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GROWTH OF COCOA SEEDLINGS AS AFFECTED BY DIFFERENT GROWTH MEDIA AND DIFFERENT POLYBAG SIZES

BY

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DECLARATION

I, Gifty Sosu, the author of this thesis, hereby declare that except for the references cited, which have been duly acknowledged, this work "growth of cocoa seedlings as affected by different growth media and different polytene bag sizes" is an original research work carried and completed by me at the Forest and Horticultural Research Centre, Okumaning-Kade, College of Agriculture and Consumer Sciences, University of Ghana, Legon from November, 2013 to June, 2014. It has not been presented elsewhere in part or in whole for award of any degree in this University or elsewhere.

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ABSTRACT

A study was conducted to determine the effects of different growth media and different poly bag sizes on the growth of cocoa seedlings in the nursery. The experimental design was split plot design with three replicates. The treatments were soil (S), carbonated rice husk (CRH), cocoa pod husk (CPH), cocopeat (CP) , sawdust (SD), S+CRH, S+CPH, S+CP, S+SD, CRH+CPH, CRH+CP, CRH+SD, CPH+CP, CPH+SD, CP+SD and the three polytene bag sizes were 12.5 cm x 18.5 cm (small), 10.0 cm x 35.0 cm (medium) and 17.3 cm x 23.3 cm (large). For the media mixes, the combination by volume used was 1:1. Number of leaves, plant height, girth, leaf area and total dry matter per plant were used for determining the most suitable media and polybag size. The results showed significant differences ($p<0.05$) in plant height, girth, number of leaves and total dry matter between cocoa seedlings in the different growth media and poly bag sizes. The results showed that soil and carbonated rice husk media mix and soil and cocoa pod husk media mix increased significantly ($p<0.05$) the plant height, stem diameter, number of leaves, leaf area and total dry matter weight. The highest number of leaves (27.7) was obtained from soil and carbonated rice husk media mix, followed by soil and cocoa pod husk media mix which recorded 26.7 leaves. In all the growth parameters, the lowest values were obtained from sawdust and its media mixes. At six months, the highest total dry matter weight was recorded in S+CPH and was 13% higher than the soil only.

The size of poly bag significantly ($p<0.05$) affected the number of leaves, plant girth, plant height, root length, root and shoot dry weight, and total dry matter weight of the cocoa seedlings. Root weight and root length were also significantly influenced by poly bag size with the 10.0 cm x 35.0 cm recording the highest root weight. The poly bag sizes, 10.0 cm x 35.0 cm and 17.3 x

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23.3 cm increased significantly ($p<0.05$) the plant height, stem diameter, leaf area, number of leaves and dry weights of cocoa seedlings as compared to the 12.5 cm x 18.5 cm. Generally, seedlings raised in 10.0 cm x 35.0 cm polybags produced bigger and taller seedlings, longer tap root length, and had significantly higher ($p<0.05$) total root weight and total dry matter per seedling than those raised in 12.5 cm x 18.5 cm polybags. However, there were no significant difference between the 10.0 cm x 35.0 cm and the 17.3 cm x 23.3 cm polybag sizes. Based on the results obtained, the poly bag size 10.0 cm x 35.0 cm would be ideal for raising cocoa seedlings since it significantly ($p<0.05$) produced longer root length. Additionally, the size of the 10.0 cm x 35.0 cm prevented root coiling or spiraling as compared to the 17.3 cm x 23.3cm polybag size. Generally, soil and cocoa pod husk media mix increased the growth of cocoa seedlings more than any other media mix.

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DEDICATION

This work is dedicated firstly to the Almighty God, for taking me through my academic work.

Secondly, to my Husband, Mr. Thomas Sosu and Children, Rabbi-Judah Delasi Kodzo Sosu and Jeremiah John Mawuko Kobla Sosu.

INTEGRI PROCEDAMUS

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LIST OF ACRONYMS

S – SOIL

CRH – CARBONATED RICE HUSK

CPH – COCOA POD HUSK

CP – COCOPEAT

SD – SAWDUST

S + CRH – MIXTURE OF SOIL AND CARBONETED RICE HUSK

S + CPH – MIXTURE OF SOIL AND COCOA POD HUSK

S + CP – MIXTURE OF SOIL AND COCOPEAT

S + SD - MIXTURE OF SOIL AND SAWDUST

CRH + CPH – MIXTURE OF CARBONATED RICE HUSK AND COCOA POD HUSK

CRH + CP – MIXTURE OF CARBONATED RICE HUSK AND COCOPEAT

CRH + SD – MIXTURE OF CARBONATED RICE HUSK AND SAWDUST

CPH + CP – MIXTURE OF COCOA POD HUSK AND COCOPEAT

CPH + SD – MIXTURE OF COCOA POD HUSK AND SAWDUST

CP + SD – MIXTURE OF COCOPEAT AND SAWDUST

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CHAPTER ONE

1.0 INTRODUCTION

Cocoa (*Theobroma cacao L.*) is one of the most important tropical crops in the world (FAOSTAT, 2006). 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 (FAOSTAT, 2011).

In Ghana, it is the highest export crop, accounting for 8.2% of the country's GDP, 30% of total export earnings in 2010 (GAIN, 2012) and providing employment for over 30% of the population (Anthonio and Aikins, 2009). 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 drink, chocolate and various chocolate based products, biscuits and confectioneries). The processed cocoa bean is also used to make sweets, sweetening products, cocoa butter, cosmetics and is used in the pharmaceuticals. The cocoa pod husk is used in making soap locally (GAIN, 2012).

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 ageing trees, unproductive trees and

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deficiencies in macro and micro nutrients in the soils (COCOBOD, 2013). Adejobi *et al.* (2011) and Moyin- Jesu (2008) reported that the use of organic residues have been found capable of increasing and balancing soil nutrients with consequential increase in crop performance and yield. Recent studies had revealed the use of agricultural wastes such as rice husk, cocoa pod husk, cocopeat and sawdust has soil amendments and potting media for raising of seedlings and vegetables (Anda *et al.*, 2010 and Adejobi *et al.*, 2013).

In Ghana, plantations of cocoa have been established through seedlings raised in the nursery with only top soil as the growth media and these soils are suitable or moderately suitable (COCOBOD, 2010). As a result of the new emphasis on cocoa rehabilitation in the country, there will be the need to increase cocoa seedling production and this will require large quantities of soil for nursery work. However, assessing large quantities of suitable soil for nursery work will pose serious challenge since suitable land is limited and 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 nutrient requirement. There is therefore a 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 longer time for establishment in the field after transplanting or die resulting in high

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mortality of transplanted seedlings. Healthy seedlings with strong undisturbed root system are required since they establish quickly in the field and their subsequent growth is fast.

In recent years, the use of polybag in the nursery practices has been increased considerably due to its many advantages such as easy transportation, easy to make holes for aeration and drainage as well as its unbreakable characters. However, there are different sizes of polybags for the raising of seedlings and there is the need to determine the suitable polybag size that will promote good growth and development of cocoa seedlings in the nursery and prevent root curling at the bottom of the polybag or growing into the ground. There is the need to find a suitable poly bag size that will enhance root development, prevent root curling or spiraling at the bottom of the polybag as well as prevent the growth of roots into the ground at the nursery after 4-6months. Also, the over reliance on forest top soil for raising cocoa seedlings is a major constraint to 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 rice husk, cocoa pod husk, and cocopeat could be investigated.

The objectives of the study were therefore to:

- Evaluate the effects of organic wastes (rice husk, coconut coir, cocoa pod husk and sawdust) as potting media on the growth of cocoa seedlings at the nursery.
- Evaluate the effect of different polybag sizes on the growth of cocoa seedlings.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Description of Cocoa

Cocoa (*Theobroma cacao L.*) belongs to the family *Malvaceae* which is known for having flowering plants that are entomophilous and are bisexual. It consists of about 200 genera and close to 2,300 species distributed throughout the world and particularly abundant in the tropics (APG, 2009). Cocoa (*Theobroma cacao* L.) is one among the 22 species assigned to the genus *Theobroma* and the only species of economic importance whiles *Theobroma bicolor* Humb. and Bonpl. are cultivated for the edible pulp around the beans.

The plant is a native species of tropical humid forests on the lower eastern equatorial slopes of the Andes in South America. Today, cocoa is cultivated globally, and it's grown in the tropical rainforest of Africa, Asia and Latin America. In Ghana, cocoa is grown in the forest areas of the country (Ashanti, Brong Ahafo, Eastern, Western, Central and Volta) where the rainfall is between 1000 and 1500 mm per year. It was introduced into the Southern region of the Gold coast in the mid-19th century (Opoku *et al.*, 2010).

Cocoa (*Theobroma cacao*) is a small, wide-branching evergreen tree that is native to tropical rainforest areas. It thrives best in soils that are moist, nutrient rich, well- drained and aerated. Cocoa cultivation requires a well-drained, well aerated soil with good crumb structure which contains adequate supplies of water and nutrients. Cocoa seedlings requires nutrients such as nitrogen, phosphorous, potassium, etc. and metabolites (proteins, lipids, carbohydrates) for their growth and development (Gockowski *et al.*, 2004).

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2.2 Botany of Cocoa

Cocoa (*Theobroma cacao L.*) is an evergreen tree that grows to about 4 m - 8 m. The fruit and flowers grow directly from its trunk. Cocoa plants are tropical evergreen trees that like humid tropical climates and are best grown in fertile, organically rich, consistently moist but well drained soils. The leaves are alternate, entire, unlobed, 10 - 40 cm long and 5 - 20 cm broad. The flowers are produced in clusters directly on the trunk and older branches. The flowers are small (1 – 2 cm) in diameter with pink calyx and are pollinated by insects especially aphids. The fruit, called a cocoa pod is ovoid, 15 – 30 cm long and 8 -10 cm wide, ripening yellow to orange and weighs about 500 g when ripe. The cocoa pod contains 20 - 60 seeds called beans which are usually arranged in five rows along a central axis and are surrounded by a white sugary pulp. (Prabhakaran, 2010).

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2.2.1 The Roots

Cocoa has a dimorphous root, orthotropic taproot and plagiotropic lateral root. The taproot which grows predominately downward with only few branches serves as anchorage for the cocoa tree. The tap root grows very deep when the soil is deep and there are favourable weather conditions. The roots that arise from the tap root and grow laterally are the main feeding roots which are mostly concentrated just below the soil surface up to a depth of 15 - 20 cm.

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2.2.2 The Stem

The cocoa plant grows in tiers. The shoot of the seedling grows upwards and this is called chupon. The growth of the chupon ceases after it grows to a height of 1 – 1.5 m, then three to five lateral branches arise. These lateral branches are called “fans” or “fan branches”. The point at which fans arise is called “jorquette” and the process of the formation of fans from jorquette is called “jorquetting”. Therefore, a layer of fans may be called a “tier”. When the cocoa plant is allowed to grow unchecked, new chupon buds arise on the main stem below the first jorquette and grow up to jorquette again. The difference between a chupon and a fan are that chupon leaves will have longer petioles than those of fans and also fan growth is predominately to the sides whereas chupons grow vertically up. Additionally, the leaf arrangement of the chupons are spiral with a phyllotaxy of three to eight whiles leaves of the fans are arranged in one plane and are alternate (Prabhakaran, 2010).

2.2.3 The flowers

The cocoa flower grows from small cushions on the trunk or older branches of the tree. There are thickened leaf axils on the stems which bear the flowers. The cocoa flowers have five sepals and five petals. The male flower consists of five double stamens with each stamen bearing up to four anthers. The female flowers consist of five united carpels, each containing 4 - 12 locules (cavities). Among the ten stamens, five of the outer whorls are sterile and five of the inner whorl, which occurs opposite the petals are fertile. These fertile stamens occur concealed in the pouched portions of petals. The ovary is simple and five-lobed which contains 40 - 60 ovules per flower. The style has five stigmatic lobes. The flowers open at dawn and the pollen is released from the anthers just before sunrise. The stigma is receptive to pollination only from

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sunrise to sun set on the day that the flower opens. Cocoa flowers are produced in large numbers but only a few of them develop into fruits whiles those that are not fertilized fall off within 24 hours. In every 500 flowers, 10% are successfully pollinated and 2% grow into mature fruits. Pollination of the flowers is carried by insects but higher rates of pollination can be achieved by hand. However, cherelle wilt prevents much higher rates of fruits set from being obtained. Cherelle wilt is a natural fruit thinning mechanism whereby the young fruit called cherelle stop growing, turn black and shrivel but do not fall off the tree. Therefore, cherelle wilt is not a disease. In view of this, boron has been found to increase pod set and reduce cherelle wilt. Hence, in some places boron is applied to trees as an annual foliar spray (Prabhakaran, 2010).

2.2.4 The fruits

The cocoa fruit is botanically a drupe, often called a "pod". The mature pod consists of a thick husk containing 30-50 seeds. The seeds are held in position with the help of a placenta. The pods can be of green or reddish colour when immature. The green pods change to yellow when mature and the reddish pods change to orange or yellow in colour. The husk (pericarp) is fleshy and thick (Prabhakaran, 2010).

2.2.5 The Seeds

The seeds, which are called "beans", form the economic part of the crop. The number of beans per pod ranges from 30-60 seeds; each seed contains two convoluted cotyledons, a small embryo and a thin membrane, the remains of the endosperm and a leathery testa (shell). The seeds contain a significant amount of fat (40 - 50%) as cocoa butter and are the main ingredient of chocolate, while the pulp is used in making juices, smoothies and jellies. The pulp covering the

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seed contains about 10-15% sugar and is sweet, tangy with its flavor reminiscent of mango. The pulp plays central role in the fermentation of cocoa beans and during fermentation, yeast grows on the sweet pulp and converts sugar to alcohol. The alcohol is oxidized by bacteria, a process that ultimately produces carbon dioxide, water and heat. After fermentation, the cocoa beans must be dried to halt fermentation, reduce water content in the bean and to drive out acetic acid which was formed during fermentation. The drying of cocoa beans by sunlight takes one to two weeks with the beans being turned about four times a day and if not adequately dried, they are likely to become mouldy. The cocoa beans are put into sacks after fermentation and drying and are transported to a central location for grading. After grading, the cocoa beans are packed into 60kg sacks for storage.

2.3 Cultivation of Cocoa

Cocoa can be propagated by cuttings but is generally raised from seeds, the seedlings being kept shaded in the nursery for 3 - 7 months. In Ghana, plantations of cocoa have been established through seedlings raised in the nursery and transplanted into the field.

To start a new cocoa farm, the farmer first clears the undergrowth and thins out the forest, leaving sufficient trees of suitable species to provide shade. After clearing, the farmer burns the cleared land after which he plants maize, cocoyam and plantain to protect the young cocoa. The cocoa itself is grown from seedlings raised in nurseries; less often it is grown directly from seeds. When the seedlings grow and weather conditions are favourable they are transplanted to the field. Hybrid cocoa may give a first yield after 3 years.

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2.4 Economic Importance of cocoa

The significant role of cocoa as a driver of economic growth has gained overall acceptance in all cocoa growing economies. According to the United Nations Conference on Trade and Development, UNCTAD (2004), cocoa is a highly competitive and lucrative economic cash crop ranked highest in terms of income generation amongst other agricultural activities in the global markets. Cocoa is the economic mainstay of countries such as Cameroon, Ivory Coast and Ghana. It also plays an important role in the development of many African countries by generating foreign exchange earnings, government revenues and household incomes (UNCTAD, 2005). Cocoa has been the mainstay of the economy and provides the largest source of export earnings representing about 30% of Ghana's total export earnings and is still the main economic activity of small holders and ranks among one of the highest income generating cash crop to the GDP of Ghana.

Cocoa directly or indirectly employs about two million people and offers livelihoods for over 700,000 farmers. It feeds, shelters, clothes and takes care of the livelihood needs of farmers. In households where cocoa is an important source of income, it contributes roughly one third of their revenue (Mckay *et al*., 2004).

The nutritional value of cocoa to man (health supportive) with regards to its constituent elements like butter (54%), protein (11%), cellulose (9%), pentosan (7.5%), tannin (6%), water (5%), theobromin (1.3%), sugar (11%) and caffeine (0.2%) have made it a more dependable cash crop which is encouraged worldwide. Due to its nutritional value millions of people around the world enjoy consuming chocolate whether as part of snack drink or desert (ICCO, 2009).

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Cocoa is a source of dietary Magnesium shown to be effective in treating diabetes, epilepsy, sleeplessness arthritis and migraine. It also contains minerals such as copper, magnesium, potassium and calcium that may help support a healthy cardiovascular system. Cocoa helps stimulate the nervous system to calm those who are hyperactive or to improve digestion and kidney function. It also reduces the risk of heart diseases and strokes.

The cocoa butter produced from cocoa is rich in stearic, palmitic and oleic acid which is used in the manufacture of chocolate, chocolate products, cosmetics as well as used in the pharmaceuticals (Adomako, 1995)

2.5 GROWING MEDIA AND THEIR ROLE IN RAISING SEEDLINGS

A growing media is any substance (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 (Miller and Jones, 1995).

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 (Chen *et al*., 1988; Verdonck and Gabriels, 1988). The quality of a potting media is based on its physical and chemical properties. Argo (1997) 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. Reis *et al*., (2007), 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.

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In seedling production, one of the most important aspects is the quality of the growth media (Argo, 1997). 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 (Nelson, 1991). Thus,a good quality growing media must have acceptable physical and chemical properties to perform these functions to enhance seedling growth and development. However, there is no one growing medium that works best in all situations therefore the grower must choose the growth media with the optimum physical and chemical properties (Argo, 1997).

The physical properties include the distribution of air, water and solid volume in the media and it's dependent on factors such as pore space, particle size distribution, container height and media settling in the growth media (Argo, 1997). These factors determine the bulk density, water holding capacity and porosity of the growth media (Awad, 2010). The chemical properties of a media directly affect nutrient solubility and retention, in other words the nutrient availability for plant uptake. It therefore ensures the movement of nutrients through mass flow and diffusion for plant uptake. The components that contribute to a media's chemical make-up are pH, cation exchange capacity (CEC) and electrical conductivity (EC).

2.5.1 The Physical properties of a growing media

Studies by Spiers and Percy (2007), shows that the physical make up of the soil or soilless media can be divided into four parts. The four parts are the solid volume (20 - 30%), air space (10 – 30%), available water (10 - 25%) and residual water (15 - 45%). The essential parts are the air space and the available water, which depend mainly on the particle size and shape of the media components. The physical property of a growing media is regarded as one of the most important

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factors that affect plant performance in a potting media. The air, water and solid volume in a potting media affects factors such as bulk density, water holding capacity and porosity (Richard, 2007). Bulk density is an indicator of the degree of compaction of a growing media and it is expressed as the dry weight of the growing medium divided by its volume. Generally, loose porous growing media that are rich in organic matter have lower bulk density and when mixed with a growing media that has a higher bulk density such as soil, it decreases the bulk density of the soil (Arshad *et al,* 1996). Thus amendment of soil with sufficient amounts of organic matter alleviates compaction and provides a favourable environment for root growth. Hence, the lighter the soil, the easier it is for the seedling to emerge up through the soil to reach the light as well as to extend its delicate new roots through the media to establish an effective feeding mechanism. Savvas and Passam (2002) reported that, increasing the bulk density of a growing media with soil provides support to the plant in lightweight growth media and prevents container instability. The bulk density of a growing media is essential as it affects the growth of roots and shoots. The air space, also referred to as air filled porosity is the volume of air in a mix after it has been watered heavily and then allowed to drain. This can be defined as the amount of water retained by the growing media which is made available for the plants. A growing media appropriate for plant growth is one that allows water to be held without water logging and does not need regular irrigation (Awad, 2010). It must also permit gaseous exchange to provide aeration for the root as well as to permit water infiltration and movement (Larson, 1980).

Water retention capacity can be defined as the amount of water retained by the growing media to be made available for the plants. The plant available water is defined as the volume of water removed from a just-drained mix by a suction of 10 kPa or a metre column of water and this represents the available water to the plant roots. Although plants can extract more than the

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available water, they must exert extra energy to do so and this restricts growth (Spiers and Percy, 2007).

Porosity is defined as the total volume of pore space in a growing medium this controls the movement of water through the soil profile (Richard, 2006). The amount of total pore space in a root media is inversely proportional to the bulk density (Bunt, 1983). Therefore, as the bulk density decreases, total pore space increases linearly. The total porosity of a media controls the movement of water through the soil profile (Richard, 2006). Harris *et al*., (1966) found that media aggregation increases growing media porosity and decreases its bulk density. This is in agreement with Chan *et al*., (2007) who showed that biochar application had improved some physical soil properties such as increased soil aggregation, water holding capacity and decreased soil strength. Thus media aggregation in turn increases total porosity and at the same time increases the water retention of the growing media (Sharma and Uehara, 1968). Hence, since water retention in micro pores (equal to a matrix potential of –15 MPa) is relatively constant, this process will increase the available growing media water.

Particle size and pore space distribution influence the water to air ratio held in the root media. According to Spiers and Percy (2007), the balance between the plant available and the air space depends on the size and shape of the particles in the soilless mix or the pores between the solid particles. Large particles (0.5 mm or more) which have more air space between the pores contribute air space to the mix. Medium- sized particles (0.1 mm- 0.5 mm) contribute to the available water. Fine particles (less than 0.1 mm) will hold some water but this water is unavailable to the plant. For fine particle mixes, very little air is held in it. Therefore the ideal mix must have a balance between medium and coarse particles with a small amount of fine particles. A higher percentage of large particles are suitable for a mix that will be watered

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regularly in order to have lower available water level. On the other hand, a mix that will be watered once a week will need to have a higher proportion of medium sized particles.

Generally, a good balance is achieved with two thirds to three quarters of coarse particles and the remainder being medium particles with a minimal volume of fine particles (less than 5%). Particle size also affects the amount of air space or available water since a more fibrous material has more available water than a less fibrous material (Spiers and Percy, 2007).

There are two types of pore space within a root media; the capillary and non-capillary pores. The capillary pores are smaller (less than 0.3mm) pores which retain much of water after watering whiles the non-capillary pores are larger (greater than 0.3mm)poresthat provide aeration for the roots. The water held in a root media that is available to the plant is held at a tension between 1kPa and 10kPa (DeBoodt and Verdonck, 1971). Thus, the smaller the particle size, the greater percentage of smaller pore spaces and the greater amount of water held in the root media after irrigation. A suitable growing medium should maintain a balance between capillary and non-capillary pores in order to enhance optimal root growth.

The size of the media container also affects the percentage water retention and aeration of a media. As an example, a tall pot will have drier mix in the top layers than a wider, shallower container of the same volume. According to Argo (1997), for every 1cm increase in height above the bottom of the pot, there is a 0.1kPa increase in moisture tension resulting in less water held. In view of this, additives such as water-holding gel example are crystal rain or surfactants example, slippery water). Milks *et al.* (1989) showed that the percent moisture held in a 17cm tall pot decreased from 69% at the bottom of the pot to 32% at the top of the pot. Nelson (1998), also reported that as container size becomes shorter, there was a decrease in percentage air and an increase in percentage water.

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Root- medium settling affects the physical properties of a root media by decreasing column height and altering the distribution between capillary and non-capillary pores. Settling occurs when the small particles settle into the large non capillary pores located between the larger particles (Nash and Pokorny, 1990). Nash and Pokorny (1990) found that excess settling occurred in a two component root media when there was a large difference in the particle size of the two components. The greatest amount of settling occurred when the components were mixed in equal volumes (50% each by volume), (Argo, 1997). The use of similar size components in a root media could reduce or eliminate settling in a root media (Nash and Pokorny, 1990).

The state of decomposition of organic material may affect the ability to rewet after drying. For example, peats in a greater state of degradation have a greater amount of humic acid and this humic acid plays an important role in cation exchange capacity of peat based root media. When the peat dries, the humic acid may form hard granules that have lost their initial capacity to absorb water and nutrients and this result in adverse effect on the structure of the peat (Argo, 1997).

Irrigation method also affects water absorption. Argo and Biernnbaum (1994) found that with the same media, an average of 0.5 L was absorbed with top watering, 0.38 L was absorbed with drip irrigation and 0.19 L was absorbed with flood irrigation. Under the conditions of the experiment, a maximum of 0.60 L was needed to be absorbed by the medium to reach the air/water ratio which was measured in the laboratory with standard physical property testing methods.

The volume of water applied to the medium influences water absorption. Many growers apply only small quantities of water to the medium at any one time in order to control shoot growth and with this, the air/water ratio never gets close to that of the minimum value measured in the

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laboratory. Water that is held in the root media after irrigation can be divided into two; namely, water available to plant and water that remains in the root media even when the plant is wilted, this is the unavailable water (Bunt, 1998; Milks *et al*., 1989).

2.5.2 The Chemical properties of a growing media

The chemical properties are determined by the pH, the cation exchange capacity (CEC) and the electrical conductivity (EC) of the media. The pH of a media is the measure of the concentration of hydrogen ions in a media/ water solution. The practical definition of soil pH however is the negative logarithm of the active hydrogen ion (H+) concentration in the soil solution. Since pH is measured using a logarithmic scale, a decrease of 1 unit of pH means that the acidity increases by a factor of 10, so small changes in pH values can have important consequences (Fernandez and Hoeft, 2009). The pH affects the availability of nutrients to plant roots and this is influenced by the lime concentration, the plant species, plant uptake of nutrients and water alkalinity (Richard, 2006). When the soil pH falls below 5.5, the major plant nutrients required for growth (N, P, K, S, Ca, and Mg) become significantly less available to plants resulting in aluminum toxicity and pH above 7.5, causes micronutrients (Fe, Mn, B, Cu, and Zn) to become less available (Mathers, 2003).

According to Pawuk (1981), soil mixes must have a pH of 4.5 to 6.0 to promote seedling growth and reduce disease occurrence. Bunt (1988) also reported that organic media must have an optimal pH range of 5.2- 6.3 and Hartman *et al*., (1997), reported that for soilless media the pH must between 5.4 -6.0 whiles for soil –based media the pH must be between 6.2 – 6.8.

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The cation exchange capacity is the capacity for a mix to hold nutrients or it is a measure of the plant available nutrient exchange capacity (Spiers and Percy, 2007). According to Hartman et al., (2002) root media components such as peat moss, vermiculite and bark have a negative electrical charge which attracts positively charged ions in the medium water solution. The cation exchange capacity indicates the strength of the electrical charge for a medium as well as determines the capacity of the medium to hold positively charged nutrient ions. Plants available nutrients are either held on exchange sites on the media particles by adsorption or dissolved in the media water. (Spiers and Percy, 2007). Loss of nutrients can occur when this water drains out of the container and this can be minimized by avoiding over-watering or using additives such as zeolite which increases the CEC and thereby allows the media to hold more nutrients in plant-available form. The CEC varies between different types of media. A higher CEC is desirable as it ensures an even supply of nutrients to the roots and causes fewer nutrients to be lost through over- watering. A higher CEC can be attained by increasing the surface area of the media.

Hartman *et al*., (2002), reported that the CEC is based on the volume of the soilless media and this must be high to allow the medium to retain nutrients for the plant. The plant nutrient ions are cations (NH_4^+, K^+ , Ca^{++} , Mg^{++} , Zn^{++} , Cu^{++} , Mn^{++} , and Fe^{++}) and anions ($H_2PO_4^-$, NO_3^- , SO_4^- and Cl^-) of which SO_4^- and Cl^- are not in limited supply. Media components with high CEC include soil, peat moss and vermiculite and components with low CEC include perlite, Styrofoam and sand (Hartman *et al*., 2002). The unit of measure for CEC can also be defined as the sum of exchangeable cations (bases) per weight of soil. Cation exchange capacity is usually expressed as milligram equivalents per 100 g (meq.100 g^{-1}) but currently it is expressed as cmol $(^{+})kg^{-1}$. The CEC of a media mix depends on the individual components in the media mix. Composted or decayed organic components have higher CEC than fresh organic materials.

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Electrical conductivity (EC) is the measure of salt content of water based on the flow of electrical current. The electrical conductivity is measured by the amount of soluble salt in the media thus it is related to the quantity of dissolved ions (obtained from fertilizer salts) in solution. In effect, the more salts present, the higher the soluble salt level and this provides a general indication of soil fertility. Organic media supply small amounts of available nutrients to plants thus the need to apply fertilizers (Richard, 2006). The acceptable EC for seedlings is 1.0 – 2.0 dS/m and 2.0- 3.0 for established plants. Plant growth rates decreases when EC is high and sensitive plants may be damaged. Soils with high exchangeable sodium are characterized by poor tilth and lead to low permeability resulting in poor plant growth (Corwin and Lesch, 2005) Soil electrical conductivity is influenced by the amount of clay, soil water, bulk density, organic matter, soil temperature and the cation exchange capacity (Corwin and Lesch, 2005). Electrical conductivity is influenced by soil moisture and texture, especially in most saline soils (Brevik and Fenton, 2002). Excessive soluble salt levels are caused by over fertilization, poor drainage inadequate watering and leaching. Soluble salt damage may show up as root injury, leaf chlorosis, burning of leaf margins and /or wilting. Seedlings, transplants and crops grown in media containing more than 20% field soil are less tolerant to higher soluble salts. Leaching regulates electrical conductivity in soils by displacing salt ions into solution and subsequently flushes the soil water out of the pot. Another way of regulating electrical conductivity in soils is by stratification, which involves the movement of nutrient salts to the upper top (1cm) of the medium. Some examples of salt tolerant crops are barley, canola, cotton, beetroot soybean, wheat, olives and sorghum. Moderately salt tolerant crops include lucerne, tomato, cabbage, potato and carrots whiles some low salt tolerant crops include maize, sugarcane, celery, lettuce and pumpkin.

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2.5.3 Types of Growing media

There are two types of growing media namely, a soilless media which refers to a potting medium that contains peat, usually perlite or vermiculite and/or any organic material without soil. This is sometimes referred to as sterile mix. The second type is termed a soil based media mix which refers to a potting media which contains some percentage of soil (Spiers and Percy, 2007). The media must meet the entire basic plant requirements to facilitate proper shoot and root growth. The growing media must supply plants with a means of support, good drainage, nutrients, adequate air circulation and water (Nelson, 1991).

2.5.4 Soilless Media

"Soilless mixes" as their name implies do not contain any soil mineral particle thus they are extremely lightweight, nutrient retentive and sterilized (heated to kill microorganism and weed seeds). Soilless media are generally kept at a pH between 5.5 – 6.0 whiles the mixes that contain soil are best maintained at a pH ranging from 6 - 6.5 (Wander, 2010). Soilless mixes are made up of different organic ingredients including peat moss, shredded bark, sawdust, vermiculite, perlite, etc. Some alternative materials that are being used recently include shredded coconut husk, rice husk, other crop husks (cocoa pod, kola nut, and cowpea) and peanut hulls. The soilless mixes are typically lightweight as well as weed and disease free. The soilless media must be porous enough for root aeration, have good drainage to prevent waterlogging as well as being capable of retaining water and nutrients. A coarse mineral component is used to improve drainage and aeration by increasing the proportion of large air-filled pores. Sand is used to

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promote good drainage and its substitutes include perlite and polystyrene. Some examples of mineral components include sand, perlite, vermiculite, clay granules and rockwool (Hartman *et al.*, 1997). Quality soilless mixes should be low in soluble salts with pH of 5 – 6.5. Molson (2008) recommended one part perlite, one part peat moss and one part ground or milled sphagnum moss for a soilless mix.

Until the 1970s, seedlings or potted plants were grown in potting mixes which were based on soil amended with coarse sand and peat (Spiers and Percy, 2007). Currently, many seedlings or container plants whether in nursery or greenhouse are grown in soilless media where the soil is replaced by other materials and they provide the physical and chemical properties needed for plant growth. This is a way to prevent soil-borne organism and weed seeds present in soils. The use of soilless media is relatively inexpensive and environmentally friendly. Some materials used for soilless media are peat, rock wool, sand as well as organic materials such as rice husk, sawdust, bark, coconut fibre, cocoa pod husk, kola nut husk. Kambooh (1984) reported that organic matter content of the planting medium has effect on the biological, chemical and physical properties. As the organic matter decomposes, the chemical elements become available to the plants.

2.5.5 Soil based media mix

A soil based media mix refers to a potting media which contains some percentage of soil (Spiers and Percy, 2007). Soil mixes have the same characteristics as soil itself, except that the bulk density is reduced and aeration is increased by adding perlite, peat moss, washed river sand or sea sand and organic residues. A medium is considered soil based if it contains at least 25% soil (Fonteno, 1996). The soil in soil based media provides buffering capacity to withstand pH

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changes and provides support as well as nutrients to the plant. One advantage of soil based media over soilless media is the high CEC soil contributes to the mix. The high CEC of soil based mix increases the difficulty of reducing high soluble salts or micronutrients level before leaching. Additionally, nutrient retention is increased and this makes soil based media mix useful for long term crops such as stock plants (Hartman *et al.*, 1997). 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. Soil based mixes contain equal parts of loamy soil, concrete-grade sand and sphagnum peat moss (Wang *et al.*, 2002). For a seed soil based mix, one part loam, one part leaf mould or peat moss and one part sand was recommended (Molson, 2008).

2.5.6 Media mixes

There are two types of growing medium, these are the soil-based mixes (contain a portion of field soil) and the soilless mixes (contain no field soil). Farms and nurseries use various potting media in the production of seedlings, container plants and greenhouse crops (Kuepper and Everett, 2010). According to Hartman *et al.*, (1997), soil mixes or soil based mix have the same characteristics as soil itself, except that the bulk density is reduced and aeration is increased by adding amendments such as perlite, peat moss, wood bark, rice husk and other organic materials. A typical media mix consists of two or three components. Ideally, organic and inorganic components are used due to their opposite and complementary, physical and chemical properties. Some organic components used include cocoa pod husk, cola nut husk, cocopeat, peat moss, compost, rice hulls, and sawdust. These materials are usually low in weight with high water-holding capacity, high CEC and highly resistant to compaction. Additionally, they contain

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significant quantities of nutrients. Inorganic components such as gravel, sand, vermiculite, perlite improves physical properties of the media by increasing aeration, pore space and enhancing drainage (Jacobs *et al*., 2009).

Rice husk, cocoa pod husk, sawdust and cocopeat are mixed with the soil to serve as an organic matter to the soil so as to increase the nutrient retention, water holding capacity and aeration of the soil.

2.6 THE USE OF AGRICULTURAL RESIDUES AS SOIL AMENDMENTS

Global annual production of agricultural residues is estimated to be more than 500 million tonnes (Sanchez, 2009). Ghana's agricultural sector is characterized by a large number of dispersed small-scale producers, employing manual cultivation techniques, and dependent on rain fed with little or no purchased inputs (Duku *et al*., 2011). Major crop residues generated in Ghana include straw or stalk of cereals such as rice, maize/corn, sorghum and millet, kola pod husk and cocoa pod husk, while agro-industrial by-products include corn/maize cob, cocoa husk, coconut shell and husk, rice husk, oil seed cake, sugarcane bagasse and oil palm empty fruit bunch (EFB). It is estimated that about 4159×10^{3} tonnes of agricultural crop residues were generated in the country in 2008.

The 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. Obatolu and Agboola (1991) reported that cocoa pod husk (CPH) manure contains Ca, P, K, and also sizeable amount of useful organic constituents. Also, Moyin Jesu and Atoyosoye (2002) observed that cocoa pod husk (CPH) manure is effective in raising cocoa seedlings in the nursery. Grounded cocoa pod husk when applied to

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the soil, as reported by Egungobi (1996) increased maize yield by 12.4% and the uptake of P, K and Mg by the crops. Hsieh and Hsieh (1990) reported that agricultural residues can be properly managed by using them as soil amendments (compost or biochar) to enrich the degraded soils with very low organic matter content.

One of the technologies that have been practiced for raising seedlings in many countries is the use of alternative growing media such as the use of sawdust and rice husk (Gungula and Tame, 2006).

Propagating media can be described as 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 (Adejobi *et al*., 2011). Organic matter either fresh or composted plays a critical role in maintaining nutrient availability and thus enhancing plant productivity (Ajayi *et al*., 2007). It has however been shown to be of greatest value in soils with low fertility where large fertility improvements occurs (Sall *et al*., 2003). Organic matter improves the physical, chemical and biological properties of a soil. It also supplies plants with essential nutrients and soil organisms with energy (Marinari 2000; Nyberg *et al*., 2006).

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2.6.1 Rice husk

Rice husks also known as rice hulls are the outermost covering of the paddy grain rice which is separated from the brown rice during rice milling. It is one of the most widely available agricultural waste in the world. Globally, approximately, 600million tonnes of rice paddy are produced every year and an average 20% of the paddy rice is husk. Rice husk contains 75-90% organic matter such as cellulose, lignin etc and the rest being mineral component such as silica, alkalis and trace elements (Kumar *et al.*, 2012). Rice husk biochar improves nitrogen content and soil biomass. (Ebaid and El-Refaee, 2007). They are light in weight, uniform in quality and grade are resistant to decay which allows drainage and retains less water (Hartman *et al.*, 1997). Rice husk contains potassium, phosphorous, calcium and other micro-elements for growing plants. It also contains high amounts of silicon dioxide which makes it unuseful to feed either animal or human. It is an agricultural waste that can cause serious environmental problems but it had been used as a soil amendment (Anda, 2006). Studies have shown that rice husks have been used in media trials as an alternative to peat and peat/perlite mixes (Jarahian, 2010). Rice husk had been used as a media for hydrophonic gardening and has been found to have the same properties as sand or rock wool. It also has similar properties as peat moss and could be used as a substitute for peat. Smith (2009) reported that the best organic way to amend a clay soil was to use rice husk.

Rice husk is an organic material that can be used as a mulching material or in compost or mix with soil to improve aeration and water holding capacity of the soil (Hirschey, 2003). It is effective in loosening a heavy soil and providing organic matter to the soil which enables the soil to retain water and nutrients and this will encourage plant growth and development.

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Studies have shown that decomposition and nitrogen depletion do not occur in rice husk thus best used with compost or soil as a soil amendment (Smith, 2009). In Thailand, carbonated rice husks have exhibited alkaline properties and large water absorption capacity which functioned as a suitable soil conditioner for the acid sandy soils (Miles, 2007). The use of rice husk as an organic fertilizer is essential as it plays the role of improving soil physical properties, nutrition and water use efficiency (Soliman *et al*., 1990).

2.6.2 Cocopeat

Cocopeat is made from coconut husks which are by-products from the processing of coconut. It is the binding material that comes from the fibre fraction of the coconut husk (Abad *et al*., 2002). Cocopeat is a proven natural alternative to mined peat moss, therefore using it helps slow down peat extraction from environmentally sensitive swamps worldwide. It is used as a growing medium and as a soil addictive due to its unique characteristics such as its high good physical properties, high total pore space, high water content, low shrinkage, low bulk density and slow biodegradation (Prasad, 1997). Cocopeat makes an excellent growing medium for hydroponics, soil mixes and container plant growing (Yau and Murphy, 2000). This is because the coir has natural rooting hormones and anti-fungal properties. It has being mixed with sand, compost and fertilizer to make good quality potting soil as it prevents root rot and drying up of the soil. Research has shown that cocopeat used alone, or as a component of soil medium is suitable for many potted plants (Treder and Nowak, 2004). It also has the ability to store and release nutrients to plants and provide suitable aeration for plant and has oxygenation properties which are essential for healthy root development.

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2.6.3 Sawdust

Sawdust is the waste product of milling, cutting, grinding or drilling wood with a saw or other machine. The use of sawdust as a mulch and soil amendment has been studied and has been used for raising seedlings and vegetables in many countries (Gungula and Tame, 2006). Sawdust is produced in many varieties of sizes, densities and wood types. In Ghana, wood such as white and black odum, ofram, mahogany, wawa and oyina are used during manufacturing. Sawdust amounts to roughly one third of wood product exports. The benefits of sawdust are derived from the use of these wood wastes in improving the physical properties of the soil. It increases the water holding capacity of the soil and prevents rapid changes in moisture and temperature. Sawdust is composed of about 40% lignin and about 60% cellulose along with small amounts of waxes, resins and oils (Odedina *et al*., 2007). It is low in nutrient density, only containing 0.048% nitrogen, 0.007% phosphorous, 0.017% potassium and 0.106% calcium which varies depending on the wood the sawdust comes from. Sawdust consists of very small particles of wood which have lots of surface area, thus there is a lot more surface for microbes to attack (it serves as places for them to attach to the wood particles and eat it). This results in a much quicker breakdown of the wood as mulch. Sawdust breaks down into humus, develops soil structure, increases aeration and soil water holding capacity as well as increasing microbial activity after it has broken down. It has a high C: N ratio, which can result in nutrient imbalance resulting in nutritional problems for the plant, however, it can be a beneficial soil amendment when used correctly. Nevertheless, 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). Also, sawdust robs soil of nitrogen and becomes hydrophobic when dry, hard to rewet

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and may repel water. When used in mixes, sawdust oxidizes readily and compact easily. The problems of sawdust can be overcome by compositing it with manure or commercial fertilizers. However, in spite of these disadvantages, the benefits that are being derived from the use of these wood wastes in improving the physical properties of the soil cannot be overlooked. According to Grubinger (2007), the compost becomes more useful when it makes up less than 50% of the growing medium by volume depending on the type of crop that will be grown. He indicated that compost by itself is rarely used as a potting medium and sawdust alone does not have the desirable properties for potting mix.

2.6.4 Cocoa pod husk

Cocoa pod husk is a major by-product from the cocoa industry in Ghana and forms over 70% (w/w) of the whole matured fruit. It is highly fibrous with significant amounts of cell wall components. Cocoa pod husk is commonly collected as heap nearby in the field and is being considered a waste. This can be used to amend soils to minimize the waste produced hence efforts must be done to utilize the husk by incorporating it in potting media for cocoa seedling production. The cocoa pod husk offers some opportunities in improving the soil physical properties, thus enhancing the growth of seedlings. Cocoa pod husk is an organic source of feritilizer which is often wasted. There is therefore the need to research into its use as a soil amendment. Plant derieved ash, as liming materials have been found to increase soil pH and crop yield (Ayeni *et al.*, 2008). Several studies carried out in parts of Africa revealed that plant derived ash including those of wood and cocoa pod husk increased N, P, K, Ca, Mg, status of soil, soil pH and yield of vegetables, rice, millet and maize (Ojeniyi *et al.*,2002; Ojeniyi and Adejobi, 2002; Owolabi *et al.*, 2003; Odedina *et al.*, 2003).

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In a study conducted by Moyin-Jesu and Atoyosoye (2002) on the utilization of agricultural waste for the growth, leaf and soil chemical composition of cocoa seedlings at the nursery stage, the results showed that soil amended with organic residue significantly increased ($p<0.05$) plant growth, leaf N, P, K, Ca, Mg compared to the control (soil) and the recommended N.P.K (15:15:15) fertilizer treatments.

Agele and Agbona (2008) in their study on the effects of cocoa pod husk amendment on soil and leaf chemical composition and growth of cashew (A*nacardiumOccidentale* L.) seedlings in the nursery, observed that the addition of CPH to soil increased soil pH, organic carbon, and organic matter, percent nitrogen, potassium,sodium and calcium. CPH also lead to increase in the value of % ash, nitrogen, potassium and sodium in the cashew leaves. The effects of 3% level and 97% of pure top soil were significant on growth characters and soil and leaf nutrient contents.

2.7 SOIL

Soil is the heaviest of all growing media and is usually low in organic matter which reduces its ability to hold water (Khan *et al.*, 2002). Soil is a mixture of minerals, organic matter, gases, liquids and organisms that serves as a medium support for plant growth. Soils supply plants with mineral nutrients held in place by the clay and humus content of the soil. The soil texture is determined by the relative proportions of sand, silt and clay in the soil. The presence of organic matter, water, gases causes the soil of a certain texture to develop into a larger soil structure called aggregates. The presence of soil pores determines the ability of the soil to absorb and hold water and making it readily available for plant uptake. This is vital for plant survival. The pore space allows for the infiltration and movement of air and water and is critical for life in the soil.

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The most influential factor in stabilizing soil fertility are the soil colloidal particles, clay and humus, which behave as repositories of nutrients and moisture and acts to buffer the variations of soil solution ions and moisture. They act to store nutrients that might otherwise be leached from the soil or to release the ions in response to changes of soil pH as well as to make them available to plants. The greatest influence on plant nutrient availability is soil pH, which is the measure of the hydrogen ion (acid-forming) soil reactivity, and is in turn a function of the soil materials, precipitation level and plant root behaviour. Soil pH strongly affects the availability of nutrients. Cation exchange, between colloids and soil water buffers (moderates) soil pH, alters soil structure and purifies percolating water by adsorbing cations of all types. The negative charges on a colloid make it able to hold cations to its surface. Cations held to the negatively charged colloids resist being washed downward by water and out of reach of plant roots, thereby preserving the fertility of soils. Cation exchange capacity is the soil's ability to remove cations from the soil water solution and sequester those to be exchanged later as the plant roots release hydrogen ions to the solution. Sixteen nutrients are essential for plant growth and reproduction. They are carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, sulphur, calcium, magnesium, iron, boron, manganese, copper, zinc, molybdenum and chlorine. A wide variety of soils have been successfully used in different countries. These include sandy soil partially sterilised by heating over a fire; deep friable topsoil, overlying alluvial clay mixed with a small proportion of coarse river sand in the proportion 3:2; peat and sand mixed in equal proportions; sandy soil; inland clay-loam topsoil and silted forest topsoil (Hartley, 1988). In general, fertile topsoil, sufficiently free-draining to prevent 'puddling' or sealing of the surface has been recommended (Hartley,1988).

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2.8 WHAT IS BIOCHAR

According to Lehman and Joseph (2009), biochar is a carbon-rich product obtained when organic residues such as rice husk, husks, shells and leaves are heated in a closed container with little or no available air. Biochar is defined as a fine-grained, highly-porous charcoal produced from carbon-rich biomass feedstocks, including forestry waste, animal manures and agricultural waste products such as husks, shells and stover. (stover is the dry stalks of crops such as corn, sorghum or soybean that remain in a field after harvest). Biochar is produced by pyrolysis or gasification (heating the biomass with little or no air) in a process similar to the production of charcoal. However, the primary use of biochar is as a soil improver and has been shown to add value to soils in terms of fertility, particularly to acidic soils. Its influence on the physical properties, exchange and buffering capacities of the soil and providing a rich source of nutrients for plants has been observed (Rondon *et al*, 2007). When added to the soil it can significantly improve soil fertility (Rodriguez *et al*., 2009) and also acts as a sink for carbon (Lehmann, 2007). Besides that, biochar can act as a soil conditioner, enhancing plant growth by supplying and more importantly retaining nutrients and improving the physical and biological properties of the soil (Lehmann and Rondon, 2005).

Current studies are focusing on using plant growth media that are strongly organic-based, appropriate, less expensive, lightweight and readily available as biochar. The beneficial effects of organic materials such as biochar in raising seedlings have well been documented by several researchers (Hartz *et al.*, 1996, García-Gómez *et al.*, 2002, and Akanbi *et al.*, 2005).

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2.8.1 The influence of biochar on plant growth

Biochar can be used as a soil amendment to improve crop quality and crop productivity in a variety of soils (Blackwell *et al*., 2009).

Greenhouse and field studies have been conducted to look at the effect of biochar on crop yields (Glaser *et al*., 2002; Yamato, *et al*., 2006; Chan *et al*., 2007 and 2008) and most studies revealed that biochar addition increased crop yields. For example, a plot trial where soil was amended with a green waste-derived biochar, showed benefits that included increase in plant growth, increased crop yield and improved soil quality (Chan *et al*., 2007). Field experiments have also reported substantial crop yield increase in response to soil biochar application (Glaser *et al*., 2002; Yamato, *et al*., 2006)

In a pot experiment, Lehmann *et al* (2003) found biochar to increase rice biomass by 17% and cowpea by 43% when applied at rates of 68t C ha-1 to 135t C ha-1. This growth was attributed to direct nutrient additions from biochar of P, K and Copper (Cu). Other studies have attributed positive plant growth to positive changes in soil biogeochemistry as a result of biochar additions (Chan *et al*. 2007; Hoshi 2001; VanZwieten *et al*., 2007; Wardle *et al*. 1998).

Hoshi (2001) found a 20% increase in volume and 40% increase in height of tea trees with biochar additions. Additionally, larger yield increases have been reported with biochar additions applied together with inorganic or organic fertilizer treatments (Chan *et al*., 2007; Glaser *et al*., 2002; Lehmann *et al*., 2002; Steiner *et al*., 2007; Van Zwieten *et al*.,. 2007), with increases reported at 200% relative to unamended, unfertilized treatments (Yamato *et al*., 2006). This is in agreement with Siregar (2007) who observed that the growth of two industrial forest plant species raised in poly-bags using sub-soils of an Ultisol from Java increased by about 100%

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when the soil was amended with charcoal made from wastes in woody forests and without any chemical fertilizer.

Carter *et al* (2013) in their study to verify the Impact of Biochar Application on Soil properties and plant Growth of Pot Grown Lettuce (*Lactuca sativa*) and Cabbage (*Brassica chinensis*) revealed that The biochar treatments were found to increase the final biomass, root biomass, plant height and number of leaves in all the cropping cycles in comparison to no biochar treatment.

An experiment conducted by Kumah (2012) at the University of Ghana Forest and Horticultural Research Centre to investigate the effect of type of initiation and growing media on growth and nutrient uptake of plantain (*Musa* aab) at the nursery stage, the biochar (CRH) induced the greatest pseudostem height, pseudostem girth, number of roots/corm, and root diameter and was significantly different from that of the sawdust and sawdust and carbonated rice husk.

2.8.2 The benefits of biochar in soil

Biochar is receiving a growing interest as a sustainable technology to improve soil fertility, nutrient use efficiency and plant growth (Zhang *et al*., 2010). Biochar are organic material that is partially burnt (carbonated with little or no oxygen). Biochar has lower bulk density than soil thus the addition of biochar to soil reduces the bulk density of the soil. The decrease of soil strength with application of biochar has been observed by Chan *et al.* (2007). The increase in soil porosity with as a result of soil aggregation with application of biochar has been observed by for hard settling soil in Australia (Chan *et al*., (2007). This will in turn increase porosity and soil water retention which consequently leads to an increase in available soil water for plant uptake.

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Biochar alters the physical and chemical properties of soil by increasing aeration and water holding capacity of the soil, increasing soil pH and cation exchange capacity and a decrease in exchangeable aluminum and soluble ion. The increase in cation exchange capacity and soil pH with the addition of organic materials has been shown by Bot and Benites (2005). The increase in soil cation exchange capacity with the application of biochar has also been shown by Chan *et al.* (2007). He also showed that, the application of biochar increased soil organic carbon, soil pH and cation exchange capacity. The addition of biochar also results in the addition of elemental plant nutrients such as phosphorus, potassium and calcium. Biochar has low to neutral pH thus making it useful in acidic soils hence used as a liming material. Consequently, biochar alleviates soil acidity which in turn improves nutrient uptake and growth of plants (Lehman *et al.*, 2003).

2.9 EFFECT OF DIFFERENT POLYBAG SIZES ON PLANT GROWTH

In developing countries, polybags filled with soil are mostly used for the raising of tree seedlings (Annapurna, 2004). In Ghana, cocoa seedlings are usually raised in small black polybags and are kept at the nursery for 3- 6 months. The advantages in using polybags to raise seedlings includes its low cost and unbreakable qualities, its easy handling ability and the ability to perforate the bottom of the polybags for aeration and drainage (Adu Berko *et al*., 2011). Studies have also shown that seedlings raised in polybags have problems with root development since the roots of the seedlings tend to grow in spirals when the roots hit the inner bottom of the polybag and consequently this leads to deformed taproot (Edwin *et al*., 2005). Although polybags produce seedlings that have spiral roots the degree of deformation depends on the size of the polybag. The size of polybag influences root development as optimal root growth depends on media

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conditions such as water, nutrients as well as the physical rooting environment. Seedlings raised in small polybag size have high incidence of spiraled roots due to limited space in the polybag and this consequently leads to restricted growth (Hess and De Kroon, 2007). Cedamon, 2005 showed that seedlings raised in smaller polybags had high incidence of deformed roots. Root growth affects carbohydrate metabolism (Ronchi *et al*., 2006), nutrient acquisition (Yang *et al*., 2007), hormone production and plant growth (Carmi, 1995). When roots have limited space, it restricts their growth which leads to decreased rooting volume and consequently results in reduced dry matter accumulation as well as total plant biomass. Root growth is important as it ensures better uptake of nutrients and water from the soil as well as increases the formation of amides, amino acids, proteins, lipids, hormones and other organic substances (Singh, 2003). Studies have shown that photosynthetic rate decreased with increased root restriction (NeSmith *et al*., 1992). Recent studies have shown that larger containers produce better growth of seedlings (Haldankar *et al*., 2014). It has also been reported that large containers enhanced better root growth and produce vigorous plants (Annapurna, 2004). According to Audet and Charest (2010) pot sizes influences plant growth. The results of the experiment showed that when container size was reduced, plant growth also reduced and this may be to decreased rooting volume and poor nutrient uptake. This is due to the large volume of soil in the container which allowed the seedlings roots to absorb more nutrients and soil moisture to increase plant growth due to an increase in dry matter accumulation. Cantliffe (1993), also reported that increased container size results in an increase in plant leaf area, shoot biomass and root biomass. It is also reported that seedlings have a well developed root system which increases nutrient and water uptake when raised in large polybags (Abugre *et al*., 2011).

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CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Experimental Site

The experiment was carried out at the University of Ghana Forest and Horticultural Crops Research Centre (FOHCREC) nursery at Kade. Kade is in the Eastern region of Ghana about 135km North-West of Accra. FOHCREC lies in the deciduous forest zone and is 114m above sea level on latitude 60.0854'N and longitude 0^{o} 5400W.

3.2 Geology and soil

The soils of the area according to Owusu-Bennoah *et al.* (2000) are generally developed from rocks of the Birrimian system (middle-Pre-Cambrian) which consist mainly of argillaceous sediments metamorphosed into phyllite. The well-drained upland soils belong to the forest Ochrosol. Great Soil Group of the Ghanaian soil classification system (Brammer, 1962) and are generally classified as Acrisols in the FAO-Unesco Revised Legend (FAO, 1988) and as Utilsols in Soil Taxonomy (Soil Survey Staff, 1998). The soils are well drained, rich in iron oxides, strongly leached with pH ($CaCl_2$) of 3.7-4.4 in the subsoil but the ion-pump maintains relatively high pH ($CaCl_2$) 5.4-5.9 and base saturation in the top soil.

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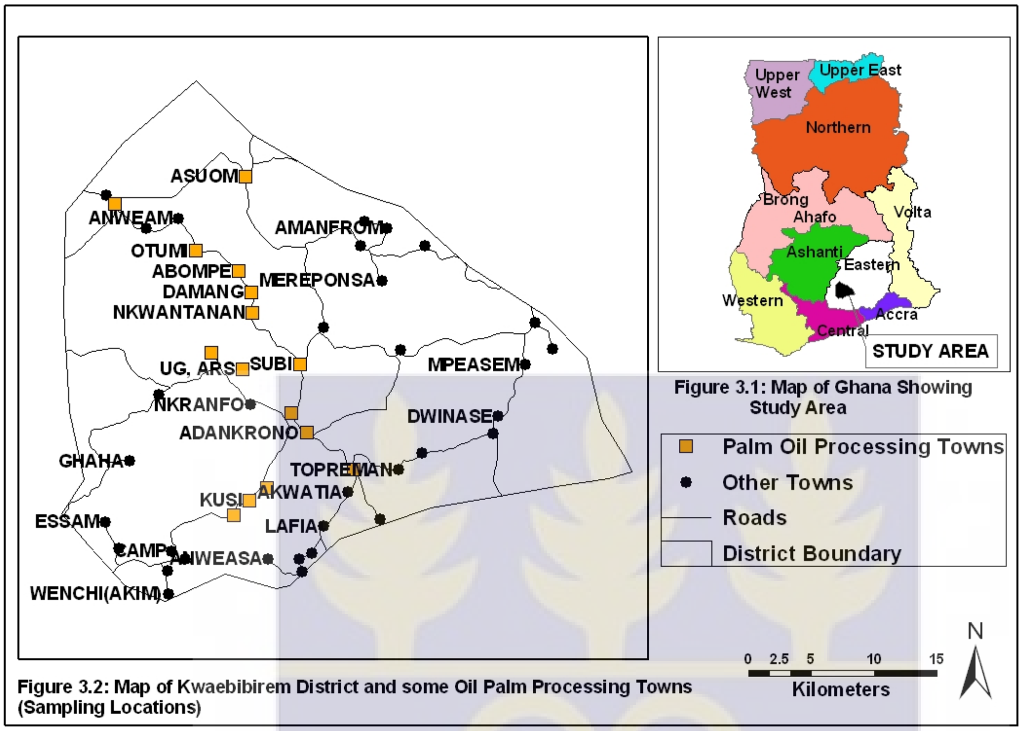

Figure 3.1: Map of Ghana Showing Study Area

Figure 3.2: Map of Kwaebibirem District and some Oil Palm Processing Towns (Sampling Locations)

Figure 1: Map of Kwaebibirem District and University of Ghana Forest and Horticultural Crops Reseach Centre (FOHCREC)

Source: Survey Department ; Composed by Albert Allotey, Remote Sensing & GIS Laboratory, Department Of Geography and Resource Development, University of Ghana, Legon

3.3 Experimental Materials

The materials used in the study were top soil, rice husk, cocoa pod husk, cocopeat, sawdust and poly bag of sizes 13cm x 12 cm, 20 cm x18 cm and 32 cm x 10 cm. The soil (Kokofu series) was collected from the field of the forest and horticultural research station from a depth of 0-15 cm, air dried and crushed. The rice husk was obtained from the University of Ghana rice mill at Kade and the decomposed cocoa pod husk was obtained from the Asamankese Cocoa Station

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and sun dried for 32 hours. The sawdust was obtained from a saw mill at Kade. The rice husk and sawdust were carbonated in other words they were partially burnt and cooled (biochar). The hybrid cocoa seeds for sowing were obtained from the Asamankese Cocoa Station.

3.4 Treatments and Experimental Design

The design used was conducted using a split plot design involving fifteen different types of growth media assigned to the main plot and three sizes of polybag assigned to the subplots. The fifteen growth media treatments used in the experiment are soil, cocoa pod husk, carbonated rice husk, cocopeat and sawdust and their mixtures (S+CRH, S+CPH, S+CP, S+SD,CRH+CPH, CRH+CP, CRH+SD, CPH+CP, CPH+SD and CP+SD). These treatments were replicated three times with twenty seedlings per treatment per replication. Three different polybag sizes were used namely, 12.5 cm x 18.5 cm (small), 10.0 cm x 135.0 cm (medium) and 17.3 cm x 23.3 cm (large). The polybags used for the experiment were black and were perforated at the base for aeration and drainage. The poly bags were filled with the growth media and their mixtures. For the mixtures, the constituents were mixed in the ratio 1:1 by volume. The bags were arranged under a shade net and the cocoa seeds sown directly into the bags and watered as and when necessary.

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3.5 Data Collection and Field Operations

3.5.1 Nursery Establishment

A cocoa nursery was established at the University of Ghana Forest and Horticultural Crops Research Centre at Kade. Three types of poly bag sizes (13 cm x12 cm, 20 cm x18 cm and 32 cm x10 cm) were used. Drainage holes were made at the bottom (lower third) of the poly bags which were filled with the different potting media as well as the media mix (carbonated rice husk, cocoa pod husk, cocopeat, sawdust, soil and their mixtures in a 1:1 (v/v) ratio). First fertilizer application was done at two months after sowing. Top soil used was taken at a depth of 0-15 cm, air-dried and all plant debris, soil clogs and stones were removed in order to obtain a fine tilth. All the media constituents were thoroughly mixed to obtain a uniform mixture. Polybags filled with the different potting media were watered 24 hours before cocoa seeds were sown. The seeds were sown at a seeding rate of two seeds per poly bag which were thinned to one seedling per bag. The seedlings were kept under a shade net to reduce the light intensity. The seedlings were kept at the nursery for six months and were watered when necessary. Weeds in the polybags were handpicked regularly to prevent weeds from serving as host to pests and also competing with the seedlings for nutrients.

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Plate 1: Nursery layout for the experiment

3.5.2 Chemical Analysis

The chemical analysis of the growth media were carried out at the Department of Geography laboratory of the University of Ghana, Legon. The various growth media were air dried before the various measurements and analyses were carried out. These included; (i) Electrical conductivity (EC), (ii) pH, (iii) Cation exchange capacity (CEC), (iv) Organic carbon, (v) Nitrogen, (vi) Phosphorous, (vii) Potassium, (viii) Magnesium and (ix) Calcium.

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3.5.3 Electrical conductivity

The media samples were air dried and passed through a 9.5 mm sieve. A suspension was prepared by adding 10g of the sample to 50 ml of distilled water. The suspension was shaken for 20mins at room temperature. The Jenway conductivity meter was used to measure the electrical conductivity of the media.

3.5.4 pH of media

The distilled water method was used to determine the pH of the growth media. This was done by mixing 10 g of the media in 10 ml of distilled water in a beaker to form a suspension. The suspension was allowed to stand for 30 minutes and the pH was measured using a digital water proof pH meter.

3.5.5 Total Nitrogen

The Kjeldahl digestion procedure as described by Koopmann and Janssen (2003) was used to determine the total nitrogen in the media. The sample was air dried, grounded and sieved through a 0.25 mesh. One gram (1g) of each media sample was weighed into a test tube and 5mls of concentrated sulphuric acid (H_2SO_4) was added. The test tube and its content was placed in the digestion chamber and heated for 45 minutes. Magnesium oxide (MgO) powder was used as a catalyst to speed up the digestion process. The digest was allowed to cool and then diluted with distilled water before it was decanted into a 50 ml conical flask. 5 mls of the aliquot pipetted plus 5 mls of 40% sodium hydroxide was distilled with 2% boric acid indicator mixture;

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until the colour changed from purple to green. The distillate was then titrated against 0.01M HCl from green to purple end point. The titer value obtained for the sample was recorded. Total nitrogen in sample was calculated as shown below:

$$\%N \text{ in sample} = \frac{(a - b) \times 0.01 \times 14 \times v \times 10}{1000 \times w \times al}$$

Where a = concentration of potassium in the digest

b= concentration of flask in the blank digest

v= final volume of the digestion = 1000 ml

w= weight of the sample taken in grams

al= aliquot of the solution taken for analysis

0.011= molarity of acid

14= molar weight of nitrogen

3.5.6 Total Phosphorous

The Kjeldahl digestion procedure as described by Okalebo *et al*., (2002) was used in determination of total phosphorus in media. The samples were air dried ground and sieved through 0.25mm mesh and stored. Sulphuric acid- selenium mixture (consisting of 3.5 g selenium powder to 1 litre H_2SO_4) was prepared. The sulphuric acid-selenium powder mixture was heated in a beaker while it was covered with watch glass until the original blackish colour of selenium suspension turns via green-blue to clear light yellow. A digestion mixture was prepared by dissolving 3.2 g salicylic acid in 100 mls of the clear light yellow sulphuric acid-selenium powder mixture. 1 g of each of sieved stored soil sample and compost was weighed into 500 mls

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Kjeldahl flask and about 2.5 mls of the digestion mixture was added to each flask and heated to 330 °C.

3.5.7 Colour development for P determination

First, a stock solution known as A was prepared and about 1 to 5 ml of sample solution was pipetted. A drop of P-nitrophenol and Ammonium solution was added until the sample solution turned yellow. About 8 mls of L- Ascorbic Acid i.e. solution B (prepared by dissolving1.056 g of L- The solutions were made up to 50 ml volume with water and P concentration in samples was read on the Spectrophotometer (model Perkin Elmer Lamda 45).

Total P in samples was calculated as shown in the equation below.

$$\text{Total P (\%)} = \frac{\text{meter reading x extraction volume x 100}}{\text{weight of sample x aliquot x 1000000}}$$

3.5.8 Total Potassium (K)

About 1 g of air dried and sieved soil, carbonated rice husk, cocoa pod husk, cocopeat, sawdust or oven dried (70 ^{o}C) ground plant tissue was each weighed into a labeled dry and clean digestion tube. The samples were then digested in a fume chamber at 360 ^{o}C for 2 hours until the solution turned colourless and remained sand white. The sample and blank solution potassium concentrations were read by aspirating directly into Jenway flame photometer (PFP7). The concentration of potassium in the compost or plant sample expressed in percentage was be calculated as follows:

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$$K\ (\%)\ \text{in the sample} = \frac{(a-b) \times v \times f \times 100}{1000 \times w \times 1000}$$

Where a = concentration of Potassium in digest.

b = concentration of potassium in the digest

w = the weight of sample

v = volume of digest and f = dilution factor

3.5.9 Exchangeable Calcium (Ca) and Magnesium (Mg)

10 grams portion each of growing media, compost and CRH was weighed into an extraction bottle and 100 ml solution of 1 M ammonium acetate (NH4OAc, pH 7) was added. The bottle was shaken on a mechanical shaker for 1 hour and content filtered through Whatman No. 42 filter paper into clean empty bottles. Ca and Mg in the extract were determined using the Atomic Absorption Spectrometer (AAS). The concentration of calcium and magnesium in the soil or plant sample expressed in percentage was calculated as follows:

%Ca and Mg= (meter reading*extract volume*100)/(weight of sample*1000000)

3.5.10 Determination of ammonium nitrogen (NH_4+-N) and nitrate nitrogen (NO_3-N) in growth media and organic materials

One gram (1g) of air-dried ground compost sample that was passed through 2.0 mm sieve was weighed into a 200 ml plastic bottle, and 40ml of 2MKCl extracting solution was added. The bottle was covered and the content shaken for one hour. The sample was then centrifuged and filtered through No. 5 or No. 42 Whatman filter paper.

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Steam Distillation

First the steam distillation apparatus was set up by using NH3 - free distilled water. The steam was passed through the apparatus for 30minutes and the blank was determined by collecting 50ml of the distillate into a conical flask containing 5ml of 2% boric acid, and titrated with 0.01 M HCl after mixed indicator (bromocresol green and methyl red) was added.

(i) Measurement of NH_4 – N in media and soil extracts (Okalebo *et al*., 2002)

Five millilitres (5 ml) of the 2% boric acid indicator solution was poured into a 50ml conical flask and placed under the condenser of the steam distillation so that the end or tip of the condenser was about 40cm above the surface of the boric acid indicator solution. An aliquot of 10ml of the compost extract was pipetted into the distillation flask and about 0.2 g of MgO was added directly to reach the bulb of the distillation flask. The flask was then attached to the distillation apparatus and the stopcock on the steam- by pass tube closed. The tip of the condenser was rinsed with distilled water and the ammonium nitrogen in the various extracts of the compost was collected in the same way as described for steam. Ammonium –N content in the distillate was determined by titrating with 0.01M HCl.

The colour changed at the end point from green to a permanent faint pink.

(ii) Measurement of NO_3 – N in soil and compost extracts (Okalebo *et al.*, 2002).

After ammonium nitrogen was distilled from the sample extracts in the above, the stopper at the side arm of the distilling flask was removed and 0.2g of Devarda's alloy was added. The stopper was then replaced immediately into the neck of the side arm and nitrate nitrogen was

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distilled into fresh boric acid indicator. The NO_3 is converted to NH_4 and trapped in the conical flask.

This ammonium was then estimated by titrating with 0.01M HCl as described above.

Calculations

Ammonium nitrogen (NH_4 – N) and nitrate – nitrogen ($N0_3$ – N) were each calculated as follows:

$$\% \quad NH_4 - N = 0.4\,(a - b) \times \frac{v}{al} \times \frac{100}{w}$$

$$\% \quad N0_3 - N = 0.4\,(a - b) \times \frac{v}{al} \times \frac{100}{w}$$

where,

a = Titre volume of 0.01 M HCl for the sample (ml)

b = Titre volume for the blank (ml)

v = Volume of the extracting solution used – 40ml

al = Aliquot of solution taken

w= Weight of media sample (mg)

3.6 Data collected on seedlings

Morphological growth measurements such as plant height, girth, number of leaves, root length were recorded to evaluate treatment effects. In addition, leaf area, leaf, stem and root dry weight and total plant dry matter production were also measured.

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3.6.1 Plant height

Plant height was determined using a meter rule by measuring from the base (soil surface) to the tip of the apical leaf at the 3rd and 6th month.

3.6.2 Plant girth

With the aid of a vernier caliper, the girth of the stem was measured 1cm from the surface of the soil at the 3rd and 6th month.

3.6.3 Number of leaves

The number of fully developed leaves was counted on each plant and recorded 3rd and 6th month.

3.6.4 Chlorophyll content

The chlorophyll content of the fully developed leaves was determined in broad day lightwith the aid of the chlorophyll meter, Minoltabmodel SPAD-502 at the 3rd and 6th month.

3.6.5 Root length

The root length at 3rd and 6th month was measured using the line intersect method (Newman, 1966, Tennant, 1975). The line intersect method consists of scattering the roots on a grid and counting the number of root grid line interaction points. The number of points was then multiplied by the conversion factor 2.3571 appropriate for the 3 cm x 3 cm grid used.

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3.6.6 Dry weights

Three seedlings were randomly taken at 3 months and 6 months for the determination of dry matter yield. The seedlings were grouped according to the various treatments after which the seedlings were uprooted from the poly bags and their roots were carefully immersed in a bucket of water to wash the media off the roots. Plant samples were then separated into the leaves, stem and roots and oven dried at 70 ^{o}C for 72 hours, after which the dry weights were taken. The total dry matter production of the cocoa seedlings was calculated from the shoot and root dry weights measured.

3.6.7 Statistical analysis

The data collected was analysed by the Analysis of Variance (ANOVA) using Genstat statistical package, version 9.2 (Genstat 2012). The least significance difference (LSD) at p= 0.05 was used to separate the means where significant differences were observed.

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CHAPTER FOUR

4.0 RESULTS

4.1 Physical and Chemical properties of planting media used in the experiment

The physical and chemical characteristics of the growing media used in the experiment are presented in Table 1.0, 1.1a and 1.1b.

Table 1.0: Physical properties of growing media used in the study

Growing media	Bulk density g/cm^3	Water Holding Capacity (%)
S	0.99	41.30
CRH	0.47	92.07
CPH	0.23	93.47
CP	0.28	95.07
SD	0.34	76.13
S+CRH	0.67	87.60
S+CPH	0.53	92.40
S+CP	0.75	94.97
S+SD	0.88	81.63
CRH+CPH	0.28	78.60
CRH+CP	0.27	88.17
CRH+SD	0.29	73.43
CPH+CP	0.27	84.53
CPH+SD	0.33	78.43
CP+SD	0.38	76.57
LSD (0.05)	0.03	3.037

Values are the means of triplicate samples

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4.2 Effect of the physical and chemical properties of the growing media on bulk density, water holding capacity and cation exchange capacity

The bulk density of the top soil (0.99 gcm^{-3}) was significantly higher ($p<0.05$) than that of the other treatments. The addition of the organic material based growing medium to the soil reduced the bulk density of the soil. However, the cocoa pod husk was more effective in reducing the bulk density of the soil than CRH, CP and SD (Table 1.0). The bulk density of soil and cocoa pod husk media mix (0.53 gcm^{-3}) was significantly lower ($p<0.05$) than S+CRH, S+CP, S+SD which recorded 0.67 gcm^{-3}, 0.75 gcm^{-3} and 0.88 gcm-^{3} respectively.

The water holding capacity of the various growing media was highest in CP (95.07%) and the lowest was in soil only (41.30%). The water holding capacity of soil based media mix ranged between 81% - 94% (Table 1.0). This confirms that the addition of organic materials such as CPH, CRH, CP and SD increased the water holding capacity of the soil significantly.

Table 1.0 also shows that the water holding capacity of the soilless media mixtures ranged between 73% and 88% which is significantly higher than the soil only.

Table 1.1 a. Some selected chemical properties of growing media.

Growing Media	pH	EC ds/cm	%C	%OM	%N	%P	%K	Ca cmol/kg	Mg cmol/kg
S	5.9	300	21.4	36.8	0.92	0.33	0.4	2.1	1.5
CRH	9.5	480	1.0	1.7	0.84	0.08	2.6	0.4	1.4
CPH	7.9	910	2.4	4.2	0.98	0.11	3.3	6.5	7.5
CP	6.2	3000	27.9	48.2	1.06	0.22	4.4	2.5	6.4
SD	9.6	740	22.0	37.9	1.06	0.06	2.6	8.8	9.0
S+CRH	7.2	190	34.7	59.8	1.20	0.07	0.9	3.4	1.7
S+CPH	7.5	970	5.0	8.6	0.84	0.07	1.9	8.0	5.9
S+CP	5.9	730	0.8	1.3	0.78	0.06	1.0	2.6	1.9
S+SD	7.7	390	37.7	64.7	1.32	0.06	1.0	7.8	2.7
CRH+CPH	8.4	970	16.3	28.1	0.87	0.08	3.4	8.6	10.4
CRH+CP	7.3	1,650	3.9	6.67	0.92	0.09	3.2	2.7	3.3
CRH+SD	9.6	460	17.9	30.9	0.78	0.11	2.2	5.8	4.7
CPH+CP	7.6	870	38.1	65.6	0.89	0.09	3.3	8.7	10.1
CPH+SD	9.2	580	31.4	54.1	1.12	0.10	2.7	8.2	10.7
CP+SD	7.3	910	20.8	35.8	0.70	0.26	2.1	4.7	3.6
LSD (0.05)	0.3	2.9	1.2	0.04	0.05	0.03	0.04	0.02	2.0

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Results presented in Table 1.1a shows that the organic materials (CRH, CPH, CP and SD) had slightly alkaline properties with pH ranging from 6.2- 9.6. The pH of biochar made from rice husk had a pH of 9.5 which was significantly higher ($p<0.05$) than CPH, CP and SD. The pH of the soil only was slightly acidic (5.9) and the addition of the organic based media increased the pH of the soil to slightly alkaline with the soil based media recording pH ranging from 7.2- 7.7 except for S + CP which recorded a value of 5.9.

The results also showed that % K, % Ca, % Mg. % N of the organic material based growing medium was relatively higher than the soil only treatment, except for % P (Table 1.1a).

Table 1.1b. Some selected chemical properties of growing media.

Growing Media	CEC (cmol/kg)	NH_4 (mg/kg)	NO_3 (mg/kg)
S	6.2	705.6	316.8
CRH	6.3	662.4	403.2
CPH	6.0	648.0	676.8
CP	8.3	734.4	237.6
SD	5.4	763.2	424.8
S+CRH	13.6	669.6	396.0
S+CPH	8.3	698.4	482.4
S+CP	9.2	676.8	288.0
S+SD	16.7	612.0	230.4
CRH+CPH	12.5	784.8	338.4
CRH+CP	11.5	734.4	295.2
CRH+SD	4.0	691.2	352.8
CPH+CP	6.5	835.2	367.2
CPH+SD	5.9	691.2	475.2
CP+SD	6.2	511.2	144.0

The highest CEC was recorded in S+SD, S+CRH, CRH+CPH and CRH+CP (16.7 cmol/kg, 13.6 cmol/kg, 12.5 cmol/kg and 11.5 cmol/kg respectively). The SD and CRH significantly ($p<0.05$) increased the CEC of soil than the other organic based media (Table 1.1b). The results show that NH_4-N fraction did not differ among the growing media however, NO_3-N fraction differed

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among the growing media with CPH recording the highest (676.8 mg/kg) as against soil which recorded 316.8 mg/kg. Addition of CPH increased then NO_3-N fraction more than that of CRH, CP and SD, suggesting that the CPH may supply significant amounts to the soil (Table 1.1b).

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4.2.1 Mean germination % of cocoa in the different media, different polybag sizes and their combinations

The mean germination percentage of cocoa on the 10th day after sowing in the different media and polybag sizes are reported in Table 2. Significant differences were observed in the media and the poly bag sizes as well as their interaction.

Media Effect: Type of growing media significantly ($p<0.05$) affected the emergence percentage of cocoa at ten days. Percentage emergence in CP, CPH+CP, CRH+CP and CP+SD were significantly ($p<0.05$) higher than soil. Potting media (CP) was consistently different compared to all treatments recording the highest germination of 88.9% and was 41% higher than soil only. The order of mean emergence percentage decreased as follows: S+CPH>S+CP>S+CRH>S (Table 2).

Poly bag Effect: The different polybag sizes significantly influenced germination of cocoa. Poly bag size 10.0 cm x 35.0 cm produced the highest germination percentage of 80.89 followed by 17.3 cm x 23.3 cm and were significantly ($p<0.05$) higher than the 12.5 cm x 18.5 cm. There was however no significant difference between 10.0 cm x 35.0 cm and 17.3 cm x 23.3 cm polybag sizes.

Interactive Effect: Interaction between polybag size and growing media was significant ($p<0.05$) at 10 days after sowing. The highest germination percentage was recorded by CP in the 10.0 cm x 35.0 cm poly bag size and the lowest was recorded by S in the 12.5 cm x 18.5 cm polybag size. At two weeks after sowing there was no significant difference in the potting media with a 99% germination recorded in all the potting media (Table 2).

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Table 2: Mean germination % of cocoa seedlings in different growing media, different polybag sizes and their interactions.

Germination % at 10 days after sowing

Media	Poly bag size			Mean
	12.5x18.5(cm)	17.3x23.3(cm)	10.0x35.0(cm)	
S	35.0	43.3	63.3	47.2
CRH	80.0	80.0	81.7	80.6
CPH	68.3	93.3	80.0	80.6
CP	85.0	85.0	96.7	88.9
SD	66.7	81.7	85.0	77.8
S+CRH	38.3	45.0	60.0	47.8
S+CPH	50.0	56.7	60.0	55.6
S+CP	41.7	41.7	60.0	47.8
S+SD	66.7	81.7	85.0	87.2
CRH+CPH	81.7	85.0	88.3	85.0
CRH+CP	81.7	76.7	86.7	81.7
CRH+SD	68.3	58.3	86.7	71.1
CPH+CP	83.3	88.3	91.7	87.8
CPH+SD	78.3	76.7	92.0	82.2
CP+SD	83.3	83.3	93.3	88.3
Mean	68.6	72.4	80.9	

LSD ($P \leq 0.05$); Media = 5.9
Poly bag size= 2.2
Media*Poly bag size= 8.9

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4.2.2 Mean plant height of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Data on mean plant height of cocoa seedlings in the different media, polybag sizes and their interactive effect are shown in Table 3.

Media effect: Seedling height was significantly affected by the type of growth media used. Seedling height in growing media S+CRH and S+CPH were significantly ($p<0.05$) higher compared to S only.

At the 6th month, the highest plant height (63.9cm) was recorded in S+CRH and the lowest plant height (33.2 cm) was recorded in SD. There was however no significant difference between S+CRH and S+CPH. In the soilless media mix, the highest seedling height was recorded in CPH+CP and this was significantly different ($p<0.05$) form the other soilless media mix except CRH+CPH (Table 3).

Polybag effect: The results in table 3 show that mean plant height of seedlings sown in 10.0 cm x 35.0 cm and 17.3 cm x 23.3 cm were significantly ($p<0.05$) higher than 12.5 cm x 18.5 cm poly bag size. There was however no significant difference ($p<0.05$) in seedling height between 10.0 cm x 35.0 cm and 17.3 cm x 23.3cm polybag sizes.

Interactive Effect: The interaction between growing media and poly bag size was significant ($p<0.05$). S + CRH media mix in 10.0 cm x 35.0 cm polybag size recorded the highest plant height of 65.5 cm and 77.1 cm in the third and sixth month respectively (Table 3). This was significantly ($p< 0.05$) higher than all the other treatments. Plants grown in SD in 12.5 cm x 18.5 cm poly bag size recorded the lowest plant height of 30.6 cm. In the soilless media mix the highest seedling height was recorded in CPH+CP media mix in the 10.0 cm x 35.0 cm poly bag size and this was significantly ($p<0.05$) higher than the other soilless media mix (Table 3).

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Table 3: Mean plant height (cm) of cocoa seedlings in different plant media, different polybag sizes and their interactions at three and six months after sowing.

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0(cm)		12.5x18.5	17.3x23.3	10.0x35.0	
S	35.5	59.3	50.1	48.3	44.8	69.5	65.4	59.9
CRH	31.3	37.7	46.8	38.6	36.6	43.3	48.1	42.7
CPH	23.7	25.5	29.3	26.1	33.0	37.6	39.3	36.6
CP	30.2	22.0	33.8	28.7	38.0	38.6	39.2	38.6
SD	25.1	25.7	36.0	28.9	30.6	31.5	37.6	33.2
S+CRH	49.8	65.5	47.5	54.3	49.3	77.1	64.8	63.9
S+CPH	46.1	50.7	41.7	46.2	51.9	69.2	67.5	62.9
S+CP	37.2	50.3	53.5	47.0	41.07	57.1	54.5	50.9
S+SD	33.3	45.6	43.7	40.9	47.17	48.8	55.2	50.4
CRH+CPH	32.1	33.9	37.2	34.4	42.23	41.0	46.2	43.1
CRH+CP	26.4	27.8	26.7	27.0	36.6	37.2	37.1	36.9
CRH+SD	29.8	26.3	30.1	28.7	33.9	36.9	33.0	34.6
CPH+CP	34.4	26.3	55.5	38.8	40.2	39.7	53.2	44.3
CPH+SD	22.3	25.8	30.7	26.3	38.8	41.8	39.5	40.0
CP+SD	23.1	29.3	35.5	29.3	36.0	35.4	37.2	36.2
Mean	32.0	36.8	39.9		40.1	47.0	47.9	

LSD ($P \leq 0.05$); Media = 2.9   1.9
Poly bag size= 1.5   1.0
Media*Poly bag size= 5.6   3.8

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4.2.3 Mean plant girth of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Mean plant girth of the cocoa seedlings in the different media and polybag sizes are reported in Table 4.

Media Effect: High plant girth were recorded in S+ CRH, S+CP, S and S+CPH (1.26 mm, 1.18 mm, 1.17 mm and 1.16 mm respectively) (Table 4). There was no significant difference ($p<0.05$) between S+CRH, S+CP, S and S+CPH. The order of mean plant girth also decreased as follows: CRH+CPH> CP+SD> CPH CRH+SD>SD (0.94mm, 0.90mm, 0.81mm, 0.80mm and 0.69mm respectively).

Poly bag Effect: The results show that mean plant girth of seedlings grown in 10.0 cm x 35.0 cm and 17.3 cm x 23.3 cm were significantly ($p<0.05$) higher than those grown in 12.5 cm x 18.5 cm poly bag size. There was however no significant difference ($p<0.05$) between poly bag sizes 10.0 cm x 35.0 cm and 17.3 cm x 23.3 cm (Table 4).

Interactive Effect: The interaction between growing media and poly bag size was significant ($p<0.05$). The thickest mean plant girth (1.47mm) was recorded in S + CRH media mix in the 10.0 cm x 35.0 cm polybag size. This was not significantly different ($p< 0.05$) compared to S+CPH and S which recorded mean plant girth of 1.43 mm and 1.37 mm. The lowest plant girth of 0.63 mm was recorded by SD in the 12.5 cm x 18.5 cm (Table 4).

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Table 4: Mean plant girth (mm) of cocoa seedlings in different plant media, different polybag sizes and their interaction at three and six months after sowing.

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	0.7	0.9	0.8	0.8	1.0	1.4	1.2	1.2
CRH	0.7	0.7	0.7	0.7	1.0	1.1	1.2	1.1
CPH	0.5	0.6	0.7	0.6	0.8	0.8	0.8	0.8
CP	0.6	0.6	0.9	0.7	0.9	0.8	1.2	0.9
SD	0.6	0.6	0.7	0.6	0.7	0.6	0.8	0.7
S+CRH	0.7	1.0	0.9	0.9	1.0	1.4	1.5	1.3
S+CPH	0.8	0.9	0.8	0.9	0.9	1.4	1.2	1.2
S+CP	0.7	0.9	0.8	0.8	1.0	1.3	1.2	1.2
S+SD	0.6	0.8	0.8	0.7	1.0	1.2	1.0	1.0
CRH+CPH	0.6	0.7	0.7	0.7	0.8	1.0	1.2	0.9
CRH+CP	0.6	0.8	0.7	0.7	0.8	1.1	1.2	1.0
CRH+SD	0.7	0.6	0.7	0.6	0.7	0.9	0.8	0.8
CPH+CP	0.8	0.7	0.9	0.8	1.0	1.0	1.2	1.0
CPH+SD	0.5	0.7	0.6	0.6	0.9	1.2	1.0	1.0
CP+SD	0.7	0.6	0.6	0.6	0.9	0.9	0.9	0.9
Mean	0.7	0.8	0.8		0.8	1.1	1.1	

LSD ($P \leq 0.05$); Media = 0.06   0.13
Poly bag size= 0.03   0.06
Media*Poly bag size= 0.11   0.22

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4.2.4 Mean number of leaves of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Mean number of leaves per plant of the cocoa seedlings in the different growing media, different polybag sizes and their interaction are shown in Table 5.

Media effect: The highest number of leaves per plant was recorded in S+CPH (23.9) and this was not significantly ($p<0.05$) higher than S+CRH. It was however significantly ($p<0.05$) higher than S, S+CP S+SD and all the other treatments. The lowest number of leaves was recorded by CRH+CP. In the soilless media mix, the highest number of leaves per plant (19.3) was recorded in CPH+CP and this was the same as the mean number of leaves per plant recorded by S+SD (Table 5).

Polybag effect: The results showed that mean number of leaves per plant grown in 10.0 cm x 35.5 cm and 17.3 cm x 23.3 cm were significantly ($p<0.05$) higher than 12.5 cm x 18.5 cm poly bag size. There was however no significant difference ($p<0.05$) between poly bag sizes 10.0 cm x 35.0 cm and 17.3 cm x 23.3 cm (Table 5).

Interactive effect: The highest number of leaves of 27.7 was recorded at 6 months in 17.3 cm x 23.3 cm poly bag size filled with S+CRH. This was not significantly different from seedlings grown in 10.0 cm x 35.0 cm filled with S+ CPH. The lowest number of leaves of 7.7 was produced by seedling grown in 12.5 cm x 18.5 cm filled with SD. In the soilless media mix, the highest number of leaves (19.3) was recorded in CRH + CPH and CPH + CP in 10.0cm x 35.0 cm poly bag size and this was significantly different from the other soilless media mix.

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Table 5: Mean number of leaves per plant of cocoa seedlings in different plant media, different poly bag sizes and their interaction at three and six months after sowing

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	15.7	24.3	19.7	19.9	17.0	22.7	21.3	20.3
CRH	11.0	15.0	15.0	13.7	11.0	16.7	17.3	15.0
CPH	9.0	9.7	13.0	10.6	10.3	14.7	11.7	12.2
CP	9.3	5.7	15.0	10.0	11.0	11.3	16.7	13.0
SD	4.3	9.3	9.3	7.7	7.7	11.7	11.7	10.3
S+CRH	18.3	23.7	18.3	20.1	20.7	27.7	20.0	22.8
S+CPH	19.7	23.0	19.3	20.7	19.7	25.3	26.7	23.9
S+CP	13.3	19.7	19.3	17.4	16.3	22.3	22.0	20.2
S+SD	11.7	19.0	150	15.2	14.7	21.7	21.7	19.3
CRH+CPH	9.3	9.3	11.3	10.0	9.3	13.3	22.3	15.0
CRH+CP	6.3	8.0	6.3	6.9	8.3	12.7	8.3	9.8
CRH+SD	9.0	8.3	9.3	8.9	9.3	13.0	9.3	10.6
CPH+CP	13.7	6.3	24.0	14.7	14.3	21.3	22.3	19.3
CPH+SD	6.7	12.0	11.7	10.1	10.7	21.3	18.0	16.7
CP+SD	8.0	8.3	10.7	9.0	11.7	11.7	13.0	12.1
Mean	11.0	13.4	14.5		12.8	17.8	17.5	
LSD ($P \leq 0.05$);	Media = 1.7				1.9			
	Poly bag size= 0.8				0.8			
	Media*Poly bag size= 2.9				3.1			

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4.3 Dry matter production (shoot and root dry weight) of cocoa seedlings grown in different growing media and different polybag sizes and their interaction atthree and six months after sowing

The growing media affected significantly ($p<0.05$) the dry matter production of cocoa seedlings at the sixth month stage. The highest shoot dry weight, root dry weight and total plant dry weight were recorded in S+CPH, S+CP and S+CPH respectively. The highest dry matter of 22.5 g/plant was observed in plants grown in S+CP as compared to soil only (S) which recorded 19.9 g/plant. The interaction between growing media S+CPH and poly bag size 17.3 cm x 23.3 cm recorded the highest total plant dry weight of 35.7 g/plant as compared to soil only (S) which recorded 29.5 g/plant. However, the total dry matter weight of S+CPH was not significantly ($p<0.05$) different from S+CRH which recorded total dry matter of 34.3 g/plant (Table 9).

The partitioning of dry matter to the shoot and root was also influenced by the potting media. The influence of the growing media on shoot dry weight was also significant with growing media, S+CPH recording the highest shoot dry weight of 17.32 g/plant as compared to soil only which recorded 15.9 g/plant (Table 10). The interaction between growing media S+CPH and poly bag size 17.3 cm x 23.3 cm recorded the highest total shoot dry weight of 29.3 g/plant as compared to the 22.9 g/plant recorded by soil in the 17.3 cm x 23.3 cm poly bag size. The root produced by S+CP recorded the highest dry weight of 5.7 g/plant as compared to soil only which recorded a root dry weight of 4.9 g/plant (Table 6).

The interaction between growth media CP and poly bag size 10.0 cm x 35.0 cm was significant ($p<0.05$). The root dry weight of cocoa seedlings that grew in CP were significantly higher than those that grew in soil with growth media CP recording 8.3 g/plant as compared to the 6.2 g/plant recorded by soil only treatment.

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The different polybag sizes significantly influenced dry matter production and partitioning to the shoot and root. Increasing poly bag size consistently increased the dry matter production of the cocoa seedlings.

At third month, soil and carbonated rice husk mixture recorded the highest plant height of 65.0 cm and this increased to 77.0 cm in the sixth month (Table 3). The height, girth and number of leaves did not differ significantly ($p<0.05$) between soil/carbonated rice husk mixture and soil/cocoa pod husk mixture. The pattern was similar at sixth month for all the recorded parameters.

Plant height, girth and dry matter weights showed significant differences among the treatments.

It was observed that poly bag size had significant influence on root length of seedlings, root length of seedlings decreased drastically with reducing polybag size. Root length was longest in the 10.0 cm x 35.0 cm sized polybag size and differed significantly ($p<0.05$) from the roots of the 12.5 cm x 18.5 cm sized polybag.

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4.3.1 Mean leaf dry weight of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Mean dry leaf weight of cocoa seedlings in the different growth media, different polybag sizes and their interaction are presented in Table 6.

Media effect: The highest leaf dry weight was recorded in plants grown in S+CPH followed by S+CRH and this was significantly different ($p<0.05$) from those grown in soil. The order of mean leaf dry weight decreased as follows: CP>CRH+CP>CPH>CRH+SD>SD.

Polybag effect: The results show that mean leaf dry weight of seedlings grown in the 17.3 cm x 23.3 cm and 10.0 cm x 35.0 cm poly bag sizes were significantly ($p<0.05$) higher than those in 12.5 cm x 18.5 cm polybag size.

Interactive effect: Significant ($P<0.05$) interaction was observed between the growth media and polybag sizes. S+CPH in 17.3 cm x 23.3 cm recorded the highest leaf dry weight of 15.1 g/plant. This was significantly ($p<0.05$) higher than all the other interactions excluding S+CRH in 17.3 cm x 23.3 cm that recorded 13.5 g/plant (Table 6). Seedlings grown in CRH+CP in 12.5 cm x 18.5 cm polybags recorded the lowest mean leaf dry weight and this was not significantly different from those in CRH+CPH, CRH+SD, SD, CP, CPH and CRH.

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Table 6: Mean leaf dry weight (g) of cocoa seedlings in different plant media, different poly bag sizes and their interaction

Media	3 months				6 months			
	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	2.1	4.3	3.2	3.2	4.7	11.6	5.6	7.3
CRH	1.2	1.1	2.4	1.6	1.7	3.6	4.6	3.3
CPH	1.1	1.2	1.1	1.1	1.3	2.6	2.4	2.1
CP	1.0	0.7	1.8	1.2	1.5	2.1	4.8	2.8
SD	0.7	1.0	0.9	0.9	1.3	1.1	1.9	1.4
S+CRH	2.8	5.7	3.4	3.9	5.2	13.5	5.9	8.2
S+CPH	2.8	2.9	3.1	2.9	5.7	15.1	7.1	9.3
S+CP	3.3	4.0	3.8	3.7	4.3	8.6	7.4	6.8
S+SD	1.7	2.2	2.0	2.0	4.0	5.6	5.1	4.9
CRH+CPH	1.2	0.5	1.4	1.0	1.3	4.6	6.1	4.0
CRH+CP	0.9	1.0	1.2	1.0	0.8	5.2	1.9	2.7
CRH+SD	1.0	0.8	0.8	0.8	1.1	3.0	1.2	1.7
CPH+CP	1.1	0.6	3.0	1.6	3.2	6.3	8.4	5.9
CPH+SD	0.6	0.7	1.0	0.8	2.7	3.9	3.4	3.3
CP+SD	0.8	1.2	0.8	0.9	3.3	3.5	1.9	2.9
Mean	1.5	1.9	2.0		2.8	6.0	4.5	

LSD ($P \leq 0.05$); Media = 0.3 | 1.3
Poly bag size= 0.1 | 0.5
Media*Poly bag size= 0.5 | 2.1

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4.3.2Mean stem dry weight of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

The mean stem dry weight of cocoa seedlings in the different media, different polybag sizes and their interaction are presented in Table 7.

Media effects: The type of potting media significantly affected mean stem dry weight. The highest stem dry weight was recorded by plants grown in S+CP and this was significantly different from all other treatments. The order of mean stem dry weight decreased as follows: CP+SD>CRH+SD>SD>CPH.

Poly bag effects: The results show that mean stem dry weight of seedlings grown in 17.3 cm x 23.3 cm and 10.0 cm x 35.0 cm were significantly ($p<0.05$) higher than those in 12.5 cm x 18.5 cm polybag size.

Interactive effect: The interaction between growth media and size of poly bag was significant ($p<0.05$). The seedlings grown in S+CP in 17.3 cm x 23.3 cm poly bag size recorded the highest mean stem dry weight and this was not significantly ($p<0.05$) different from those of S+CPH, S+CRH and S in the 17.3 cm x 23.3 cm poly bag size. The lowest mean stem dry weight was recorded in growth media CPH in 12.5 cm x 18.5 cm polybag size. The stem dry weight of seedlings produced in soilless media CRH+CP in poly bag size 17.3 cm x 23.3 cm and CPH+CP in polybag size 10.0 cm x 35.0 cm recorded stem dry weight of 7.4 g/plant and 6.4 g/plant respectively. This was however significantly higher than the other soilless media (Table 7).

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Table 7: Mean stem dry weight (g) of cocoa seedlings in different plant media, different poly bag sizes and their interaction

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	1.00	2.21	1.95	1.7	5.1	11.7	6.3	7.7
CRH	0.9	1.1	1.2	1.1	3.6	4.9	5.1	4.5
CPH	0.6	0.9	0.8	0.8	0.7	1.0	1.3	1.0
CP	1.0	1.4	1.1	1.2	2.6	1.2	6.1	3.3
SD	0.9	1.3	1.2	1.1	1.6	0.9	1.9	1.5
S+CRH	1.8	2.4	1.5	1.9	5.4	14.0	5.1	8.2
S+CPH	1.8	2.2	1.5	1.8	5.0	14.3	4.8	8.0
S+CP	1.7	1.8	2.0	1.8	5.9	14.3	9.8	10.0
S+SD	1.1	1.8	1.5	1.4	7.2	6.2	5.3	6.2
CRH+CPH	0.7	0.7	1.2	0.8	1.5	4.0	4.8	3.4
CRH+CP	1.0	1.0	1.4	1.1	0.8	7.4	2.1	3.4
CRH+SD	1.3	0.8	1.2	1.1	1.8	2.2	2.1	2.0
CPH+CP	0.9	0.8	1.3	1.0	3.7	3.5	6.4	4.6
CPH+SD	0.6	1.3	1.1	1.0	2.4	3.5	2.5	2.8
CP+SD	0.8	1.3	1.1	1.1	3.7	1.9	1.5	2.4
Mean	1.1	1.4	1.3		3.4	6.1	4.3	

LSD ($P \leq 0.05$); Media = 0.2   1.7

Poly bag size= 0.1   0.7

Media*Poly bag size= 0.4   2.8

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4.3.3 Mean root dry weight of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

The mean root dry weight of cocoa seedlings in the different media, different polybag sizes and their interaction are presented in Table 8.

Media effects: Results in Table 8 shows that the highest mean root dry weight was recorded by seedlings grown in S+CP followed by S+CRH and this was not significantly ($p<0.05$) higher than S and S+CPH. The lowest mean root dry weight was recorded by CPH.

Poly bag effect: The size of poly bag affected the mean root dry weight of cocoa at six months. The highest mean root dry weight was recorded in the 10.0 cm x 35.0 cm polybag size and this was not significantly ($p<0.05$) higher than the 17.3 cm x 23.3 cm polybag size. The 12.5 cm x 18.5 cm polybag size recorded the lowest mean root dry weight (Table 8).

Interactive effect: Data in Table 8 indicates that media and polybag size interaction was significant on the mean root dry weight of the cocoa seedlings. Plant media, CP in the 10.0 cm x 35.0 cm poly bag size recorded the highest mean root dry weight of 8.3 g/plant and this was not significantly different from those in S+CP and S+CRH. However, this was significantly ($p<0.05$) different from S+CP and S. The seedlings grown in soilless media CRH+CP and CPH+CP in poly bag size 17.3 cm x 23.3 cm produced heavier root weight than S+SD and the other soilless growth media (Table 8).

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Table 8: Mean root dry weight (g) of cocoa seedlings in different plant media, different poly bag sizes and their interaction at three and six months after sowing

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	0.6	0.9	1.0	0.8	4.1	6.2	4.4	4.9
CRH	0.8	0.8	1.5	1.1	1.7	3.0	4.2	3.0
CPH	0.4	0.6	0.8	0.6	0.5	0.7	0.7	0.6
CP	1.0	1.0	1.8	1.3	1.9	2.1	8.3	4.1
SD	0.8	1.0	0.8	0.9	1.3	1.1	2.5	1.6
S+CRH	0.8	0.9	1.0	1.0	3.6	6.8	5.4	5.3
S+CPH	0.8	0.7	1.0	0.8	2.3	6.4	4.1	4.3
S+CP	1.1	1.0	2.3	1.5	4.3	6.1	6.8	5.7
S+SD	0.7	0.5	1.1	0.7	3.2	4.7	4.3	4.1
CRH+CPH	0.5	0.5	0.9	0.6	1.2	3.2	3.8	2.8
CRH+CP	1.1	1.0	1.2	1.1	1.3	5.5	1.7	2.8
CRH+SD	0.9	0.8	1.3	1.0	1.4	2.6	2.1	2.0
CPH+CP	0.8	0.6	0.8	0.8	2.4	4.0	4.9	3.8
CPH+SD	0.4	0.7	0.8	0.7	1.3	2.9	2.4	2.2
CP+SD	0.8	1.2	1.1	1.0	3.2	2.5	2.8	2.9
Mean	0.8	0.8	1.2		2.3	3.9	3.9	1.7

LSD ($P \leq 0.05$); Media = 0.2 — 1.1
Poly bag size= 0.1 — 0.4
Media*Poly bag size= 0.3 — 1.7

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4.3.4 Mean dry matter of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

The mean dry matter of cocoa seedlings in the different media, different polybag sizes and their interaction are presented in Table 9.

Media effect: The growth media significantly ($p<0.05$) affected dry matter production of the cocoa seedlings. The highest mean dry matter (22.5 g/plant) was produced in S+CP and the lowest total dry matter (3.7 g/plant) was recorded by CPH. There was however no significant difference between S+CP, S+CRH and S+CPH. The order of total plant weight in the soilless media mix also decreased as follows:

CPH+CP>CRH+CPH>CRH+CP>CPH+SD>CP+SD>CRH+SD (Table 9).

Poly bag effect: The highest mean dry matter weight was recorded in the 17.3 cm x 23.3 cm polybag size and was not significantly ($p<0.05$) higher than the 10.0 cm x 35.0 cm polybag size. The 12.5 cm x 18.5 cm polybag sizes recorded the lowest mean root dry weight (Table 9).

Interactive effect: The highest total dry matter was recorded by seedlings grown in S+CPH in the 17.3 cm x 23.3 cm poly bag size and this was significantly ($p<0.05$) higher than S. The order of total dry matter increased as follows: S+SD <S < S+ CP< S+CRH<S+CPH. The lowest dry matter was recorded by SD in the 17.3 cm x 23.3 cm polybag size (Table 9). In general, the total plant dry matter of cocoa seedlings in the interaction of soil based media mix and poly bag size recorded the highest weight and they were significantly heavier than those grown in the soilless media mix (Table 9).

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Table 9: Mean dry matter weight (g) of cocoa seedlings in different plant media, different poly bag sizes and their interaction

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	3.7	7.5	6.1	5.7	13.9	29.5	16.4	19.9
CRH	2.9	3.0	5.2	3.7	7.0	11.5	13.9	10.8
CPH	2.1	2.8	2.7	2.5	2.5	4.3	4.3	3.7
CP	3.1	3.1	4.8	3.7	6.0	5.4	19.1	10.2
SD	2.4	3.2	2.9	2.9	4.2	3.1	6.3	4.5
S+CRH	5.5	8.9	6.1	6.8	14.2	34.3	16.3	21.6
S+CPH	5.4	5.8	5.6	5.6	13.0	35.7	16.0	21.6
S+CP	6.1	6.8	8.0	7.0	14.6	29.0	23.9	22.5
S+SD	3.4	4.5	4.5	4.1	14.4	16.5	14.7	15.2
CRH+CPH	2.3	1.7	3.5	2.5	4.1	11.8	14.7	10.2
CRH+CP	3.0	3.1	3.8	3.3	2.9	18.2	5.7	8.9
CRH+SD	3.1	2.3	3.2	2.9	4.3	7.8	5.3	5.8
CPH+CP	2.8	2.0	5.1	3.3	9.3	13.8	19.7	14.3
CPH+SD	1.6	2.8	2.9	2.4	6.3	10.3	8.3	8.3
CP+SD	2.4	3.7	3.0	3.0	10.2	7.9	6.3	8.1
Mean	3.3	4.1	4.5		8.5	16.0	12.7	

LSD ($P \leq 0.05$); Media = 0.4 | 3.6
Poly bag size= 0.3 | 1.4
Media*Poly bag size= 0.9 | 5.5

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4.3.5Mean shoot weight of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

The mean shoot weight of cocoa seedlings in the different media, different polybag sizes and their interaction are presented in Table 10.

Media effect: Results in Table 10 indicates that the growth media affected the total shoot dry weight of cocoa seedlings. The highest total shoot weight of 17.3 g was recorded by S+CPH which was followed by S+CP recording a total shoot dry weight of 16.8 g. The lowest shoot dry weight of 2.9 g was recorded by SD and was not significantly different from CPH, CP, CRH+CP, CRH+SD, CRH+CP, CPH+SD and CP+SD. However, seedlings grown in CPH+CP produced higher shoot weight than the other soilless media (Table 10).

Poly bag effect: The highest mean shoot dry weight was recorded in the 17.3 cm x 23.3 cm polybag size and this was not significantly ($p<0.05$) higher than the 10.0 cm x 35.0cm polybag size. The 12.5 cm x 18.5 cm polybag size recorded the lowest mean dry shoot weight (Table 10).

Interactive effect: Significant ($p<0.05$) interaction was observed between the plant media and the polybag sizes (Table 10). The highest dry shoot weight of 29.3 g was recorded by S+CPH in the 17.3 cm x 23.3 cm poly bag size and this was significantly ($p<0.05$) higher than S. There was however, no significant difference between S+CPH and S+CRH. The lowest dry shoot weight was recorded by SD and their combinations and this was not significantly different from CPH, CP, CPH+SD and CP+SD.

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Table 10: Mean shoot weight (g) of cocoa seedlings in different plant media, different poly bag sizes and their interaction at three and six month after sowing

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	3.1	6.5	5.1	4.9	10.3	22.9	11.9	15.0
CRH	2.1	2.2	3.7	2.6	5.3	8.5	9.7	7.8
CPH	1.7	2.2	2.0	1.9	2.0	3.6	3.6	3.1
CP	2.1	2.1	3.0	2.4	4.2	3.3	10.8	6.1
SD	1.6	2.2	2.1	2.0	2.9	2.0	3.8	2.9
S+CRH	4.7	8.0	4.8	5.8	10.6	27.5	10.9	12.4
S+CPH	4.6	5.1	4.6	4.8	10.7	29.3	11.9	17.3
S+CP	5.0	5.8	5.7	5.5	10.2	22.9	17.1	16.8
S+SD	2.7	4.0	3.5	3.4	11.2	11.8	10.4	11.1
CRH+CPH	1.9	1.2	2.6	1.9	2.8	8.6	10.9	7.4
CRH+CP	1.9	2.1	2.6	2.2	1.6	12.7	4.0	6.1
CRH+SD	2.3	1.6	2.0	1.9	5.0	7.4	5.9	3.8
CPH+CP	2.0	1.4	4.3	2.6	6.9	9.8	14.8	10.5
CPH+SD	1.2	2.0	2.1	1.8	5.0	7.4	5.9	6.1
CP+SD	1.6	2.5	1.9	2.0	7.0	5.4	3.4	5.3
Mean	2.6	3.3	3.3		6.2	12.1	8.8	

LSD ($P \leq 0.05$); Media = 0.3 2.5
Poly bag size= 0.2 1.1
Media*Poly bag size= 0.7 4.2

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4.3.6 Mean shoot /root ratio of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Data on the mean shoot/root ratio of cocoa seedlings in the different growth media, polybag size and their interactions are presented in Table 11.

Media effect: Seedlings in CPH recorded the highest shoot/root ratio and this was significantly ($p<0.05$) higher than all other treatments. No significant differences ($p<0.05$) were recorded between S+CPH, S+CRH and S as well as between S+SD, CRH+CPH, CPH+CP and CPH+SD. The lowest shoot/root ratio was recorded by CP (Table 11).

Poly bag effect: The results show that no significant differences were recorded between the poly bag sizes, 17.3 cm x 23.3 cm, 10.0cm x 35.0 cm and 12.5 cm x 18.5 cm (Table 11).

Interactive effect: Growth media and poly bag size interaction was significant at $p<0.05$. The growing medium CPH and poly bag size 17.3 cm x 23.3 cm recorded the highest shoot/root ratio (6.11) and this was significantly ($p<0.05$) higher than all other treatments. There was however no significant difference among S+CPH, S+CRH, S+SD, S and CPH+SD. The lowest shoot/root ratio was recorded in CP and poly bag size 10.0 cm x 35.0 cm (Table 11).

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Table 11: Mean shoot/root ratio of cocoa seedlings in different plant media, different poly bag sizes and their interaction at three and six months after sowing

	3 months				6 months			
	Poly bag size				Poly bag size			
Media	12.5x18.5	17.3x23.3	10.0x35.0	Mean	12.5x18.5	17.3x23.3	10.0x35.0	Mean
S	4.8	7.3	5.4	5.8	2.6	3.7	2.7	3.0
CRH	2.5	3.1	2.4	2.7	3.1	2.8	2.4	2.8
CPH	4.1	3.6	3.0	3.6	4.3	6.1	5.3	5.2
CP	2.1	2.0	1.6	1.9	2.2	1.6	1.3	1.7
SD	2.0	2.2	2.6	2.3	2.4	1.7	1.6	1.9
S+CRH	5.7	8.8	3.9	6.1	3.1	4.0	2.1	3.1
S+CPH	5.8	7.6	4.6	6.0	4.6	4.6	3.0	4.1
S+CP	4.7	5.5	2.6	4.3	2.4	3.9	2.5	2.9
S+SD	4.2	7.8	3.3	5.1	3.5	2.5	2.4	2.8
CRH+CPH	4.0	2.3	2.8	3.0	2.3	2.9	2.9	2.7
CRH+CP	1.8	2.0	2.1	2.0	1.2	2.3	2.4	2.0
CRH+SD	2.6	2.1	1.5	2.1	2.2	2.0	1.7	1.9
CPH+CP	2.6	2.3	5.6	3.5	3.1	2.4	3.0	2.8
CPH+SD	3.1	2.8	2.6	2.8	4.0	3.0	2.4	3.2
CP+SD	2.1	2.1	1.7	2.0	2.2	2.1	1.4	1.9
Mean	3.5	4.1	3.1		2.9	3.1	2.5	

LSD ($P \leq 0.05$); Media = 0.7 0.7

Poly bag size= 0.3 0.3

Media*Poly bag size= 1.2 1.3

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4.3.7 Mean leaf area (cm^2) of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Table 12 shows data on the leaf area of the cocoa seedlings in the growing media, polybag size and their interactions.

Media effect: The type of potting media significantly affected the leaf area of the cocoa seedlings. The leaf area of the cocoa seedlings grown in S+CPH produced the highest leaf area of 181.8 cm^2. This was significantly higher than all the other growth media excluding S. There was however no significant difference between S+CRH, S+CP, S+SD and CPH+CP. The lowest leaf area (58.8 cm^2) was recorded in SD (Table 12).

Poly bag effect: The size of poly bag affected the mean leaf area of cocoa seedlings at six months. The highest mean leaf area was recorded in the 17.3 cm x 23.3 cm polybag size and this was significantly ($p<0.05$) higher than the 10.0 cm x 35.0 cm polybag size. The 12.5 cm x 18.5 cm polybag size recorded the lowest mean leaf area (Table 12).

Interactive effect: Significant ($p<0.05$) interaction was observed between the plant media and the polybag sizes. The highest leaf area of 268.7 cm^2 was recorded by S+CPH in 17.3 cm x 23.3 cm poly bag size and this was significantly ($p<0.05$) higher than all the other media except S which recorded a leaf area of 242.9 cm^2. The leaf area of cocoa seedlings that grew in S in 17.3 cm x 23.3 cm poly bag was also significantly larger than those that grew CRH+CPH in 17.3 cm x 23.3 cm poly bag size. The lowest leaf area was recorded by CRH+CPH in 12.5 cm x 18.5 cm polybag size and this was not significantly different from CRH+CP and SD (Table 12).

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Table 12: Mean leaf area (cm^2) of cocoa seedlings in different growth media, different poly bag sizes and their interactions

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5x18.5	17.3x23.3	10.0x35.0		12.5x18.5	17.3x23.3	10.0x35.0	
S	60.8	63.3	97.6	73.9	142.6	242.9	125.3	170.3
CRH	97.4	54.4	61.7	71.2	105.2	139.1	131.4	125.2
CPH	122.0	80.5	96.2	99.6	112.1	110.8	109.8	110.9
CP	52.0	32.3	50.9	45.1	68.1	60.1	131.0	86.4
SD	45.1	48.7	43.9	45.9	62.5	54.4	59.6	58.8
S+CRH	77.0	102.7	109.3	96.3	101.3	187.2	114.8	134.4
S+CPH	59.1	101.0	93.3	84.5	122.7	268.7	154.1	181.8
S+CP	54.7	60.0	72.6	62.4	116.9	125.1	150.3	130.8
S+SD	61.4	56.5	56.4	58.1	152.3	169.7	125.6	149.2
CRH+CPH	107.4	83.4	161.2	117.4	48.9	182.8	144.3	125.3
CRH+CP	47.9	49.1	51.7	49.6	52.1	102.6	101.2	85.3
CRH+SD	48.3	48.6	55.3	50.7	56.0	114.2	99.9	90.1
CPH+CP	102.2	100.6	85.4	96.1	103.4	131.7	166.1	133.7
CPH+SD	130.7	90.2	107.1	109.3	117.8	97.2	144.9	119.7
CP+SD	49.3	60.8	49.7	53.3	85.2	104.4	88.1	92.2
Mean	75.1	68.1	79.5		96.4	139.3	123.2	

LSD ($P \leq 0.05$); Media =7.5 10.7
Poly bag size= 5.1 4.5
Media*Poly bag size= 17.8 17.6

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4.3.8 Mean root length (cm) of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Significant differences were observed in the effects of growth media, polybag size and their interactions on the mean root length (cm) of cocoa seedlings as reported in Table 13.

Media effect: The type of potting media significantly affected the mean root length of the cocoa seedlings. The growing media S+CP, CPH+CP and CP resulted in significantly ($p<0.05$) higher root length of cocoa seedlings than S+CPH, S and S+CRH. The longest root length was observed in S+CP, this was significantly higher than S+CPH and S+CRH and the root length of S+CPH was also significantly higher than S+CRH. The root length of CPH+SD was the lowest (17.5 cm) and this was not significantly different from SD, CPH and CRH (Table 12).

Poly bag effect: The size of poly bag significantly affected the root length of cocoa seedlings. The 10.0 cm x 35.0 cm polybag size produced significantly ($p<0.05$) longer root length than the 17.3 cm x 23.3 cm and 12.5 cm x 18.5 cm poly bag sizes. The root length of seedlings in the 17.3 cm x 23.3 cm poly bag size was also significantly ($p<0.05$) higher than those in 12.5 cm x 18.5 cm polybag size (Table 12).

Interactive effect: Significant ($p<0.05$) interaction was observed between the plant media and the polybag sizes. The seedlings grown in S+CRH and the 10.0 cm x 35.0 cm poly bag size produced the longest root length (38.8 cm) and this was not significantly ($p<0.05$) different from S+CPH and CP in 10.0 cm x 35.0 cm poly bag size. The interaction between S, S+SD, CPH+CP, CRH+SD, CP+SD and the 10.0 cm x 35.0 cm poly bag size was the same and these were significantly different from the interaction between CRH, CPH, SD, CPH+SD and the poly bag size 10.0 cm x 35.0 cm. The shortest root lengths were observed in the interaction between S+SD and SD and the 12.5 cm x 18.5 cm poly bag size (Table 12).

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Table 12: Mean root length (cm) of cocoa seedlings in different plant media, different poly bag sizes and their interactions

	3 months				6 months			
Media	Poly bag size			Mean	Poly bag size			Mean
	12.5 x18.5	17.3 x23.3	10.0 x35.0		12.5x18.5	17.3x23.3	10.0 x35.0	
S	14.5	23.6	16.5	18.2	16.4	20.9	35.1	24.1
CRH	17.8	18.1	28.4	21.5	14.5	18.3	24.8	19.2
CPH	12.3	20.5	20.9	17.9	15.0	18.2	24.9	19.3
CP	14.4	17.1	31.3	21.0	20.9	26.1	37.1	28.0
SD	15.0	16.6	24.1	18.6	14.2	13.6	30.0	19.3
S+CRH	18.5	19.2	27.8	21.8	13.8	15.4	38.8	22.7
S+CPH	12.6	17.2	23.0	17.6	21.3	16.5	37.7	25.2
S+CP	17.6	22.6	28.3	22.9	13.2	19.5	24.9	29.2
S+SD	19.1	23.9	25.1	22.7	10.1	13.3	32.0	18.4
CRH+CPH	12.1	19.3	20.8	17.4	15.6	19.9	30.0	21.8
CRH+CP	22.0	20.2	14.4	18.9	19.2	20.8	27.7	22.6
CRH+SD	16.5	21.7	27.9	22.0	14.4	23.1	33.0	23.5
CPH+CP	11.5	15.7	13.6	13.6	25.4	27.1	33.5	28.7
CPH+SD	11.8	14.9	28.3	18.3	10.9	15.7	25.8	17.5
CP+SD	24.6	21.2	20.2	22.0	15.3	16.0	34.5	22.0
Mean	16.2	18.8	23.9		16.0	19.0	31.3	

LSD ($P \leq 0.05$); Media = 2.2 2.2
Poly bag size= 1.0 1.0
Media*Poly bag size= 3.8 3.6

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4.3.9 Mean relative growth rate of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Data on the mean relative growth rate of cocoa seedlings in the different growth media, polybag size and their interactions are presented in Table 13.

Media effect: The type of potting media significantly ($p<0.05$) affected the relative growth rate of the cocoa seedlings between the 3rd and 6th months. Plants in the growth media CPH+CP recorded a maximum relative growth rate of 0.4976 and this was significantly ($p<0.05$) different from those grown in soil only which recorded a relative growth rate of 0.4035 (Table 13).

Poly bag effect: The size of poly bag significantly affected the relative growth rate of cocoa seedlings. The 17.3 cm x 23.3 cm poly bag size produced significantly ($p<0.05$) higher relative growth rate than the 10 cm x 35 cm and 12.5 cm x 18.5 cm poly bag sizes. The relative growth rate recorded in 17.3 cm x 23.3 cm was 0.4063 as compared to the 0.3160 recorded in the 10 cm x 35 cm poly bag size (Table 13).

Interactive effect: Significant ($p<0.05$) interaction was observed between the plant media and the polybag sizes. The growth media, CPH+CP and 17.3 cm x 23.3 cm poly bag size recorded the highest relative growth rate of 0.6326 and this was not significantly different ($p<0.05$) from CRH+CPH, S+CPH and CRH+CP in 17.3 cm x 23.3 cm poly bag sizes. The lowest relative growth rate of 0.0575 was recorded by potting media, CPH in the 12.5 cm x 18.5 cm poly bag size. The order of mean relative growth rate decreased as follows: CRH+CPH>SD>CRH+SD>CPH>CRH+CP (Table 13).

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Table 13: Mean relative growth rate of cocoa seedlings in different plant media, different poly bag sizes and their interaction on cocoa seedlings

RELATIVE GROWTH RATE OF COCOA SEEDLINGS IN DIFFERENT MEDIA AND POLYBAG SIZES

Media	Poly bag size			MEAN
	10cmx35cm	12.5cmx18.5cm	17.3x23.3cm	
S	0.3	0.4	0.5	0.4
CRH	0.3	0.3	0.5	0.4
CPH	0.2	0.1	0.2	0.1
CP	0.5	0.2	0.2	0.3
SD	0.3	0.2	0.1	0.1
S+CRH	0.3	0.3	0.5	0.4
S+CPH	0.4	0.3	0.6	0.4
S+CP	0.4	0.3	0.5	0.4
S+SD	0.4	0.5	0.4	0.4
CRH+CPH	0.5	0.2	0.6	0.4
CRH+CP	0.1	0.01	0.6	0.2
CRH+SD	0.1	0.1	0.4	0.2
CPH+CP	0.4	0.4	0.6	0.5
CPH+SD	0.3	0.5	0.4	0.4
CP+SD	0.2	0.5	0.3	0.3
Mean	0.3	0.3	0.4	

LSD ($P \leq 0.05$); Media = 0.09
Poly bag size= 0.04
Media*Poly bag size= o.16

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4.3.10 Mean leaf weight ratio of cocoa seedlings in different growth media, different poly bag sizes and their interaction at three and six months after sowing

Data on the mean leaf weight ratio of cocoa seedlings in the different growth media, polybag size and their interactions are presented in Table 14.

Media effect : The type of potting media significantly ($p<0.05$) affected the leaf weight ratio of cocoa seedlings at three and six months after sowing. At three month after sowing, the potting media S+CPH recorded the highest mean leaf weight ratio of 0.5 and this was significantly($p<0.05$) different from all the other treatments. At the sixth month, S+CPH again recorded the highest mean leaf weight ratio of 0.6 and this was significantly higher than S and S+SD. However, no significant difference was observed among S+CPH, S+CRH and S+CP. The lowest mean leaf weight ratio (0.3) was recorded in SD and CP+SD (Table 14).

Poly bag effect: The leaf weight ratio was not significantly ($p<0.05$) in the 10 cm x 35 cm and the 17.3 cm x 23.3 cm. However, seedlings grown in 12.5 cm x 18.5 cm poly bag size produced the lowest mean leaf weight ratio (Table 14).

Interactive effect: Significant ($p<0.05$) interaction was observed between the growth media and the polybag size. Growth media, S+CPH and poly bag size 17.3 cm x 23.3 cm recorded the highest mean leaf weight ratio of 0.6 and this was not significantly ($p<0.05$) different from S+CRH, S+CP and CPH+CP in 17.3 cm x 23.3 cm poly bag sizes. The lowest mean leaf ratio (0.2) was recorded in CP and CRH+SD in the 12.5 cm x 23.3 cm poly bag. In general, S+CPH, S+CRH and S+CP were consistently significantly different from S and S+SD (Table 14).

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Table 14: Mean leaf weight ratio of cocoa seedlings in different plant media, different poly bag sizes and their interactions

	3 months				6 months			
	Poly bag size (cm)				Poly bag size (cm)			
Media	12.5x18.5	17.3x23.3	10x35	Mean	12.5x18.5	17.3x23.3	10x35	Mean
S	0.4	0.4	0.3	0.4	0.5	0.5	0.6	0.5
CRH	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.4
CPH	0.3	0.3	0.3	0.3	0.4	0.5	0.5	0.5
CP	0.3	0.4	0.3	0.3	0.2	0.3	0.4	0.3
SD	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
S+CRH	0.4	0.4	0.5	0.4	0.5	0.6	0.6	0.6
S+CPH	0.5	0.6	0.6	0.6	0.5	0.6	0.6	0.6
S+CP	0.3	0.3	0.3	0.3	0.5	0.6	0.5	0.5
S+SD	0.3	0.4	0.4	0.3	0.4	0.5	0.5	0.5
CRH+CPH	0.3	0.4	0.4	0.4	0.3	0.5	0.4	0.4
CRH+CP	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
CRH+SD	0.3	0.4	0.2	0.3	0.2	0.3	0.3	0.3
CPH+CP	0.3	0.5	0.4	0.4	0.3	0.4	0.6	0.4
CPH+SD	0.2	0.4	0.4	0.4	0.3	0.4	0.4	0.3
CP+SD	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3
Mean	0.3	0.4	0.4		0.4	0.4	0.4	

LSD ($P \leq 0.05$); Media = 0.050.04

Poly bag size= 0.023 0.012

Media*Poly bag size= 0.09 0.08

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4.3.11 Effects of growing media, poly bag size and their interactive effect on the mean leaf area ratio of cocoa seedlings at three and six month

Significant differences were observed in the planting media, polybag size and their interactions on the leaf area ratio of cocoa seedlings as shown in Table 15.

Media effect: The type of potting media significantly affected the leaf area ratio of cocoa seedlings at 3 months and 6 months after sowing. At 3 and 6 months, the planting media, S+CPH recorded the highest leaf area ratio of 11.9 and 26.8 respectively and was significantly ($p<0.05$) different from all other treatments (Table 14). The order of mean leaf area ratio decreased as follows; S+CPH>S+CRH>S+CP>S>CRH+CPH>CRH+CP>S+SD>CRH>CPH. The lowest leaf area ratio (12.2) was recorded by SD and this was not significantly different ($p<0.05$) from CP+SD (Table 15).

Poly bag effect: At 6 months, leaf area ratio was significantly affected ($p<0.05$) by the different poly bag sizes.The 17.3 cm x 23.3 cm polybag size produced significantly ($p<0.05$) higher leaf area ratio than the 10 cm x 35 cm and 12.5 cm x 18.5 cm poly bag sizes (Table 15).

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Interactive effect: Significant ($p<0.05$) interaction was observed between the plant media and the polybag sizes. The potting media, S+CPH in 17.3 cm x 23.3 cm poly bag size recorded the highest leaf area ratio of 27.9 and the lowest leaf area ratio of 10.5 was recorded in media, SD in 12.5 cm x 18.5 cm poly bag size (Table 15). In general, the seedlings grown in the soil based media mixes produced higher RGR, LWR and LAR than those grown in the sawdust and its mixtures (Table 15).

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Table 15: Mean leaf area ratio of cocoa seedlings in different plant media, different poly bag sizes and their interactions at three and six month after sowing

	3 months				6 months			
	Poly bag size (cm)				Poly bag size (cm)			
Media	12.5x18.5	17.3x23.3	10x35	Mean	12.5x18.5	17.3x 23.3	10 x 35	Mean
S	7.5	9.7	8.3	8.5	19.8	21.3	20.6	20.6
CRH	6.5	7.6	7.1	7.1	17.1	19.9	19.3	18.8
CPH	7.4	8.5	8.5	8.2	17.2	19.1	17.4	17.9
CP	5.4	6.7	6.9	7.3	13.2	17.4	16.2	15.6
SD	5.2	6.5	6.3	6.0	10.5	13.2	12.9	12.2
S+CRH	8.8	10.1	10.1	9.7	22.7	26.0	23.4	24.0
S+CPH	8.6	10.8	12.5	11.9	25.5	27.9	26.8	26.8
S+CP	8.8	10.0	9.1	9.3	21.7	20.7	21.5	21.3
S+SD	6.5	10.0	9.4	8.6	17.6	21.0	20.6	19.1
CRH+CPH	7.3	8.4	8.6	8.1	19.6	20.3	19.6	19.8
CRH+CP	6.1	7.9	7.3	6.5	12.2	13.9	14.9	13.6
CRH+SD	5.6	6.5	6.1	6.1	11.2	17.9	14.1	14.4
CPH+CP	7.6	9.5	8.7	8.6	18.9	20.4	19.8	19.7
CPH+SD	6.2	7.6	7.5	7.1	13.9	17.4	15.0	15.4
CP+SD	5.8	8.1	7.2	7.0	11.2	13.0	12.6	12.2
Mean	7.4	8.2	8.0		16.8	19.4	18.0	

LSD ($P \leq 0.05$); Media = 0.72 — 1.0
Poly bag size= 0.29 — 0.5
Media*Poly bag size= 1.15 — 1.7

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CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of media on the growth of cocoa seedlings

The soil based mixes produced the highest mean leaf weight, stem weight, shoot weight and leaf area of cocoa seedlings compared to soil only. The increase in these parameters is an indication of higher growth. Growth is measured as an increase in length, width, volume, fresh and dry weight of a plant. The results agree with Ogbodo (2009) who reported that plants of greater heights with larger leaf area intercept more sunlight faster which is required for photosynthesis to take place to promote growth than plants with smaller leaf area. The soil based mixes did not only have significant influence on the growth rate of the seedlings but also produced seedlings with a higher shoot and root dry weights. This may be due to the fact that the soil mixes had soil environmental conditions such as ideal pH and electrical conductivity that supported the growth and development of the seedlings.

The addition of rice husk, cocoa pod husk, cocopeat and sawdust to the soil had significant influence on the physical and chemical properties of the top soil (Shamshuddin *et al.*, 2004). In the present study the results show that seedlings grown in the soil and carbonated rice husk and/or cocoa pod husk media mix recorded the highest plant height, girth, leaf, leaf area, shoot dry weight, root dry weight and total dry matter weight as compared to the cocoa seedlings grown in soil only and soilless media. The cause of the difference in growth of the seedlings may be due to the differences in the properties of the media. Some soil properties that enhance plant growth are bulk density, water holding capacity, cation exchange capacity (CEC), porosity,

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organic matter content, pH, total phosphorous , soluble Fe, exchangeable al and exchangeable K and Ca. (FFTC. 2008).

This is in agreement with Bot and Benites (2005), who reported that the addition of organic matter increases CEC and soil pH and decreases soil bulk density. The rice husk significantly reduced the bulk density of the soil due to its lighter weight. This is in agreement with the findings of Chan *et al.*, (2007) who showed that application of biochar improved soil properties such as decreasing bulk density, decreasing soil strength and increasing soil water retention. It also agrees with the findings of Griffin (2008), who reported that density of soil decreased upon application of organic matter to the soil.

In the soil and carbonated rice husk media mix, the rice husk had some influence on the water holding capacity of the soil. This agrees with Chan *et al.*, (2007) who reported that the addition of organic wastes such as rice husk to soils increases soil aggregation and soil water retention which in turn increases the water holding capacity of the soil. Thus, the addition of rice husk or cocoa pod husk to the soil in the media mix decreased the bulk density and increased the organic matter in the media which binds the soil particles together to retain water for better plant growth. The application of organic wastes improves soil structure and soil fertility which provides favourable conditions for plant growth and development. In the present work, the soil based media mix produced seedlings with the longer root length and higher root dry weight than those that grew in soil only or soilless media. This can be attributed to the fact that the organic residues that were added to the soil 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 Graffin (2008) that organic matter such as rice hulls loosens the soil and increases the amount of pore space to support root growth. Thus, the decrease in density leads to an increase in air

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space of the media and subsequently creating adequate pore space for roots to move through the soil to establish an effective feeding mechanism to support the seedling growth and development. The increase in soil porosity and soil water retention enhances the absorption of mineral nutrients, water and air by roots for their development (Ogbodo, 2009). Carbonated rice husk acts as soil conditioner by supplying and retaining nutrients which in turn improves the physical and chemical properties of the soil (Glaser *et al.*, 2002; Lehman and Glaser 2003; Lehmann and Rondon, 2005).

In the present study, the number of leaves, total shoot weight and total dry matter weight of soil and cocoa pod husk media mix were higher 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 cocoa pod husk and kola pod husk as nutrient sources produced a positive effect on cocoa seedlings. Ayanlaja (2002), Adejobi *et al.* (2011) and Moyin-Jesu (2008) reported that the use of organic residues helps in increasing and balancing soil nutrients with consequential increase in crop performance.

Thus adding cocoa pod husk 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 organic matter alters the physical properties of the soil such as increasing soil aggregation, aeration and water holding capacity.

Soil and cocopeat media mix recorded a significant increase in the root and stem dry weight of cocoa seedlings. It was observed from the study that, plants grown in cocopeat and its mixes developed good root system which supported stem growth. The results of many experiments had revealed that cocopeat used alone or as a component of soil medium enhances root development due to its oxygenation properties (Treder and Nowak, 2002). This is in consistent with the

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findings of Howard (1975) who reported that oxygen is needed to stimulate root development of plants in both soilless and soil based medium. The significantly higher root dry weight recorded by soil and cocopeat media mix may have been due to cocopeat having good physical properties such as high water content, low shrinkage, low bulk density and slow biodegradation (Evans *et al.*, 1996; Prasad, 1997). The results showed that cocopeat significantly increased the water holding capacity of the soil and decreased its bulk density. The cocopeat has a lighter weight and low bulk density which decreased soil bulk density and soil strength, thereby improving on soil porosity and at the same time enhancing root development (De Kreij and Leeuven, 2001: Treder and Nowak, 2002). The amount of total porosity of a rooting media is inversely proportional to the bulk density (Richard, 2006).

The incorporation of organic residues into soils significantly improves some properties of the soil namely: decreasing soil bulk density, soil strength as well as exchangeable aluminium and soluble iron and increasing soil pH, soil organic matter, total phosphorous, exchangeable potassium and calcium as well as the cation exchange capacity (Goodman and Ennos, 1999).

5.2 The effect of the different polybag sizes on the growth of the cocoa seedlings

Results from the study showed that polybag size had significant influence on root length development by the cocoa seedlings. Root length of seedlings decreased drastically with reducing polybag sizes. Research has shown that plant height, number of leaves, root and shoot dry weight and whole plant dry weights were increases by poly bag size. Annapurna *et al.*, (2004) has reported similar results that larger containers produce better growth of Santalium album seedlings. This may have resulted from the large volume of growth media which increased nutrient availability as well as nutrient uptake in the larger poly bag size for the

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development of root and primary shoots. A well-developed root system contributes to better uptake of nutrients and water leading to increased formation of proteins, amides, hormones and other organic substances (Singh, 2003).

In the present investigation, the growth parameters namely plant height, plant girth, number of leaves, shoot dry weight and root dry weight was significantly higher in 17.3 cm x 23.3 cm and 10 cm x 35 cm. These sizes provided greater volume of plant media with more nutrients which enhanced vigorous growth of the cocoa seedlings. The increase in plant height, number of leaves and leaf area also improved the rate of photosynthesis which consequently contributed to better growth and this confirms the report of Ouma (2005), who reported that plant height and height of canopy increased with increased container size. Root length was highest in the large sized polybags but differed significantly from the roots of the small sized poly bags only. Studies have shown that smaller poly bag seedlings develop deformed or J- shaped tap root (Cedamon et al., 2005). The seedlings that were raised in the small poly bags had limited space for root growth and this consequently affected general plant growth. Audet and Charest (2010) also reported similar findings in marigold. This may be due to limited space in the smaller poly bags which decreases rooting volume and restricts root growth and this consequently results in reduced plant biomass. The differences in the root length in the various polythene bag sizes may be due to differences in leaf growth and supply of photosynthate to the roots (Adu-Berko *et al*., 2011). It is also reported that better uptake of water and nutrients which enhanced vigorous plant growth was observed in seedlings raised in large bags (Abugre *et al*., 2011). The larger poly bags produce the best performance in plant growth and root length and weight was influenced by poly bag size with the 10cm x 35 cm outperforming the others. Thus, seedlings raised in the 10 cm x 35 cm are more likely to survive on the field than the 12.5 cm x 18.5 cm poly bag size.

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CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

From the experiment conducted, the soil based media mixes significantly supported better growth of cocoa seedlings than the sawdust media mixes. The soil and cocoa pod husk media mix and soil and rice husk media mix were observed to be the best. However, the soil and cocopeat media mix also resulted in better root development as it produced the longest root length and root weight.

The sawdust media only and its mixtures in general did not support adequate growth of cocoa seedlings, however when added to soil, it supported the growth and development of the cocoa seedlings.

For the soilless media mix, the cocoa pod husk and cocopeat media mix and the cocoa pod husk and rice husk media mix performed better than the other treatments.

From the results, poly bag size had significant effect on the growth of cocoa seedlings at the nursery. The 17.3 cm x 23.3 cm and 10 cm x 35 cm poly bag sizes were observed to be the best that produced seedlings with the highest plant height, plant girth, root length and dry weights of the stem, leaves and roots. However, the best and most suitable poly bag size is the 10 cm x 35 cm as it produced the longest root length and highest root weight. Additionally, there was no root coiling and root penetration through the bottom of the poly bag in the 10 cm x 35 cm poly bag size. Moreover, a greater number of seedlings can be transported at a time compared to the

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17.3 cm x 23.3 cm poly bag size which is much bigger and will occupy much more space compared to the 10 cm x 35 cm poly bag size.

6.2 RECOMMENDATIONS

1. Based on the performance of the cocoa seedlings at the nursery in this experiment, nursery operators could add cocoa pod husk and/or carbonated rice husk to the top soil for the raising of cocoa seedlings. However, considering that cocoa pod husk is more readily available on cocoa farms, the soil and cocoa pod husk mix is recommended as a growth media for raising cocoa seedlings at the nursery.

2. For the production of cocoa seedlings, the 10 cm x 35 cm polybag size may be used instead of the 12.5 cm x 18.5 cm poly bag size that is currently in use.

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APPENDICES

Appendix 1. Seedlings produce from soil based mixtures at three months

Plate 2. Seedlings produce from soil based mixtures at three months

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Appendix 2. Root development from seedlings grown in soil and coco peat mixture at three months

Plate 3. **Root development from seedlings grown in soil and coco peat mixture at three months**

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Appendix 3. Root development from seedlings grown in coco peat at three months

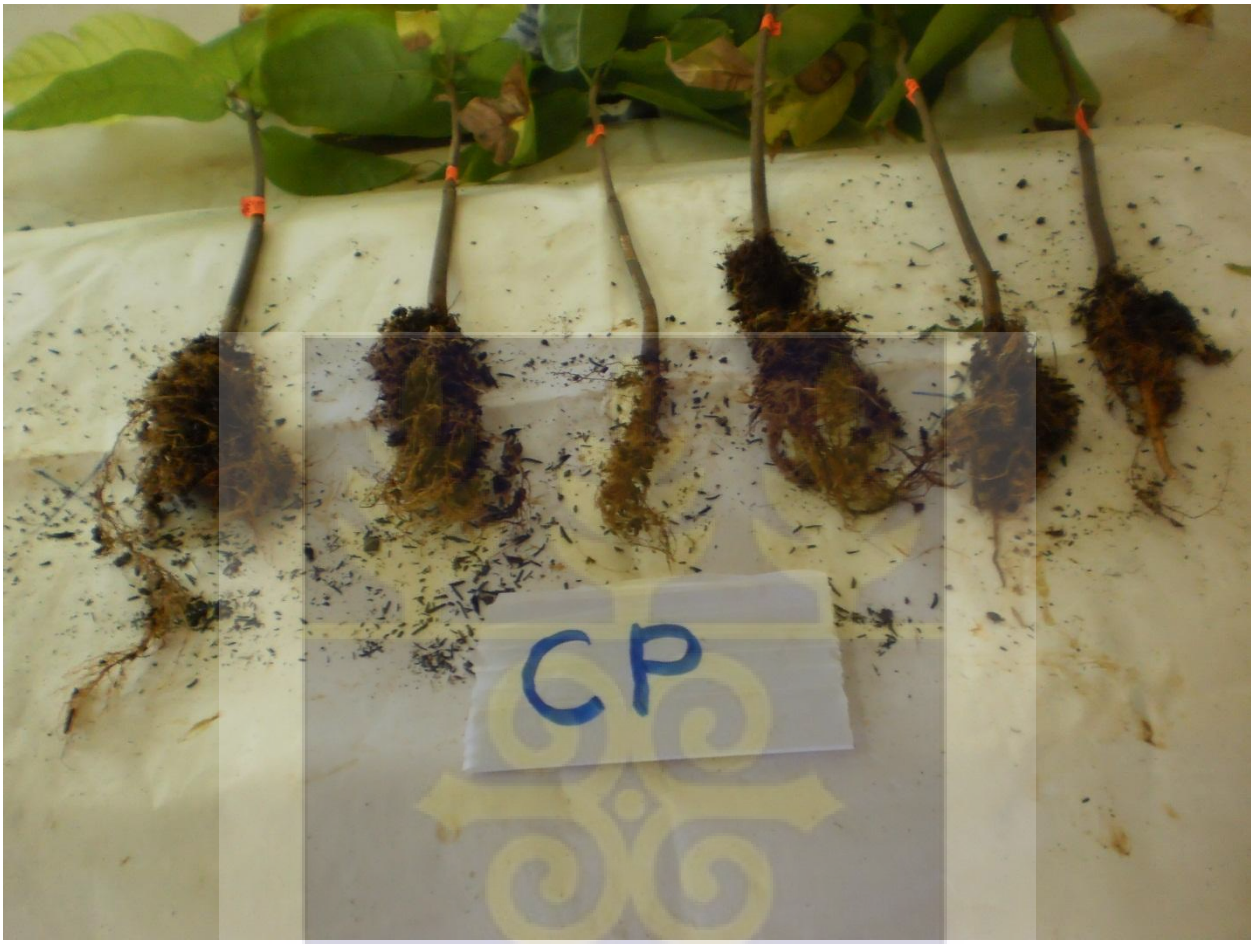

Plate 4. **Root development from seedlings grown in coco peat at three months**

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Appendix 4. Root development from seedlings grown in soil at three months

Plate 5. Root development from seedlings grown in soil at three months

INTEGRI PROCEDAMUS

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Appendix 5. Seedlings grown in soil + cocoa pod husk medium compared with soil only at three months

Plate 6. Seedlings grown in soil only (a) and soil + cocoa pod husk (b)

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Appendix 6. Seedlings grown in carbonated rice husk + cocoa pod husk medium compared with cocoa pod husk + cocopeat at three months

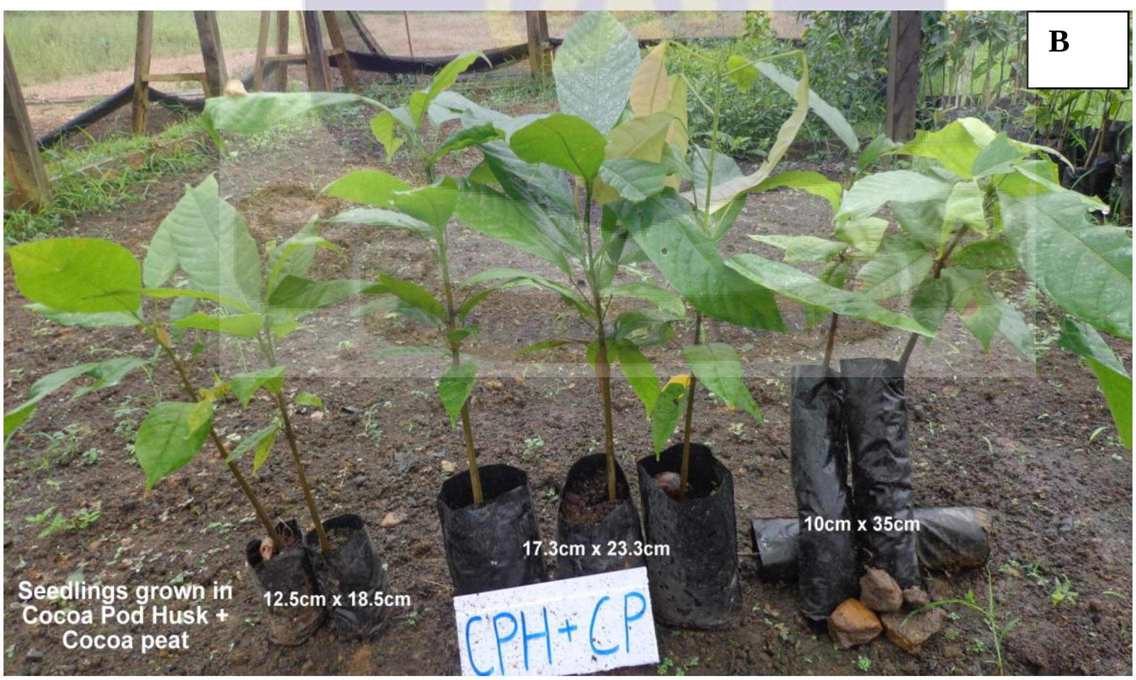

Plate 7. Seedlings grown in carbonated rice husk + cocoa pod husk (a) and cocoa pod husk + cocopeat (b)

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Appendix 7. Seedlings grown in sawdust only at three months

Plate 8. Seedlings grown in saw dust only

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Appendix 8. Analysis of variance for total dry matter yield of seedlings at three months

Variate: Total dry matter yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0373	0.0186	0.14	
REP.MEDIA stratum					
MEDIA	14	303.9817	21.7130	160.59	<.001
Residual	28	3.7857	0.1352	0.36	
REP.MEDIA.POLYBAG stratum					
POLYBAG	2	31.2966	15.6483	41.70	<.001
MEDIA.POLYBAG	28	65.1930	2.3283	6.21	<.001
Residual	60	22.5138	0.3752		
Total	134	426.8081			

Appendix 9. Analysis of variance for leaf dry weight of seedlings at three months

Variate: Leaf dry weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0350	0.0175	0.25	
REP.MEDIA stratum					
MEDIA	14	151.7497	10.8393	152.61	<.001
Residual	28	1.9887	0.0710	0.69	
REP.MEDIA.POLYBAG stratum					
POLYBAG	2	6.0534	3.0267	29.41	<.001
MEDIA.POLYBAG	28	33.1027	1.1822	11.49	<.001
Residual	60	6.1745	0.1029		
Total	134	199.1041			

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Appendix 10. Analysis of variance for shoot root ratio of seedlings at three months

Variate: Shoot root ratio

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0110	0.0055	0.01	
REP.*Units* stratum					
MEDIA	14	305.2883	21.8063	41.43	<.001
POLYBAG	2	24.7037	12.3518	23.46	<.001
MEDIA.POLYBAG	28	114.8007	4.1000	7.79	<.001
Residual	88	46.3231	0.5264		
Total	134	491.1267			