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EFFECT OF SEED PELLETING AND BIOCHAR ON NODULATION, GROWTH AND YIELD OF SOYBEAN (*Glycine max* L.)

BY

IRENE EYRAM AFI CAMARA-WILLIAMS

(ID: 10303861)

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DECLARATION

I, Irene Eyram Afi Camara-Williams hereby declare that with the exception of the duly cited references of other researchers, this thesis I am submitting to the University of Ghana for the Master of Philosophy Degree is my original research work carried out under supervision. Its entirety or part has not been previously presented elsewhere to another institution for the award of a degree.

Irene Eyram Afi Camara-Williams — Signature.....

(Student) — Date 28/05/2020

Rev. Prof. F. K. Kumaga — Signature.....

(Supervisor) — Date 28/05/2020

Dr. (Mrs.) Christiana Amoatey — Signature.....

(Supervisor) — Date ...28/5/2020

ABSTRACT

Pelleting materials and soil amendments have the ability to enhance nitrogen fixation through improved nodulation in leguminous species. Pot and field experiments were conducted in the Sinna Garden, Department of Crop Science, and University Farm, University of Ghana, Legon, during the 2018 minor and 2019 major rainy seasons respectively, to access the effect of seed pelleting with different materials and different soil amendments on nodulation, growth and yield of soybean (*Glycine max* L.). Data were taken on the following: days to emergence, days to flowering, plant height, number of branches, plant girth, leaf number, leaf area, nodule number, nodule fresh weight, nodule dry weight, leaf dry weight, shoot dry weight, root dry weight, total dry matter, number of pods per plant and N. P. K. content of the plant. The pot experiment was laid in a Completely Randomized Design with four replicates and 12 treatments comprising 2 soybean varieties (Jenguma and Quarshie) inoculated with rhizobium and pelleted using 6 pelleting materials (rice straw biochar, rice husk biochar, saw dust biochar, groundnut husk biochar, rock phosphate and calcium carbonate).

The field experiment was conducted using split plot design with 3 replicates made up of the two soybean varieties, 4 soil amendments (rice husk, saw dust, rice straw biochar and rock phosphate fertilizer at 200 g/plot), inoculated soybean only and an uninoculated check. Data were taken on seed yield per plant, 100 seed weight, seed weight per plant, seed yield per plot, total seed yield, harvest index, leaf area index, relative growth rate, organic carbon, soil pH in addition to data as taken in the pot experiment. All data were subjected to analysis of variance (ANOVA) using GENSTAT 12th edition and means separated using LSD ($P<0.05$).

In both experiments, mean nodule number, nodule fresh weight and nodule dry weight were significantly improved by both seed pelleting and soil amendments for the two soybean varieties.

Groundnut husk biochar produced highest nodule number of 126 for Quarshie variety in the pot experiment. In the field experiment soil amendments resulted in significantly increasing nodule number, nodule dry weight and shoot dry weight over the inoculated alone and uninoculated check at week five. However, no significant differences in plant height, crop growth rate, relative growth rate, leaf area index, harvest index, 100 seed weight, total dry matter and root dry weight among all treatments were observed.

Strong positive correlations were observed for number of pods per plant and total dry matter ($r = 0.73$, $P < 0.001$); total dry matter and root dry weight were ($r = 0.70$, $P < 0.001$) and total dry matter and shoot dry weight ($r = 0.88$, $P < 0.001$). There were no significant differences ($P>0.05$) in yield among the treatments but soybean with seeds pelleted and addition of soil amendments recorded slightly higher yields over the control.

DEDICATION

To my Husband Mr. Bill Benjamin Camara-Williams whose insistence and motivation for me to pursue a higher education, my father C. B. K. Ahiataku and my uncle Patrick K. Mensah for giving me the opportunity to have my first degree, my sister Ellen Xornamm Afi Dotsey whose love and support throughout the entire program, my mother Joyce Nana Boatemaa Mensah and Geovanni and Geovanna Camara-Williams.

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LIST OF ABBREVIATIONS

CGR	Crop growth rate
FAO	Food and Agriculture Organization
IITA	International Institute of Tropical Agriculture
K	Potassium
LAI	Leaf area index
MoFA	Ministry of food and agriculture
mm	Millimeter
Mt/ha	Metric tonnes per hectare
N	Nitrogen
n.d	Not dated
P	Phosphorus
RHB	Rice husk biochar
RSB	Rice straw biochar
SSA	Sub-Saharan Africa
S	Sulphur
RGR	Relative Growth Rate
INS	Inoculation alone/ inoculated seed
GHB	Groundnut husk Biochar
WAP	Weeks after Planting

CHAPTER ONE

1.0 INTRODUCTION

Soybean (*Glycine max* L. Merrill) is one of the leading leguminous crops in the world in terms of total production, with 352,643,548 tonnes in 2017 (FAOSTAT, 2019). It is high in protein and an abundant source of vegetable oil (Mahamood, 2008; Dogra *et a*l., 2014; Yagoub *et al*., 2015). Soybean is cultivated in different Ecological Zones in Africa (IITA. 2008 cited in Kolapo, 2011). In Ghana, it is cultivated in nearly all ecological zones including semi deciduous rain forest, rain forest, Guinea savannah and costal savannah. Soybean production is done in Volta region, Upper West Region, Upper East Region, Central Region and Northern Region. Among these regions, Northern Region is known to be the largest producer of soybeans in Ghana (Lawson *et al.*, 2008), producing about 77% of the national total production with the average yield of 509 to 642 kilograms per hectare (kg/ha) (SRID, 2012). Soybean production in Ghana is done on small scale with low yield because it is usually intercropped with other crops like maize and cassava by local farmers. Farmers produce an average yield of 1.9 metric tonnes per hectare (mt/ha) which is below the achievable yield of 2.3 mt/ ha in the country (Ministry of Food and Agriculture Ghana, 2013). In Sub Saharan Africa (SSA) the average soybean yield has remained at 1.1t/ha in the last forty years below the world average of 2.4t/ha (Khojely *et al.*, 2018).

Fertilizer applications, varieties and lack of rhizobia inoculant application may contribute greatly to the small returns in soybean cultivation in Sub Saharan Africa (SSA) (Khojely *et a*l., 2018). Another constraint affecting soybean production and yield is low soil fertility. Growth and nodulation of the crop is also affected by soil acidity and soil phosphorus status (Ferguson *et a*l., 2013).

Despite the crop's ability to grow on marginal soils, the genetic potential of improved varieties may not be fully exploited resulting in low yield as a result of nutrient deficiency which affects the growth and yield of the crop (Xiang *et al.*, 2012). The tropical and subtropical soils are low in nutrients, caused by weathering, Erosion also causes low nutrients when rainfalls are erratic and immobilization and fixation of some major nutrients (FAO, 2005; Agwe et al., 2007; Muntala, 2012). Soybean does very well in fertile soil and it is capable of fixing nitrogen due to the symbiotic relationship with *Bradyrhizobium* Spp. Soils in Ghana are highly weathered soils and have a moderate to strongly acidic surface soil (Owusu-Bennoah et *a*l., 1995; Ghartey *et a*l., 2012;FAO, 2005; Issaka *et al.*, 2012). These have resulted in low organic carbon content with nitrogen and phosphorous being the most limiting nutrients in the Ghanaian soils (Owusu-Bennoah *et al*., 1995). The presence of Aluminium ion (Al^{3+}) that gets its way into the soil during weathering increases the pH of the soils. This results in the lack of pH dependent nutrients like phosphorus and nitrogen leading to high level of these nutrients not being available for plants to use. The most effective means of improving soil fertility is to increase productivity by the use of mineral fertilizers; however, usage is very minimal due to high cost (Bump, 1994 and Gerner *et al*., 1995 as cited in Quansah, 2010; Tetteh *et al*., 2002). In many places, the low level of fertility has a tendency of worsening due to leaching and erosion. There is a severe imbalance in nutrient resources of soils in the country causing a major problem to sustainable management of soils for improved crop growth and yield (Bumb, 1994 and Gerner *et al*., 1995 as cited in Quansah, 2010; Tetteh *et al*., 2002).

Biochar is a technology that ensures a retention of organic materials in the soil by preventing rapid degradation of organic materials. It provides conditions suitable for crop production by creating conducive environments for the activities of soil microorganisms, improvement of soil texture,

provision of some necessary nutrients especially P and K as a cheap source of organic fertilizer for growth, development as well as the yield.

Soybean is a heavy feeder of nitrogen and fixes more than 70% of its required N nutrient by forming a symbiotic association with effective rhizobia (Herridge *et al*., 2008). Soybean requires as much K as N, but P and K uptake are usually required in large amount in the early pod filling stages. Although fertilization is quint essential for the growth and yield of soybean, most farmers are unwilling to apply fertilizers to soybean due to high cost of fertilizers and irregular supply.

Soybean production is the greatest in the northern part of Ghana where the soils are generally poor in P and K which are necessary for nodulation and seed formation. Soybean production is the greatest in the northern part of Ghana where the soils are generally poor in P and K which are necessary for nodulation and seed formation (FAO, 2005). Inoculation with rhizobia has been introduced to farmers in the northern regions of Ghana and biochar has been found to increase nodulation when applied to either the soil or the inoculated seed (Kumaga, 2020). Hence, a huge amount of biochar needs to be applied to the soil aside the application of the biochar which requires much labor. Therefore, the essence of the seed pelleting is to use small quantity of the biochar which will be coated on the inoculated seeds thereby making the farmer reduce or avoid huge spending on purchasing of biochar and labor cost during application.

The objectives of this study were therefore:

- To assess the effect seed pelleting on nodulation, growth and yield of soybean
- To evaluate the impact of different types of amendments on growth and yield of soybean.
- To compare the growth response of the two soybean varieties to pelleting and soil amendments.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 ORIGIN AND DISTRIBUTION

The origin of soybean is uncertain, but many botanists believe it to have been derived from *Glycine ussuriensis*, a legume native to Central China (Hymowitz, 2008). However, cultivation of soybeans which has been long confined mainly to China has gradually spread to other countries. Other articles have however stated that it originated from South East Asia, from where it spread into many parts of the world (Crawford *et al*., 2003 and Xu *et al*., 2002) and was introduced for the first time to sub Saharan Africa by Chinese traders in the 19th century. Cultivation as an economic crop was as early as 1903 in South Africa (Khojely *et al*., 2018). It was cited that about 70% of the world's production of soybean was in the United States of America (USA) followed by Mainland China (Asamoah, 2009). The story is not so different from today because the United States of America is still the leading producer with 112.95 million metric tonnes for 2017/2018, China ranking fourth with Brazil and Argentina taking the second and third position respectively (USDA, 2019). Soybean is a native to East Asia and China is where the spread started from to Europe and America and other parts of the world (USDA, 2011). History shows its existence more than 5,000 years ago, being used as food and a component of drugs (Norman *et al*., 1995). The earliest known cultivation of the crop in Africa was in 1885, in Algeria (Shurtleff and Aoyagi, 2010). In 1908 there was increase in soybean cultivation in Africa and serious attempts to establish the crop in Ghana took off in the early 1970s (Mercer-Quarshie and Nsowah, 1975; Shurtleff and Aoyagi, 2010). This was as a result of collaborative breeding efforts between Ghana's Ministry of Food and Agriculture (MoFA) and The International Institute of Tropical Agriculture (IITA) (Tweneboah, 2000). IITA has since introduced, different soybean varieties belonging to different maturity groups into Ghana and are being cultivated together with some local varieties such as

"Salintuya I" and "Salintuya II" , Anidaso, Ahoto and Nangbaar released by Crop Research Institute (CRI) in 2005 (MoFA and CSIR, 2005). More new varieties have now been introduced namely Favour, Afayak, Quarshie, Jenguma, among others (SARI, 2017).

2.2 CLASSIFICATION

The genus name *Glycine* was originally introduced by a Swedish botanist Carl Linnaeus (1737) in first edition of Genera Plantrum (Hymowitz and Newell, 1981). The book Species *Plantarum*, (Published in 1753) reveals that the cultivated soybeans appeared in the species Plantarum, Linnaeus under the name *Phaseolus max* L.; and the other was *Dolichos soja* based on what have been described by Hermann and Kaempfer (Shurtleff and Aoyagi, 2010). The contribution, *Glycine max* (L.) Merr., as proposed by Elmer Drew Merrill in 1917, has become the name of this advantageous plant; Due to the confusion concerning the selection of botanical name for soybean plant, the combination name "*Glycine max* (L) Mer" as proposed by Elmer Drew Merrill in 1917, has since become the valid botanical name (Hymowitz and Newell, 1981). Appiah-Kubi (2012) revealed *Glycine* is the genus of the wild species of soybean which is composed of the subgenera Soja and max (Moench). Wild soybean of the genus *Glycine* is a group of about 6 species that are perennial (Singh *et al.*, 1984). These wild types have varying forms, cytology and genetic makeup (Singh *et al.*, 1988).

2.3 PHYSICAL CHARACTERISTICS AND DESCRIPTION

Soybean is an annual crop growing up to 2 meters (2m) tall, it is usually erect, (Townley-Smith, 1993). Kim *et al.* (1995) reported the crop varies in growth habit and height which may grow prostate, not higher than 20 centimeters (cm) or grow up to a height of 2 m. Soybean is an herbaceous plant ranging in height from 30 to 183 cm, depending on the genotype (Ngeze, 1993).

Various soybean genotypes have varied growth habits: determinate and indeterminate type (MoFA and CSIR, 2005). The intermediate genotypes grow taller; produce more leaves and pods right from the stem to shoot than the determinate type. However, many varieties have been developed to have the determinate growth habits (Norman *et al.*, 1995). The main leaves of soybean are alternate, unifoliate, ovate and opposite. The stipules of the leaves are broadly ovate about 3 to 7 millimeters (mm) long, and the petioles of the lower leaves are about 2 to 20cm long. The secondary leaves of soybean are alternate and trifoliate which are mostly compound with approximately four leaflet (Appiah-Kubi, 2012). The flowers of the crop are mostly purple or white, or purple and white borne on the same plant, and these are borne in axillary racemes on peduncles found on the nodes of the plant (Appiah-Kubi, 2012). The flower which is papilionaceous in nature have a tubular calyx and corrolla of five sepals and petals respectively, a pistil, about nine stamens borne on separate single posterior stamen (Acquaah, 2007). The collection of stamen forms a kind of ring at the basal section of the stigma which elongate about a day to pollination, and the elevated anthers make a ring around the stigma (Townley-Smith, 1993). Soybean plants are self-pollinated and produce many flowers but only a few of about two-thirds or about 25% of the flowers produce pods which are pubescent and either light-yellow or black at maturity (Appiah-Kubi, 2012). The shapes of the pods are mostly curved or straight with varying length which ranges between 2 to 7cm and comprises of carpels which are fused by a dorsal and ventral suture in two halves (Asafo-Adjei *et al.*, 2005). The pod of soybean mostly contains about one to three seeds and four sometimes. Soybean seeds are usually oval but some cultivars have flattened, spherical and elongated seeds which are typically straw-yellow, brown, green, black and sometimes greenish-yellow (Acquaah, 2007).

2.4 CLIMATIC REQUIREMENTS

Soybean is a grain legume that grows well in the temperate, tropical and subtropical climates (IITA, 2007). Cultivation is successful in climates with hot summer, with optimum growing conditions in mean temperature of 20- 30 ^{o}C (Nzege, 1993) the minimum temperature at which soybean develops is 10 ^{oC} and that of the optimum and the maximum being 22 ^{o}C and about 40 ^{o}C respectively. Optimum temperature for germination is 23 ^{o}C to 25 ^{o}C. For better seed production it is suitable to select a place having wide range of day and night temperature (cooler night in mountain foot areas) so that it can produce more fulfilled large seeds. From seed development stage to harvesting time it needs dry conditions but humid condition during pod setting. Through plant breeding, several varieties have been produced and have performed differently in the various climatic or ecological zones in the world (FAO, 2009).

2.5 SOIL AND NUTRIENT REQUIREMENTS

Soybean has the ability to adapt to broad-spectrum environment, also thrives best in thoroughly drained loose loam or sandy soil that are fertile. An optimum pH range of about 5.5 to 7.0 is ideal due to nutrient availability within this range (Seiter *et al*., 2004).

Soybean is a heavy feeder of nitrogen hence fix more than 70% of its required N nutrient by forming a symbiotic association with *Bradyrhizobium Japonicum* bacterium. Nitrogen nutrient is usually applied as a starter dose to give the plant a good start while infection by the bacteria for nodulation takes place. The starter dose is applied at very low levels. Phosphorus and Potassium fertilizer are the recommended fertilizer at a rate of 60 to 70 kg per hectare while about 300 kg per hectare of K_2O is required.

2.6 NUTRIENT ELEMENT EFFECT ON SOYBEAN GROWTH

In soybean production, any level of yield attainable on any farm is completely dependent on nutrient availability and water supply (Tamagno *et al*., 2016). High yields obtained in soybean is directly proportional to high level of nutrient in the soil and consequently high level of nutrient uptake in the plant (Tamagno *et al*., 2016). Soybean growth and yield is dependent on soil essential nutrients. While there is the need to supply other essential nutrients for soybean growth, the plant is able to fix its own nitrogen nutrient.

Soybean requires nitrogen (N) for growth, seed formation and for its oil and protein content making the plant a heavy nitrogen feeder. This N is supplied through fixation and also from the soil, however the soil N is mostly lost through leaching and immobilization. Biochar is able to make immobilized N available and also prevent the leaching of the fixed N and hence increase the availability of N for growth in soybean.

Phosphorus is also very essential in the growth of soybean and this is because phosphorus is needed in soybean to convert solar energy to chemical energy which is required in soybean for protein synthesis (Hellal *et al.*, 2013).

The third most important element required by plants for growth is Potassium. Soybean plant uses potassium for photosynthesis, transportation of sugars, water and nutrient movement. It also uses potassium in protein synthesis and the formation of starch. Research has proved that adequate K levels in plants improves resistance to diseases, water stress tolerance, tolerance to pest and aids the uptake of other nutrients. Soybean requires as much K as N. However P and K uptake is usually required in large amounts during early pod filling (Usherwood, 1998).

Being the component of amino acids, Sulphur (S) is used in the building of protein in plants. Interestingly, plants require about equal amount of S as P for good growth. Just as N is mobile, S is also mobile in the soil and is easily lost through leaching. Since S is immobile in plants, S deficiency is first noticed in the younger tissues of any plant. S is added as primary nutrient in some fertilizer formulations. Calcium (Ca) is one of the constituent elements of the plant cell wall. It is useful in membrane stability. Deficiency in Ca is mostly seen at growing points of most plant and these points include the fruit, the shoot tips, the root tips as well as the stem of any plant. Magnesium (Mg) also forms a major part of chlorophyll molecule and is used for photosynthesis. It helps in energy metabolism in plants and protein formation. Magnesium deficiency is rarely seen but is common in soils with low cation exchange capacity (CEC) (Agbanu, 2017).

Finally, plants require micronutrients in negligible quantities for growth. Micronutrients used by plants include Copper, for respiration, protein synthesis, seed formation and chlorophyll production. Zinc (Zn) is required for starch formation, root development, for growth hormones and enzyme systems. Manganese (Mn) is also required for chlorophyll formation, nitrate assimilation, enzyme system and metabolism (Agbanu, 2017).

2.7 ROOT SYSTEM AND NODULATION

Rooting system development and nodulation of soybean are affected by soil texture, nutrient, moisture and temperature (Torrion *et al*., 2012; Purcell and Ashlock, 2014). The root system has three different parts: taproot system, lateral roots and the tertiary root. Soil compaction and waterlogging conditions can restrict rooting and obstruct root hair formation required for infection by rhizobia bacteria.

Soybean roots form nodules as a result of a symbiotic relationship with the specific rhizobia bacteria host strain known as *Bradyrhizobium japonicum* specifically when the soil is deficient in Nitrogen nutrient. Native rhizobia can be present in the soil or soybean seeds may be inoculated to present the bacteria in the soil. Fixing of atmospheric nitrogen by the soybean plant due to effective nodules on the root results in no or little nitrogen fertilizer application during production. The effectiveness of nodules are determined by cutting and examining for a Pink to bright red coloration which signifies that nitrogen is being fixed actively (Agbanu, 2017). A white coloration shows immaturity and no fixing of nitrogen but usually indicative of the roots colonization by rhizobia. The nodules are ineffective if they are black, brown, green or tan in color.

2.8 NODULATION AND NITROGEN FIXATION

Nodulation requires inoculation of seed or soil prior to planting with the bacteria *Rhizobium* (Leonard, 2018). However, the field with the history of soybean production may have the bacteria *Rhizobium* present in the soil. Inoculation of seed or soil for the field already having soybean production history is suggested when new strains of bacteria are to be introduced (Kokobun, 1991).

Soybean has the ability to fix nitrogen from the atmosphere if properly nodulated, but nodulation can be hindered by the acidity of soils and extreme soil moisture. , Very dry soil can affect nodulation and reduce nitrogen fixation as the bacteria needs water to move in the soil (Leonard, 2018). Fields containing high level of residual soil nitrogen from the previous forage legume or manure application, coarse textured soil due to inadequate moisture levels to sustain bacteria, flooded and saturated soil conditions lasting seven days or more due to oxygen deprivation. Soil pH below 5.7 or above 7.3 and compacted soils due to oxygen availability (Staton, 2011).

Inoculation nowadays is done by the use of inoculum, inoculum is materials used for inoculation and it can also be called inoculant. Inoculum should be refrigerated or stored in cool place before and after purchase for a short time. Inoculum is easily killed by direct sunlight therefor exposure of inoculated seed or soil to sunlight or excessive heat should be avoided (Giller and Wilson, 1991). Stored in the wrong conditions even for a short period of time can significantly reduce the likelihood of nodulation due to the sensitivity of the inoculum (Leonard, 2018).

2.9 Response of Soybean to Inoculation in the Field

Biological nitrogen fixation (BNF) is seen as a cheap way to get renewable nitrogen in agriculture as it uses photosynthetically produced energy and is environmentally cleaner (Albareda *et al*., 2009). Many research experiments have clearly justified the positive effect of inoculation in enhancing BNF (Kadiata *et al*., 2012; Solomon *et al*., 2012; Mohammadi *et al*., 2012) and true benefits of inoculation on legumes are made known to farmer and researchers since most commercial microbial and micronutrient products claim to increase BNF and consequently crop yield.

Rhizobia inoculation significantly increased nodule dry weight of soybean reported by (Katulanda, 2011). This agrees with the findings of (Okogun *et al*., 2005; Chemining'wa *et al*., 2007) who reported no significant increase in nodulation following rhizobia inoculation. (Rechiatu *et al*., 2015) reported that inoculation resulted in over 50% increase in soybean yield. This was not far-fetched from (Nyaguthii, 2014) who reported that legume inoculation or co-application of rhizobia inoculants and phosphorus fertilizers only, without proper soil fertility diagnosis, must be revised to optimize the benefits expected from inoculation including biological nitrogen fixation. (Levitan *et al*., 2007) also reported rhizobium inoculation significantly increased grain yield at Yendi and

this yield was comparable to those obtained from the treatments with PK only or PK with Rhizobium inoculants in their experiment.

2.10 The Nodulation Process

The soybean nodulation process as described by Beuerlein (2004) and Sadowsky (2005) is dependent on penetration of *Bradyrhizobium japonicum* bacteria. The bacteria may infect the plant through root hairs, wounds, lesions, or cavities surrounding adventitious roots. Germinating seeds release chemical signals called flavanoids that are received by the bacteria. The bacteria respond with a return signal known as a nod factor that allows the plant to prepare for infection by curling the root hair. The curling of the root hair essentially traps the bacteria on the root surface. The development of an infection thread allows for the bacteria to grow in number until reaching the center of the root. Meanwhile, the root cells divide ultimately forming a nodule, about 6 to 18 days after initial infection. The nodule is fundamental because it is where leghemoglobin is produced, which creates the environment essential for the enzyme nitrogenase to convert N2 to NH3. The bacteria receive energy to obtain N2 from sugar in the leaf that moves down to the roots.

Nodulation first occurs on the crown roots and then the lateral roots (Beuerlein, 2004; Sadowsky, 2005). Nodules reach mature size at approximately four weeks after the beginning of nodule formation and will continue to fix N for two or three more weeks before they begin to senesce. Soybeans begin to fix N at the V2 growth stage (second trifoliate) and reach maximum fixation rates later at approximately the pod development stages, R5 and R6. Active nodules contain a red to pink color caused by leghemoglobin (Conley and Christmas, 2006).

2.11 BIOCHAR

Biochar is a form of charcoal produced from plant biomass by heating in the absence of oxygen which halt total burning of the organic biomass which takes place in open fire (Sohi *et al.*, 2009). Biochar is rich in a stable form of carbon which is not oxidized by soil microorganism. It is a charcoal like substance made from biomass and can be used for soil amendment. It has been credited with multiple benefits including the ability to improve soil fertility, protect water quality, and generate carbon neutral energy (Brick, 2010). Biochar is an organic material produced by heating in the absence of oxygen, of carbon based feedstock (biomass) and is best described as a soil conditioner. In spite of numerous materials suggested as biomass feedstock for biochar (including wood, crop residues and manures), the suitability of each feedstock for such an application is dependent on a number of chemical, physical, environmental, economic and logistical factors (Verheijen *et al.*, 2010; Kloss *et al.*, 2012). Feedstock used on a commercial scale or in research facilities include wood chip and wood pellets, tree bark, crop residues (which includes straw, nut shells, cocoa pods and rice hulls), organic waste including distillers grain, bagasse from the sugarcane industry and cow dung. The elemental ratio of carbon, oxygen and hydrogen are key feedstock parameters in commercial use and the quality of fuel products (Fried *et al.*, 2005).

2.12 Biochar Feedstock

The quality and quantity of the biochar produced is reliant on the feedstock composition and availability of the material (Laufer and Tomlinson, 2013). The physical and chemical composition of biochar is dependent on the type of biomass feedstock and the pyrolysis method adopted (Laird *et al.*, 2010, Laufer and Tomlinson, 2013; Biederman *et al.*, 2013; Xie *et al.*, 2015). Reports by

several authors indicate that biochar biomass feedstock are usually from plant residues like sawdust, wheat straw, wood pine, rice straw, rice husk, groundnut shell, corn cob and stalk, coconut fiber, animal residues like poultry litter and pig manure, forestry wood waste and sewage sludge.

2.13 STABILITY OF BIOCHAR IN THE SOIL

Biochar has long been used to date and it has been quantifies as carbon 14 decay (Arnold and Libby, 1951). Biochar persists in the environment longer than any other form of organic carbon. Finely divided biochar has remained in soils in humid tropical climates, such as the Amazon, for thousands of years resisting the rapid rate of mineralization common to organic matter in these environments and producing a distinct black colour (Sombroek *et al*., 2003). In is in agreement with (Goldberg, 1985) who reported that soil organic matter would be dominated by Biochar accumulated over geological time scales.

2.14 EFFECT OF BIOCHAR ON PLANT GROWTH AND PRODUCTIVITY

Several reviews have highlighted biochars' ability to promote plant productivity and yield compared to the control (Jeffery *et al*., 2011). Glaser *et al*. (2001) reported that an increase in aboveground biomass with high potassium tissue concentration and belowground productivity of plants; Laird *et al*. (2010) reported Biochar treated plots showed rapid germination giving the plant enough duration for biomass accumulation and Lehmann *et al*. (2011) reported nodulation by rhizobia in legume plants increases. The increase seen in the belowground productivity has been attributed the porous nature of biochar which enhances water holding capacity and reduces soil compaction. These help in the development of a more fibrous root system for movement and

interception of soil nutrients and water. In their research, Biederman *et al*. (2013) reported that there was an increase observed in plant biomass when biochar was added.

2.15 AGRONOMIC BENEFITS OF BIOCHAR

Biochar soil amendment improves crop productivity mainly by increasing nutrient use efficiency and water holding capacity. However, improvements to crop production are often recorded in highly degraded and nutrient-poor soils, while its application to fertile and healthy soils does not always increase crop yield. Since biochar is produced from a variety of feedstocks, certain contaminants can be present. Heavy metals in biochar may affect plant growth as well as rhizosphere microbial and faunal communities and functions (Hussain *et al.,* 2017).

When biochar is added to the soil it helps to improve plant growth and enhance crop yields increasing food production and sustainability in areas with depleted soil limited organic resources, insufficient water and access to fertilizers. Not all soils react the same to biochar and it frequently can take up to a year to compare results. The optimum application rate for biochar depends on the specific soils and crop management. Application of biochar to soil is proposed as novel approach to establishing a significant long term sink for atmospheric carbon dioxide in terrestrial ecosystems. Aside the constructive results within lessening discharges and enlarging sequestration of greenhouse gases, biochar production and application to the soil delivers instant gains by better soil fertility including crop production increased

(Lehman *et al.,* 2006). Biochar may be an immediate solution to reducing the global impact of farming by reducing the impact from all agricultural waste (Sisomphone *et al.,* 2012). It has been shown that biochar has multiple uses. When added to soil it can significantly improve soil fertility and also act as a sink for carbon (Lehman, 2007). Carbon in this way is removed from the atmosphere in a process called sequestration (Zwietenoe, 2006; Davies, 2007).

Biochar can act as a soil conditioner by ameliorating the physical and biological properties of soil such as water holding capacity and soil nutrient retention and also enhancing plant growth (Sohi *et al.*, 2009; De Gryze, 2010). Biochar has the potential to: decrease aluminum toxicity, improve fertilizer use efficiency, improve soil conditions for earthworm populations, decrease soil tensile strength and increase soil pH (Amonette and Joseph, 2009, Chan and Xu, 2009, Spokas *et al.*, 2009, Cunha *et al.*, 2009; McLaughlin, 2010). The combined application of biochar and inorganic fertilizer has the potential to increase crop productivity, thus providing additional incomes and reducing the quality of inorganic fertilizer use and importation (De Gryze, 2010; Quayle, 2010). Biochar additions to hard setting soils in Australia for instance reduced tensile strength and further improved plant growth (Gaskin *et al.*, 2007; Amonette and Joseph, 2009). Steiner *et al.* (2008), described the application rate of 5 tons of biochar per ha decreased fertilizer need by 7%. Crops are reported to grow about three times faster in soils conditioned with biochar than on un-amended soil (Sohi *et al.*, 2009). Similar results have been demonstrated in places in West Africa such as Benin and Liberia and Savannah of South Africa (Cunha *et al.*, 2009; Sohi *et al.*, 2009). The pH increase in sandy and loamy soils upon addition of biochar has been reported to be larger than in clayey soils (De Gryze, 2010). In a study on effects of charcoal production on soils physical and hydrological properties in Ghana (Oguntunde *et al.*, 2008) reported that the saturated hydraulic conductivity of soils under charcoal kilns increased significantly. When mixed with organic matter biochar can result in enhanced retention of soil water as a result of its pore structure which contributes to nutrient retention because of its ability to trap nutrient-rich water within the pores (Oguntunde *et al.*, 2008, Major *et al.*, 2009; De Gryze *et al.*, 2010). Oguntunde *et al.* (2004) revealed a notable inflation in soil pH, electrical conductivity and exchangeable Na, P, K, Ca and Mg in the soil at a charcoal production site compared to adjacent soils under no charcoal production.

2.16 NITROGEN FERTILIZER AND BIOCHAR INTERACTION

The technology used in increasing fertilizer efficiency is integrated crop management which includes the application of organic manure and other organic materials to soil (Fageria and Baligar, 2005). Under wet tropical condition, organic materials applied to the soil decompose very rapidly. Biochar is more resistant when applied to soil. When applied to soil it increases nitrogen utilization from the applied chemical fertilizer (Seiner *et al.,* 2007; Widowati *et al.,* 2011). This is as the result of the decrease of nitrogen lost due to the increase of soil cation exchange capacity with biochar application (Chan *et al.,* 2008; Masulili *et al.,* 2010) or because of the biochar ability to inhibit N-NO_3 transformation from N-NH_4 released by fertilizer (Widowati *et al.,* 2011).

2.17 EFFECT OF BIOCHAR ON SOYBEAN GROWTH

In recent times, biochar has been extensively researched into and positively recommended for crop production. Soybean is one of the crops on which biochar and its impact have been fairly determined. In research for instance, Wang *et al*. (2016) observed an improvement in soybean growth. He observed that biochar was able to improve the structure of soils and also improve upon the nitrogen absorption properties and water holding capacity of soils. He therefore concluded that biochar increased the growth of soybean giving them a more uniform growth during the reproductive phases on biochar fields compared to fields without biochar. Suppadit *et al*. (2012); Yooyen *et al*. (2015); Egamberdieva *et al*. (2016) an increase in nutrient uptake, growth, dry matter, nodulation and yield after biochar application has been reported. Positive effect of rice straw biochar on nodulation, growth, dry matter accumulation and yield of some soybean varieties and improved soil nutrient uptake of the plant (Agbanu, 2017). Darko (2013) reported positive effect of biochar seen in the grain yield of rice.

2.18 PELLETING OF LEGUME SEED

A seed pellet is characterized by its ability to totally obscure the shape of the encased seed, because seeds are coated with materials that changes the shape and the size to become rounder and heavier (Copeland and McDonald, 2012). An amalgam of fillers such as limestone, vermiculite, clay, Calcium Carbonate and more including cementing additives such as gelatin, gum Arabic and more are used to form the pellet and other compound such as fungicides, inoculants and more may be added to enhance seed performance (Taylor and Harman 1990). Inoculants are used in pelleting Legume seeds and the process is called inoculation. Seeds treated with seed pellets increase yield, ameliorated standard and emergence, Treating seeds with adhesive mixed with active ingredient, has been reported to be effective (Moude and Snett, 1998). Seeds obtain early growth advantage with pelleting in other words, seed protection against stresses, invigoration of seed, synergetic effects of fungicides on seeds, nutrients and hormones for seeds and seed protection from diseases and pests.

2.19 CHALLENGES ASSOCIATED WITH SEED PELLETING

If pelleted materials are too dry and strong germination seeds may be affected because the radicle may not emerge through the pelleted material. The pelleting material must be suited with the seed to ensure the quality of seed is maintained and germination is not impeded. An instance can be where pelleting materials are wet during pelleting so that inadvertent seed hydration occurs that leads to increased respiration and possibly reduced seed quality (Copeland and McDonald, 2012).

2.20 CHALLENGES OF ORGANIC AND INORGANIC NUTRIENT SOURCE APPLICATION

Adoption of inorganic and organic fertilizer application technologies in Ghana has been slow due to certain constraints. Application of inorganic fertilizers are inadequate due to high costs, type

and quantity supplied, variations in the soils and a characteristic low nutrient conversion rate (Gruhn *et al*., 2000). The inefficient and improper use of inorganic fertilizers result in low nutrient use efficiency of most crops. This causes low yield and loses to farmers. This has deterred most farmers from adopting the use of inorganic fertilizers to improve yield. Total dependence on rainfall and only few irrigated farms characterize Ghana' farming system. The low efficiencies of applied fertilizers have thus been attributed to the unreliable and poorly distributed rainfall pattern in Ghana mostly. Other issues identified with inorganic fertilizers include leaching from root zones, which reduces fertilizer utilization by crops. FAO (2005) identified that, for fertilizer use to increase, several farm lands will have to be under irrigation.

Organic material as a source of soil nutrition in the tropics is also not dependable due to high decomposition rate of materials which is about 3-5 times greater than that of temperate conditions. Composting for example is very laborious and organic waste on small farms is limited. Also in cover cropping, grass and legume cover crops compete with food crops for land. Farmers find it difficult in allocating land to cover crops when they could have used it to grow cash crops. Soil conservation technologies have also been used such as agro-forestry systems which have been slow to adopt due to the fact that these are long term solutions but farmers would rather have short term results.

The recent issues of global warming and climate change demand for a more conservative approach to improve soil productivity to increase yield of crops. Biochar provides a viable option for improving soil fertility and nutrient use efficiency of crops. The use of readily available plant biomass that are usually agricultural waste serve as feedstock that are pyrolysed into biochar.

2.21 APPROACHES TO IMPROVING MANAGEMENT OF SOIL FERTILITY

The right nutrition at a time is a major crop yield maximization factor. Plant nutrition management is defined as the application of the accurate form, amount, and proportions of nutrient at the right growth stages of any crop to improve yield per area with the least possible nutrient loss.

Nutrient recycling using organic materials is necessary to restore the productivity of any soil. Nonetheless, the use of organic fertilizer has being unable to increase the yield per unit area of any crop because the nutrient content is not balanced, whiles a bulk application also leads to nutrient loss. To manage this anomaly, integrated plant management (IPNM) has been introduced. IPNM is the combination of mineral and organic fertilizer for the maintenance of soil fertility for improvement in crop yield per area.

The IPNM concept basically optimizes the exploration of the nutrients in organic fertilizers for good yield and synergistic nutrient use efficiency. In a study, Quansah (2010) characterized poultry manure and two other composted materials which were household waste and market waste plus faecal sludge mixes at a ratio of 3:1 to assess the effect of organic and inorganic fertilizers and their combined effect on maize growth and yield. The result indicated that poultry manure has the major N, P, and K at 2.06 %, 0.52 % and 0.73 % respectively, while the composted material had a moderate level of these nutrients. At the end of the experiment, they noticed a higher nutrient levels in the combination of both organic and inorganic nutrients than just sole organic or sole inorganic.

When applied to the soils, the combined treatments had significantly higher nutrient uptake values than the sole organic and inorganic fertilizers alone. This result is a clear indication of the need to combine both organic and inorganic nutrients for full exploitation of the genetic potentials of the plant for better plant growth and increased yield.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE DESCRIPTION

Two experiments were conducted for this study. The first experiment was conducted in the Sinna Garden, Department of Crop Science, University of Ghana and the second at the University of Ghana farms, Legon, located in the coastal savannah zone of Ghana. The area had an annual rainfall of about 354.3 mm with a range of 171.6 mm to 223.8 mm. The rainfall in this region is highly erratic with two distinct rainy seasons. The major season which begins in March and ends in July and the minor season from September to November. The soil used belong to the Adenta series (USDA Classification).

3.2 PLANTING MATERIALS AND EXPERIMENTAL SETUP

Two varieties of soybean, Jenguma and Quarshie were used in the experiments. Jenguma is the popular variety grown by farmers while Quarshie is another high yielding variety from SARI. Soybean seeds were obtained from Department of Crop Science, at University of Ghana, Legon. Biochar was obtained from Department of Soil Science at University of Ghana, Legon and Soil and Irrigation Research Center (SIREC), Kpong in the Eastern Region of Ghana.

Two experiments were conducted, from October 2018 to March 2019. The experiment conducted, from October 2018 to March 2019 evaluated the effect of different seed pelleting materials and the different soil amendments on nodulation and growth of soybean. The impacts of the amendments on soil characteristic were also evaluated.

3.3 PELLETING MATERIALS

Pelleting materials used included Rock phosphate, Calcium Carbonate ($Caco_3$) and biochar that includes Saw dust biochar, groundnut husk biochar, rice husk and rice straw biochar.

3.4 Pot Experiment

In the pot experiment two soybeans varieties (Jenguma and Quarshie), and four (4) types of biochar (Rice Husk, Groundnut Husk, Saw Dust and Rice Straw) in addition to Rock Phosphate and Calcium Carbonate were used. The combination of the 2 factors giving 12 treatments were replicated 4 times in a Completely Randomized Design. The total number of experimental pots used in the experiment was 48 pots.

The dimension of pots used in the experiment were 12 cm wide and 30 cm in height. The pots were perforated with three holes at the bottom to allow drainage of excess water. The base of the pot was lined with a filter paper to prevent loss of soil through the perforated holes. Soils of the Adenta series found in portions of University of Ghana farms near the botanical garden was collected and transported to the Sinna Garden for the pot experiment. The soil was air-dried and sieved using a 2 mm sieve. Each pot was filled with 8.0 kg of soil.

3.5 Inoculation

20g of sugar was dissolved in 80mls of water and seeds to be inoculated was put into the bowls. The Seeds were moistened with sugar solution and the Inoculant was added to seed and swirled around and seeds were air-dried for 30min.

Prior to sowing the inoculated seeds of the two varieties were allowed to air dry for 30 min to allow the inoculant to adequately stick onto the surface of the seeds. The inoculated seeds were finally coated with the pelleting materials and mixed thoroughly by swirling continuously for 2 minutes then allowed to air dry before planting. The rate of the pelleting materials used was

5g/100g of seeds. Five (5) seeds were sown per pot for each variety. The medium was watered and brought to field capacity with tap water.

3.6 Field Experiment

The experimental design used was a factorial experiment conducted in split plot design with three (3) replications. Two varieties of soybean served as the main plot treatments and the sub plot treatments comprising three biochar treatments (rice husk, saw dust and rice straw biochar) and rock phosphate fertilizer (200 g/plot), inoculation alone and no inoculation were used.

The land was ploughed and harrowed on the 15th of November, 2018. The field was levelled before lining and pegging to demarcate plots for treatment application. The soil amendments were placed directly into the soil when the drills were made before placement of the seeds. The drills were then covered after the seed placement and the entire field was watered.

Soybean seeds were inoculated by the same inoculant used for the pot experiment. The main plots (varieties) had a dimension of 10m X 5.3m and the sub plot consisted of the treatments with a dimension of 3.0 m X 2.4 m. The inter-row spacing was 100 cm and intra row of 50 cm (1.0 m x 0.5 m). The total experimental site was 9.6m X 27.0 m.

Weeding was done manually. Pests and diseases were controlled regularly using Mancozeb 80WP fungicide (Agrithane) and insecticide Emamectin Benzoate (Attack). One week after emergence, seedlings were sprayed with an Emamectin Benzoate insecticide at the rate of 250mls/15L was used to control caterpillars and cypermethrin 36 g at the rate of 35ml/15L was used to control grasshoppers, once a week spaying was done with (Attack and Cydim Super) when the plants were 6 weeks old. The field experiment was manually watered to maintain soil moisture. Watering was done with watering cans and this was done plot by plot until the entire field was covered. This was mostly done early in the morning or in the evening every day of the week.

3.7 Pod Harvesting

Plants were harvested at physiological maturity when all the pods on the plants had turned brown. They were parked in sacks and sent to the laboratory. The pods were later removed for determination of yield and yield component.

3.8 Sampling of Soil

Soil samples were taken from the experimental plot to a depth of 0-20 cm using an auger, for soil characterization. Before ploughing clod samples were collected with the core sampler for the determination of the bulk density. The soil samples were bulked and bulk composite samples were air dried and sieved with 2mm sieve to remove unwanted materials and for fine earth fraction.

Soil samples were air dried and sieved for the physical and chemical properties like available N, P and K, Ph.' Organic Carbon and bulk density. Analysis of soil was done in the Ecological Laboratory, Department of Earth Science.

3.9 Bulk density

Samples for bulk density determination were obtained from the field by driving a known volume core sampler with both ends open into the soil to about 0-15cm deep. The core sampler together with the sampled soil were brought out and both open end closed immediately to avoid moisture loss. Samples were oven dried at a temperature of 70^{o}C for 48 hours to a constant weight. With the known volume of the core sampler and soil, the dried soil was weighed and the bulk density determined. The formula used in the calculation of the bulk density was:

$$\text{Bulk density} = \frac{weight\ of\ oven\ dried\ soi\ L}{Volume\ of\ soil\ core\ sampler}$$

3.10 Soil pH

The pH was determined by weighing 10g of the soil into a beaker and 20 ml of distilled water added in a 1:1 ratio. The solution was stirred for 30 minutes and the pH read using the pH meter (Oakton PH Meter PC 2700, which also measures millivolts, conductivity and temperature).

3.11 Analysis of pelleting material (Biochar)

The rice husk, rice straw, groundnut husk and saw dust biochar used in the study as pelleting materials were air-dried, crushed and passed through a 2 mm sieve. Composite sample of the sieved biochar was taken for laboratory analysis of pH, total N, P and K.

3.12 Treatment combinations with soybean varieties

Pelleting materials and soil amendments with the two soybean variety Jenguma and Quashie used for labeling in the study (Table 1).

Table 1. Treatment code and description

Treatments Code	Treatment Description
Con J	Control Jenguma
Con Q	Control Quashie
INS J	Inoculated Jenguma
INS Q	Inoculated Quashie
CACO J	Calcium Carbonate Jenguma
CACO Q	Calcium Carbonate Quashie
RPF J	Rock phosphate Jenguma
RPF Q	Rock phosphate Quashie
RHB J	Rice Husk Biochar Jenguma
RHB Q	Rice Husk Biochar Quashie
GHB J	Ground nut Husk Biochar Jenguma
GHB Q	Ground nut Husk Biochar Quashie
SDB J	Saw Dust Biochar Jenguma
SDB Q	Saw Dust Biochar Quashie
RSB J	Rice Straw Biochar Jenguma
RSB Q	Rice Straw Biochar Quashie

3.13 Data Collection

Data were collected on vegetative crop growth, yield and yield components.

3.14 Vegetative Parameters

Vegetative parameters used were Days to emergence, plant height, stem girth, number of leave per plant, leaf area, shoot dry weight, Root dry weight, Total plant biomass production, Number of nodules, Nodule weight and Days to Flowering.

i. Days to emergence: This was determined as the number of days from sowing to first appearance of the cotyledons above the soil surface.

ii. Plant height (cm): This was determined by measuring ten soybean plants from the base or the stem to the top of the apical meristem.

iii. Stem girth (cm): This was measured around the largest part of the plant using the automated Vernier callipers.

iv. Number of leaves per plant: Total number of leaves per plant were counted for all record plants.

v. Leaf area (cm): This was measured using a cork borer method. Leaves were detached and weighed to determine that total weight of the leaves on the plant. Ten leaves were sampled at random and arranged uniformly, the cork borer with a known diameter was then positioned at the centre of the leaves and pushed down till disks from the leaves were obtained. Using the area of a circle the area of the disk was obtained and the disks were weighed. By equating the leave area of the disk to the weight of the leaf disks and by proportion the leaf area of the whole leave was obtained.

vi. Shoot dry weight (SDW) (g): The harvested plant shoots were oven dried at 70 ˚C to a constant weight before weighing.

vii. Root dry weight (RDW) (g): The roots were oven dried after washing to a constant weight at 70 ˚C and then weighed.

viii. Total plant biomass production: This was computed using the sum total of the shoot and root dry weights

ix. Number of nodules: Nodules were counted after detaching them from the roots.

x. Nodule weight (g): The nodules were oven dried at a temperature of 70 ^{o}C and then weighed using a weighing scale.

xi. Days to Flowering: The number of days to flowering was recorded as days from emergence to flower appearance.

3.15 Yield and Yield Components

Yield and yield component used were as follow: Number of pods per plant, Number of seeds per pod, Pod weight per plant, 100 seed weight, seed weight per plant, Harvest index and Grain Yield Determination.

i. Number of pods per plant: The pods on ten randomly selected plants were counted. The average number of pods per plant was determined by dividing the total number of pods counted by ten.

ii. Number of seeds per pod: the number of seeds per pods were determined by counting the number of seeds from ten pods selected at random. The total number of seeds was divided by ten to get the average number of seeds per pod.

iii. Pod weight per plant (g): Ten soybean plants were selected and all the pods were detached from the main stem of each plant and weighed.

iv. 100 seed weight (g): 100 uniform seeds were randomly selected and weighed using the weighing scale.

v. Seed weight per plant: Seeds removed from pods of each plant were weighed using the weighing scale.

vi. Grain Yield Determination: At physiological maturity, an area of 1.8 m^2 of bordered row plants were harvested. Soybean pods per plot were air-dried. The grains were weighed and used in estimating the grain yield.

3.16 Growth Analysis

Growth analysis parameters were carried out using plant biomass and leaf area. They were:

Crop Growth Rate (CGR) g (Crop) $m^{-2}d^{-1} = Increase\ in\ dry\ weight/unit\ land\ area/time$ (Watson, 1956).

Leaf Area Index (LAI) m^2 (leaf) m^{-2} $= leaf\ area/land\ area.$ (Williams, 1946)

Relative Growth Rate (RGR) g (crop) g^{-1}(crop) d^{-1} = $dry\ weight/dry\ weight/time$ (Williams, 1946)

3.17 Total Nitrogen Determination

Macro-Kjeldhal method was used in the Total nitrogen determination. The air-dried soil was sieved through a 2mm diameter mesh and 2g of the soil weighed into a 50 ml Kjeldhal flask. The weighed soil was moistened with distilled water and 5 ml of concentrated sulphuric acid was added. The solution was digested and cooled. The cooled digested solution was transferred into a 50ml volumetric flask using distilled water. 5 mL of the digested solution and sodium hydroxide solution was distilled into 2% boric acid in a conical flask. The distillate was titrated against a 0.0012M HCl solution which turned from green to a reddish end point.

3.18 Determination of Total Phosphorus (P)

Total P was determined by first weighing 2 g of sieved soil. 25 mL concentrated perchloric acid mixed with nitric acid in a ratio of 2:3 was used to digest 2 g of the soil sample. After digestion, the cooled sample was diluted using distilled water and filtered with the Whatman filter paper No. 42 into a 100 mL volumetric flask and topped up to the 100 mL mark with the distilled water. Phosphorus in the filtrate was measured by colour development and read on the spectrophotometer. Percent phosphorus was calculated using the equation:

$$\text{P (\%)} = \frac{\text{spectrophotometer reading } (mgL^{-1}) \times \text{total volume of extract}}{\text{volume of aliquot} \times \text{weight of soil sample} \times 10^6} \times 100$$

3.19 Exchangeable Bases

Ten gram soil was weighed into an extraction bottle and 100 mL of 1N ammonium acetate solution of pH 7.0 was added. The mixture was shaken for one hour after which the content was filtered with Whatman No 42 filter paper. Aliquot of the extract were used for the determination of Ca^{2+}, $Mg^{2+,}$ K^{+} and Na^{+}. Exchangeable Na and K were determined using the Atomic Absorption Spectrometer by calibrating the photometer with standard 10 ppm of Na and K solutions and reading the Na and K concentrations of the extracts.

$$\text{K (Cmol/Kg soil)} = \frac{G \times vol\ of\ extract \times 10^3 \times 10^2 \times H}{weight\ of\ soil \times 10^6 \times \text{I}}$$

I = Atomic mass of I

G = AAS Reading (µg/L)

H = Charge

CHAPTER FOUR

4.0 RESULTS

4.1 Pot experiment

Table 2. Characterization of soil, rice husk biochar, rice straw biochar, Groundnut husk biochar and Saw dust biochar.

Properties	Soil	Rice Husk Biochar	Rice Straw Biochar	Groundnut Husk Biochar	Saw Dust Biochar
Bulk Density	1.1	0.20	0.23	0.24	0.25
pH	4.9	10.60	8.00	8.54	9.54
Total N	0.6	1.20	1.04	0.87	0.90
Total P	5.1	0.45	0.46	0.46	0.42
Total K	2.1	0.19	0.81	0.83	0.24

4.1.1 Effect of Pelleting Material on Days to emergence

Days to emergence are shown in Fig.4.1. Seeds started emerging from day 4 and continued to day 7. The main effect of varieties were significant on days to emergence, Quarshie on the average emerged earlier than Jenguma, The analysis of variance showed no significant differences in the effect of the different pelleting materials on the days to emergence. The interaction was also not significant.

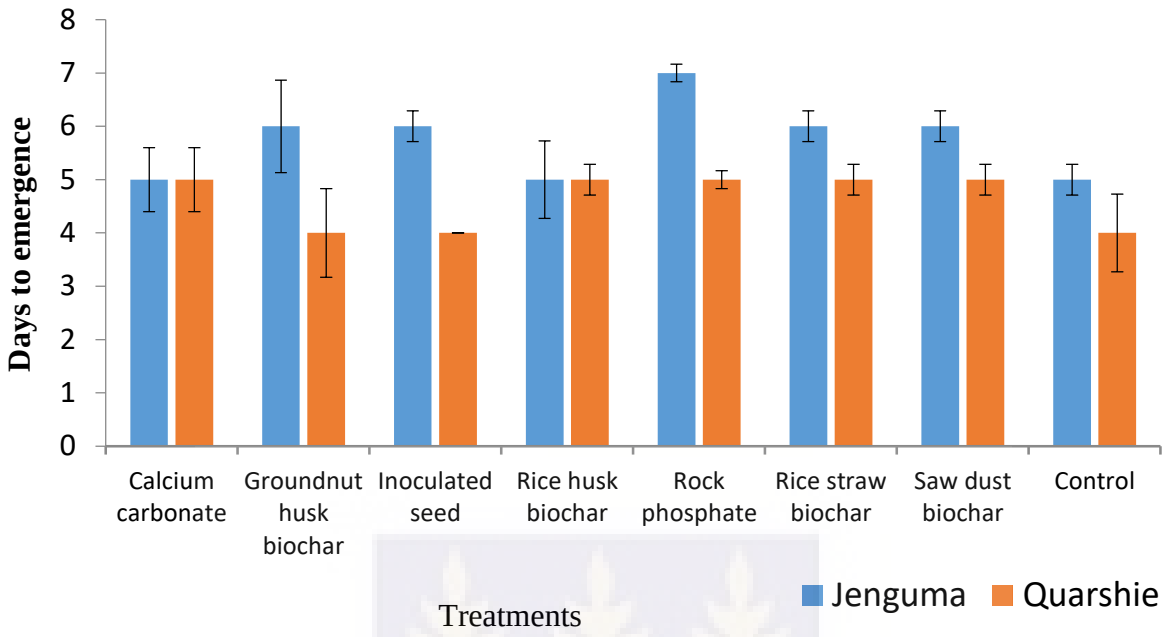


Figure 4.1. Days to emergence in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar

4.1.2 Effect of Pelleting Material on Days to flowering

Number of days to flowering was between 39 and 47 from sowing, the treatments and the interaction between the varieties and treatments was not significant but the two varieties were significantly different in the number of days to flowering (Fig. 4.2). However Jenguma were late to flower generally.

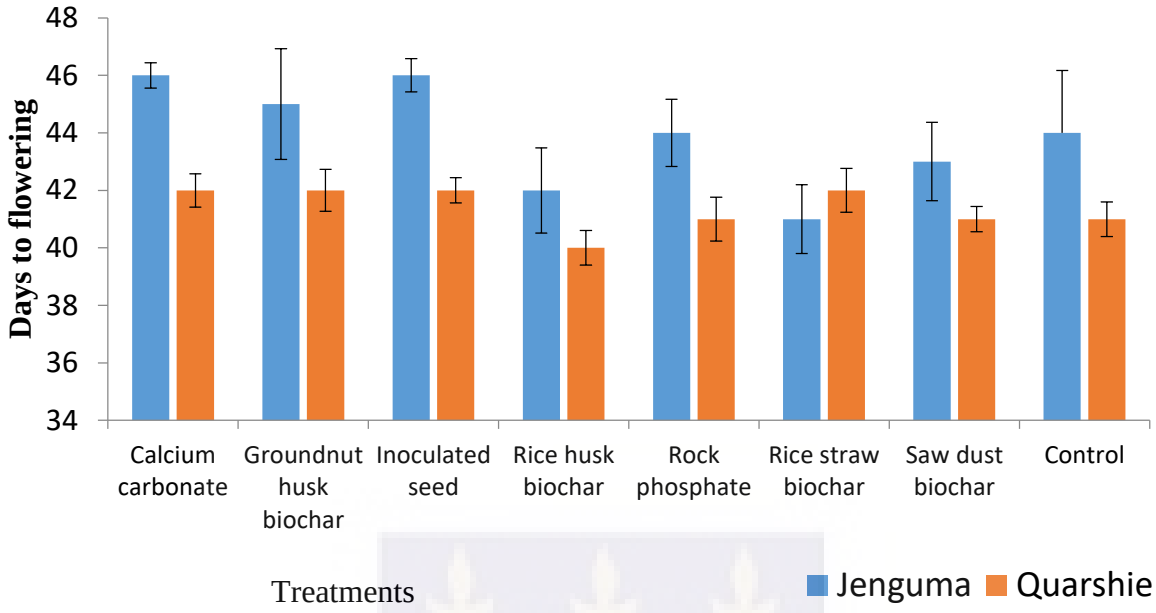
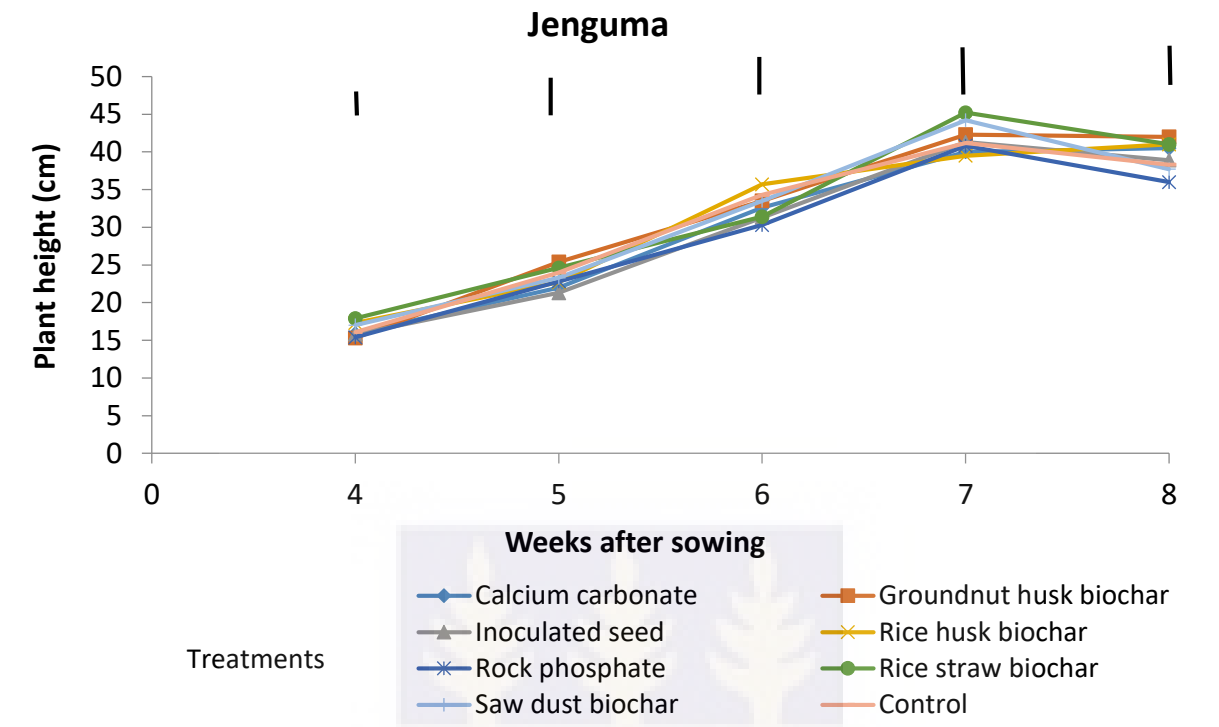


Figure 4.2. Days to flowering in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.3 Effect of Pelleting Material on Plant height

Plant heights measured at weekly interval after 4 weeks of sowing are presented in figure 4.3. The interaction between varieties and treatments were not significant on plant height in all the weeks the record was taken. Differences between the varieties was significant at the 4th and 8th week after sowing but not at weeks 5, 6 and 7. Treatments affected plant height only at the 8th week. At weeks 4, 5, 6 and 7 plant height was not affected by treatments. Quarshie sown with rice husk biochar had a higher plant height of 48.4 at the 7th week after sowing. Jenguma recorded the highest plant height of 45.2 at the 7th week as well but from rice straw biochar. The lowest plant height recorded was at the 4th week after sowing in plant grown from seeds pelleted with calcium carbonate 16.3 in Quarshie and Jenguma (15.3) grown with groundnut husk biochar.



B

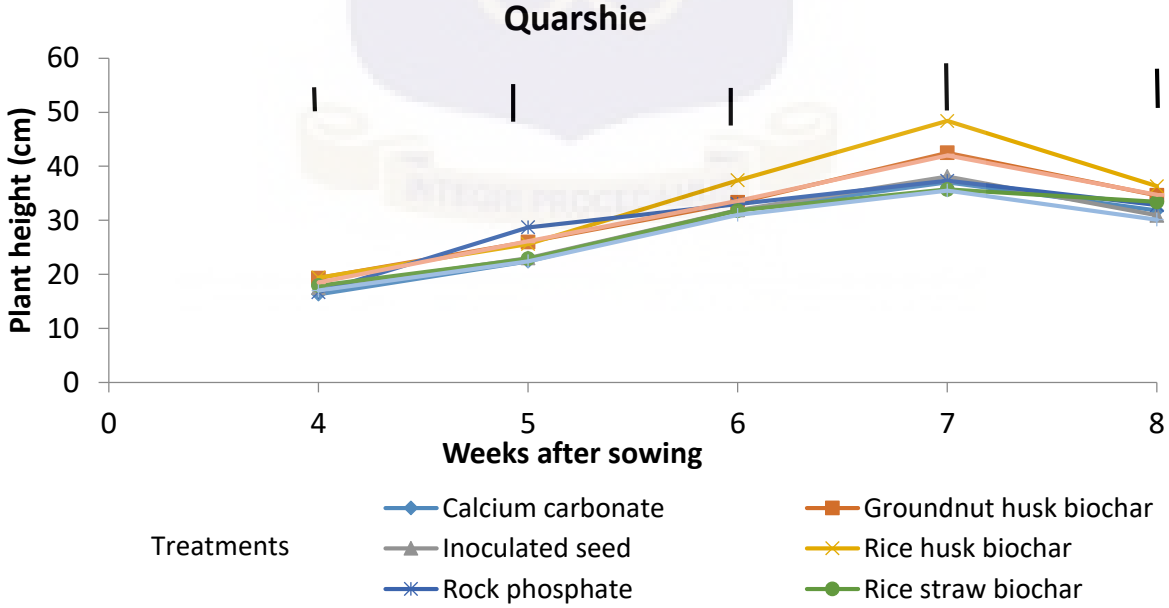


Figure 4.3. Plant height of soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and Saw Dust biochar.

4.1.4 Effect of Pelleting Material on Number of branches at flowering

The number of branches at flowering is shown in Figure 4.4., the effect of varieties were significant on number of branches at flowering. The analysis of variance showed no significant differences in the effect of the different pelleting materials on the number of branches at flowering. The interaction was also not significant. The highest branch number 7 (Quarshie) was recorded on groundnut husk biochar and the least 5 (Quarshie) on inoculated seed and control whiles least for Jenguma was on groundnut husk and rice husk biochar, inoculated seeds, rock phosphate and the control.

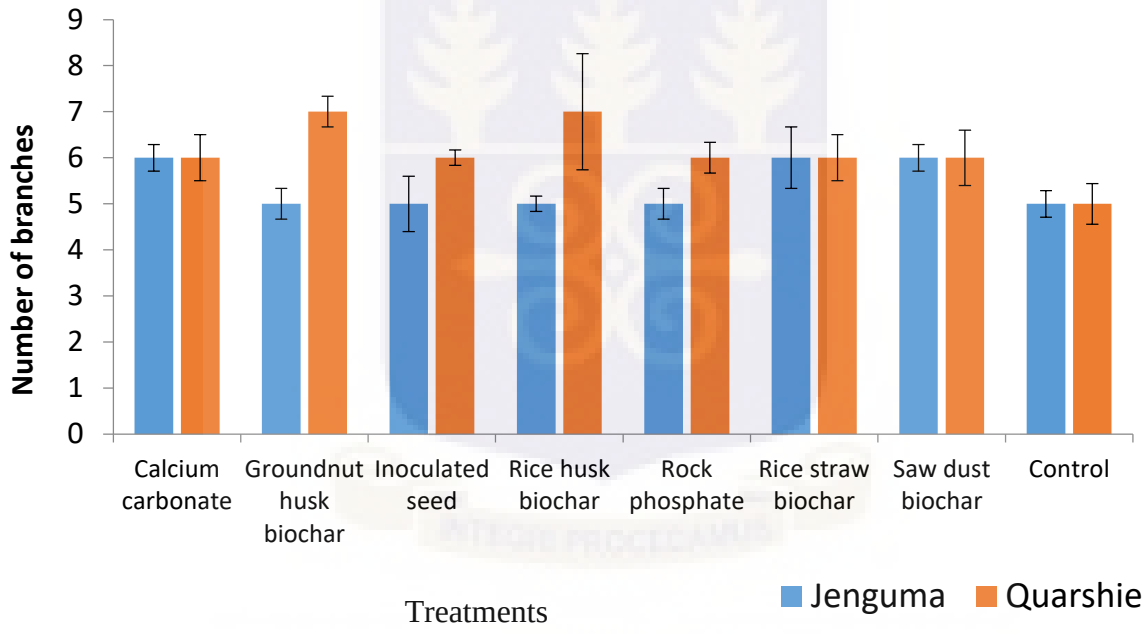


Figure 4.4. Number of Branches at flowering in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.5 Effect of Pelleting Material on Plant stem girth

There was no significant interaction between variety and seeds pelleting treatments on stem girth from sowing to maturity. Treatment effect were also was not statistically significant in all the weeks after sowing. However, varietal effect on plant stem girth revealed significant differences

at week 5 after emergence though at week 4, 6, 7 and 8 there was no significant difference. Even though the effect on pelleting materials were not significant, groundnut husk biochar and calcium carbonate gave larger plant stem girth (6.65 mm and 6.62 mm) for Jenguma and Quarshie respectively than all the other pelleting materials at the 8 week after sowing. Plants with groundnut husk biochar as pelleting material had significantly bigger plant stem girth than pelleting with calcium carbonate. The minimum plant stem girth of 2.99 mm (calcium carbonate) was observed in Jenguma. Quarshie recorded a minimum of 3.01 mm (rice husk biochar) in the 4th week after sowing and emergence (Fig. 4.5).

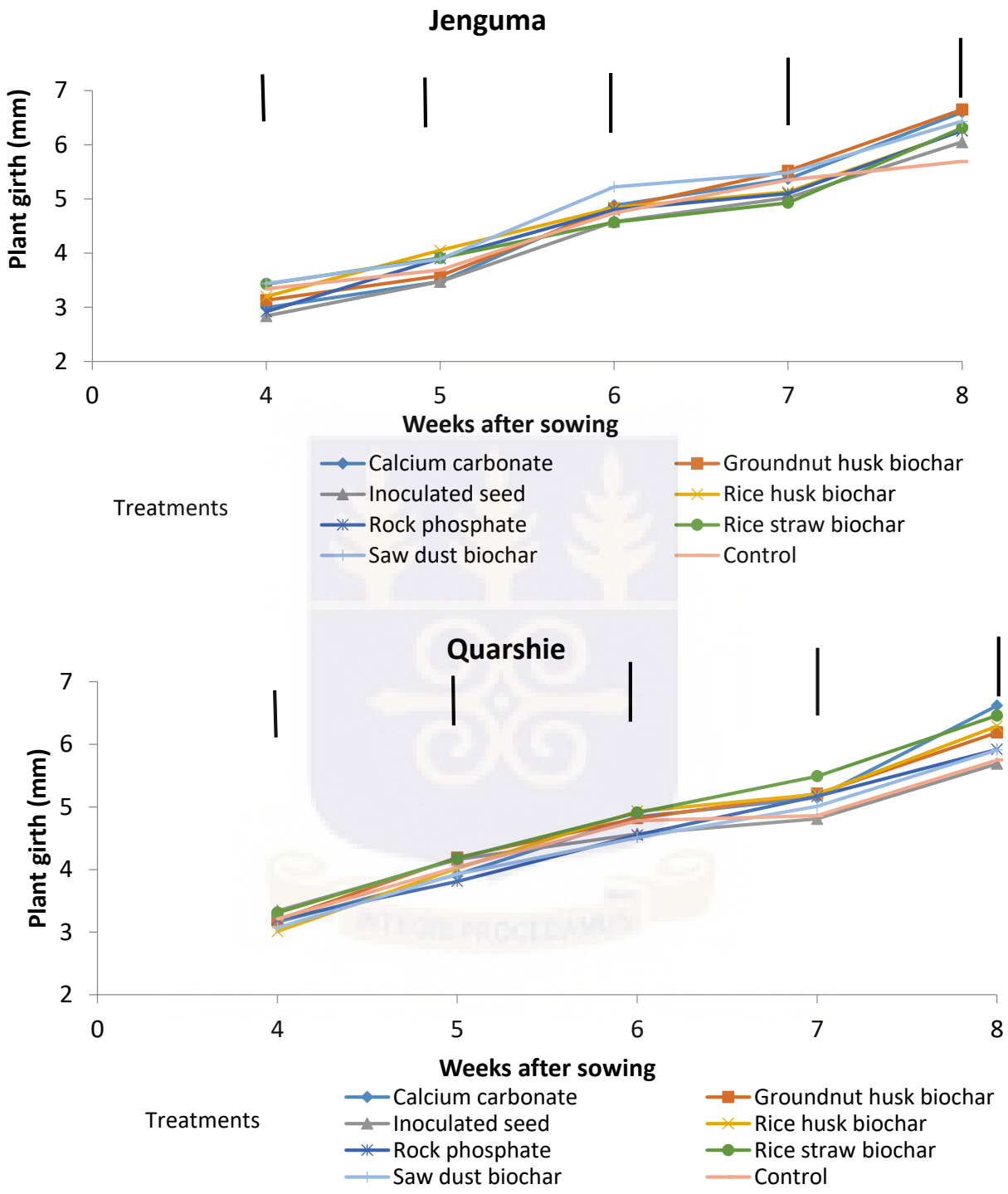


Figure 4. 5. Plant girth in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.6 Effect of Pelleting Material on Number of leaves

The number of leave produced per plant by the different pelleting treatments at 4th, 5th, 6th and 7th week after sowing were not significantly different. However significant differences were observed at 4th, 5th, 6th and 7th week after sowing between the varieties. The highest number of leaves 85.0 (Quarshie) and 73.0 (Jenguma) were produced by soybean plants grown with groundnut husk biochar and rice straw biochar respectively. It was observed that plants produced from pelleted seeds produced green leaves throughout the experiment. Quarshie produced higher number of leaves than the Jenguma throughout the experiment (Fig. 4.6).

Interaction between variety and treatment (all the pelleted seeds) was not significant at all the weeks from weeks 4, 5, 6 and 7 after sowing. The number of leaves produced per plant ranged from18.0 to 85.0 for both varieties. The smallest leaf number 17.0 (Quarshie) and 14.0 (Jenguma) were produced by soybean plants grown with calcium carbonate and rock phosphate pelleting indicating that pelleting with biochar resulted in the plant producing higher number of leaves.

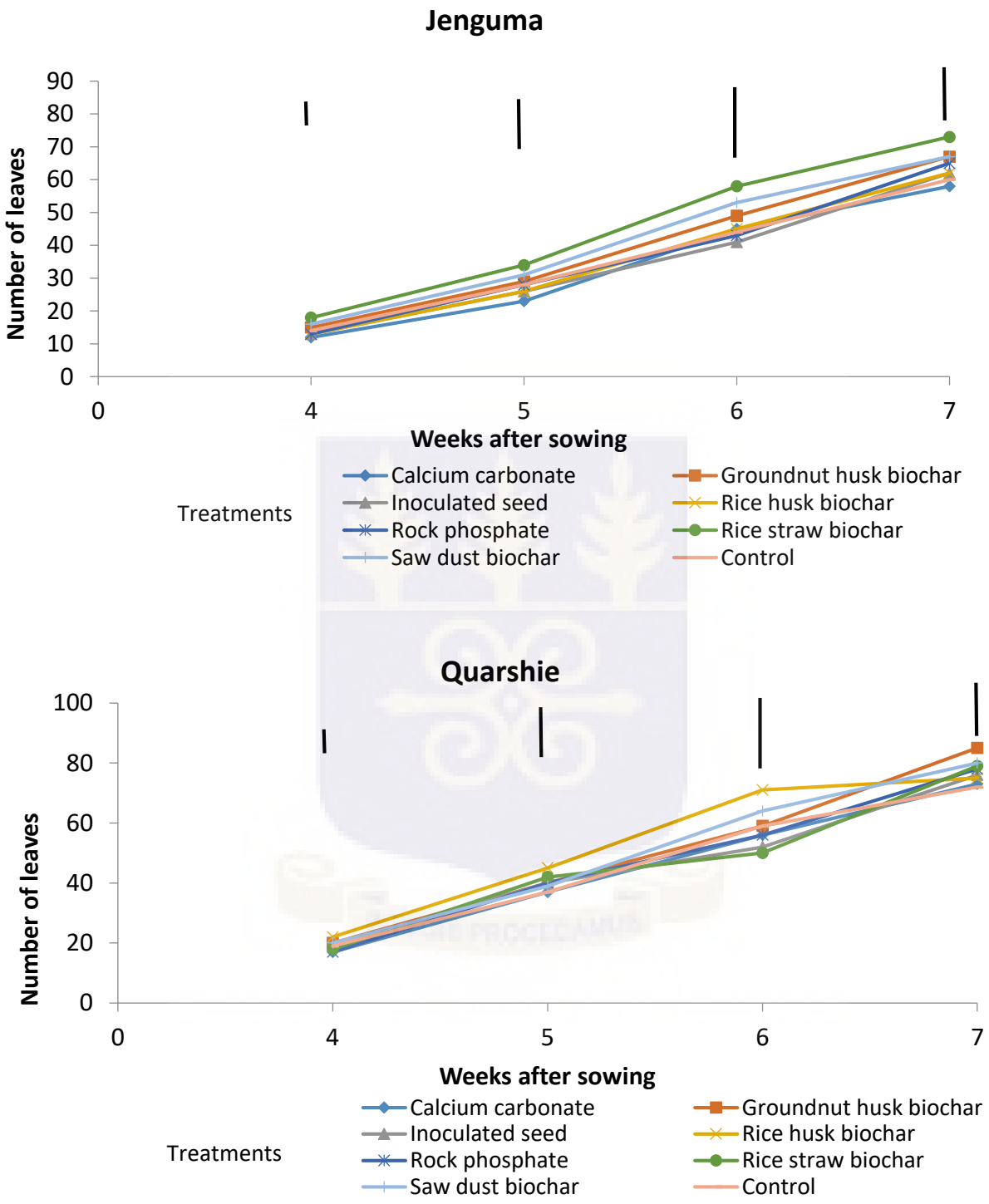


Figure 4.6. Number of leaves in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.7 Effect of Pelleting Material on Leaf area (cm^2)

Leaf area of the different treatments on the two varieties (Fig. 4.7). Leaf area was not significantly affected by varieties of the soybeans and the treatments did not significantly affect the leaf area of the soybean. The interaction between the treatments and varieties was also not significant for leaf area. The leaf area ranged from 1026.6 to 2258.0 for Quarshie with control and rice husk biochar respectively. However for Jenguma it ranged from 1231 for control to 1909.0 for groundnut husk biochar.

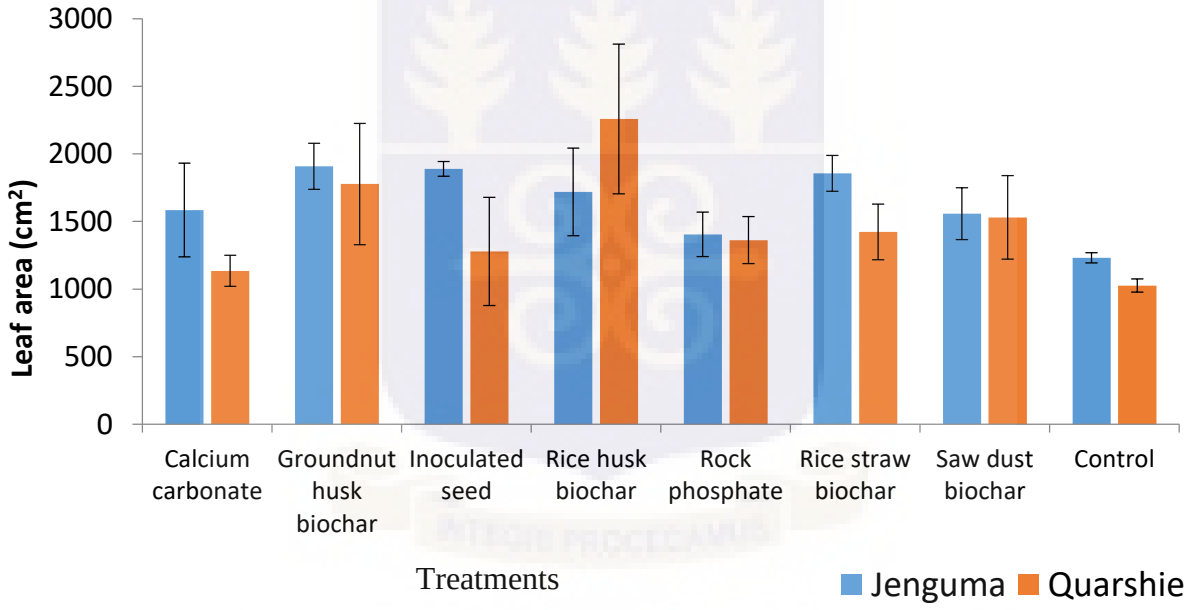


Figure 4. 7. Leaf area for two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.8 Effect of Pelleting Material on Number of nodules

For nodule numbers there was no significant difference between the varieties and the interaction between the varieties and treatments was also not significant, however with the treatments there significant differences with groundnut husk biochar, producing the highest nodule number

followed by rice husk biochar. The inoculated seed performed better than saw dust biochar which also performed better than rice straw biochar, calcium carbonate, rock phosphate and control in that order (Fig. 4.8).

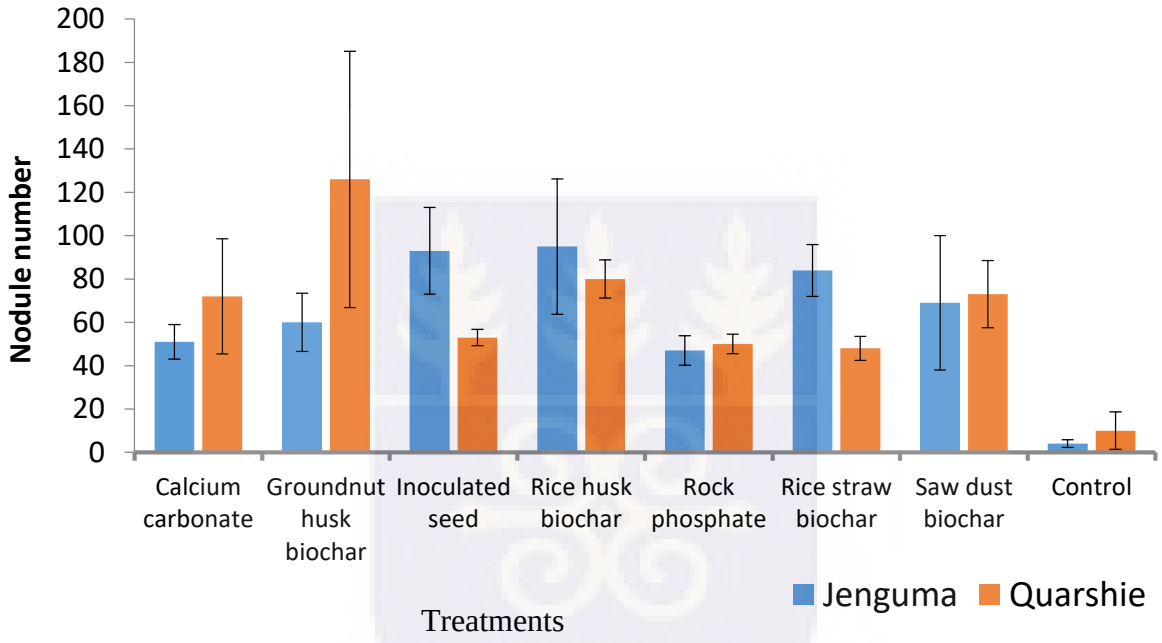


Figure 4. 8. Nodule numbers in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.9 Effect of Pelleting Material on Nodule fresh weight (g)

For nodule fresh weight was not significantly different between the varieties and the interaction between the varieties and treatments was not significant, however with the treatments there were significant differences with groundnut husk biochar producing the highest nodule fresh weight followed by the other treatments. Rock phosphate yielded higher nodule weight then the calcium carbonate and control (Fig. 4.9).

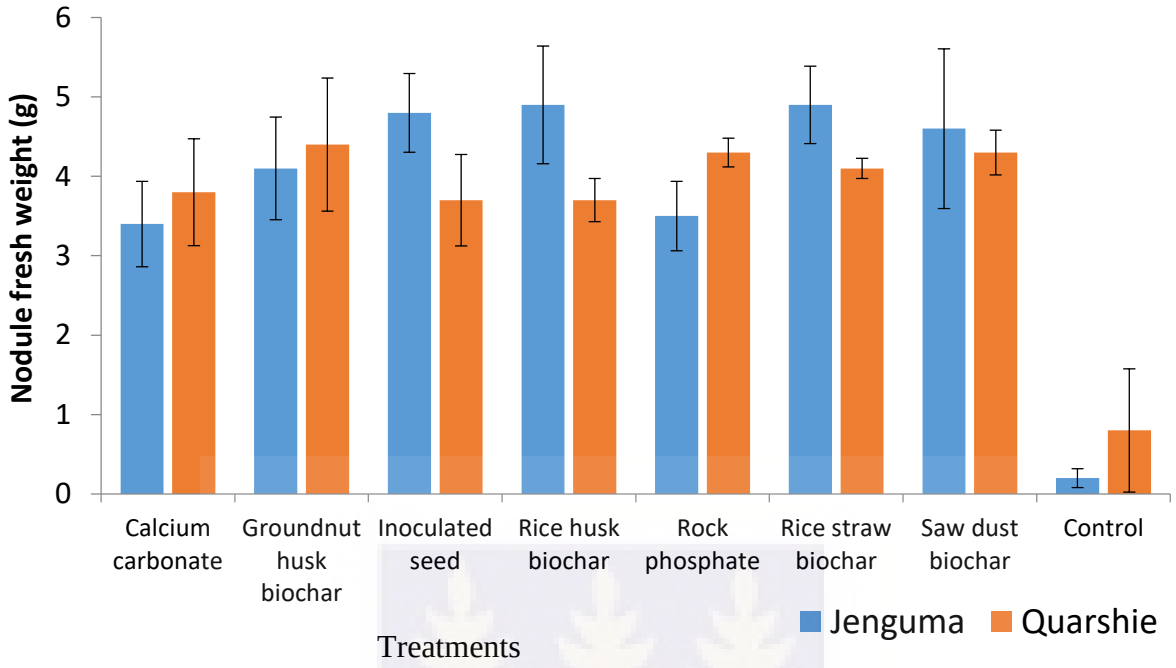


Figure 4. 9. Nodule numbers in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.10 Effect of Pelleting Material on Nodule dry weight (g)

Nodule dry weight was not significantly between the two varieties but treatments was significant. The interaction between the varieties and treatments was not significant. Rice husk biochar produced the highest nodule dry weight of 1.05 g per plant on Jenguma. Rice straw biochar produced nodule dry weight of 0.94 g on Jenguma and 0.91 g inoculation alone on the same variety and 0.91 g Groundnut husk biochar on Quashie. Saw dust biochar on Jenguma gave nodule dry weight of 0.9 g. Rock phosphate on Quashie gave a nodule weight of 0.84 g, Calcium Carbonate on Quashie produced 0.83 g of nodule dry weight but both Rock phosphate and Calcium Carbonate on Jenguma produced 0.64 g which was the least among the treatments. Control gave 0.14 g nodule dry weight with Quashie and 0.02 g with Jenguma (Fig. 4.10).

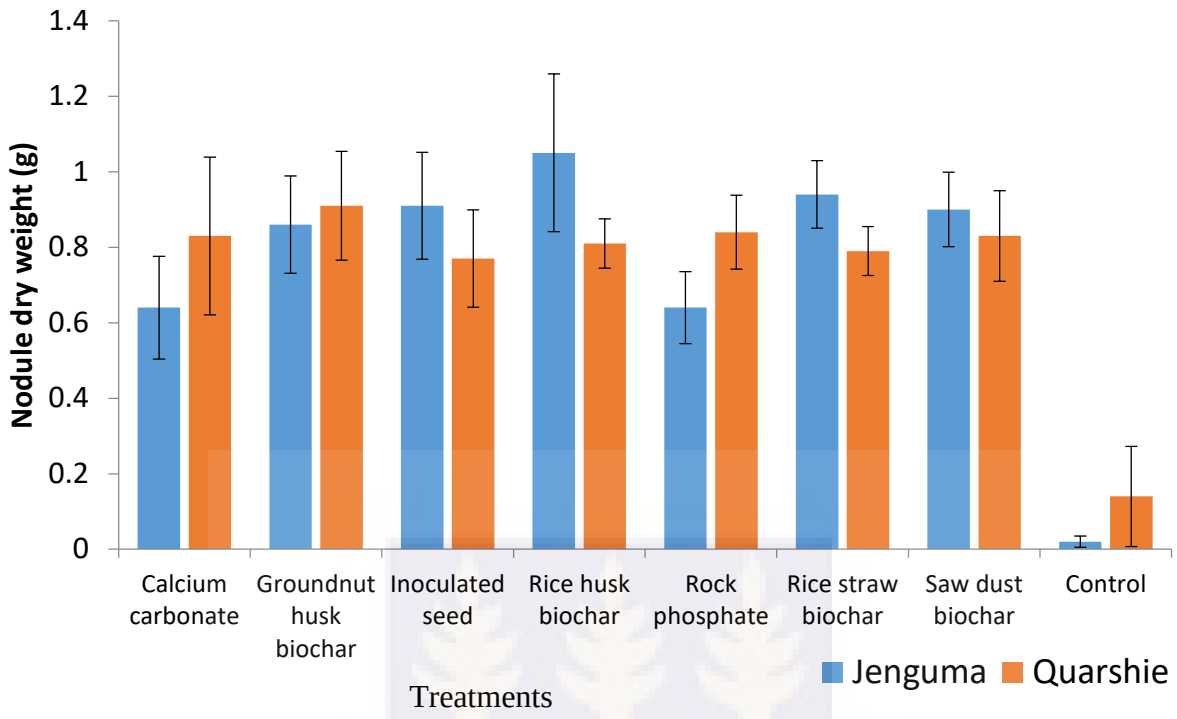


Figure 4. 10. Nodule dry weight in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.11 Effect of Pelleting Material on Leaf dry weight

Leaf dry weight showed no significant differences for either the variety or the treatments. The interaction between variety and treatments was also not significant. The maximum leaf dry weight of 6.8 (Quarshie) was produced by plants pelleted with rice husk biochar and 5.9 (Jenguma) for those pelleted with rice straw biochar were observed. The minimum of 3.5 (Jenguma) and 3.2 (Quarshie) were observed in the control (fig. 4.11).

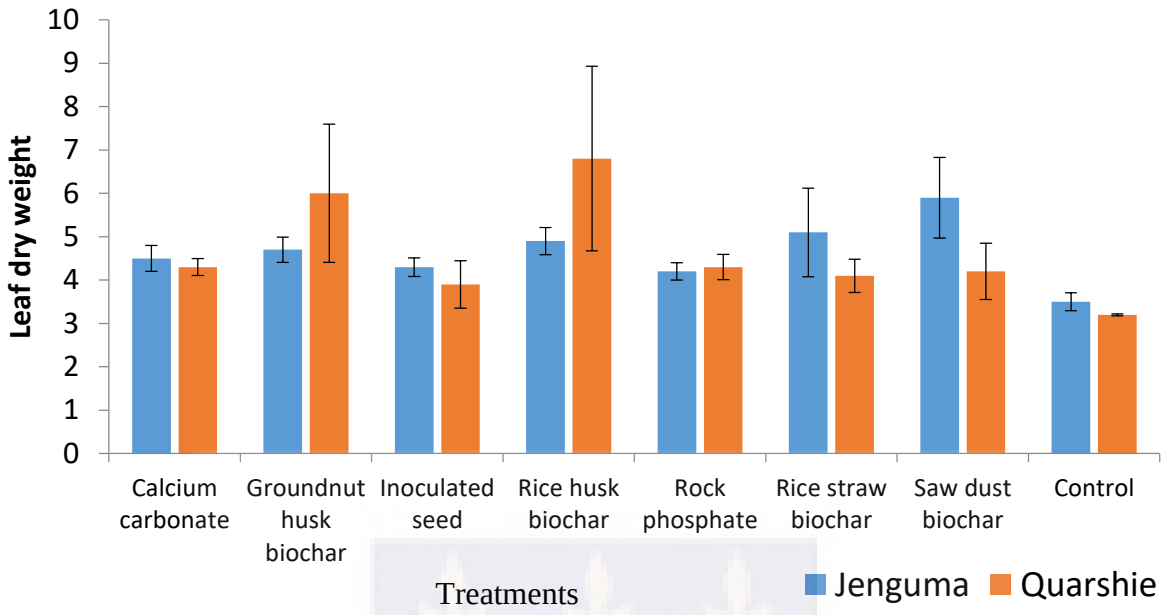


Figure 4. 11. Leaf dry weight in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.12 Effect of Pelleting Material on Shoot dry weight

There were no significant differences observed between the varieties and interaction between variety and treatments on shoot dry weight of the plants was not significant. The treatments were also not significantly different. The maximum of 6.1 (Quarshie and Jenguma) was obtained from plants pelleted with rice husk biochar and saw dust biochar respectively and the minimum of 3.4 (Quarshie and Jenguma) was obtained in the control plants (Fig. 4.12).

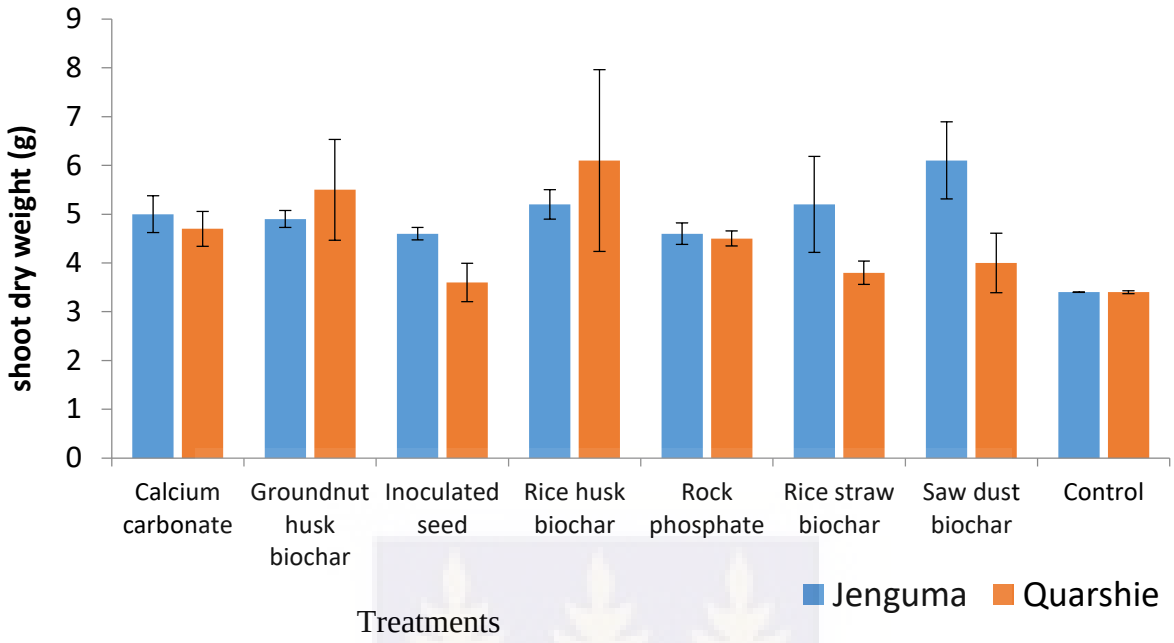


Figure 4. 12. Shoot dry weight in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.13 Effect of Pelleting Material on Root dry weight

There were no significant differences observed between the two varieties and the interaction between variety and treatments on root dry weight of the plants was not significant. The treatments were also not significantly different. The maximum root dry weight of 11.9 (Quarshie) and11.1 (Jenguma) were from plants pelleted with calcium carbonate and rice straw biochar respectively, and the minimum of 6.1 (Quarshie) and 8.8 (Jenguma) from the control plants in (Fig. 4.13).

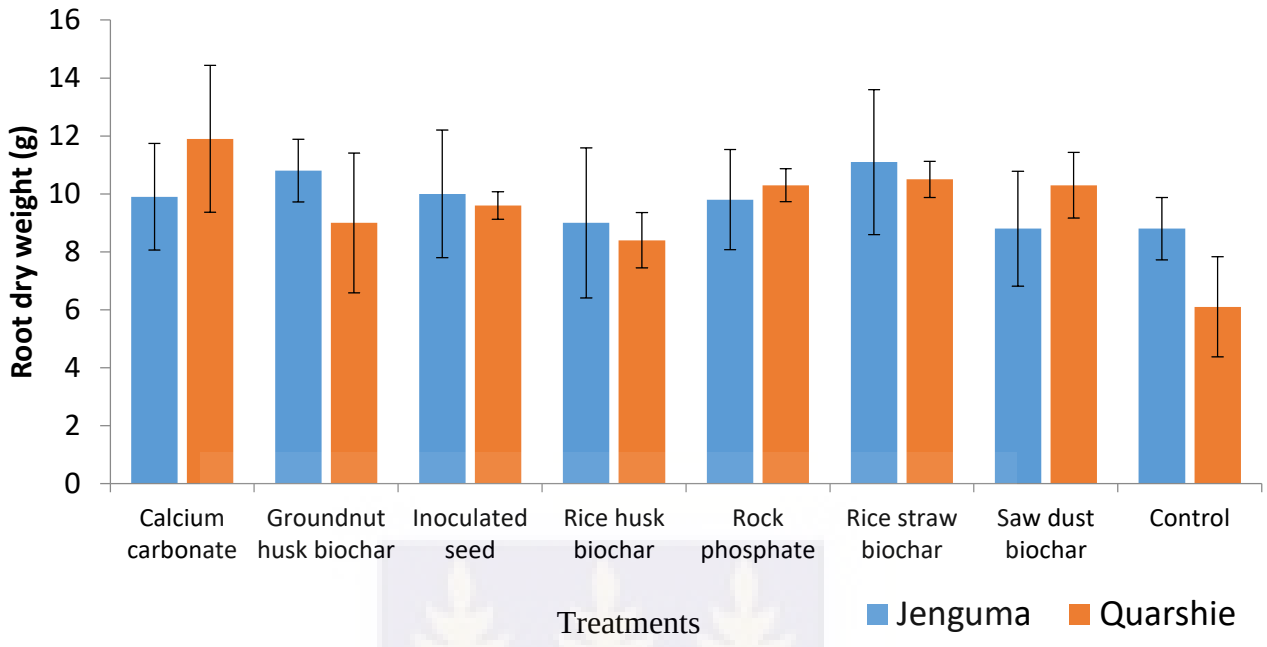


Figure 4. 13. Root dry weight in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.14 Effect of Pelleting Material on Number of pods per plant

Figure 8 shows the results from number of pods per plant. Treatments and interaction between treatment and variety were not significantly different however the difference between the two varieties was statistically significant ($P < 0.05$). The maximum pod number of 27.0 (Quarshie) and 15.0 (Jenguma) were produced by plants from seeds pelleted with groundnut husk biochar and rice straw biochar respectively while the minimum pod number of 2.0 (Quarshie and Jenguma) was produced by the controls (no pelleting) in (Fig. 4.14).

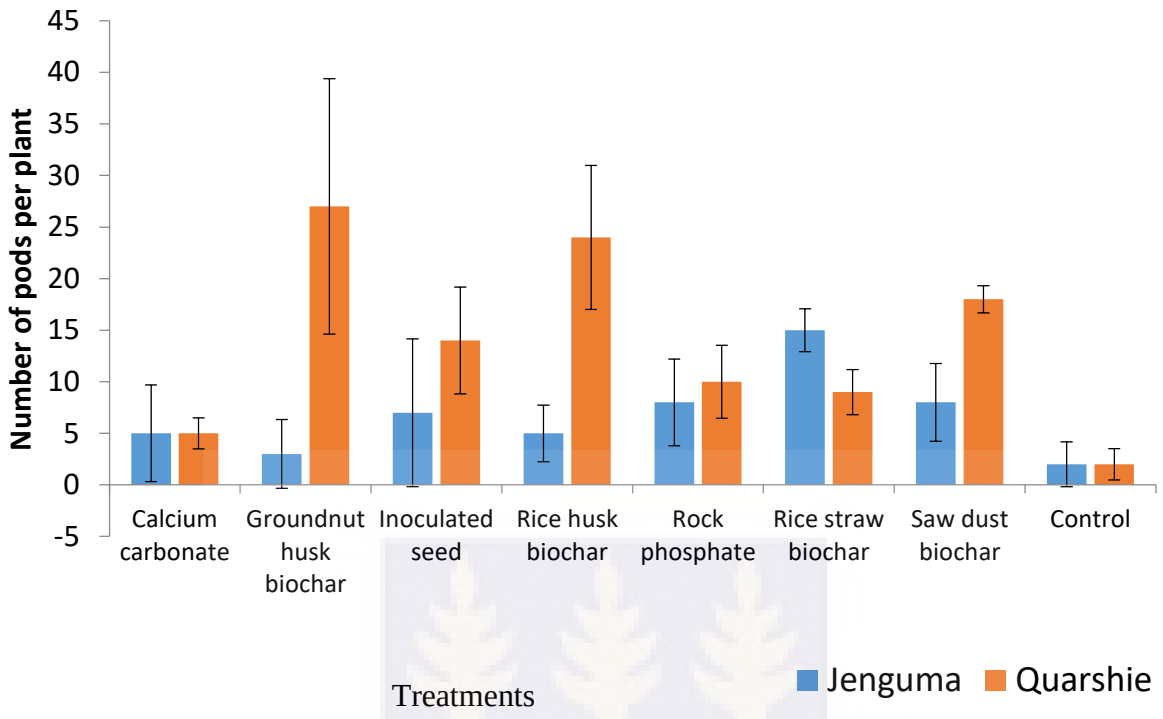


Figure 4. 14. Number of pod per plant in two soybean cultivars (Jenguma and Quarshie) pelleted with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and saw dust biochar.

4.1.15 Effect of Pelleting Material on Nitrogen, Phosphorus and Potassium content of Plant

Nitrogen (N) concentration ranged from 1.28% to 2.38% in the aboveground dry matter and these were not significantly different among treatments. The highest accumulated nitrogen content of 3.06% was observed in soybean plants with rice straw biochar as the pelleting material and the lowest content of 1.28% was observed in plants in the control (no pelleting). The aboveground dry matter of Jenguma showed an increase in accumulated N content irrespective of biochar amendments than in Quarshie. An increase in N% content observed in Quarshie variety was 2.10% when pelleted with Rock Phosphate Fertilizer and decreased to 2.00% when pelleted with Groundnut husk biochar. The lowest N% content observed in Quarshie was 1.39% which was higher than the lowest N% content observed in Jenguma of 1.28%.

The amount of phosphorus accumulated in the aboveground dry matter of soybean plants were not significantly different among the different pelleting Materials. A high P of 0.59 was observed in the Jenguma when seeds were pelleted with rice straw biochar. The least P of 0.50 was observed in the control of Quarshie. Control plants of Quarshie accumulated higher P than plant from rice straw biochar and carbonate pelleting.

Differences observed in % K accumulation in the two soybean varieties were not significantly different. Seed pelleted with Rice Straw Biochar produced soybean plants that accumulated more K in their aboveground dry matter on Quarshie (2.63) than Jenguma (2.01). The no pelleting (control) produced more K compared to the other treatments in expectation of rice straw biochar on Quarshie (Table 3).

Table 3: Nitrogen, Phosphorous and Potassium concentration in the two soybean varieties above ground dry matter with Calcium Carbonate, Rock Phosphate, Ground nut husk biochar, Rice husk biochar, Rice Straw biochar and Saw Dust biochar.

	Total N		**Total P**		**Total K**	
Treatments	Jenguma	Quarshie	Jenguma	Quarshie	Jenguma	Quarshie
Calcium Carbonate	1.55	1.54	0.53	0.47	1.25	1.27
Groundnut husk biochar	1.09	2.00	0.43	0.51	1.53	1.02
Inoculated seed	1.51	1.87	0.51	0.53	1.16	1.72
Rice husk biochar	1.59	1.40	0.43	0.51	4.20	0.83
Rock phosphate	1.67	2.10	0.49	0.50	1.29	1.36
Rice straw biochar	2.38	1.44	0.59	0.49	2.01	2.63
Saw dust biochar	1.48	1.79	0.46	0.58	1.91	1.20
Control	1.28	1.39	0.51	0.50	1.25	1.42
Lsd (P>0.05)	0.58	0.58	NS	NS	NS	NS

4.2. Field experiment

4.2.1: Effect of Soil Amendments on Days to Emergence

In the field experiment, there was no significant difference among the various treatments as well as the two cultivars of soybean. The days to emergence varied among soybean cultivars and the treatments as well. Days to emergence ranged from 4 to 5. Treatments such as inoculated alone, rice husk biochar and rock phosphate recorded 5 days to emergence in Quarshie. Both Jenguma and Quarshie grown in soils treated with rice straw biochar recorded 4 days to emergence. Quarshie in soil amended with saw dust biochar and the control recorded 4 days to emergence. It was observed that Jenguma treated with rock phosphate, rice straw biochar, rice husk biochar and inoculation alone recorded 4 days to emergence whereas saw dust biochar and the control recorded 5 days to emergence in Jenguma (Fig. 4.15).

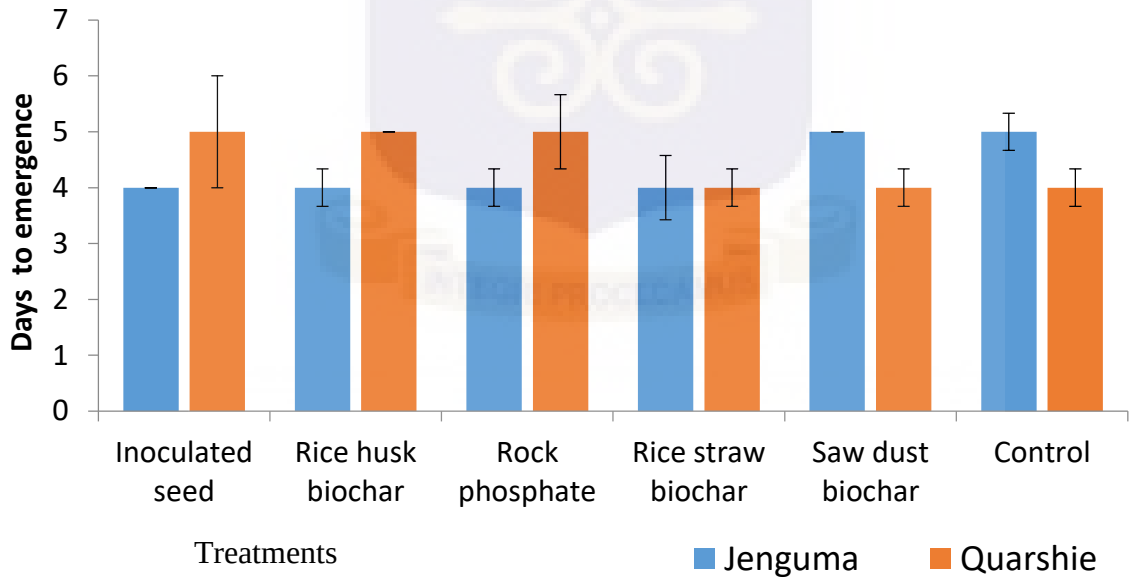


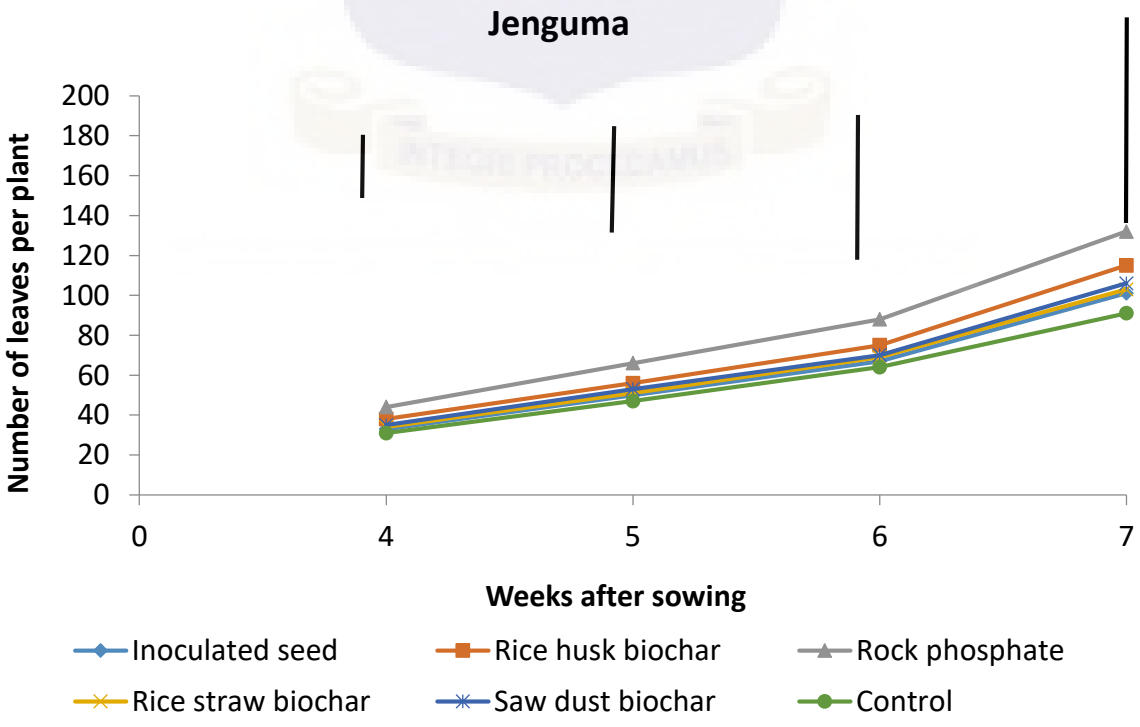
Figure 4. 15. Days to emergence in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.2. Effect of Soil Amendments on Number of leaves

The number of leaves under different soil amendments application were not significantly different. Interaction between variety and treatments was not significant and the two varieties were also not significantly different from each other. Jenguma with different soil amendments at week four, produced the number of leaves per plant of 44.0 which increased through the weeks to week 7 which recorded 132.0

For Quarshie, the number of leaves per plant produced was 64 on the fourth weeks with increasing numbers throughout the weeks and produced the highest leaf number at the 7th week after planting which was 190.0. Inoculation alone recorded the highest from week 4 to week 7 after planting. Soil amended with rock phosphate recorded the minimum leaf number for Quarshie and the control recorded the minimum for Jenguma (fig. 4.16).

A



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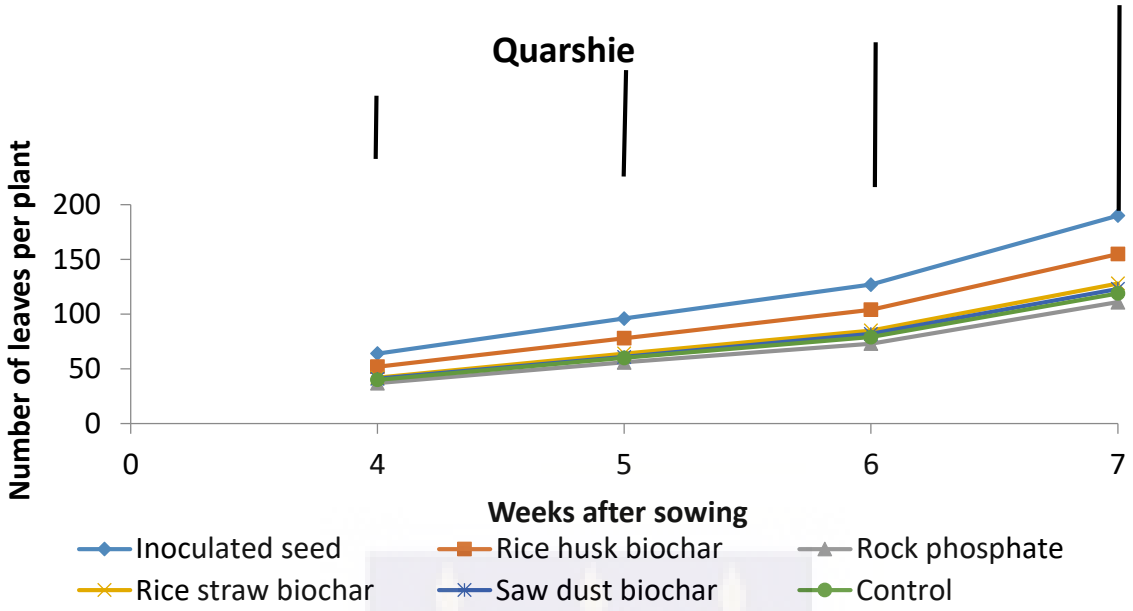

Figure 4. 16 . Number of leaves per plant in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.3. Effect of Soil Amendments on Plant Height

Soybean plant heights at 4, 5, 6 and 7 weeks recorded no significant ($p>0.05$) difference among the different soil amendments and the interaction between soil amendment and variety was also not significant. Plant height continued to increase for rice husk biochar, rock phosphate, rice straw biochar and saw dust biochar at weeks 4, 5, 6 and 7 after planting in figure 4.17. The maximum plant height observed in the 7th week was for saw dust biochar on Jenguma and rice straw biochar on Quarshie was 71.1 cm. followed by rice husk biochar and rice straw biochar with 70.1 cm for Jenguma, for Quarshie saw dust biochar recorded 68.9 and 64.1 by rice husk biochar.

The control recorded 67.2 cm in Jenguma which was the least plant height and inoculation alone recorded the least plant height of 55.1 cm for Quarshie in the 7th week after planting (Fig. 4.17). There was no significant difference ($p>0.05$) among the two soybean varieties.

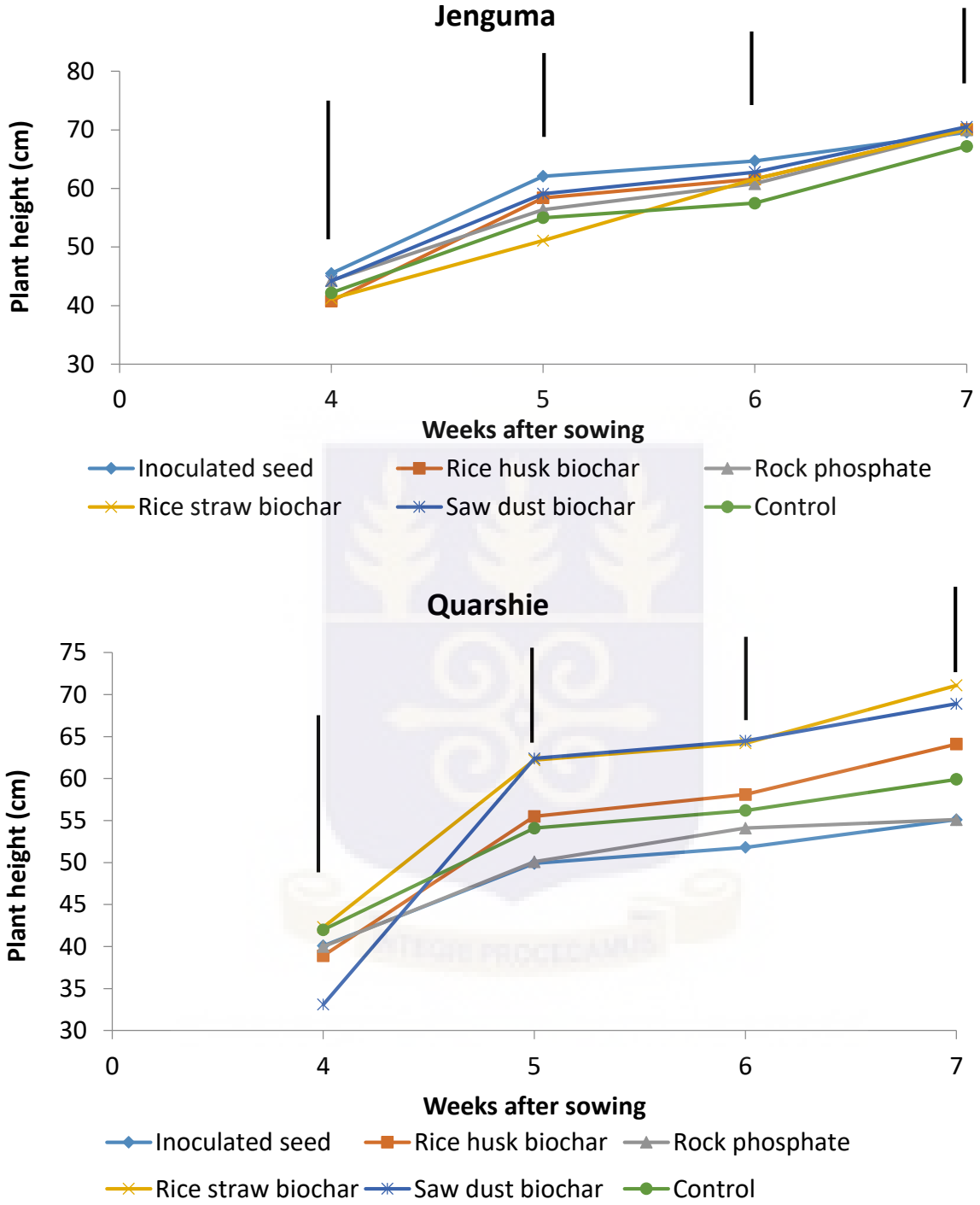

Figure 4. 17. Plant height in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.4. Effect of Soil Amendments on Days to Flowering

Days to flowering among treatments and the cultivars recorded no significant differences. However, it was observed that for plants of Quarshie, addition of saw dust biochar, rice straw biochar, inoculation alone and the control took 39 days to flower whereas the same variety treated with Rock phosphate took 40 days to flower in table 4.3. The least number of days to flowering was recorded in Quarshie in soil amended with Rice husk biochar. On the other hand, Jenguma planted in soil amended with rice straw biochar and saw dust biochar recoded 39 days to flowering. This was followed by Jenguma planted in soil amended with rice husk biochar, rock phosphate and inoculation alone which all recorded 40 days to flowering. Control plants recorded 41 days to flowering (Table 4).

Table 4: Days to flowering in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

Treatment	**Days to flowering**	
	Jenguma	Quarshie
Inoculated seed	40.0	39.0
Rice husk biochar	40.0	38.0
Rock phosphate	40.0	40.0
Rice straw biochar	39.0	39.0
Saw dust biochar	39.0	39.0
Control	41.0	39.0

LSD ($P \leq 0.05$); Variety = 1.04 NS
Treatment = 1.35 NS
Treatment*Variety = 1.81 NS

4.2.5. Effect of Soil Amendments on Stem Girth

Soil amendments on stem girth was not significant and interactions between the treatments and variety was also not significant. For Jenguma rock phosphate recorded the highest stem girth of 5.61 at the 4th week followed by inoculation alone (5.12) then rice straw biochar that recorded 5.10. The least recorded stem girth at the 4th week was the control which was 3.97. At the 5th week the stem girth increased through to the 7th week where rice straw biochar recorded the highest of 7.48, followed by inoculation alone was 7.07 and the least stem girth was recorded by the control was 6.16 (Fig. 4.18).

The two varieties were not significantly ($p>0.05$) different from each other.

For Quarshie inoculation alone recorded 6.07 as the highest stem girth at week 4 and saw dust biochar recorded the least of 4.91. this increased throughout the weeks to the 7th week where the control recorded the highest of 7.81, followed by 7.73 by inoculation alone, then rice husk biochar recorded 7.58, rice straw biochar recorded 7.22, rock phosphate recorded 7.21 and the least stem girth was 6.33 by saw dust biochar.

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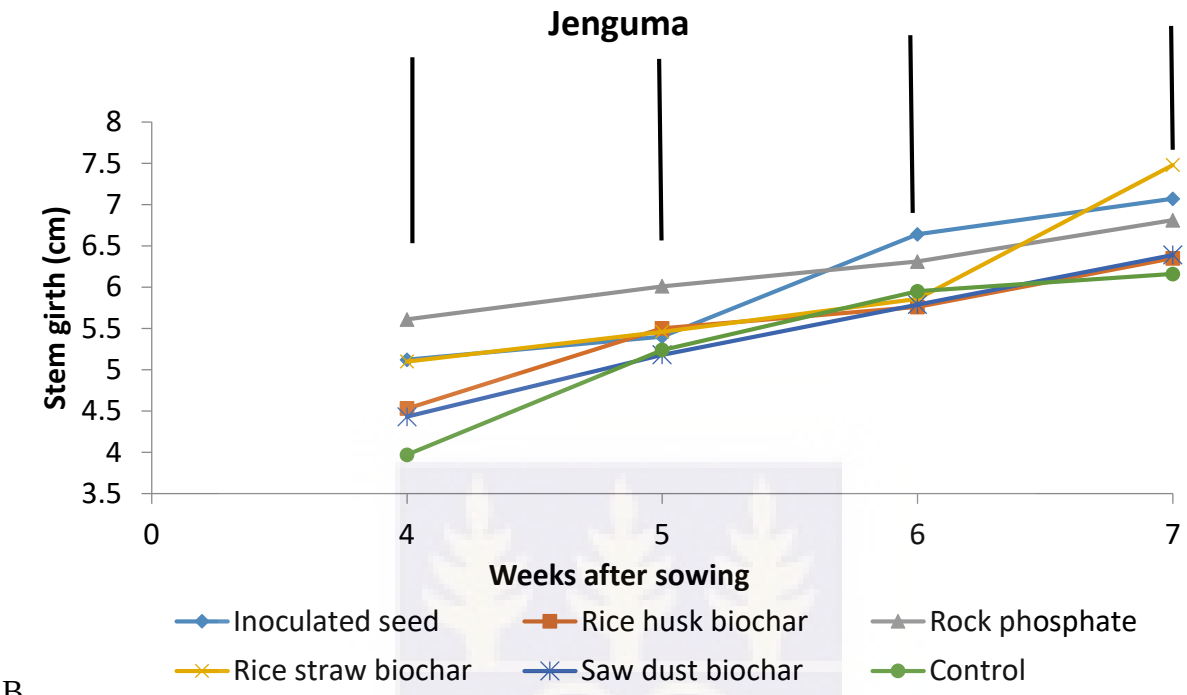

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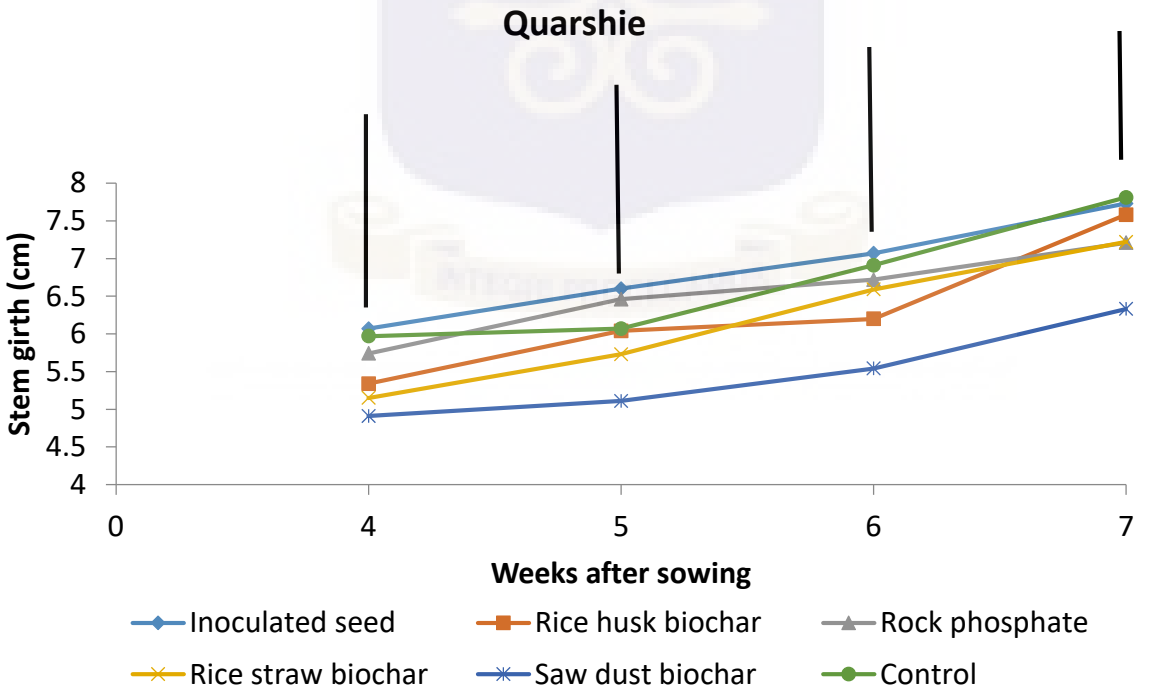


Figure 4. 18. Plant or stem girth in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.6. Effect of Soil Amendments on Number of Branches

Results from the different soil amendment and the two cultivars showed no significant differences at $p<0.05$. However Jenguma in soil amended with saw dust biochar, rice straw biochar, inoculation alone, rice husk biochar, and control recorded the lowest (5) number of branches at flowering whereas Jenguma in soil amended with rock phosphate recorded 6 branches at flowering (Table 5). Quarshie in soil amended with rice husk biochar had the highest number of braches (7) at flowering. Treatments such as inoculation alone, addition of rock phosphate and rice straw biochar recorded the second highest (6) number of branches at flowering whereas the control and saw dust biochar addition recorded the lowest (5) number of branches at flowering.

Table 5: Number of branches in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

Treatment	**Number of branches at flowering**	
	Jenguma	Quarshie
Inoculated seed	5.0	6.0
Rice husk biochar	5.0	7.0
Rock phosphate	6.0	6.0
Rice straw biochar	5.0	6.0
Saw dust biochar	5.0	5.0
Control	5.0	5.0

LSD ($P \leq 0.05$); Variety = 0.42
Treatment = 1.06 NS
Treatment*Variety = 1.38 NS

4.2.7. Effect of Soil Amendments on Leaf Area

Results obtained from leaf area measurements indicated no significant differences ($p<0.05$) among treatments. However, inoculation alone on Jenguma recorded the highest leaf area of 1151 cm^2 followed by rice husk biochar (986.0), saw dust biochar (915.0), rock phosphate (842.0) and rice straw biochar (780.0) Control recorded 952.0 which was higher than saw dust biochar, rock phosphate and rice straw treatments . On the other hand, Quarshie in soil amended with rice husk biochar recorded the highest leaf area of 1267.0, saw dust biochar recorded the second highest mean leaf area of 1119.0, rice straw biochar recorded 1087.0, inoculation alone recorded 877.0, rock phosphate recorded 873.0 and control recorded the least leaf area of 747.0 (Table: 6).

Table 6: Leaf area in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

Treatment	**Leaf area**	
	Jenguma	Quarshie
Inoculated seed	1151.0	877.0
Rice husk biochar	989.0	1267.0
Rock phosphate	842.0	873.0
Rice straw biochar	780.0	1087.0
Saw dust biochar	915.0	1119.0
Control	952.0	747.0

LSD ($P \leq 0.05$); Variety = 814.4 NS
Treatment = 403.3 NS
Treatment*Variety = 685.6 NS

4.2.8. Effect of Soil Amendments on Leaf Area Index

There was no significant difference in the LAI for the two varieties. Jenguma had higher leaf area index which ranges from 2.60-3.84 and for Quarshie it ranged from 2.49 - 3.76. The LAI of inoculated soybean plants were significantly higher (P <0.05) than those grown with rice straw biochar and rock phosphate (Table 7). The interaction between varieties and treatments was not significant for leaf area index.

Table 7: Leaf area index in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

Treatments	**Leaf area index**	
	Jenguma	Quarshie
Inoculated seed	3.84	3.38
Rice husk biochar	3.29	3.76
Rock phosphate	2.81	2.86
Rice straw biochar	2.60	3.11
Saw dust biochar	3.05	3.39
Control	3.17	2.49

LSD ($P \leq 0.05$); Variety = 814.4 NS
Treatment = 403.3 NS
Treatment*Variety = 685.6 NS

4.2.9. Effect of Soil Amendments on Number of Nodules

The interaction between variety and amendments was not significant. However, the difference among the treatments were highly significant in all the weeks. Jenguma treated with saw dust biochar produced 14 nodules at four week after planting, this increased to 63 in the 6th week and

decreased to 35 in the 7th week. Rice straw biochar recorded the highest nodule number of 17 at the 4th week after planting and this increased to 59 in 6th week of planting but decreased in the 7th week to 21. Control recorded the minimum nodule number of nodules from 4th week after planting to the 7th week after planting. On Quarshie plots treated rock phosphate fertilizer and rice husk biochar recorded the highest number of nodules of 18 at the 4th week after planting. At week 5 inoculation alone recorded the highest nodule number of 51 followed by saw dust biochar with nodule number of 49. At the 6th week saw dust biochar recorded the highest (98) number of nodules but this decreased in the 7th week to 44. Control recorded the minimum nodule number right from 4th week after planting to the 7th week after planting. There was no significant difference between the varieties (Fig. 4.19).

4.2.10. Effect of Soil Amendments on Nodule dry weight

Nodule dry weight of the two soybean varieties under the different treatments were significantly different at 4, 5 6 and 7 weeks after planting, in figure 4.20. The different treatments were significant at 4th and 5th weeks. However, at 6 and 7th week after planting nodule dry weight of soybean plants under different treatments were significantly different from each other. The controls for the two varieties recorded the minimum nodule dry weight, Jenguma recorded minimum of 0.09 g and Quarshie recorded the minimum of 0.08. The nodule dry weight produced by soybean plants in soil amended with rock phosphate fertilizer recorded the maximum for the two cultivars of soybeans followed by saw dust biochar for Quarshie and inoculation alone for Jenguma.

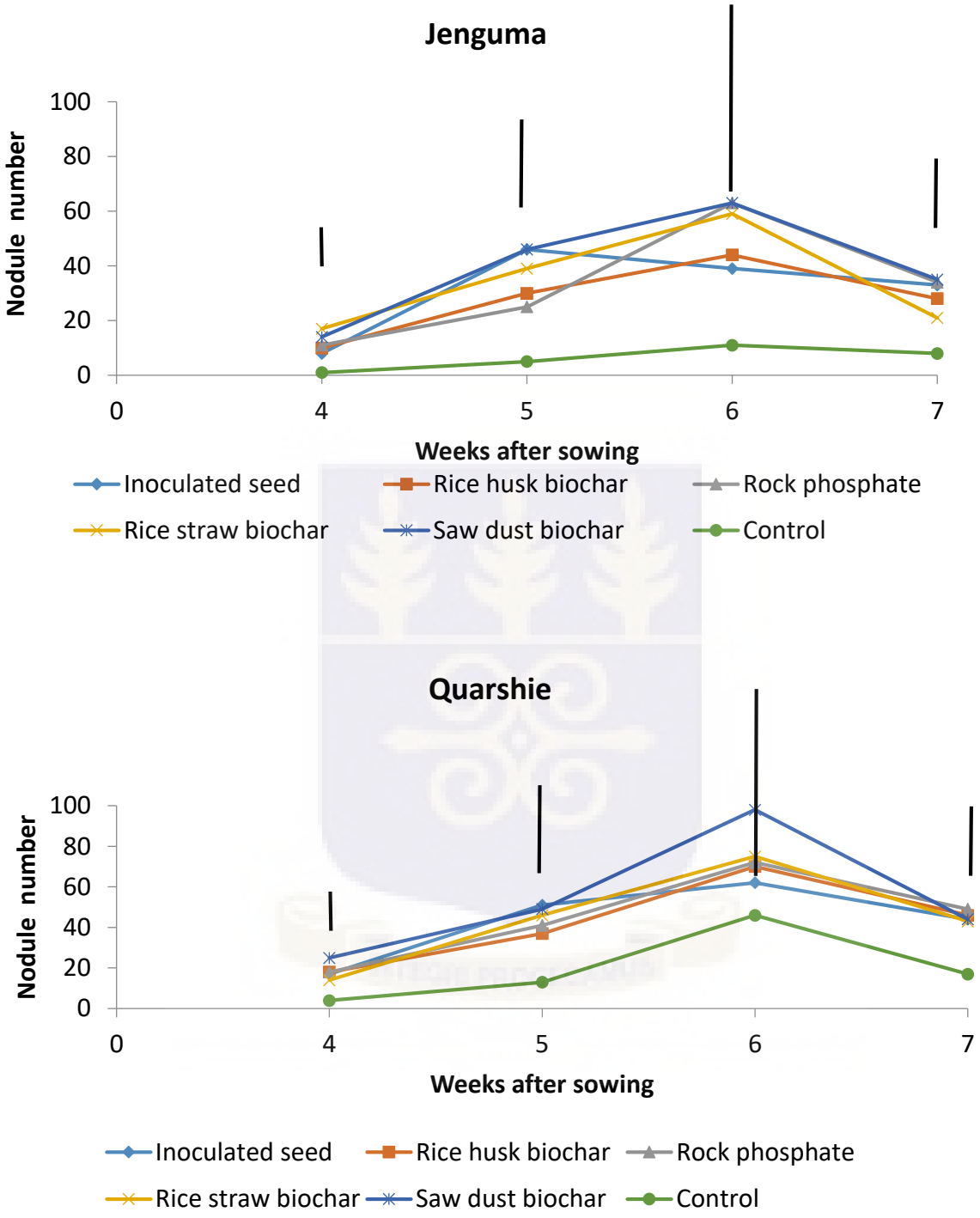
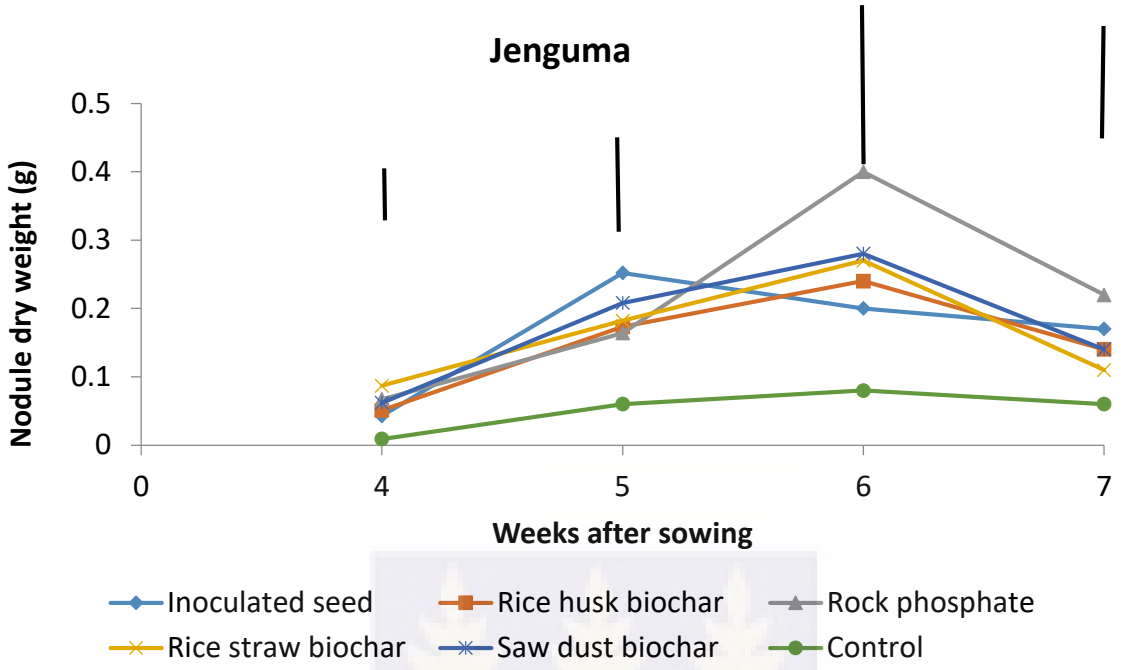


Figure 4. 19. Nodule number on Jenguma and Quarshie variety in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.



B

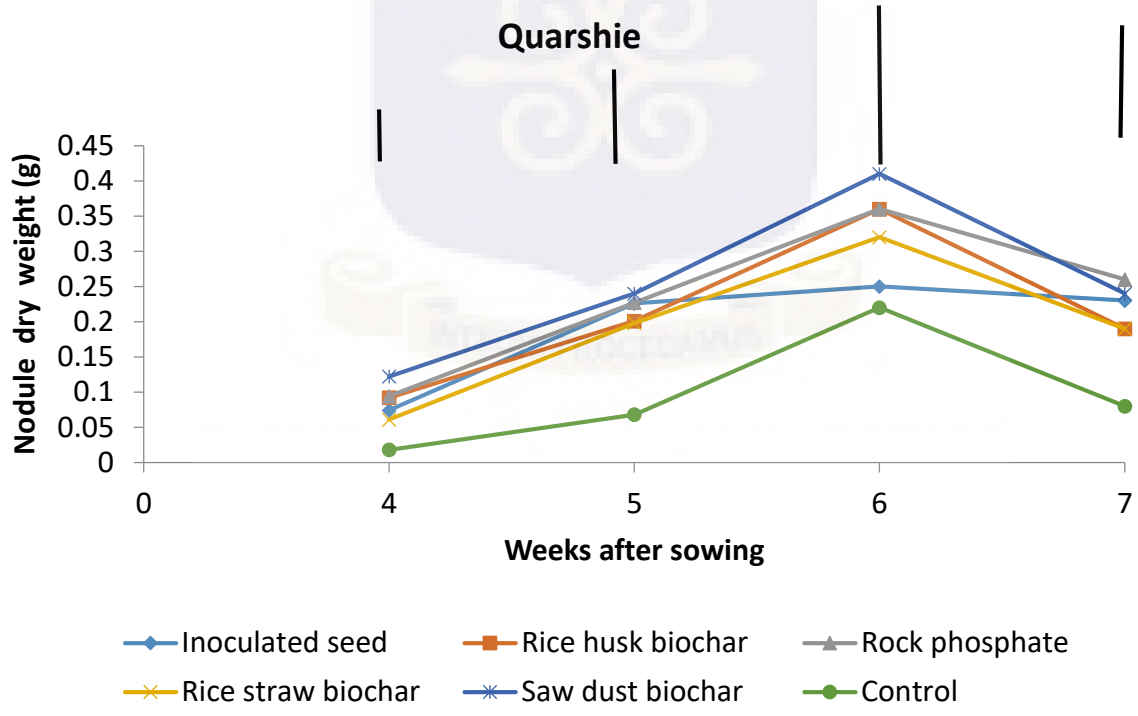
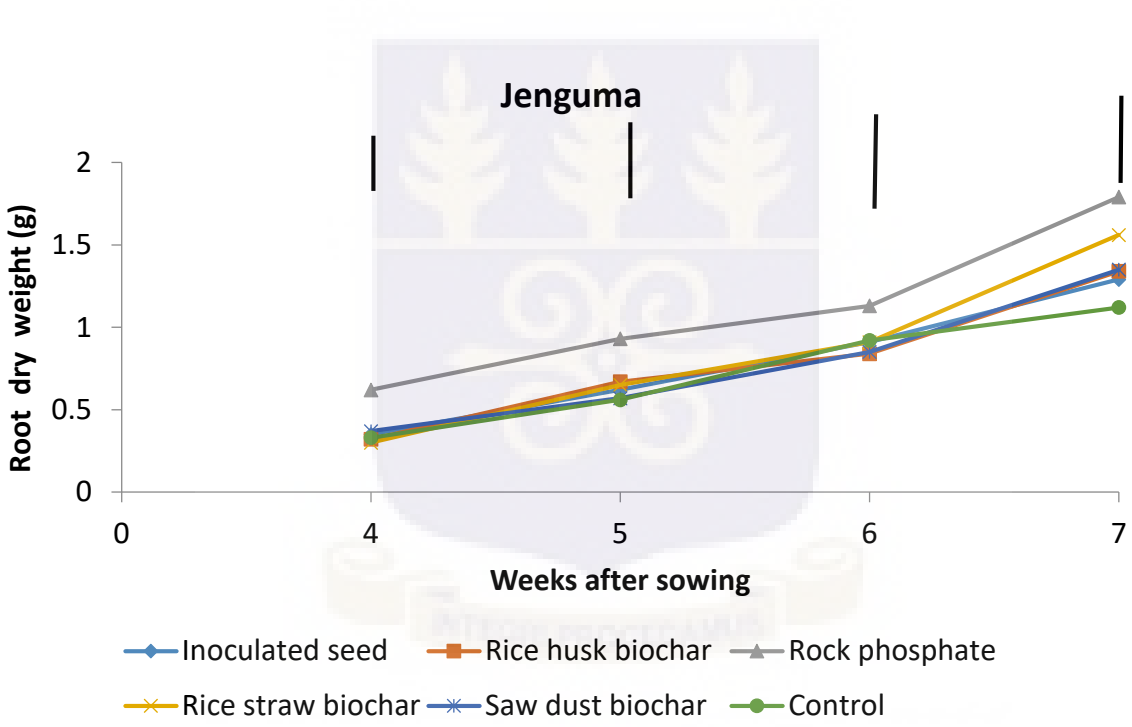


Figure 4. 20. Nodule dry weight (A&B) in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.11. Effect of Soil Amendments on Root Dry Weight

No significant difference was observed at 4, 5, 6 and 7 WAP between varieties under the different treatments (Fig. 4.21). At 4, 5, 6 and 7 WAP soybean plants under the different treatments recorded no significant differences in root dry weight. Root dry weight ranged from 0.45 (Quarshie) with inoculation alone at 4WAP to 1.87 (Quarshie) with inoculation alone at 7WAP, Interaction between variety and treatments was not statistically significant.



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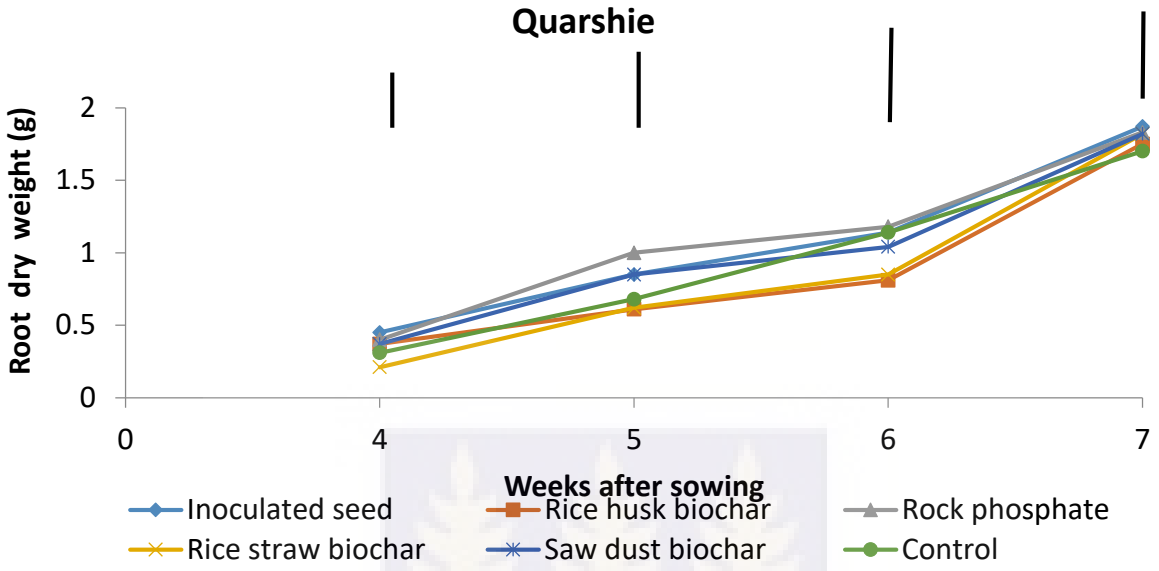
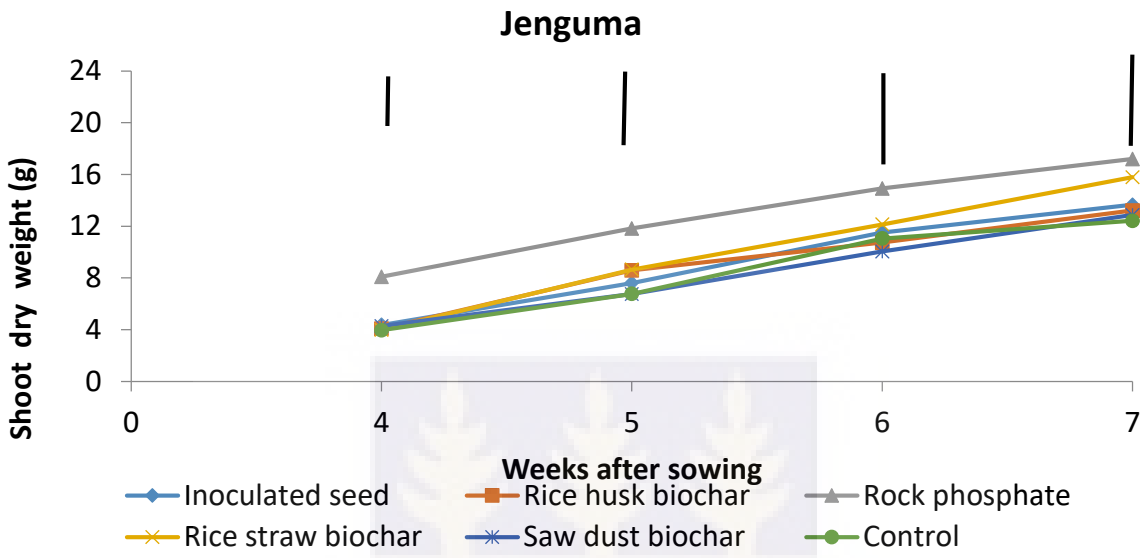


Figure 4. 21. Root dry weight in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.12. Effect of Soil Amendments on Shoot Dry Weight

There was no significant difference observed in the shoot dry weight of soybean plants under the different soil amendments at 4th, 6th and 7th week after planting but at 5th week after planting, the different soil amendments had a significant effect on shoot dry weight (Fig. 4.22). The interaction was not significant. On average Quarshie produced higher shoot dry weight than Jenguma, but the maximum shoot dry weight recorded was 8.09 (Jenguma) with rock phosphate fertilizer at 4th week to 17.19 at 7th week after planting, and 5.28 for Quarshie at 4th week to 22.17 at 7th week after planting on inoculation alone. Rice straw biochar recorded the minimum shoot dry weight with Quarshie and the control recorded the minimum for Jenguma.

A.



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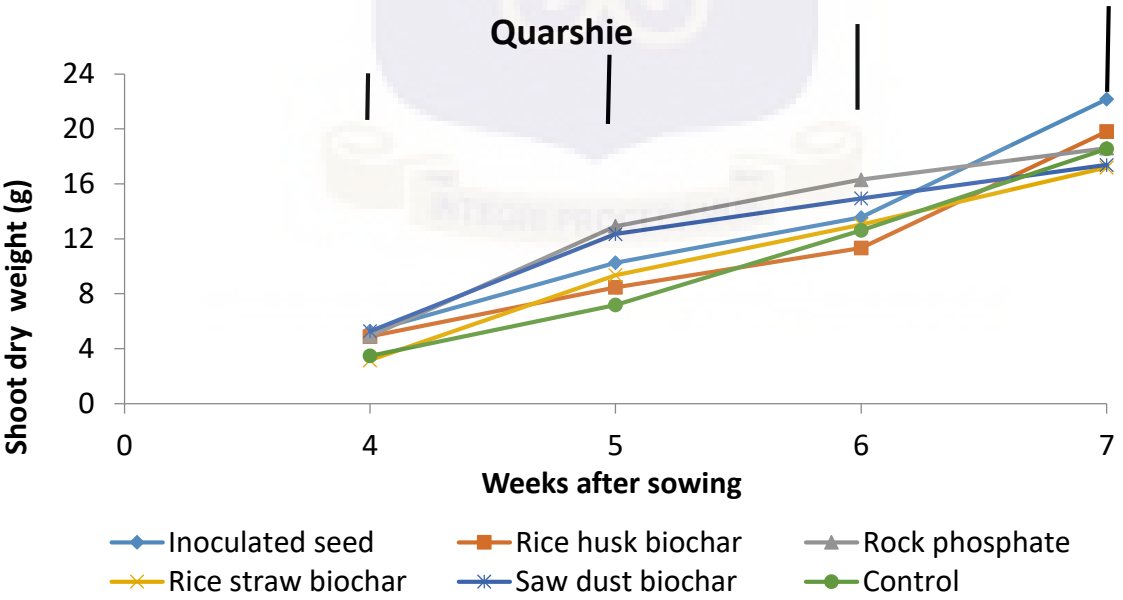
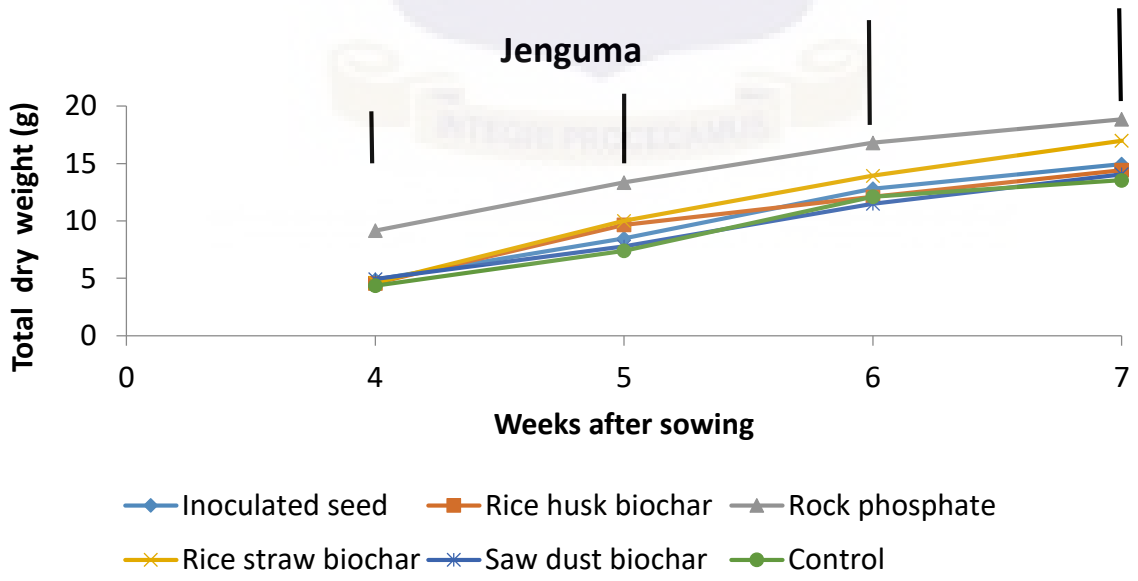


Figure 4. 22. Shoot dry weight in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.13. Effect of Soil Amendments on Total Dry Matter

There was no significant difference between the two varieties for total dry weight. The interaction between variety and soil amendments was also not significant. Jenguma in soil amended with rock phosphate fertilizer recorded the highest total dry weight of 9.16 g at week 4 which increased to 18.86 g at 7th week after planting, followed by saw dust biochar which produced 4.93 g at week 4 and 14.06 at the 7th week after planting. Rice straw biochar produced the second highest dry weight of 16.99 g at 7th week after planting. For Quarshie inoculation alone recorded the highest total dry weight of 6.33 g at 4th week after planting which increased to 23.55 g at week 7. This was followed by rice husk biochar at 6.24, at the 4th week after planting to 21.14 at the 7th week. The minimum total dry weight recorded for Quarshie was 3.96 in soil amended with rice straw biochar at week 4 which increased to 18. 89 at week 7. Result in total dry mater weight indicated no significant difference between the treatments (Fig. 4.23).

A



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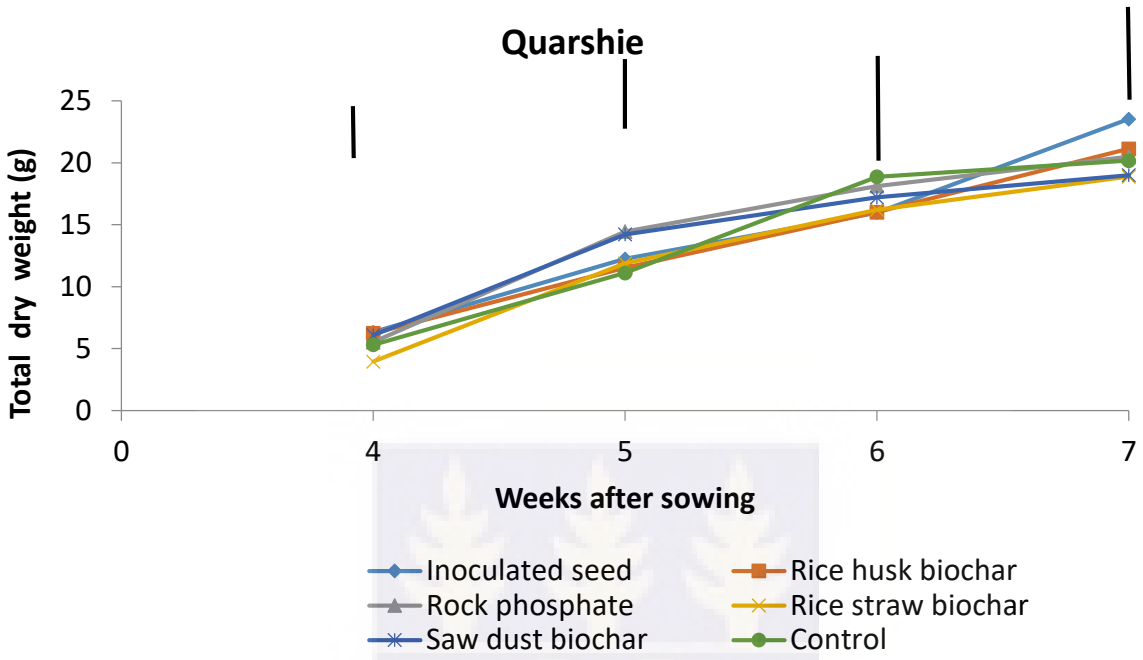

Figure 4. 23. Total dry matter in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.14. Effect of Soil Amendments on Pod number and pod weight per plant

The results revealed that number of pods per plant for the two soybean varieties and the different treatments showed no significant difference (Fig. 4.24). The interaction between variety and soil amendments was also not significant. Mean values indicated that Quarshie produced the maximum number of pods per plant (108) in soil amended with rock phosphate fertilizer and the minimum was 60 produced by the control, with Jenguma. The soil amended with rock phosphate produced a maximum pod number of 71 while a minimum number of pods of 41 was produced under rice husk biochar.

Statistical analysis of weight per pod produced by soybean plants indicated that treatments were not significantly different from each other and the control. Quarshie produced a maximum pod weight of 32.5 g under rock phosphate fertilizer and a low pod weight of 22.7 g in the control. Jenguma produced the highest pod weight of 22.2 g under Rice straw Biochar and the lowest was 16.7 in the control. It was observed that the number of pods per plant did not correlate to the weight of the pods per plants (Fig. 4.25).

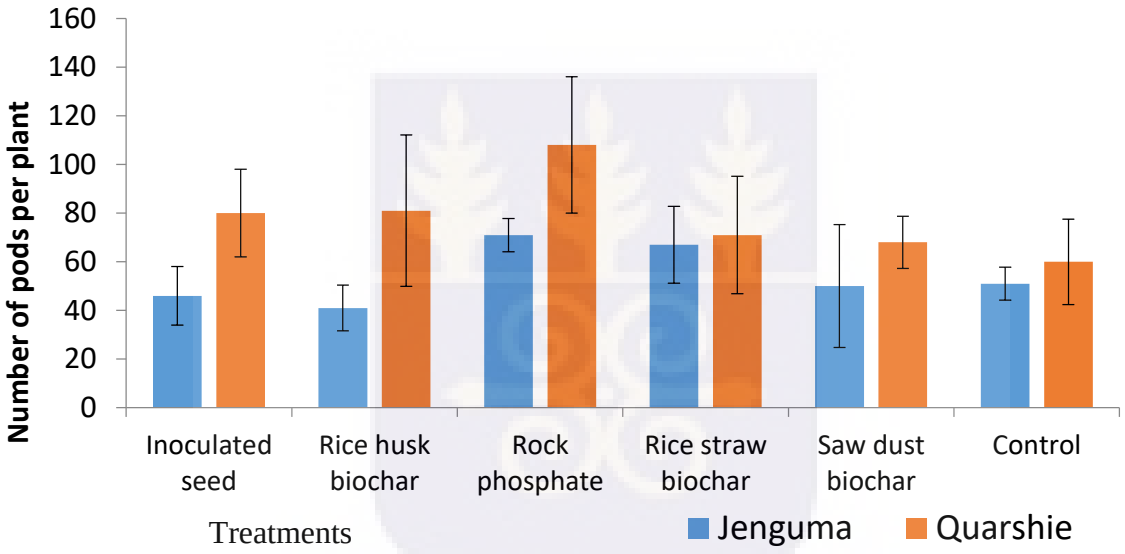

Figure 4. 24. Number of Pods per plant in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

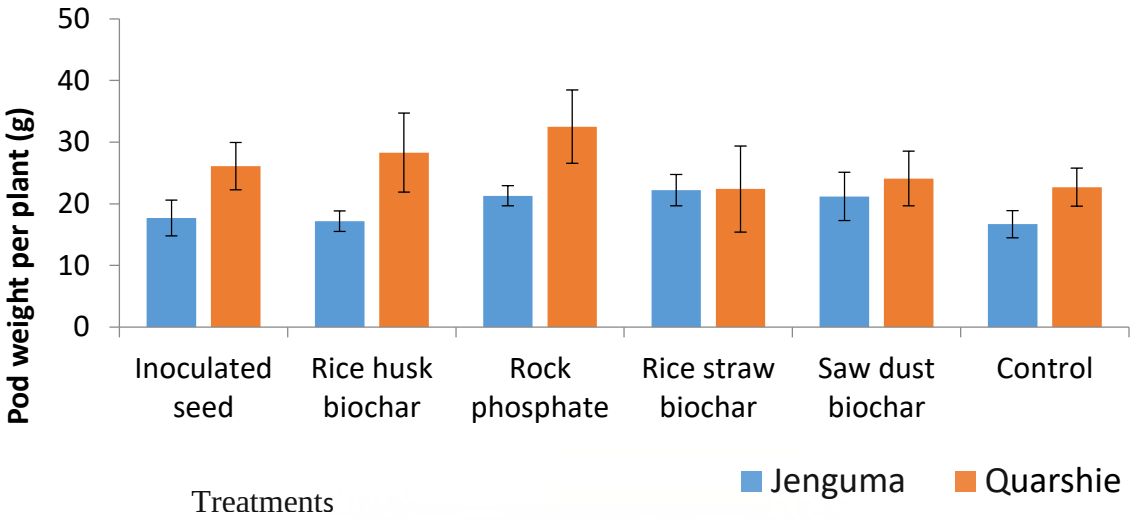

Figure 4. 25. Pod weight per plant in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.15. Effect of Soil Amendments on Number of seeds per pod and 100 seed weight per plant

There were no significant differences observed in 100 seed weight produced by soybean plants under the different treatments (Fig. 4.26). The 100 seed weight per plant ranged from 11.2 to 13.3 g. for both varieties of soybean. 100 seed weight in Quarshie (12.1- 13.3) was higher than 100 seed weight for Jenguma (11.2 -13.2)

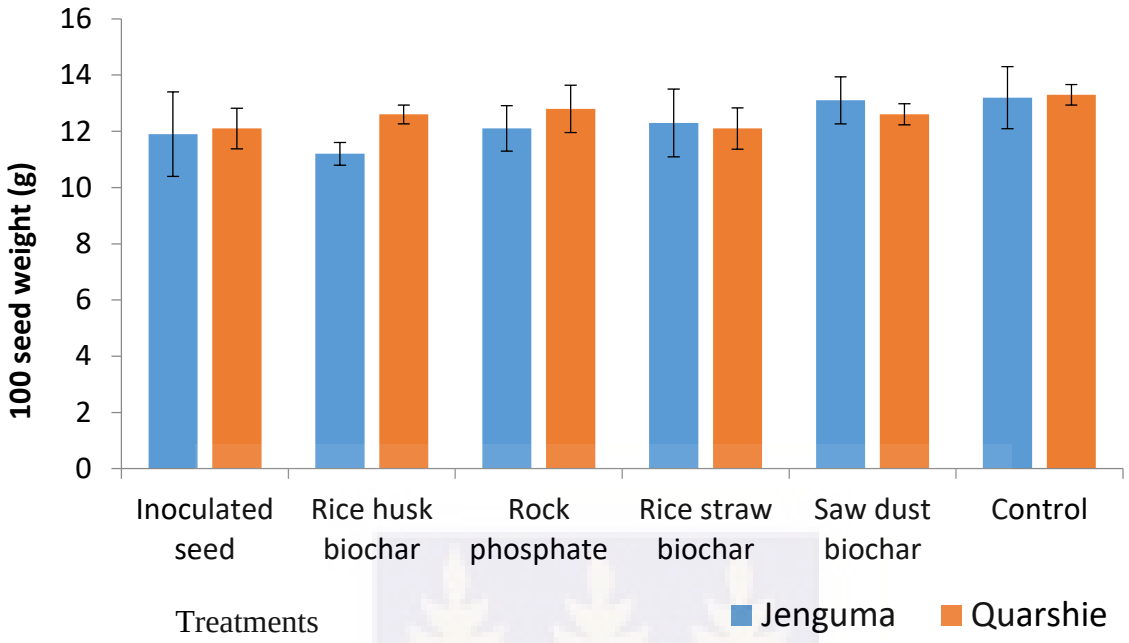

Figure 4. 26. 100 Seed weight in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.16. Effect of Soil Amendments on Seed weight per plant and Seed weight per plot

Seed weight per plant was not significantly different among the different treatments. The maximum seed weight per plant (19.9 g) was recorded by soybean plants in soil amended with rock phosphate for Quarshie and 13. 7 g in soil amended with saw dust biochar for Jenguma. Whiles the minimum seed weight per plant of 12.5 g in Quarshie and 11.3 g in Jenguma were observed in the control. Interactions among varieties and treatments was not statistically significant (Fig. 4.27).

There was no significant difference observed among the different treatments and between the varieties. The highest seed weight per plot of 887.0 g was recorded by soybean plant grown in soil amended with rock phosphate for Quarshie and 668.0 with inoculation only for Jenguma variety. The lowest seed weight per plot was 598.0 g in Quarshie and 512.0 g in Jenguma control and rice

husk biochar, respectively. The interaction among variety and treatment was not significant, (Fig. 4.28)

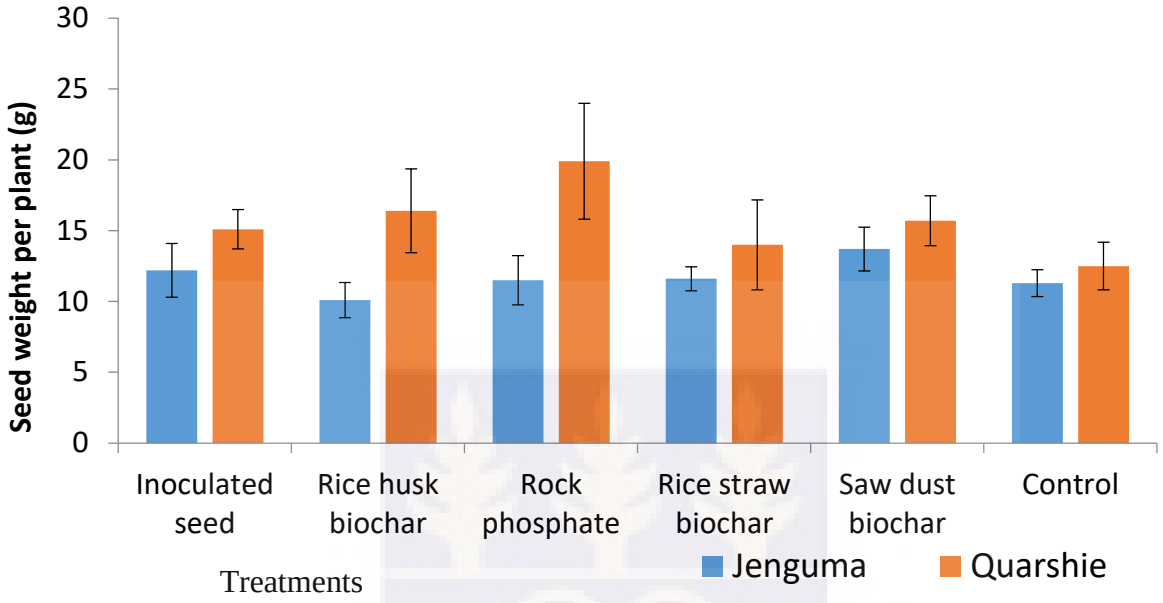

Figure 4. 27. Seed weight per plant in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

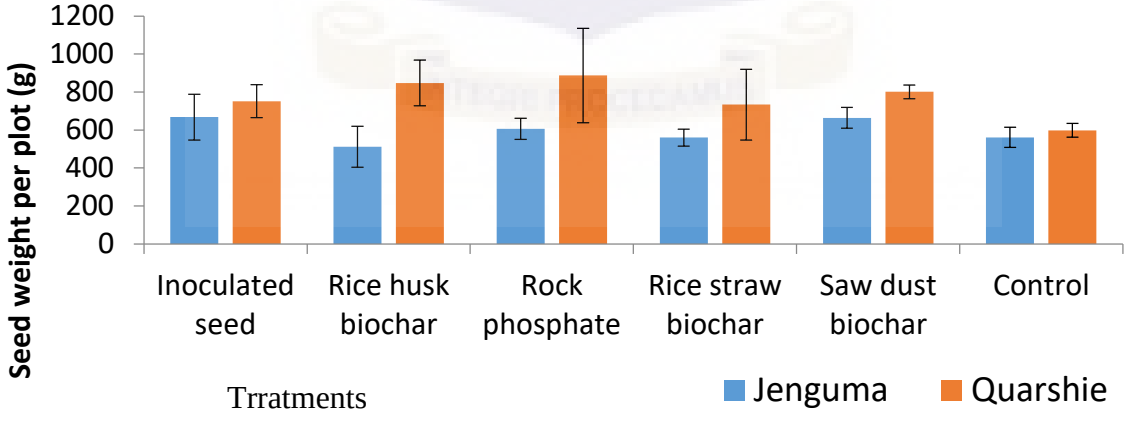

Figure 4. 28. Seed weight per plot in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.17. Effect of Soil Amendments on Seed yield (ton/ha) and Harvest index

Seed yield of soybean varieties, estimated in ton per hectare, was not affected significantly by the different treatments. Plants with grown with rock phosphate addition had higher yield of 3.53 ton/ha in Quarshie. For Jenguma, the highest yield of 2.78 ton/ha was produced by inoculation alone. A minimum yield of 2.49 and 2.13 ton/ha was observed in the control and rice husk biochar treatment respectively. Interactions between varieties and the different biochar amendments was not significant. There were no significant differences observed in yield among the two varieties (Fig. 4.29).

For harvest index no significant difference was observed between the two varieties and among all the treatments. Interaction between variety and treatments was also not significant. The highest harvest index recorded 0.439 on Jenguma and 0.421 on Quarshie were obtained from soils amended with saw dust biochar and rice husk biochar respectively, in figure 4.27 b. The minimum of 0.318 on Jenguma and 0.331 on Quarshie were both recorded under rice straw biochar, (Fig. 4.30)

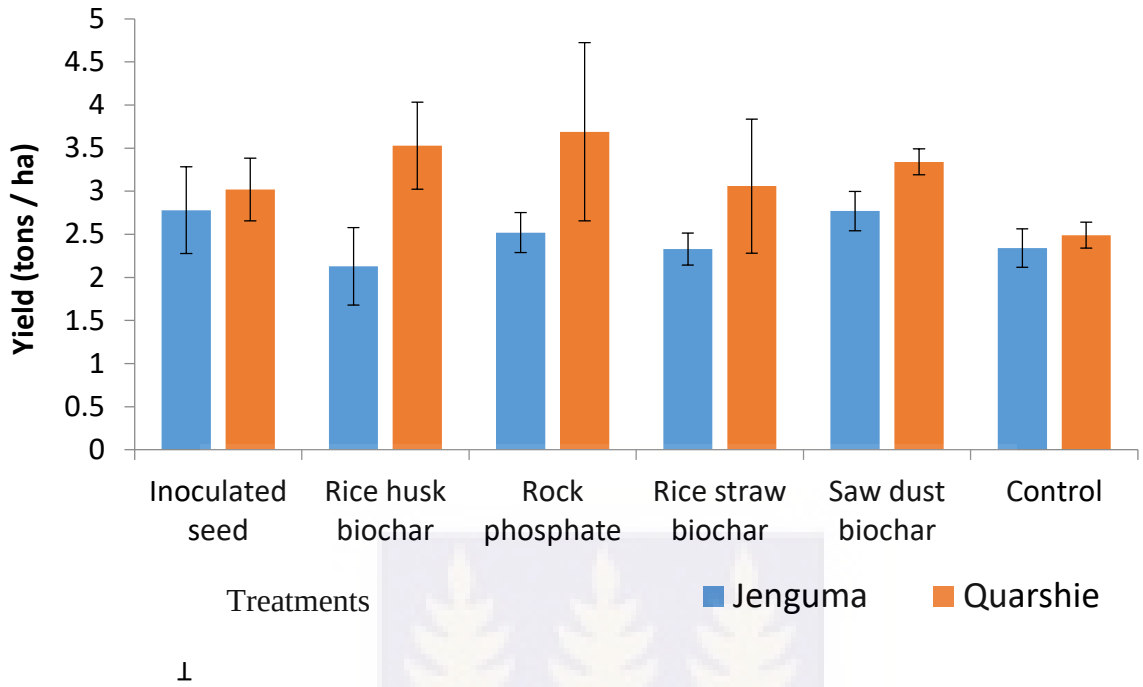

Figure 4. 29. Yield (tons / ha) of two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

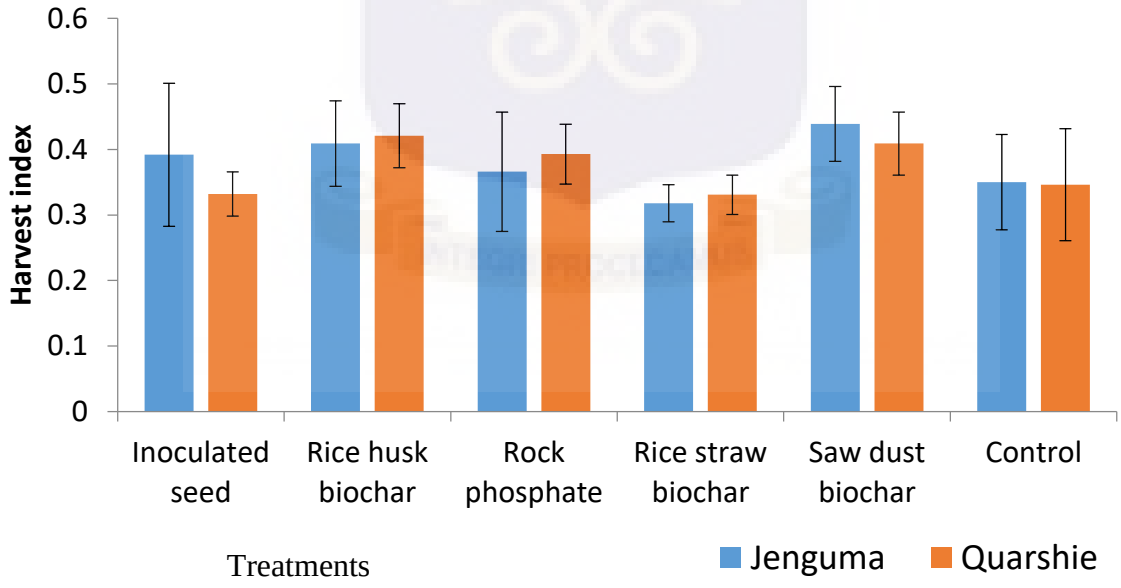

Figure 4. 30. Harvest index in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.18. Effect of Soil Amendments on Crop Growth Rate

Crop growth rates at 7th week after planting were significantly different ($P < 0.05$) among the different treatments (Fig. 4.31). Weight of plants per unit area increased in inoculated seeds for the two varieties over the control of both varieties. For rice husk biochar, rice straw biochar rock phosphate and saw dust biochar the increase was observed at 5th week and started decreasing from the 6th to 7th week.

The crop growth rate between the two varieties was not significant and the interactions between the treatments and variety was not significant for week 5, 6 and 7 after planting.

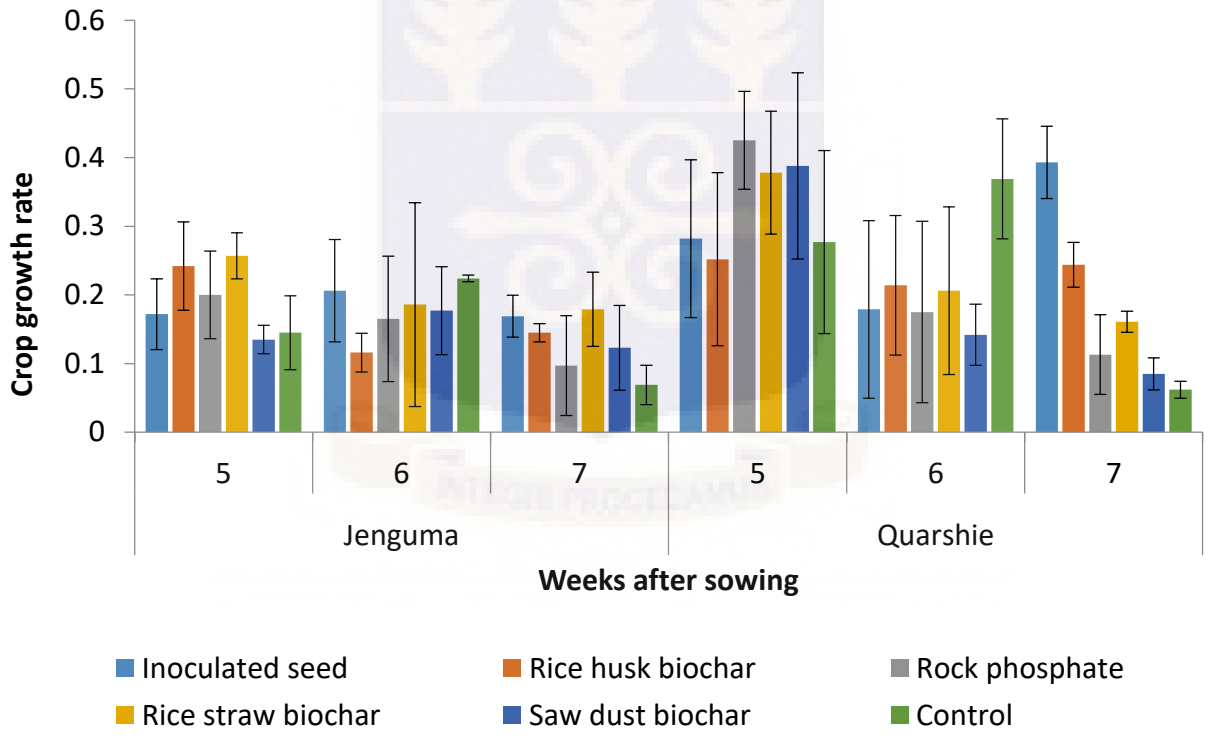

Figure 4. 31. Crop Growth Rate in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.19. Effect of Soil Amendments on Relative Growth Rate

Relative growth rate was not significantly different among the treatments in 5th, 6th and 7th weeks after planting, however there was a significant difference between the varieties at the 6th week. Interaction between treatments and variety were also not significant. Relative Growth ranged from 0.010 to 0.154 for the two varieties of soybean. Jenguma recorded a maximum of 0.112 on rice straw biochar which was followed by rice husk biochar with 0.104 all at the 5th week after planting. Relative Growth Rate decreased for all the treatments from week 6 to 7. The lowest relative growth rate occurred in the controls of the two varieties (Fig. 4.32).

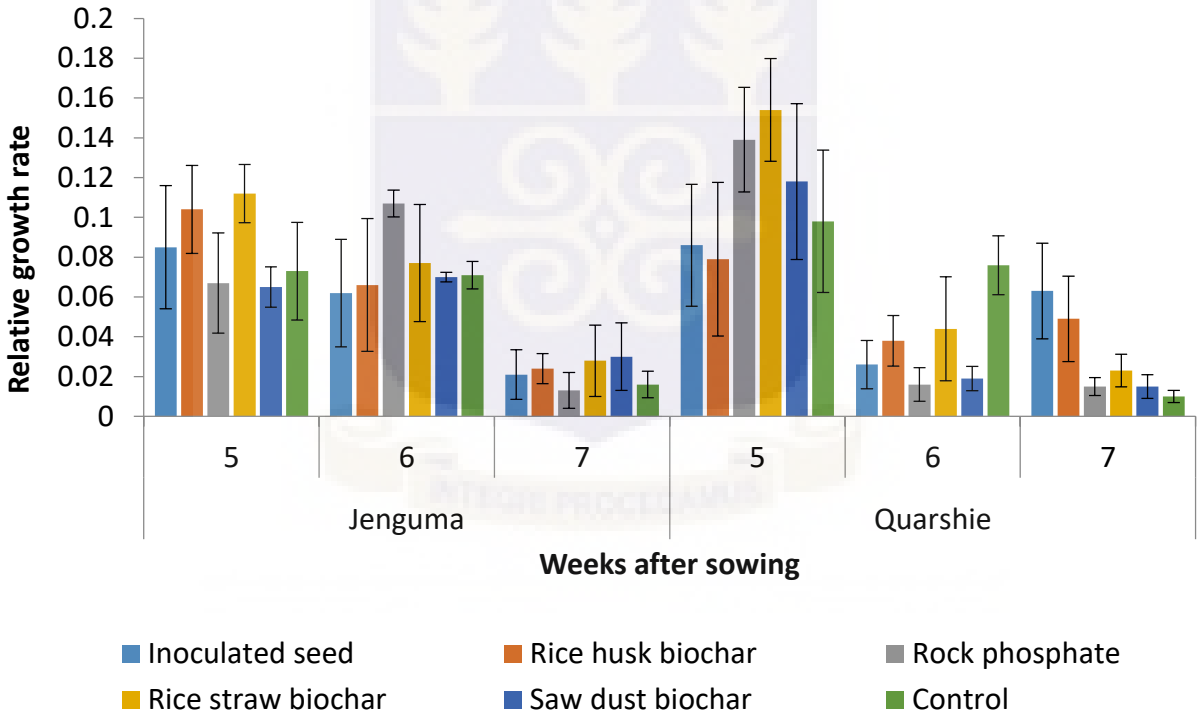

Figure 4. 32. Relative Growth Rate in two soybean varieties (Jenguma and Quarshie) in soil amended with rock phosphate, rice husk biochar, rice straw biochar and saw dust biochar.

4.2.20. Effect of Soil Amendments on Soil Nutrient content

Soils were analyzed to evaluate the residual effects of the soil amendments on the physical and chemical properties of soils sampled from a depth of 0–15 cm. Generally, there were no statistically significant ($p>0.05$) effects of amendment materials on the average soil chemical and physical properties despite a slight shift towards soil acidity. For organic carbon the treatments were significantly different. Inoculated seed on Quarshie gave the highest value of 2.44 and the lowest was 0.64 with rice straw biochar. For Jenguma, inoculation only had 1.74 which was the highest but the lowest was the control which recorded 0.60, (Table 8).

4.2.21. Effect of Soil Amendments on Nitrogen, Phosphorous and Potassium content in soybean plant

Results from the analysis of nutrient uptake of soybean varieties under different biochar amendments (Table 9). The Nitrogen content of the soybean varieties under different biochar treatments were not significantly different. Nitrogen content was higher in the rice straw biochar treatment and lower in saw dust biochar treatment for Jenguma. On Quarshie rock phosphate recorded the highest nitrogen content and the minimum was the control.

Phosphorus content in the soybean plants was significantly different among the treatments but was not significantly different between the varieties and the interactions between the treatments and the variety were also not significant. Phosphorus content in the different soil amendments was higher in rock phosphate addition and low in rice husk biochar on Jenguma. Saw dust biochar recorded the maximum Phosphorus content in Quarshie and rock phosphate was the minimum.

Table 8. Residual Effect of soil amendment on Total N, Nitrogen %, Phosphorus %, Potassium %, Organic Carbon and pH Soil.

Treatment	Total Nitrogen (%)		Phosphorus (%)		Potassium (%)		Organic carbon (%)		pH	
	Jenguma	Quarshie	Jenguma	Quarshie	Jenguma	Quarshie	Jenguma	Quarshie	Jenguma	Quarshie
Inoculated seed	0.103	0.099	25.3	23.1	0.020	0.019	1.74	2.44	5.50	5.40
Rice husk biochar	0.091	0.133	20.9	19.0	0.023	0.026	1.22	1.07	5.16	5.20
Rock phosphate	0.089	0.131	25.8	20.5	0.023	0.021	0.77	0.92	5.40	5.06
Rice straw biochar	0.089	0.107	27.8	24.1	0.024	0.022	1.03	0.64	5.16	5.36
Saw dust biochar	0.086	0.092	23.8	20.1	0.022	0.022	1.13	1.37	5.30	5.13
Control	0.093	0.120	23.6	21.3	0.023	0.020	0.60	1.31	5.20	5.03
Lsd(P>0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Potassium content in the soybean varieties under the different soil amendments did not indicate significant differences among the treatments, the interactions was also not significant and the differences between varieties was not significant. However the potassium content of the soybean in the different soil amendments was higher under rock phosphate for the two varieties. Inoculation alone recorded the minimum potassium content for Jenguma and rice husk biochar recorded on Quarshie also recorded the lowest.

Table 9: Nitrogen, Phosphorus and Potassium content of soybean grown with soil amendments of rice husk biochar, rice straw biochar, saw dust biochar, rock phosphate and inoculation.

Treatment	**Nitrogen**		**Phosphorous**		**Potassium**	
	Jenguma	Quarshie	Jenguma	Quarshie	Jenguma	Quarshie
Inoculated seed	0.269	0.288	0.610	0.519	0.247	0.377
Rice husk biochar	0.330	0.383	0.526	0.538	0.331	0.220
Rock phosphate	0.383	0.397	0.589	0.513	0.451	0.425
Rice straw biochar	1.257	0.371	0.550	0.566	0.440	0.332
Saw dust biochar	0.260	0.371	0.554	0.584	0.299	0.440
Control	0.317	0.281	0.635	0.622	0.453	0.214
Lsd(P>0.05)	NS	NS	NS	NS	NS	NS

4.2.22. Correlation coefficient *r* among variables

The correlation coefficient (r) among variables are shown in Table 10

Root Dry Weight and Number of Pods per plant were positively and significantly correlated ($r = 0.481$, $P < 0.001$). 100 Seed Weight and Number of Pods per plant were positively correlated and highly significant ($r = 0.471$, $P < 0.001$), A significant association was found between Seed weight per Plant (Seed wtplt) and Crop Growth Rate ($r = 0.52$, $P < 0.001$), a moderately correlated association was found between Seed Weight per Plant and Nodule dry weight ($r = 0.53$, $P < 0.001$), Seed weight per Plant and Number of Pods per plant were moderate and positively correlated ($r = 0.54$, $P < 0.001$), Shoot Dry Weight (Shoot Dwt) moderately correlated with Crop Growth Rate ($r = 0.53$, $P < 0.001$), a moderate correlation was found between Shoot dry weight and Nodule dry weight ($r = 0.57$, $P < 0.001$), a positive and significant correlation was found between Shoot dry weight and Number of Pods per plant were ($r = 0.61$, $P < 0.001$), a strong positive and significant correlation between Shoot dry weight and Root Dry Weight ($r = 0.72$, $P < 0.001$), a high correlation was found between Shoot dry weight and Seed weight per plant ($r = 0.67$, $P < 0.001$) and this was significant. Total Dry Weight (Total Dwt) correlated positively and significantly with Crop Growth Rate ($r = 0.60$, $P < 0.001$), moderate and positive significant correlation was found between Total dry weight and Nodule dry weight ($r = 0.57$, $P < 0.001$), a high positive and significant correlation was found between Total dry weight and Number of Pods per plant ($r = 0.73$, $P < 0.001$), Total dry weight correlated with Root Dry Weight positively and significantly ($r = 0.70$, $P < 0.001$), Total dry weight and Seed weight per plant were positively and significantly correlated ($r = 0.71$, $P < 0.001$), Total dry weight strongly correlated with shoot dry weight and was significant ($r = 0.88$, $P < 0.001$).

Table 10. Correlation coefficient r among variables

LAI	0.038 ns										
Larea	0.038 ns	1**									
Noddwt	0.164 ns	0.337 *	0.337 *								
Npodplt	0.245 ns	-0.088 ns	-0.088 ns	0.385 *							
RGR	0.409 *	0.075 ns	0.075 ns	0.021 ns	-0.234 ns						
RootDwt	0.351 *	-0.176 ns	-0.176 ns	0.211 ns	0.481 **	0.078 ns					
Seedsperpod	0.182 ns	0.175 ns	0.175 ns	0.325 ns	-0.242 ns	0.085 ns	-0.195 ns				
Seedwt100	0.038 ns	-0.138 ns	-0.138 ns	0.222 ns	0.471 **	-0.034 ns	0.217 ns	-0.298 ns			
Seedwtplt	0.522 **	0.169 ns	0.169 ns	0.528 **	0.538 **	-0.142 ns	0.399 *	0.172 ns	0.239 ns		
ShootDwt	0.525 **	-0.023 ns	-0.023 ns	0.572 **	0.614 **	0.100 ns	0.718 **	0.073 ns	0.239 ns	0.670 **	
TotalDwt	0.598 **	0.060 ns	0.060 ns	0.571 **	0.728 **	0.048 ns	0.703 **	0.079 ns	0.247 ns	0.709 **	0.880 **
	CGR	LAI	Larea	Noddwt	Npodplt	RGR	RootDwt	Seedsper pod	100 Seedwt	Seedwt plt	Shoot Dwt

* - Significant at 5% ** - significant at 1% ns - not significant

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of biochar on soil characteristics

Good soil conditions is an essential requirement for the growth and development of plants. Physicochemical properties of the soil such as minerals, water, soil organic matter, and air enhance good stands of the plants and promote nutrient assimilation of the root hairs of the plants (Chen, 2006). The determination of nutrient composition of pelleting materials, soil amendments and the soil informs the amount of nutrients limiting therein. Knowledge of the composition of biochar is key in nutrient efficient management because over application of biochar as pelleting materials or soil amendments may be detrimental to plant health hence it will result in low yields. Soil bulk density shows the status of soil compatibility and health (Azooz and Arshad, 1996; USDA-NRCS, 2014). Soil bulk density influences rooting depth or restrictions, infiltration, soil porosity, plant nutrient availability, soil microorganism activity and available of water capacity of the soil productivity and processes (USDA-NRCS, 2014).

Soil pH plays an important role in plant growth and development because it indicates availability of nutrient in the soil. Soil pH is an important indication of N nutrient in leguminous plants because it influences the survivability of rhizobia which fix N nutrient (McKenzie, 2003). The initial soil pH in the study area was 4.9. Research was conducted in Ghana to determine the response of three soybean varieties to soil amendment using biochar reported that the pH in the soil was 4.9 (Agbanu, 2017). Research also showed that the pH of soil types like Acrisol (Toje series) were found to be 4.9 (Lawson and Nartey, 2012; Mutala, 2012). It has been proven that soil pH influences number of chemical properties in the soil hence to achieve optimum yield of soybean, there is the need to maintain the soil pH (Purcell *et al.*, 2014). It was observed in this

study that there was an increment in pH from different soil amendments. This could have contributed to increase in yield. Soybean cultivated under pH between 6.0 to 6.8 was observed to record the best yield (Mallarino *et al.*, 2011). Inoculation alone on Jenguma recorded the highest pH of 5.50 which was consistent with the findings of Zolue (2013). Application of rice straw biochar was observed to increase soil pH which positively increased the yield of Quarshie variety. Sika (2012) and Uddin and Phuong (2013) stated that RSB and RHB could be used as liming agent to improve soil acidic conditions due to its alkalinity which but this was not the case in this present study. The amendment effect of soil pH by rice straw biochar compared to rice husk biochar is presumed to better produce immobilized phosphorus and other exchangeable soil nutrients obtainable to the crop (Agbanu, 2017). Low yield of the control could be attributed to the fact that low soil pH inhibited the growth and multiplication of rhizobium strain which helps in nodulation. Research has also indicated that most soil microbes thrive well at a soil of pH 5.5 (Zenni, 2017). These soil microbes enhance soil aeration which returns improved soil profile and soil structure hence increase in yield of soybean.

Organic carbon is an essential chemical properties of soil as it is one of the vital barometers of the health of the soil (Lefèvre, 2017). Organic carbon enhances the stability of soil retention, structure and contributing to the availability of plant nutrients and conservation of water-holding capacity. It plays a key role in environmental resilience and agricultural productivity. The breaking down of organic carbon make mineral nutrients available which improve plant growth and development (Van der Wal and de Boer, 2017). In this current study, organic carbon ranged from 0.4-2.44% which is in the range of those reported by Griffin (2018). Inoculation alone on Quarshie variety recorded the highest (2.44) organic carbon which was likely to increase the yield of this cultivar because soil microbes were probably in abundance which make nutrient available for uptake by

plant roots. Higher soil microbial population implies that soil conditions were in perfect state hence the higher fertility. Continual improvement of soil organic carbon may result in stable soil structure by breaking down complex soil compositions into smaller units for plant use (Lefèvre, 2017). Mukherjee *et al*. (2014) reported 7% increment of soil organic carbon by applying biochar. After characterizing different biochar types, Glaser *et al*. (2002); Luo *et al*. (2011) and Uddin and Puong (2013) observed an improvement in carbon content of soils amended with biochar and charcoal.

The potassium present in the amended soil ranged from 0.019-0026% for both soybean varieties and recorded no significant difference among the different biochar materials. This observation could be due to the fact that potassium is not dependent on the different soil amendments or pelleting materials. In this study, it was observed that initial determination of the amount of potassium in biochar was higher in the different biochars as compared to the final treatment. This could be attributed to heavily weathered soil due to soil erosion at the study area. The percentage increase in potassium was due to the fact that all the biochar used have some amount of K present in them. Research conducted in the same type of soil on compost and nitrogen fertilizer on growth and yield and residual effects on cowpea (*Vigna unguiculata* (L.) Walp) in a rotation indicated that the soil had 0.28 K (Djawu, 2018). An increase in the leaching of K in biochar observed in topsoil (Major *et al*., 2012; Lehmann *et al.*, 2003). Sandy soil was found to have higher concentration rate of K and Na leaching in biochar (Novak *et al.*, 2009). Study (Hamed *et al*., 2017) reported the P of biochar was 23.0 % and were highly significant in terms of the yield of soybean. In this current study, Jenguma treated with rice straw biochar recorded the highest P value as was observed by Hamed *et al.* (2017) however there was no significant differences among the soil amendments or pelleting materials as well as the soybean varieties. The larger amount of the P in rice straw biochar

gave an indication that rice straw has potential properties to support plant growth and development. It has been reported that P plays a major role in plant development through rapid division of cells (Tajer, 2016). Nitrogen rate of 8%observed during the initial stage of biochar was higher compared to after treatments were applied. There were relatively lower N in the biochar after treatments which was also reported after treatment with rice husk and rice straw biochar reported by (Agbanu, 2017) which may be attributed to volatilization during the charring process.

5.2 Effect of pelleting materials on vegetative and yield parameters of soybean in pot experiment

From the pot experiment it was observed that all the treatments with pelleting materials reduced the number of days to emergence for the two varieties of soybean. There was a significant difference between the two varieties in number of days to emergence. Quarshie treated with pelleting materials such as groundnut husk biochar, inoculation alone and the control took four days to emergence whiles Jenguma treated with rock phosphate took 6 days to emergence. The leaser number of days to emergence observed in Quarshie seed could due to the fact that, biochar created optimum soil conditions for the development of root growth prior to seedling emergence. Biochar has greater amount of phosphorus which could have induced early rooting that promoted seedling emergence of the cultivars in soils treated with 2% rice straw biochar (Agusalim Masulili 2010 cited in Bhattarai *et al*., 2015). Quarshie cultivar was reported to record higher germination percentage as compared to Jenguma (Awuni *et al*., 2014) and this agrees with the results of this study. Topsoil bulk density, soil water content and ammonium nitrogen are known to influence soybean growth (Wang *et al.*, 2016). Ammonium nitrogen could be held on to soil colloids in the

soil which are available for exchange and dissolves faster in soil solution. This is directly absorbed by plant which increases the growth parameters of the plant (Jin X *et al.*, 2007).

Number of days to flowering was between 39 and 47 from sowing. Quarshie treated with calcium carbonate flowered earlier than Jenguma cultivar which could be attributed to the fact that Quarshie germinated earlier than Jenguma cultivar and no significant difference was recorded in the pot experiment. There were significant differences among the various treatments for number of days to flowering. The number of branches at flowering was observed to be higher in Quarshie treated with groundnut husk biochar. This may due to groundnut husk biochar been able to provide sufficient nutrients available for node development which aided in branch formation. Quarshie treated with rice husk biochar recorded the greatest leaf area which translated into higher yield. Higher leaf area could have positive influences on yield due to higher surface areas for absorption of sunlight (photosynthesis) hence higher yield.

Plant height is a significant morphological parameter that shows straight association with grain yield (Rathod and Jadhao, 2006). Plant height observed at different growth stages was influenced by seed pelleting materials and soil amendments used in this study. Different treatments were able to increase plant height from the fourth week to the eight week after sowing. Higher lateral root formation in biochar treatments could be because of development of early primary rooting in biochar amended soil. This is due to the fact that biochar has high amount of P nutrient which could have permitted greater nutrient uptake leading to faster growth. This tendency was also observed in the leaf number produced by the plants. Higher number of leaves could be as result of increased in photosynthesis with higher biomass production by plants arising from seeds treated with pelleting materials as compared to un-inoculated and inoculated seeds without pelleting.

Quarshie treated with groundnut husk biochar recorded the highest nodule number because groundnut husk biochar promoted the growth of bacterial inoculant which resulted in higher nodule number. These bacteria also increased the rate of atmospheric nitrogen conversion into nitrate which is required by plant growth and development. The maximum root dry weight (11.9 g) was observed in Quarshie treated with calcium carbonate. This was as the outcome of the fact that calcium carbonate enhances root formation. These roots helps in absorption of nutrients and water from larger surface area during adverse soil conditions. The high carbon to nitrogen ratio of the rice husk biochar may have contributed to nutrient immobilization (Sika, 2012). Calcium carbonate plays a pivotal in supply of organic matter which aid in weathering of minerals and rocks (Hansell *et al*., 2014).

5.3 Effect of nutrient uptake on vegetative and crop growth in field experiment

There were no significant difference in number of days to seedling emergence though it was expected that the reduction in bulk density of the soil by the addition of rice husk biochar should have increased emergence rate as observed by (Chauhan, 2013; Agbanu, 2017). Emergence of soybeans was initiated after seeds had imbibed water up to 50% of the weight of the seed (McWilliams *et al*., 2009). Hence soil type and soil water content positively affect the rate of emergence of any seed (Chauhan *et al*., 2013). Water content of the soil influences emergence of seedlings more than soil bulk density (Nivedita, 1992). In this current study, the differences in the number of days to emergence could be attributed to different levels of viability among the varieties as well as the pelleting materials and soil amendments. Other researchers also reported that soybean seeds of Quarshie, Jenguma and Afayak have inherent differences in number of days to emergence (Awuni *et al*., 2014).

Leaf number has direct relationship on the leaf area as well as photosynthesis which influences the yield of soybean. Leaf number increases the rate of photosynthesis in the plant hence the higher, the leaf area the higher the amount of photosynthates produced by the plants. Leaf number and area also affect the yield potential of soybean plant. There was no significant differences among the treatment in the number of leaves per plant in the two soybean cultivars. It was observed that inoculation alone on Qurashie variety recorded the highest number of leaf per plant (190) and rock phosphate treated with Jenguma also obtained the highest number of leaves per plant. However, different results were reported by (Agbanu, 2017) where it was reported that rice husk biochar recorded the highest number of leaves. Increase in the number of leaves could lead to a reduction in the leaf area of the individual leaf but positively increase leaf area. In all the biochar treatments there was an increase in the number of leaf area per plant probably due to higher nitrogen present in the biochar materials. Among the necessary elements of photosynthesis, chlorophyll is the only plant dependent component that is affected by the number of leaves and leaf area of the crop (Bonan, 2015). The greater the chlorophyll the greater the photosynthetic rate and therefore the greater plant growth and yield. Findings by Adejumo *et al.* (2016) reported an increase in chlorophyll content in plants cultivated on biochar as compared to the control or unamended treatment.

There were significant differences in stem girth between the two cultivars of soybeans but no significant differences were observed among the different treatments with soil amendments. Previous study stated that there were significant differences in the stem girth of soybean varieties cultivated in soil treated with rice straw biochar than in soil treated with rice husk biochar (Agbanu, 2017). It was also observed in this present study that rice straw biochar recorded the largest stem girth (7.22) in Quarshie cultivar at eight weeks after planting. This differences could be attributed

to the release of higher amount of nutrients from rice straw biochar and therefore a higher uptake and accumulation of N, P, K, and S by plants raised on rice straw biochar amended soils. The availability of nitrogen and uptake by soybean plants cultivated on biochar amended soils stimulated plant growth thereby enhancing stem growth. This was also observed in similar work by other researchers (Agboola and Moses, 2015; Yooyen *et al*., 2015).

Plant height is very important in interception of light for photosynthesis for the growth and development plants. Application of biochar increased plant height tremendously but there were no significant differences among the treatments. Jenguma treated with Saw dust biochar recorded the highest plant height at 7th week after planting and but a higher plant height was obtained in the rice straw biochar treated Quarshie from the 4th week through to the 7th week. Similar results have been reported by other researchers where there was increase in plant height of rice and maize plant due to amendments using rice straw biochar (Uzoma *et al*., 2011); Mutezo, 2013) and Kamara *et al*., 2015).

The growth in early developmental stages was observed to be slow due to the growth habit of the plant (Malek *et al*., 2012) and biochar does not have immediate effect on the soil after its application because it requires time for decomposition and mineralization. Biochar has the ability to attract and hold soil nutrients on its surface hence making immobilized soil nutrients available and improving soil nutrition for plants (Yarrow, 2014). The faster root growth of soybean on soil treated with biochar could be due to high phosphorus translated into higher nutrient uptake by the plant that may have resulted into the rapid growth and development in this present study. The differences obtained in plant height may be because of varietal differences (Awuni *et al*., 2014). Good pelleting materials and soil amendments enhances desirable plant population with good stand establishment (Miller and Scoot, 1967).

There were no differences between the two varieties and among the different soil amendments used in the number of pods per plant and pod weight per plant. However, Quarshie treated rock phosphate obtained the greatest number of pods per plant (108) whereas the control or unamended recorded the lowest number of pods (60) per plant. Jenguma treated with saw dust biochar on the other hand recorded the highest number of pods per plant. Newly approaches consisting of postharvest techniques and recent seed production tools that focuses on producing higher seed yield and quality (Devi, 2013). The various post-harvest methods includes seed priming, seed halogenations, seed treatment, seed hardening and seed cleaning. Seed pelleting method has been used in many horticultural crops and agricultural, to efficiently obtain higher seed yield and quality (Devi, 2013). The higher number of pods per plant and pod weight per plant could be attributed to the fact the rock phosphate provide suitable soil conditions for optimum yield of soybean.

Seed weight is very important in the marketability of seed producers because seeds are marketed based on the weight and viability. Seed weight per plant was found to be significantly different among the soil amendments and the soybean cultivars. Quarshie treated with rock phosphate recorded the highest seed weight (887 g) per plot whiles the control obtained the lowest. Similar observation was made in the number of pods per plant. This result is consistent with previous findings by (Agbanu, 2017). Capton which is the active ingredient in Bonide and Imidacloprid which can be found in products like Admire, Condifor, Gaucho, Premier, Premise, Provado, and Marathon used as biochar agent could have offered some level of protection against soil borne pathogens, seed and insects resulting in the rapid growth of plant, which leads to early reproduction phase (Manjunath *et al.*, 2009). Seeds per pod ranged between 2 to 3 with no significant differences among the treatments. Hundred (100) seed weight was greater in rock phosphate treated plant but with no significant differences among the treatments and the two cultivars of soybeans. Rock

phosphate fertilizers have a greater calcium content between 24-33 %. This makes rock phosphate essential in increasing soil pH and cation exchange capacity (CEC) resulting in yield increases of oil palm (Zin *et al.*, 2005).

Harvest index is used for quantification of the yield of crop species and the total weight of biomass produced (Meena *et al.*, 2016). There were no significant differences among different treatments and between the soybean cultivars for harvest index although Quarshie treated with rice husk biochar recorded the highest harvest index.

The yield is the most essential determinant factor of biochar materials because the core aim is to improve on potential yield. In this study, there were no significant differences among treatments as well as soybean varieties. However Quarshie treated with rock phosphate obtained the greatest yield (3.69 ton/ha) whiles control treatment was observed to record the least yield. It was reported that rock phosphate produced the highest yield per plant than the control in acid soil (Iswaran *et al.*, 1970). Coated seeds using aldicarb and activated with Rhizobium inoculation was reported to increase yield to 840 kg per ha as compared to the control treatment of 450 kg (Iswaran, 1975). Cotton seeds treated with butyric acid enhanced growth and increased germination (Umarov *et al*., 1981).

In the present work, it could be concluded that initial capital food reserves always showed higher and rapid germination in seed. This has also been reported by Balaji, (1990); Supreethaangadi, (2004) in soybean and Masuthi (2005) in cowpea.

Nodulation in leguminous crop is very important in production especially soybean. Nitrogen fixing bacteria play core roles in fixation of atmospheric nitrogen by converting it into readily available form for plant usage. It has been reported that leguminous plants fixes approximately 50% of their own nitrogenous nutrient (Ruiz Diaz *et al*., 2009). It was observed in this study that, all pelleting

materials and soil amendments offered some level of increase in the amount of nodule dry weight as well as nodule number, four weeks after planting. There were no significant differences in both nodule dry weight and nodule number four weeks after treatment application for the different treatments and the soybean cultivars. It was also observed that rock phosphate applied to Quarshie recorded the highest number of nodule and nodule dry weight. With the result obtained, it could be said that rock phosphate created good soil conditions for microbes such as bacteria for the fixation of nitrogen which is required by the plant for food formation. The application of nitrogen fertilizer and compost influenced root dry weight and shoot dry weight with strong interaction effect on the shoot dry weight (Djawu, 2018).

The increment in root dry weight and shoot dry weight could be attributed to the fact that fertility of soil improved and nutrients were available for cowpea roots to absorb leading to growth and seed production (Djawu, 2018).

Impregnated soybean seeds with Bradyrhizobia bacteria enhance the nodulation of three soybean varieties (Agbanu, 2017). The increase in nodule number in this study could be explained due to positive effect of biochar on nodulation in soybean as a result of phosphorus availability. In another study it was observed that there was a greater increase in nodulation in clover and common beans in soil amended with biochar (Rondon *et al.*, 2007; Lehmamn *et al*., 2011 and Biederman and Harpole, 2013). Findings by Kumaga and Ofori (2004) and Devi *et al*. (2012) suggested that nodule number increased as a result of availability of phosphorus from applied fertilizer. There was greater nodulation in cowpea when phosphorus fertilizer was applied and it improved efficiency of rhizobium -legume symbiosis (Agboola and Obigbesan, 1977; Mokwunye and Bationo, 2002).

Root dry weight (g) and shoot dry weight were not significantly different among treatments and different varieties of soybean. There was increment in Jenguma treated with rock phosphate from the 4th week throughout the 7th week of application of treatment. In both cultivar and treatments Quarshie treated with inoculant recoded the highest root dry weight. The highest root dry weight observed in inoculated Quarshie seed could have enabled the plants, it was able to exploit large soil surface to mobilize more nutrients. Large root system is able to maintain water holding capacity and water uptake of plants in adverse drought conditions. Root density may be used as criteria for selection for improvement of drought tolerance in peanut (Songsri *et al.,* 2008). Increase in root dry weight could also be attributed to the fact that biochar materials provide the needed soil conditions which resulted in higher yield returns.

Total dry weight recorded no significant between the two varieties and among the different pelleting materials used as biochar. In Jenguma, rock phosphate fertilizer resulted in increase in dry weight from fourth to seventh week, whiles control was the least amongst all the treatment. Conversely, inoculated Quarshie plant recorded the highest total dry weight.

Leaf area and leaf area index were not significant by different among the treatment as well between Jenguma and Quarshie. However, Jenguma treated with rice husk biochar was observed to produce the greatest leaf area and same for leaf area index. Quarshie treated with rice husk biochar also obtained the highest total dry weight of the plant and the control recorded the lowest leaf area index.

The distribution and progressive integration of all plant processes affects the total dry matter production of a crop (Board and Kahlon, 2011). The most influencing factors of growth parameters of total dry weight accumulation comprises of Crop Growth Rate (CGR), Leaf Area Index (LAI), and Net Assimilation Rates (NAR) (Asner *et al.*, 2003; Malek *et al*., 2012). In this current study

it was observed that rice husk biochar increased leaf area and leaf area index but was not significant.

5.4 Correlation among growth and yield variables

Crop growth rate was found to be moderately positively correlated and significantly with Seed weight per plant, shoot dry weight and Total dry weight, Crop growth rate was also found to be positively correlated and significantly with Relative Growth Rate and Root dry weight. Crop growth rate was also found to be positively correlated with Leaf area index and Leaf area but this was not significant, but on the contrary Malek *et al*. (2012) reported that LA, and LAI had a strong relationship with the growth rate of soybean which affect total dry matter (TDM) eventually.

Nodule dry weight was highly correlated positively and significantly with Total dry weight and Shoot dry weight, it was found to be moderately correlated positively and significantly with seed dry weight per plant and to the Root dry weight and 100 seed weight where the correlation was positive and significant. Marschner *et al*. (1995) found a close relationship between nodule number (NN) and nodule dry weight (NDW) which is manifested in the amount of nitrogen fixed. The amount of Nitrogen fixed due to increased number of nodules was likely used by the plant for increased vegetative growth resulting in increased LA and LAI.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

It is concluded from the study that seed pelleting and addition of soil amendments using biochar, calcium carbonate and rock phosphate improved the growth nodulation and yield of the two soybean cultivars.

For the pot experiments seed emergence of both varieties of soybean were significantly enhanced by inoculation and pelleting compared to the uninoculated. Groundnut husk significantly increase number of nodules and nodule fresh weight. However, rice husk biochar recorded the highest nodule dry weight followed rice straw biochar, saw dust biochar, inoculation alone, groundnut husk biochar, calcium carbonate and rock phosphate in that order.

Both varieties of soybean responded more favorably to groundnut husk biochar as reflected in CGR, LAI, RGR, total dry matter accumulation and yield despite not been significantly different from the other treatments.

For the field experiment the highest nodule number was recorded under saw dust biochar amendments followed by rock phosphate, rice husk biochar, inoculation alone and rice straw biochar in that order. Here nodule dry weight was highest under saw dust biochar and rock phosphate compare to the other soil amendments for both varieties of soybean.

6.2. Recommendations

There is a need to repeat the experiment at other locations and also use different rates of the pelleting materials and soil amendments to ascertain the appropriate rate worthy for production of soybean.

Further studies should include investigation on the response of the two soybean varieties to groundnut husk biochar, saw dust biochar and rice husk biochar as soil amendments.

Wider promotion of the use of soybean cultivar Quarshie to farmers will enhance soybean productivity in Ghana as it was observed to have out-performed Jenguma in this study.

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8.0 APPENDICES

ANALYSIS OF VARIANCE (ANOVA) TABLES (POT EXPERIMENT)

Appendix 1: ANOVA Table for Days to emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	15.7552	15.7552	21.76	<.001
Treatment	7	4.1615	0.5945	0.82	0.577
Variety.Treatment	7	5.6198	0.8028	1.11	0.381
Residual	32	23.1667	0.7240		
Total	47	48.7031			

Appendix 2: ANOVA Table for Days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	71.297	71.297	20.10	<.001
Treatment	7	40.245	5.749	1.62	0.165
Variety.Treatment	7	27.328	3.904	1.10	0.386
Residual	32	113.500	3.547		
Total	47	252.370			

Appendix 3: ANOVA Table for Plant height 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	26.107	26.107	7.41	0.010
Treatment	7	27.193	3.885	1.10	0.385
Variety.Treatment	7	20.607	2.944	0.84	0.566
Residual	32	112.733	3.523		
Total	47	186.642			

Appendix 4: ANOVA Table for Plant height 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	22.825	22.825	2.96	0.095
Treatment	7	90.152	12.879	1.67	0.151
Variety.Treatment	7	59.436	8.491	1.10	0.385
Residual	32	246.422	7.701		
Total	47	418.835			

Appendix 5: ANOVA Table for Plant height 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.24	0.24	0.02	0.887
Treatment	7	123.24	17.61	1.50	0.201
Variety.Treatment	7	27.07	3.87	0.33	0.934
Residual	32	374.60	11.71		
Total	47	525.16			

Appendix 6: ANOVA Table for Plant height 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	59.74	59.74	2.59	0.117
Treatment	7	140.97	20.14	0.87	0.538
Variety.Treatment	7	358.54	51.22	2.22	0.059
Residual	32	737.73	23.05		
Total	47	1296.99			

Appendix 7: ANOVA Table for Plant height 8 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	481.967	481.967	65.26	<.001
Treatment	7	129.161	18.452	2.50	0.036
Variety.Treatment	7	49.416	7.059	0.96	0.479
Residual	32	236.315	7.385		
Total	47	896.860			

Appendix 8: ANOVA Table for Number of branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	5.0052	5.0052	6.36	0.017
Treatment	7	3.1615	0.4516	0.57	0.771
Variety.Treatment	7	5.7865	0.8266	1.05	0.417
Residual	32	25.1667	0.7865		
Total	47	39.1198			

Appendix 9: ANOVA for Stem girth 4 weeks after sowing (WAS)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.0078	0.0078	0.08	0.783
Treatment	7	0.6849	0.0978	0.98	0.464
Variety.Treatment	7	0.6788	0.0970	0.97	0.470
Residual	32	3.2038	0.1001		
Total	47	4.5752			

Appendix 10: ANOVA Table for Stem girth 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.9876	0.9876	6.15	0.019
Treatment	7	0.5467	0.0781	0.49	0.838
Variety.Treatment	7	0.8976	0.1282	0.80	0.595
Residual	32	5.1420	0.1607		
Total	47	7.5739			

Appendix 11: ANOVA Table for Stem girth 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.0585	0.0585	0.38	0.541
Treatment	7	0.4951	0.0707	0.46	0.854
Variety.Treatment	7	0.9902	0.1415	0.92	0.501
Residual	32	4.8948	0.1530		
Total	47	6.4385			

Appendix 12: ANOVA Table for Stem girth 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.1881	0.1881	0.84	0.367
Treatment	7	0.7382	0.1055	0.47	0.849
Variety.Treatment	7	1.2976	0.1854	0.83	0.574
Residual	32	7.1881	0.2246		
Total	47	9.4120			

Appendix 13: ANOVA Table for Stem girth 8 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.3870	0.3870	1.15	0.291
Treatment	7	3.6578	0.5225	1.56	0.185
Variety.Treatment	7	0.7679	0.1097	0.33	0.936
Residual	32	10.7530	0.3360		
Total	47	15.5657			

Appendix 14: ANOVA Table for Leaf number 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	295.021	295.021	39.12	<.001
Treatment	7	90.750	12.964	1.72	0.140
Variety.Treatment	7	64.313	9.188	1.22	0.322
Residual	32	241.333	7.542		
Total	47	691.417			

Appendix 15: ANOVA Table for Leaf number 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	1621.69	1621.69	40.67	<.001
Treatment	7	248.92	35.56	0.89	0.524
Variety.Treatment	7	134.06	19.15	0.48	0.842
Residual	32	1275.83	39.87		
Total	47	3280.50			

Appendix 16: ANOVA Table for Leaf number 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	1457.5	1457.5	12.68	0.001
Treatment	7	710.0	101.4	0.88	0.531
Variety.Treatment	7	881.4	125.9	1.10	0.389
Residual	32	3677.7	114.9		
Total	47	6726.6			

Appendix 17: ANOVA Table for Leaf number 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	2073.76	2073.76	25.79	<.001
Treatment	7	732.54	104.65	1.30	0.281
Variety.Treatment	7	122.04	17.43	0.22	0.979
Residual	32	2573.17	80.41		
Total	47	5501.49			

Appendix 18: ANOVA Table for Leaf area

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	348394.	348394.	1.56	0.221
Treatment	7	3167275.	452468.	2.03	0.082
Variety.Treatment	7	1325833.	189405.	0.85	0.557
Residual	32	7149077.	223409.		
Total	47	11990579.			

Appendix 19: ANOVA Table for Nodule number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	20.	20.	0.01	0.905
Treatment	7	30022.	4289.	3.07	0.014
Variety.Treatment	7	11776.	1682.	1.21	0.328
Residual	32	44640.	1395.		
Total	47	86458.			

Appendix 20: ANOVA Table for Nodule fresh weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.3008	0.3008	0.31	0.584
Treatment	7	75.4136	10.7734	10.94	<.001
Variety.Treatment	7	6.4106	0.9158	0.93	0.497
Residual	32	31.5181	0.9849		
Total	47	113.6431			

Appendix 21: ANOVA Table for Nodule dry weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	0.00044	0.00044	0.01	0.925
Treatment	7	3.18063	0.45438	9.44	<.001
Variety.Treatment	7	0.29303	0.04186	0.87	0.541
Residual	32	1.54048	0.04814		
Total	47	5.01459			

Appendix 22: ANOVA Table for Leaf dry weight

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Variety	1		0.037	0.037	0.02	0.893
Treatment	7		25.991	3.713	1.85	0.112
Variety.Treatment	7		13.858	1.980	0.99	0.458
Residual	31	(1)	62.096	2.003		
Total	46	(1)	100.679			

Appendix 23: ANOVA Table for Stem dry weight

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Variety	1		2.208	2.208	1.59	0.217
Treatment	7		20.926	2.989	2.15	0.068
Variety.Treatment	7		11.403	1.629	1.17	0.348
Residual	31	(1)	43.190	1.393		
Total	46	(1)	75.993			

Appendix 24: ANOVA Table for Root dry weight

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Variety	1		0.791	0.791	0.08	0.773
Treatment	7		54.204	7.743	0.83	0.572
Variety.Treatment	7		25.638	3.663	0.39	0.900
Residual	31	(1)	289.660	9.344		
Total	46	(1)	369.542			

Appendix 25: ANOVA Table for Total dry weight

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Variety	1		6.59	6.59	0.44	0.513
Treatment	7		185.33	26.48	1.76	0.132
Variety.Treatment	7		43.30	6.19	0.41	0.888
Residual	31	(1)	466.84	15.06		
Total	46	(1)	691.01			

Appendix 26: ANOVA Table for Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	584.51	584.51	8.09	0.008
Treatment	7	874.70	124.96	1.73	0.137
Variety.Treatment	7	1126.79	160.97	2.23	0.058
Residual	32	2311.33	72.23		
Total	47	4897.33			

ANALYSIS OF VARIANCE (ANOVA) TABLES (FIELD EXPERIMENT)

Appendix 27: Analysis of variance (ANOVA) Table for Days to emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	3.7222	1.8611	2.68	
Variety	1	1.7778	1.7778	2.56	0.251
Residual	2	1.3889	0.6944	1.45	
Treatment	5	1.2222	0.2444	0.51	0.764
variety.Treatment	5	4.8889	0.9778	2.05	0.115
Residual	20	9.5556	0.4778		
Total	35	22.5556			

Appendix 28: ANOVA Table for Leaf number 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	141.8	70.9	0.08	
Variety	1	920.1	920.1	1.01	0.421
Residual	2	1824.5	912.3	3.45	
Treatment	5	703.9	140.8	0.53	0.750
variety.Treatment	5	1134.3	226.9	0.86	0.527
Residual	20	5295.6	264.8		
Total	35	10020.3			

Appendix 29: ANOVA Table for Leaf number 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	323.7	161.9	0.08	
Variety	1	2030.0	2030.0	1.01	0.421
Residual	2	4015.4	2007.7	3.42	
Treatment	5	1571.2	314.2	0.53	0.748
variety.Treatment	5	2476.5	495.3	0.84	0.535
Residual	20	11754.6	587.7		
Total	35	22171.5			

Appendix 30: ANOVA Table for Leaf number 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	591.	296.	0.08	
Variety	1	3439.	3439.	0.93	0.436
Residual	2	7360.	3680.	3.54	
Treatment	5	2752.	550.	0.53	0.751
variety.Treatment	5	4393.	879.	0.85	0.534
Residual	20	20790.	1040.		
Total	35	39324.			

Appendix 31: ANOVA Table for Leaf number 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1269.	634.	0.08	
Variety	1	8010.	8010.	1.05	0.413
Residual	2	15244.	7622.	3.27	
Treatment	5	6485.	1297.	0.56	0.731
variety.Treatment	5	9467.	1893.	0.81	0.554
Residual	20	46563.	2328.		
Total	35	87038.			

Appendix 32: ANOVA Table for Plant height 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	114.4	57.2	0.29	
Variety	1	117.8	117.8	0.61	0.517
Residual	2	388.1	194.1	1.81	
Treatment	5	77.3	15.5	0.14	0.980
variety.Treatment	5	143.9	28.8	0.27	0.925
Residual	20	2147.3	107.4		
Total	35	2988.8			

Appendix 33: ANOVA Table for Plant height 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	733.99	366.99	9.10	
Variety	1	15.51	15.51	0.38	0.598
Residual	2	80.67	40.34	0.72	
Treatment	5	199.77	39.95	0.71	0.623
variety.Treatment	5	481.64	96.33	1.71	0.178
Residual	20	1125.41	56.27		
Total	35	2637.00			

Appendix 34: ANOVA Table for Plant height 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	969.24	484.62	8.44	
Variety	1	102.01	102.01	1.78	0.314
Residual	2	114.87	57.43	1.47	
Treatment	5	247.10	49.42	1.26	0.319
variety.Treatment	5	252.83	50.57	1.29	0.307
Residual	20	783.92	39.20		
Total	35	2469.97			

Appendix 35: ANOVA Table for Plant height 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	824.94	412.47	10.43	
Variety	1	472.34	472.34	11.94	0.074
Residual	2	79.09	39.54	0.64	
Treatment	5	402.97	80.59	1.31	0.298
variety.Treatment	5	319.29	63.86	1.04	0.421
Residual	20	1226.82	61.34		
Total	35	3325.44			

Appendix 36: ANOVA Table for Days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	15.500	7.750	14.68	
Variety	1	2.778	2.778	5.26	0.149
Residual	2	1.056	0.528	0.41	
Treatment	5	4.667	0.933	0.73	0.607
variety.Treatment	5	10.556	2.111	1.66	0.190
Residual	20	25.444	1.272		
Total	35	60.000			

Appendix 37: ANOVA Table for Stem girth 4 weeks after sowing (WAS)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	6.557	3.278	0.51	
Variety	1	4.874	4.874	0.77	0.474
Residual	2	12.732	6.366	5.12	
Treatment	5	4.733	0.947	0.76	0.588
variety.Treatment	5	3.824	0.765	0.62	0.690
Residual	20	24.860	1.243		
Total	35	57.580			

Appendix 38: ANOVA Table for Stem girth 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	7.1783	3.5891	0.78	
Variety	1	2.5858	2.5858	0.56	0.532
Residual	2	9.2084	4.6042	5.22	
Treatment	5	4.1694	0.8339	0.95	0.474
variety.Treatment	5	1.4786	0.2957	0.34	0.886
Residual	20	17.6404	0.8820		
Total	35	42.2609			

Appendix 39: ANOVA Table for Stem girth 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	8.3724	4.1862	1.03	
Variety	1	1.8323	1.8323	0.45	0.571
Residual	2	8.1206	4.0603	4.67	
Treatment	5	5.2620	1.0524	1.21	0.340
variety.Treatment	5	1.2514	0.2503	0.29	0.914
Residual	20	17.3843	0.8692		
Total	35	42.2229			

Appendix 40: ANOVA Table for Stem girth 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	14.278	7.139	2.79	
Variety	1	3.292	3.292	1.28	0.375
Residual	2	5.127	2.563	2.12	
Treatment	5	4.160	0.832	0.69	0.637
variety.Treatment	5	4.100	0.820	0.68	0.644
Residual	20	24.139	1.207		
Total	35	55.095			

Appendix 41: ANOVA Table for Number of branches at flowering

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Reps stratum	2		2.0801	1.0400	11.81	
Variety	1		5.8887	5.8887	66.88	0.015
Residual	2		0.1761	0.0880	0.11	
Treatment	5		4.2782	0.8556	1.11	0.387
variety.Treatment	5		2.7449	0.5490	0.71	0.621
Residual	19	(1)	14.6302	0.7700		
Total	34	(1)	29.7829			

Appendix 42: ANOVA Table for Leaf area

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	217865.	108932.	0.34	
Variety	1	30059.	30059.	0.09	0.789
Residual	2	644817.	322408.	2.88	
Treatment	5	342835.	68567.	0.61	0.692
variety.Treatment	5	469922.	93984.	0.84	0.538
Residual	20	2242470.	112123.		
Total	35	3947968.			

Appendix 43: ANOVA Table for Leaf area Index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.421	1.210	0.34	
Variety	1	0.334	0.334	0.09	0.789
Residual	2	7.165	3.582	2.88	
Treatment	5	3.809	0.762	0.61	0.692
variety.Treatment	5	5.221	1.044	0.84	0.538
Residual	20	24.916	1.246		
Total	35	43.866			

Appendix 44: ANOVA Table for Nodule number 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	40.12	20.06	0.20	
Variety	1	312.11	312.11	3.09	0.221
Residual	2	202.24	101.12	1.95	
Treatment	5	965.36	193.07	3.72	0.015
variety.Treatment	5	182.95	36.59	0.71	0.626
Residual	20	1036.86	51.84		
Total	35	2739.65			

Appendix 45: ANOVA Table for Nodule number 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	51.3	25.6	0.08	
Variety	1	518.8	518.8	1.59	0.335
Residual	2	654.5	327.3	1.05	
Treatment	5	6443.2	1288.6	4.14	0.010
variety.Treatment	5	129.1	25.8	0.08	0.994
Residual	20	6231.1	311.6		
Total	35	14028.0			

Appendix 46: ANOVA Table for Nodule number 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2532.2	1266.1	0.41	
Variety	1	5148.1	5148.1	1.68	0.325
Residual	2	6140.2	3070.1	6.05	
Treatment	5	9646.7	1929.3	3.80	0.014
variety.Treatment	5	791.2	158.2	0.31	0.900
Residual	20	10145.9	507.3		
Total	35	34404.3			

Appendix 47: ANOVA Table for Nodule number 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	330.1	165.1	0.43	
Variety	1	1787.4	1787.4	4.67	0.163
Residual	2	766.3	383.1	3.22	
Treatment	5	3369.7	673.9	5.66	0.002
variety.Treatment	5	207.7	41.5	0.35	0.877
Residual	20	2383.1	119.2		
Total	35	8844.2			

Appendix 48: ANOVA Table for Nodule dry weight 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.000642	0.000321	0.22	
Variety	1	0.005059	0.005059	3.54	0.201
Residual	2	0.002859	0.001429	0.69	
Treatment	5	0.022430	0.004486	2.16	0.099
variety.Treatment	5	0.006510	0.001302	0.63	0.681
Residual	20	0.041481	0.002074		
Total	35	0.078982			

Appendix 49: ANOVA Table for Nodule dry weight 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.00677	0.00339	0.31	
Variety	1	0.00370	0.00370	0.34	0.620
Residual	2	0.02195	0.01097	0.87	
Treatment	5	0.11570	0.02314	1.84	0.152
variety.Treatment	5	0.00667	0.00133	0.11	0.990
Residual	20	0.25216	0.01261		
Total	35	0.40696			

Appendix 50: ANOVA Table for Nodule dry weight 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.079188	0.039594	0.65	
Variety	1	0.054574	0.054574	0.90	0.443
Residual	2	0.121286	0.060643	7.15	
Treatment	5	0.202149	0.040430	4.76	0.005
variety.Treatment	5	0.037816	0.007563	0.89	0.505
Residual	20	0.169702	0.008485		
Total	35	0.664716			

Appendix 51: ANOVA Table for Nodule dry weight 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.003632	0.001816	0.17	
Variety	1	0.030141	0.030141	2.88	0.232
Residual	2	0.020901	0.010450	1.77	
Treatment	5	0.095265	0.019053	3.22	0.027
variety.Treatment	5	0.004721	0.000944	0.16	0.974
Residual	20	0.118399	0.005920		
Total	35	0.273058			

Appendix 52: ANOVA Table for Root dry weight 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.16621	0.08310	22.22	
Variety	1	0.00863	0.00863	2.31	0.268
Residual	2	0.00748	0.00374	0.11	
Treatment	5	0.22162	0.04432	1.29	0.307
variety.Treatment	5	0.09354	0.01871	0.54	0.740
Residual	20	0.68701	0.03435		
Total	35	1.18449			

Appendix 53: ANOVA Table for Root dry weight 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.19882	0.09941	1.18	
Variety	1	0.09483	0.09483	1.13	0.400
Residual	2	0.16850	0.08425	1.18	
Treatment	5	0.50260	0.10052	1.41	0.264
variety.Treatment	5	0.13943	0.02789	0.39	0.849
Residual	20	1.42700	0.07135		
Total	35	2.53119			

Appendix 54: ANOVA Table for Root dry weight 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.37505	0.18752	0.83	
Variety	1	0.09100	0.09100	0.40	0.590
Residual	2	0.45012	0.22506	2.57	
Treatment	5	0.42413	0.08483	0.97	0.460
variety.Treatment	5	0.12711	0.02542	0.29	0.913
Residual	20	1.75157	0.08758		
Total	35	3.21898			

Appendix 55 Table: ANOVA for Root dry weight 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.67150	0.33575	1.68	
Variety	1	1.36890	1.36890	6.85	0.120
Residual	2	0.39997	0.19998	4.37	
Treatment	5	0.55359	0.11072	2.42	0.072
variety.Treatment	5	0.32642	0.06528	1.43	0.258
Residual	20	0.91566	0.04578		
Total	35	4.23604			

Appendix 56: ANOVA Table for Shoot dry weight 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	15.640	7.820	6.65	
Variety	1	0.750	0.750	0.64	0.508
Residual	2	2.350	1.175	0.24	
Treatment	5	33.355	6.671	1.35	0.283
variety.Treatment	5	19.280	3.856	0.78	0.574
Residual	20	98.614	4.931		
Total	35	169.990			

Appendix 57: ANOVA Table for Shoot dry weight 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	80.020	40.010	1.61	
Variety	1	27.080	27.080	1.09	0.406
Residual	2	49.627	24.813	4.55	
Treatment	5	94.069	18.814	3.45	0.021
variety.Treatment	5	33.533	6.707	1.23	0.332
Residual	20	109.104	5.455		
Total	35	393.432			

Appendix 58: ANOVA Table for Shoot dry weight 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	195.026	97.513	2.25	
Variety	1	32.215	32.215	0.74	0.479
Residual	2	86.570	43.285	4.70	
Treatment	5	72.525	14.505	1.58	0.212
variety.Treatment	5	18.242	3.648	0.40	0.845
Residual	20	184.011	9.201		
Total	35	588.589			

Appendix 59: ANOVA Table for Shoot dry weight 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	226.40	113.20	4.46	
Variety	1	204.39	204.39	8.06	0.105
Residual	2	50.74	25.37	1.44	
Treatment	5	41.13	8.23	0.47	0.797
variety.Treatment	5	62.75	12.55	0.71	0.622
Residual	20	353.03	17.65		
Total	35	938.45			

Appendix 60: ANOVA Table for Total dry weight 4 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	17.943	8.971	8.27	
Variety	1	0.234	0.234	0.22	0.688
Residual	2	2.170	1.085	0.18	
Treatment	5	32.044	6.409	1.09	0.396
variety.Treatment	5	30.826	6.165	1.05	0.417
Residual	20	117.489	5.874		
Total	35	200.705			

Appendix 61: ANOVA Table for Total dry weight 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	101.439	50.719	1.45	
Variety	1	88.334	88.334	2.53	0.253
Residual	2	69.916	34.958	4.17	
Treatment	5	72.123	14.425	1.72	0.175
variety.Treatment	5	28.510	5.702	0.68	0.643
Residual	20	167.491	8.375		
Total	35	527.813			

Appendix 62: ANOVA Table for Total dry weight 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	254.55	127.27	2.06	
Variety	1	134.84	134.84	2.18	0.277
Residual	2	123.44	61.72	5.45	
Treatment	5	47.28	9.46	0.84	0.540
variety.Treatment	5	31.99	6.40	0.57	0.726
Residual	20	226.45	11.32		
Total	35	818.54			

Appendix 63: ANOVA Table for Total dry weight 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	261.02	130.51	3.93	
Variety	1	231.34	231.34	6.97	0.118
Residual	2	66.36	33.18	1.72	
Treatment	5	47.15	9.43	0.49	0.780
variety.Treatment	5	59.07	11.81	0.61	0.691
Residual	20	385.23	19.26		
Total	35	1050.17			

Appendix 64: ANOVA Table for Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	14649.4	7324.7	6.38	
Variety	1	5124.2	5124.2	4.47	0.169
Residual	2	2294.6	1147.3	2.59	
Treatment	5	4539.6	907.9	2.05	0.115
variety.Treatment	5	1753.2	350.6	0.79	0.568
Residual	20	8849.3	442.5		
Total	35	37210.3			

Appendix 65: ANOVA Table for Pods weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	642.13	321.06	9.05	
Variety	1	395.68	395.68	11.15	0.079
Residual	2	70.98	35.49	1.29	
Treatment	5	162.86	32.57	1.18	0.353
variety.Treatment	5	151.93	30.39	1.10	0.390
Residual	20	550.87	27.54		
Total	35	1974.44			

Appendix 66: ANOVA Table for number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.3889	1.1944	2.26	
Variety	1	0.0278	0.0278	0.05	0.840
Residual	2	1.0556	0.5278	2.71	
Treatment	5	1.1389	0.2278	1.17	0.358
variety.Treatment	5	0.4722	0.0944	0.49	0.783
Residual	20	3.8889	0.1944		
Total	35	8.9722			

Appendix 67: ANOVA Table for hundred (100) Seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.911	1.455	0.23	
Variety	1	0.751	0.751	0.12	0.763
Residual	2	12.651	6.325	3.51	
Treatment	5	8.236	1.647	0.91	0.491
variety.Treatment	5	3.172	0.634	0.35	0.875
Residual	20	36.012	1.801		
Total	35	63.732			

Appendix 68: ANOVA Table for Seed weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	78.17	39.09	2.18	
Variety	1	132.83	132.83	7.41	0.113
Residual	2	35.85	17.92	1.63	
Treatment	5	54.97	10.99	1.00	0.444
variety.Treatment	5	59.97	11.99	1.09	0.397
Residual	20	220.24	11.01		
Total	35	582.03			

Appendix 69: ANOVA Table for Seed weight per plot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	369285.	184643.	2.23	
Variety	1	261360.	261360.	3.16	0.217
Residual	2	165230.	82615.	3.97	
Treatment	5	111134.	22227.	1.07	0.408
variety.Treatment	5	107179.	21436.	1.03	0.427
Residual	20	416555.	20828.		
Total	35	1430742.			

Appendix 70: ANOVA Table for Yield in tons per hectare

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	6.4112	3.2056	2.23	
Variety	1	4.5375	4.5375	3.16	0.217
Residual	2	2.8686	1.4343	3.97	
Treatment	5	1.9294	0.3859	1.07	0.408
variety.Treatment	5	1.8607	0.3721	1.03	0.427
Residual	20	7.2319	0.3616		
Total	35	24.8393			

Appendix 71: ANOVA Table for Harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.049516	0.024758	0.63	
Variety	1	0.000410	0.000410	0.01	0.928
Residual	2	0.079046	0.039523	4.61	
Treatment	5	0.044577	0.008915	1.04	0.422
variety.Treatment	5	0.008037	0.001607	0.19	0.964
Residual	20	0.171492	0.008575		
Total	35	0.353077			

Appendix 72: ANOVA Table for Crop growth rate 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.21000	0.10500	1.89	
Variety	1	0.18023	0.18023	3.24	0.213
Residual	2	0.11111	0.05555	4.61	
Treatment	5	0.05815	0.01163	0.97	0.462
variety.Treatment	5	0.05727	0.01145	0.95	0.470
Residual	20	0.24084	0.01204		
Total	35	0.85760			

Appendix 73: ANOVA Table for Crop growth rate 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.09570	0.04785	4.13	
Variety	1	0.01111	0.01111	0.96	0.431
Residual	2	0.02315	0.01158	0.43	
Treatment	5	0.07897	0.01579	0.59	0.711
variety.Treatment	5	0.03848	0.00770	0.29	0.916
Residual	20	0.53967	0.02698		
Total	35	0.78708			

Appendix 74: ANOVA Table for Crop growth rate 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.000711	0.000355	0.10	
Variety	1	0.019041	0.019041	5.63	0.141
Residual	2	0.006769	0.003384	0.54	
Treatment	5	0.184319	0.036864	5.90	0.002
variety.Treatment	5	0.073962	0.014792	2.37	0.077
Residual	20	0.125009	0.006250		
Total	35	0.409811			

Appendix 75: ANOVA Table for Relative growth rate 5 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.024320	0.012160	5.80	
Variety	1	0.007144	0.007144	3.41	0.206
Residual	2	0.004193	0.002097	1.44	
Treatment	5	0.009822	0.001964	1.35	0.284
variety.Treatment	5	0.009670	0.001934	1.33	0.291
Residual	20	0.029050	0.001453		
Total	35	0.084200			

Appendix 76: ANOVA Table for Relative growth rate 6 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.0035785	0.0017893	2.43	
Variety	1	0.0137475	0.0137475	18.65	0.050
Residual	2	0.0014743	0.0007371	0.75	
Treatment	5	0.0038553	0.0007711	0.78	0.575
variety.Treatment	5	0.0073606	0.0014721	1.49	0.237
Residual	20	0.0197316	0.0009866		
Total	35	0.0497478			

Appendix 77: ANOVA Table for Relative growth rate 7 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.0010590	0.0005295	0.35	
Variety	1	0.0004764	0.0004764	0.31	0.633
Residual	2	0.0030659	0.0015330	3.58	
Treatment	5	0.0040531	0.0008106	1.89	0.141
variety.Treatment	5	0.0035422	0.0007084	1.65	0.192
Residual	20	0.0085696	0.0004285		
Total	35	0.0207662			