic Matter in Farm and Garden Soils. College of Agricultural, Consumer, and Environmental Sciences.

Ganeswari, I., Bariah, K. S., Amizi, M. A., and Sim, K. Y. (2015). Effects of different fermentation approaches on the microbiological and physicochemical changes during cocoa bean fermentation. *International Food Research Journal*, *22*(1), 70.

Graziosi, I., Dung, N. T., Buamas, C., Wongtiem, P., and Wyckhuys, K. A. (2017). 21 Integrated Pest Management of Cassava Crops in South-east Asia.

Gruda, N. S. (2019). Increasing sustainability of growing media constituents and stand-alone substrates in soilless culture systems. *Agronomy*, *9*(6), 298.

Grumiller, J., Raza, W., Staritz, C., Grohs, H., and Arndt, C. (2018). Perspectives for export-oriented industrial policy strategies for selected African countries: case studies Côte d'Ivoire, Ghana and Tunisia. ÖFSE Research Report 10. Vienna. https://www.oefse. at/fileadmin/content/Downloads/Publikationen/Studien/10_Case_Studies_selected _Countries.pdf

Gungula, D. T. and Tame, V. (2016). .Effects of Organic and Inorganic Fertilizer, Soil and Sawdust on Vigour of Tomato (Lycopersicon lycopersicum (L.) Kart) Seedlings in Yola, Nigeria. *Journal of Sustainable Development in Agriculture and Environment* 2(1): 137-143.

Gyamfi, A. (2017). Research on Web 2.0 Usage for Knowledge Management Processes: the case of the Ghana cocoa industry (COCOBOD).

Gyedu-Akoto, E., Yabani, D,, Sefa, J., & Owusu, D. (2015). Natural skin-care products: the case of soap made from cocoa pod husk potash. *Advances in Research,* 4(6), 365-370.

Handley, L. R. (2016). The effects of climate change on the reproductive development of Theobroma cacao *L* (Doctoral dissertation, University of Reading).

Hsieh, S. C. (2014). The Use of Organic Matter in Crop Production. Extension Bulletin No. 315, Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei. http.www.icco.org/cocoa/16/-the-world-cocoa-economy-past and present pdf (7/04/2022).

Hussain, A., Iqbal, K., Aziem, S., Mahato, P., and Negi, A. K. (2014). A review on the science of growing crops without soil (soilless culture)-a novel alternative for growing crops. *International Journal of Agriculture and Crop Sciences*, *7*(11), 833.

Ibe, G. O., and Amikuzuno, J. (2019). Climate change in Sub-Saharan Africa: A menace to agricultural productivity and ecological protection. *Journal of Applied Sciences and Environmental Management*, *23*(2), 329-335.

ICCO (2012). The World Cocoa Economy. Past and Present 142 meeting Bloomsbury House, 2-3 Bloomsbury Square, London WCIA 2RL 14-17 September 2021.

Idris, A., Rasaki, K., Folake, T., and Hakeem, B. (2013). Analysis of pesticide use in cocoa production in Obafemi Owode local government area of Ogun State, Nigeria. *J Bio Agric Healthcare*, *3*(6), 1-9.

Jara-Samaniego, J., Pérez-Murcia, M. D., Bustamante, M. A., Pérez-Espinosa, A., Paredes, C., López, M., and Moral, R. (2017). Composting as sustainable strategy for municipal solid waste management in the Chimborazo Region, Ecuador: Suitability of the obtained composts for seedling production. *Journal of cleaner production*, *141*, 1349-1358.

Katsuru, A. (2015). Effect of sawdust mulch on the growth and yield of tomato. *Journal of American society for Horticultural science*, 589-597.

Kennedy, A.J., Lockwood, G.L., Mossu, G., Simmonds, N.W. and Tan, G.Y. (2015) Cocoa breeding: Past, present and future. *Cocoa Growers' Bulleting* 38, 5-22.

Killick, T. (2010). *Development economics in action: A study of economic policies in Ghana*. Routledge.

Kochhar, S. L. (2016). *Economic botany*. Cambridge University Press.

Komlaga, G. A., Oduro, I., and Essel, E. M. (2019). Utilization of Selected Tropical Crops (Cocoa, Kola Nuts, Sorghum, Millet, and Shea Butter). *Byproducts from Agriculture and Fisheries: Adding Value for Food, Feed, Pharma, and Fuels*, 563-580.

Kongor, J. E., De Steur, H., Van de Walle, D., Gellynck, X., Afoakwa, E. O., Boeckx, P., and Dewettinck, K. (2018). Constraints for future cocoa production in Ghana. *Agroforestry Systems*, *92*(5), 1373-1385.

Krottenthaler, S., Pitsch, P., Helle, G., Locosselli, G. M., Ceccantini, G., Altman, J., and Anhuf, D. (2015). A power-driven increment borer for sampling high-density tropical wood. *Dendrochronology*, *36*, 40-44.

Kumah K.H. (2012). Effect of type of initiation and growing media on growth and nutrient uptake of plantain (Musa aab) at the nursery stage. Mphil. Thesis University of Ghana, Legon.

Kyei-Baffour, V. O. (2019). Effects of Cola Nut Extract and Powder on Fungal Growth, Mycotoxin Production, Physico-Chemical Properties and Fat Quality During Drying of Fermented Cocoa Beans (Doctoral dissertation).University of Ghana Legon

Lahive, F., Hadley, P., and Daymond, A. J. (2019). The physiological responses of cacao to the environment and the implications for climate change resilience. A review. *Agronomy for Sustainable Development*, *39*(1), 1-22.

Leiter, J., and Harding, S. (2016). Trinidad, Brazil, and Ghana: three melting moments in the history of cocoa. *Journal of rural Studies*, *20*(1), 113-130.

Lucchini, P., Quilliam, R. S., DeLuca, T. H., Vamerali, T., & Jones, D. L. (2014). Increased bioavailability of metals in two contrasting agricultural soils treated with waste wood-derived biochar and ash. *Environmental Science and Pollution Research*, *21*(5), 3230-3240.

Manjunatha, S. B., Biradar, D. P., and Aladakatti, Y. R. (2016). Nanotechnology and its applications in agriculture: A review. *J farm Sci*, *29*(1), 1-13.

Marelli, J. P., Guest, D. I., Bailey, B. A., Evans, H. C., Brown, J. K., Junaid, M., and Puig, A. S. (2019). Chocolate under threat from old and new cacao diseases. *Phytopathology*, *109*(8), 1331-1343.

Marinou, E., Chrysargyris, A., and Tzortzakis, N. G. (2013). Use of sawdust, coco soil and pumice in hydroponically grown strawberry. *Plant, Soil and Environment*.Matter Content of an Oxisol Using Rice Husk Compost: Changes in the Composition and Chemistry. *Soil Science American Journal* 74: 1167-1180.

Mensah, A. D. (2021). Growth of cocoa seedlings with soil and foliar amendments at the nursery in Akim Tafo in the Eastern Region of Ghana (Doctoral dissertation, University of Cape Coast).

Mhango. J., Akinnifesi, F. K., Mngomba, S. A. and Sileshi, G. (2008). Effect of growing medium on early growth and survival of Uapaca kirkiana Muell Arg. Seedlings in Malawi. *African Journal of Biotechnology,* 430 72, 2200-2202

Motilal, L. A., and Sreenivasan, T. N. (2012). Revisiting 1727: crop failure leads to the birth of Trinitario cacao. *Journal of Crop Improvement*, *26*(5), 599-626.

Mulcahy, D. N., Mulcahy, D. L., and Dietz, D. (2013). Biochar soil amendment increases tomato seedling resistance to drought in sandy soils. *Journal of arid environments*, *88*, 222-225.

Muller, E. (2016). Cacao Swollen Shoot Virus (CSSV): history, biology, and genome. In *Cacao diseases* (pp. 337-358). Springer, Cham.

Muniappan, R. (2012). *Arthropod pests of horticultural crops in tropical Asia*. CAB I.

Munroe, R., McGrath, D., and Henry, J. (2018). Increasing amounts of coir dust in substrates do not improve physical properties or growth of tree seedlings in a novel air-pruning propagation tray. *Journal of Environmental Horticulture*, *36*(3), 92-103.

Nair, K. P. (2021). Cocoa (Theobroma cacao L.). In *Tree Crops* (pp. 153-213). Springer, Cham.

Narayanapur, V. B., Suma, B., and Minimol, J. S. (2018). Self-incompatibility: a pollination control mechanism in plants. *International Journal of Plant Sciences (Muzaffarnagar)*, *13*(1), 201- 212.

Ndubuaku, U.M., N.V. Uchenna, K.P. Baiyeri and J. Ukonze, 2015. Anti-nutrient, vitamin and other phytochemical compositions of old and succulent moringa (*Moringa oleifera* Lam) leaves as influenced by sawdust and topsoil mix media. *Afr. J. Biotechnol*., 14: 2502-2509. New Jersey,469pp.

Niether, W., Armengot, L., Andres, C., Schneider, M., and Gerold, G. (2018). Shade trees and tree pruning alter throughfall and microclimate in cocoa (Theobroma cacao L.) production systems. *Annals of forest science*, *75*(2), 1-16.

Nyle, C. B. and Ray, R. W. (2014). The Nature and Properties of Soil.12th edition. Prentice Hall,

Obuobisa-Darko, E. (2015). Cocoa research innovations and output in Ghana. *Journal of Economics* 29 (1): 212-217

Odijie, M. (2019). Environmental change and normalization of cash crop systems in Africa: preventing agrarian change in West Africa cocoa. *International Journal of Sustainable Development & World Ecology*, *26*(7), 597-611.

Odijie, Michael. (2020). "Cocoa and Child Slavery in West Africa." In *Oxford Research Encyclopedia of African History*.

Ofori, A., Padi, F. K., and Amoako Attah, I. (2020). Field evaluation of cacao progenies derived from Guiana clones for yield and black pod disease resistance. *Crop Science*, *60*(1), 249-261.

Ofori-Frimpong K, Afrifa A.A, and Acquaye S. (2010). Relative efficacy of cocoa pod husk-based compost on growth and nutrient uptake of cocoa seedlings in the nursery. *Ghana Journal of Agricultural Science 43: 1*

Ofosu, A.K.B. (2014). Response of Oil Palm (Elaeis Guineensis Jacq) seedlings to different growing media and fertilizer rates at the nursery stage. A Thesis Submitted to the University of Ghana, Legon in Partial Fulfillment of the Requirements for the Award of Master of Philosophy, Crop

Oladele, S. O. (2019). Changes in physicochemical properties and quality index of an Alfisol after three years of rice husk biochar amendment in rainfed rice–Maize cropping sequence. *Geoderma*, *353*, 359-371.

Omokhua G.E, Ogu A, and Oyebade B.A. (2015). Effects of different sowing media on germination and early seedling growth of Terminalia ivorensis (A.Chev.). *International journal of scientific and technology research*. 4: 03 Science Degree

Ouattara, L. Y., Kouassi, E. K. A., Soro, D., Soro, Y., Yao, K. B., Adouby, K., and Aina, P. M. (2021). Cocoa pod husks as potential sources of renewable high-value-added products: A review of current valorizations and future prospects. *Bio Resources*, *16*(1), 1988.

Oviasogie, P. O., Aisueni, N. O., and Brown, G. E. (2010). Oil palm composted biomass: A review of the preparation, utilization, handling and storage. *African Journal of Agricultural Research*, *5*(13), 1553-1571.

Padi, F. K., Domfeh, O., Takrama, J., and Opoku, S. (2013). An evaluation of gains in breeding for resistance to the cocoa swollen shoot virus disease in Ghana. *Crop protection*, *51*, 24-31.

Ploetz, R. (2016). The impact of diseases on cacao production: a global overview. Cacao *diseases,* 33-59.

Purba, H. H., Jaqin, C., and Aisyah, S. (2019). Quality Development Of Bar Chocolate Products Based On Consumer Preferences: Case Study on SMEs. In *2019 1st International Conference on Engineering and Management in Industrial System (ICOEMIS 2019)* (pp. 56-61). Atlantis Press.

Rahman, M. J., Quamruzzaman, M., Begum, P., Sani, M. N. H., Chawdhery, M. R. A., Ahmed, S., and Ali, M. M. (2017). Physical and chemical properties of different substrate mixtures and their effects on growth and yield of lettuce. *Bangladesh Hort*, *3*(1), 39-46.

Raviv, M. (2011, June). Composts in growing media: what's new and what's next? In *International Symposium on Responsible Peatland Management and Growing Media Production 982* (pp. 39-52).

Saripah, B., and Alias, A. (2016). Screening of different active ingredients of insecticides to cocoa pod borer infestation. *Malaysian Cocoa Journal*, *9*(2), 76-87.

Savvas, D., and Gruda, N. (2018). Application of soilless culture technologies in the modern greenhouse industry—A review. *Eur. J. Hortic. Sci*, *83*(5), 280-293.

Singh Thakran, N. (2017). Modelling a Cocoa Supply Chain: Specific Problems and Their Countermeasures. *Available at SSRN 3068741*.

Singh, A., Meghwal, P. R., Kumar, P., and Khapte, P. S. (2021). Nursery Management for Fruit Crops. In *Horticulture Based Integrated Farming Systems* (pp. 265-273). CRC Press.

Smith, N. J., Williams, J. T., Plucknett, D. L., and Talbot, J. P. (2018). *Tropical forests and their crops*. Cornell University Press.

Snoeck, D., Koko, L., Joffre, J., Bastide, P., and Jagoret, P. (2016). Cacao nutrition and fertilization. In *Sustainable agriculture reviews* (pp. 155-202). Springer, Cham.

Sosu, Gifty (2014). *Growth of cocoa seedlings as affected by different growth media and different polybag sizes* (Doctoral dissertation, University of Ghana).

Stoffel, R. B., Felissia, F. E., Curvelo, A. A. S., Gassa, L. M., and Area, M. C. (2014). Optimization of sequential alkaline–acid fractionation of pine sawdust for a biorefinery. *Industrial Crops and Products*, *61*, 160-168.

Thompson, S. S., Miller, K. B., Lopez, A. S., and Camu, N. (2012). Cocoa and coffee. *Food microbiology: fundamentals and frontiers*, 881-899.

Van Lenteren, J. C. (2012). The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. *BioControl*, *57*(1), 1-20.

Vanhove, W., Vanhoudt, N., and Van Damme, P. (2016). Effect of shade tree planting and soil management on rehabilitation success of a 22-year-old degraded cocoa (Theobroma cacao L.) plantation. *Agriculture, Ecosystems & Environment*, *219*, 14-25.

Van-Vliet, J. A., and Giller, K. E. (2017). Mineral nutrition of cocoa: a review. *Advances in agronomy*, *141*, 185-270.

Verna, R. (2013). The history and science of chocolate. *The Malaysian journal of pathology*, *35*(2), 111.

Vigneri, M., and Kolavalli, S. (2017). Growth through pricing policy: The case of cocoa in Ghana. *Background paper for UNCTAD-FAO Commodities and Development Report*.

Vijayaraghavan, K. (2016). Green roofs: A critical review on the role of components, benefits, limitations and trends. *Renewable and sustainable energy reviews*, *57*, 740-752.

Vinod, K. K. (2012). Stress in plantation crops: adaptation and management. In *Crop Stress and its Management: Perspectives and Strategies* (pp. 45-137). Springer, Dordrecht.

Wessel, M., and Quist-Wessel, P. F. (2015). Cocoa production in West Africa, a review and analysis of recent developments. *NJAS-Wageningen Journal of Life Sciences*, *74*, 1-7.

Yusuf, C. S., Makate, N. and Jacob, R. (2014). Effect of seed size on germination and early growth of maize (Zea mays) *International Journal of Scientific and Research Publications* 4 (10): 1-3.

Zhang, R. H., Zeng-Qiang, D.U.A.N., and Zhi-Guo, L. I. (2012). Use of spent mushroom substrate as growing media for tomato and cucumber seedlings. *Pedosphere*, *22*(3), 333-342.

Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N. A., and Munné-Bosch, S. (2019). Nanofertilizer use for sustainable agriculture: Advantages and limitations. *Plant Science*, *289*, 110270.