EFFECT OF BIOCHAR AMENDMENT AND IRRIGATION REGIMES ON GROWTH AND YIELD COMPONENTS OF SCREENHOUSE GROWN *CAPSICUM CHINENSE* IN SOILLESS MEDIA

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DECLARATION

I, ANIOBI, MATHIAS MADUAKOLAM, an M.Eng. student in the Department of Agricultural and Bio-systems Engineering, Landmark University, Omu-Aran, hereby declare that this dissertation entitled “Effect of Biochar Amendment and Irrigation Regimes on Growth and Yield Components of Screenhouse Grown Chilli pepper (*Capsicum chinense*) In Soilless Media”, submitted by me is based on my original work. Any material(s) obtained from other sources or work done by any other persons or institutions have been duly acknowledged.

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Signature & Date

CERTIFICATION

This is to certify that this dissertation has been read and approved as meeting the requirements of the Department of Agricultural and Bio-systems Engineering, Landmark University, Omu-Aran, Nigeria, for the award of M. Eng.

DEDICATION

I dedicate my work to God almighty for His hand upon me that has help thus far and to my loving parent Mr. & Mrs. Boniface Aniobi and my siblings for their prayers and support throughout my studies.

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ABSTRACT

This study investigated the combined effects of amended substrates (rice husk and saw dust) and different water application rates in the cultivation of Habanero pepper (*Capsicum chinense)* crop. The substrates were amended with biochar produced from poultry liter using a fabricated pyrolysis kiln and incorporated into the rice husk and saw dust substrates at rates 30% and 50% by weight of biochar to substrates in a plastic pot planted with Habanero pepper. The produced biochar was characterized for moisture content, porosity, ash content, volatile matter, bulk density, solid density, specific surface area, pH and water holding capacity. Agronomic measures were applied to the cultivated Habanero pepper during the growing period in plastic culture system. The effect of the combined treatments on the phenological and yield of Habanero pepper was measured and recorded. The *Capsicum chinense* was grown in amended substrate with different irrigation treatment levels of I_{60}% (deficit irrigation), I_{80}% (deficit irrigation), I_{100}% (actual irrigation) and I_{120}% (surplus irrigation). The amended substrates for the experiment are define as follows; A-30% biochar, b-rice husk (Ab); A-30%, biochar, a-sawdust (Aa); B-50% biochar, a-sawdust (aB) and B-50% biochar, b-rice husk (Bb). Plant height for all treatment combinations were in the order Ab > Bb > aB> Aa. Highest stem diameter (1±0.7 mm) was obtained at I_{80}Bb and $I_{100,\ 120}$Ab. Leaf area index increased from 2 for $I_{60,120}$ Bb to 2.7 for $I_{80,120}$Ab, Aa. These shows that biochar application enhanced plant height, stem diameter, plant fresh, weights and yield components of pepper plant. Moreover, biochar application improved the efficiency of irrigation water usage. But I_{80}Ab was the best treatment combination for Habanero pepper production in screenhouse according to the analysis. However, ANOVA results were not significant, but using four test statistics were significant at 5% and significant at 1% respectively. Therefore, biochar amendment could be an effective option to improve substrate media which affected the plants.

Keywords: Biochar; Screenhouse; Irrigation regime; Soilless amendment; Treatment

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATE

Plate Number Title of Plate Page Number

LIST OF TABLES

Table Number Title of Table Page Number

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Globally, increasing constraints on water use from increased urbanization, industrialization, and climate change pose a barrier to producing more food for the world's growing population. However, the record shows that agriculture is the world's largest user of freshwater, accounting for over 70% of global freshwater use (Grafton and Hussey, 2011). Farmers must improve their water management in order to make more water accessible for crop production and thereby increase food security. Efficient water use is becoming increasingly important and alternate water application methods such as drip and sprinkler irrigation may significantly contribute to making the best use of scarce available water for crop production.

Water is delivered to the soil surface via irrigation, but a significant quantity is lost due to evaporation and deep percolation, rendering it ineffective (Wada *et al*., 2014). However, water application methods such as drip irrigation allow for considerably more equal distribution and exact control of the amount of water provided, as well as a reduction in nutrient leaching (Phene *et al.*, 1994). *Capsicum chinense* is an important source of vitamins and dietary fiber in the diet and its production is one of the most efficient in agriculture. It is crucial to examine the ability of biochar made from poultry waste to support the development and yield characteristics of *Capsicum chinense* planted in screen houses in contrast to other substrate media (Jake, 2013). Until the mid-1970s, greenhouse crop growers employed a soil-based mix as a substrate for almost all greenhouse crops. Greenhouse farmers began looking for alternate grow media in the mid-1970s because soil-based substrates were challenging for farmers with no land to access, as well as the effect of soil erosion and deterioration on specific soil locations.

Furthermore, because the amount of growth medium available to roots in the pot or container is limited, soil-less cultivation techniques have low tolerance to changes in temperature, water content and solute concentrations. Regardless, the growing media employed must provide physical functions such as plant anchoring and enough supplies of solutes, water, and oxygen (much like soil in-situ). Various materials, including peat, are utilized for this purpose.

Cornell University researchers created the Cornell A and Cornell B soilless mixes in the mid-1950s. Cornell A was made up of 50% sphagnum peat moss and 50% horticultural, medium-grade vermiculite. The Cornell B mix had 50% sphagnum peat moss and 50% horticultural grade pearlite (Nelson, 2012). Since then, soil mixtures have evolved, and they are currently typically composed of around 2/3 peat moss and 1/3 pearlite and vermiculite. The proportion of the components in soilless substrates vary depending on the producer and intended usage, but the percentages are about the same. The use of biochar as a soil amendment for carbon sequestration and better crop production is one unique technology that is gaining popularity around the world (Allohverdi *et al*., 2021; Ammor *et al*., 2018; Vijay *et al*., 2021; Torabian *et al*., 2021; Mensah and Frimpong, 2018). There has been very little research done to investigate the combined impact of biochar soilless substrate amendment and irrigation application regimes on crop output.

Biochar (biologically derived charcoal) is a fine-grained and porous substance derived from the partial combustion or pyrolysis of organic material that offers soil and soilless media with a number of favourable physical and chemical qualities (Saran *et al*., 2009). Biochar and media mixes could be effective amendments for growing horticultural crops in media. Furthermore, it entails the thermal degradation (exothermic) of biomass in the absence of oxygen to solid (charcoal or biochar), liquid (bio-oil), and gas biofuels. Rather than burning the created biochar for electricity, it is put to the soil as a conditioner, where it remains in an essentially permanent form and results in net carbon reduction from the atmosphere. Organic amendment would be beneficial in the production of nutrient-dense veggies as well as aesthetically pleasing ornamentals. Improved horticulture production encourages the use of organic waste materials such as sawdust and rice husk, which have significant disposal costs while also posing an environmental risk.

Biochar can improve plant productivity directly as a result of its nutrient content and release characteristics, as well as indirectly, via;

i) Improved retention of nutrients (Wardle *et al*., 1998; Lehmann *et al*., 2003).

ii) Improvements in soil pH (Rondon *et al*., 2007).

iii) Increased soil cation exchange capacity (Liang *et al*., 2006)

iv) Improved soil physical properties (Chan *et al*., 2008)

v) Increase in soil water retention (Laird *et al*., 2010)

Pyrolysis is a thermochemical process that involves the breakdown of big complex hydrocarbon molecules in biomass while oxygen is scarce. This biomass is then broken down into small, simple molecules of gas, liquid, and char (Demirbas and Arin, 2002). Bio-char is char made from the pyrolysis of biomass. Bio-char is a soil supplement that increases soil resource and water quality. Carbon dioxide is taken from the atmosphere during the pyrolysis process of bio-char, assimilated initially by developing plants, and then stored in a stable soil-carbon pool rather than returning to the atmosphere through decomposition (Chatterjee *et al*., 2020).

1.2 Problem statement

In the study area (Landmark University), the commonest substrates or growth media used in screen house for cultivation of vegetables are rick husk mix with coco-peat, which is usually imported. Coco-peat is added to improve the water holding capacity of the grow media particularly during the early stage of growth of vegetable planted in a grow bag culture.

There has been little research into the amendment of other grow media besides rick husk. Alternatives to rice husk in Nigeria include saw dust, pulverized maize cob, rice straw, and others, which have been researched to determine if their physical, chemical, and biological qualities improve after biochar amendment (El-Naggar *et al*., 2019; Karhu *et al*., 2011, Lehmann *et al*., 2011, Herath *et al*., 2013; Yang, X., 2019;). Crop performance is affected by different water application regimens (Monti *et al*., 2005; Mokhtasei *et al*., 2013). The two extremes of water application rate, shortfall and surplus irrigation, have an impact on vegetable performance in screen house agriculture. The ideal water application strategy for the *Capsicum chinense crop* must be reviewed.

In the research area, livestock manure is created on a daily basis. One method for dealing with the massive waste is to convert it into biochar, which may be used as an amendment for both soil and soilless media. There is not much information available about the characteristics of biochar made from cattle waste. As a result, it is impossible to recommend them as an amendment. At the time of writing this proposal, there was no research on the combined treatment of substrate amendment and irrigation regime in the study area.

Currently, little is known about the use of biochar in plant media amendment in modern screen house experiments for vegetable cultivation, and information on its agronomic value in terms of crop response and media soil health benefits is scarce. The particular processes underpinning biochar's and irrigation regimes' contributions to plant response are unknown. Agronomic characteristics such as amendment quantity, irrigation regimes, regional circumstances such as climate, media chemistry, and physio-chemical conditions all have an impact on the agronomic benefits of biochar.

1.3 Aim and objectives

The aim of this study is to determine the response of *Capsicum chinense* grown under different irrigation regimes and biochar amendments in soilless media.

The specific objectives of this study are to:

i) Locally design and fabricate of biochar kiln;
ii) Characterize poultry litter derived biochar produced in a locally constructed biochar kiln.
iii) Investigate the effect of combined application of biochar derived from poultry litter and irrigation regimes on growth and yield of *Capsicum chinense* under drip irrigation.

1.4 Justification

Although, there has been research carried out in the research area using biochar as a growing media to plant other crops, there’s a need to study the characteristics of biochar formed from poultry litter waste as ways to conserve the environment coupled with the agricultural waste from plants (rice husk and saw dust), the use of biochar as substrate amendment will be used in a soilless substrate in carrying out the experiment to determine the growth and yield of *Capsicum chinense* in a screen house.

It is also critical to identify the optimal combined treatment good for *Capsicum chinense* production based on field research, then separate treatments of irrigation regimes and soilless substrate have been conducted, there is a need to investigate the plant's response to combination treatment under the same climate conditions. *Capsicum chinense* is demanded for all year round and it is important to investigate conditions for its optimum growth and yield. This will in-turn affect positively the life and earning of farmers in the study area.

1.5 Scope of study

This study will investigate the effect of poultry litter derived biochar (PL) on the growth and development of *Capsicum chinense* pepper in a sawdust and rice husk soilless mixture with appropriate fertigation (fertilizer plus irrigation regime in screen house). Plant growth would be detected under ideal conditions, demonstrating that biochar-induced plant growth stimulation extends beyond evident benefits to plant nutrition and improved soilless physical and chemical qualities. This would therefore provide an opportunity to assess particular elements that could be causing the Biochar effect.

1.6 Significance of the study

i. The study will ensure the sustainability of the soil nutrient and moisture for good growth of crops.
ii. Ensure agricultural waste (both animal and plant waste) management and enhanced food production.
iii. It addresses the sustainable development goals: zero hunger (SDG 2), water management (SDG 6), waste management (SDG 11), and responsible consumption and production (SDG 1

1.7 Research hypothesis

The combined treatment will lead to a 2-factor experiment (irrigation regimes and substrate amendment) which will be analyzed using a 2-way ANOVA to investigate the following null hypothesis.

H_{01}: Irrigation treatments have no significant effect on the yield of *Capsicum chinense*.

H_{02}: Different biochar amendments of soil portrayed insignificant role in water retention and effective yield of *Capsicum chinense*.

H_{03}: The combined effects of the different irrigation regimes and biochar amendment will result to no difference in yield of *Capsicum chinense*.

H_{04}: The means yield from all irrigation treatments are not significantly difference.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and uses of *Capsicum chinense*

The genus Capsicum, originating from the tropical and wetlands of the central and Southern American areas, belongs to the Solanaceae family. Capsicum species exist, 3 of which are widely distributed with a hot or pungent berry: *Capsicum annuum*, *Capsicum frutescens* and *Capsicum chinense* (Menichini *et al.*, 2009). The pungency of capsicum fruit is due to a group of compounds called Capsaicinoids, which are present in hot pepper varieties in different amounts (Govindarajan, 1986).

Over the years, chili pepper has been used commonly to add flavor to food preparations as preservative and as a spice. They are grown internationally, with Asia as leading producer followed Mexico and the United States. In 2008 in the US, 159.660 metric tons, New Mexico led domestic production at around 86.183 metric tons was harvested in the United States (Huntrods, 2008), (NASS, 2009). Since chili peppers demand have increased over the years in the US, approximately 255,375 tons of chili peppers (5,6 3 million tons) had to be imported to the country to satisfy increasing demand in 2007 (Huntrods, 2008; Menichini *et al.*, 2009). The concentration of Capsaicinoids in fresh red pepper varieties, especially in paprika, ranges from 0.001% to 0.01%, and in strong chili varieties the concentration ranges from 0.1% to <1% (Govindarajan *et al*., 1987).

2.2 Soil macro and micro nutrients requirement for pepper production

Pepper, like all other plants, needs macro (nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, carbon, oxygen, and hydrogen) and micro (iron, boron, iodine, zinc, copper, molybdenum, nikel, and chlorine) elements for growth and germination. Peppers are incredibly essential in the global economy because of their economic relevance (Omotade *et al*., 2019). The type of soil, nutrient condition, and pH of the soil influence the soil nutrient requirements for pepper production.

When a nutritional deficiency exists, the plant will try to shift or translocate required elements from old growth or plant parts to new growth. As a result, the symptoms of these deficits appear first in older growth or plant parts such as leaves (Malvi, 2011). Those nutrients that manifest themselves in aged leaves are known as mobile nutrients. N, P, K, Mg, and Zn are among examples. In young leaves or medium growth, immobile nutrients like Fe, B, Mn, Cu, Ca, Mo, and S will show deficit (Shreeja, 2018).

Table 2.0: General nutrients deficiency symptoms

Element	Leaf coloration	Crop growth
Nitrogen (N)	Light green or yellow on lower leaves which eventually die (necrosis).	Plant stunted and weak; early leaf loss, small leaves; Plants mature earlier.
Phosphorus (P)	Purple or dark blue green: first appear on lower, older green. Old leaves turn dark, green, sometimes purple will move up if unchecked.	Slow growth, shortened internodes; leaves can appear wilted.
Potassium (K)	Yellow brown tissue between vein necrosis along leaf blade; symptoms on matured, lower leaves; chlorosis of white spects on leaves (legumes). Dead patches may become pinholes.	Slow growth; plant mature early.
Sulphur (S)	Yellow -green coloration in leaf blades and vein appears on younger plant parts.	Slow growth. Plants mature early. Poor root growth after middle growth.
Calcium (Ca)	White strip along leaf margins; chlorosis on younger plant; mis-shapen new growth, cupped, curled and crumpled, old growth un affected.	Death of buds and some roots; small leaves.
Magnesium (Mg)	Chlorosis beginning at center and edge of leaf blade of mature, lower leaves; old leaves turn yellow from tip inwards; vein remain green.	Slow growth delayed maturity poor fillering.
Iron (Fe)	Chlorosis between leaf veins. Yellow or white young leaves can spread across whole leaves.	Reduced plant growth or plant death.
Zinc (Zn)	Yellow or white coloration between mid- rib and leaf margin.	Shortened internodes, resetting in broadleaves.
Manganese (Mn)	Interveinal chlorosis, white or gray “spot” on younger leaves or small grains	Stunted growth; leaves in vertical position.
Copper (Cu)	Chlorosis of leaves; leaf tips turn white; appears on young leaves.	Poor growth, wilting.
Boron (B)	Yellow of younger leaves; deformed fruits.	Buds die; flowers or fruits drop off.
Chloride (Cl)	Chlorotic mottling of leaves.	Reduction in root growth.

Sources: Shreeja, 2018; World of chillies, 2019, Harriton, 2018

2.3 Biochar

Biochar, which is simply charcoal used as a soil or growth media amendment, is often made from organic waste using pyrolysis technology at temperatures between 400℃ and 700℃, when oxygen is either absent or depleted. Biochar's differ depending on the feedstock, temperature, and residence time and have been effective tools of waste management, soil remediation, and may also offer control of greenhouse gas (GHG) emissions through carbon sequestration (Lehmann and Joseph, 2015; Kern *et al*., 2017). Because biochar varies so much, one form of biochar may not be good for all growth environments and crops. Biochar-like materials, such as charred rice husks, are widely used in South America (Colombia) for the growth of cut flower species. (Quintero *et al*., 2013).

2.3.1 Biochar production

Under varied process parameters, biochar is primarily created through thermo-chemical conversion processes such as slow pyrolysis, fast pyrolysis, torrefaction, and gasification (Leng *et al*., 2019). Table 2.1 below shows the quantity of liter before & after charred, temperature and time interval for the process. Also, Plate 1shows the biochar produced for experiment.

2.3.2 Physical Properties of Biochar

Many biochar's have a total porosity similar to peat at 90%-95%. Air space and depends mostly on the particle size of the material. Bulk density is similar to H2-H4 peat, varying from 100 to 300 g/L (Blok *et al*., 2017). Pelletized biochar was tested as a component of a growing medium and was found to improve the physical properties of soil, such as hydraulic conductivity and water availability but had a variable effect on porosity (Drumroese *et al*., 2011). Zaccheo *et al*., (2014) discovered that combining biochar with peat improved the physical features of growing media, such as increased air content and reduced shrinkage. According to Zhang *et al*. (2014), adding biochar lowered bulk density and increased water-holding capacity and porosity.

Plate 1: Biochar produced from poultry liter

2.3.3 Chemical properties

Biochars have a very high pH. However, this may allow part or all of the dolomitic limestone used to neutralize peat to be replaced. Zaccheo *et al*. (2014) looked into the ability of a pinewood biochar with a pH of 10.2 to neutralize peat with a pH of 4.2. The most effective proportions for changing the pH to a moderate acidic value were 30% and 40%.

2.3.4 Plant growth

Biochar amendment causes chemical responses in plants as well as changes in the rhizosphere microbiota in some plant growth conditions (De Tender *et al*., 2016). Graber *et al*. (2010) proposed two novel mechanisms for the growth effects:

(i) Due to the chemical or physical properties of the biochar, it encourages shifts in microbial populations toward beneficial plant growth promoting rhizobacteria or fungi.

(ii) Plant growth is stimulated by modest doses of biochar compounds, many of which are phytotoxic or biocidal at high quantities (hormesis).

Table 2.1: Breakdown process of biochar production

S/N	Vessel	Material	Vessel Size (kg)	Quantity Before (kg)	Start Time (am)	Stop Time (pm)	Quantity After Char (kg)	Temperature (^0C)
1	Small Vessel	Poultry litter	5.6	5	7.40	2.06	3.8	280
2	Big Vessel	Poultry litter	13.6	8.4	9.05	6.25	6.2	300

(Source: Mathias, 2021)

Under particular temperatures and pressures, in the absence or limitation of oxygen supply, these reactions irreversibly change the physical state and chemical makeup of biomass into biochar. The chemical biomass components are severely connected together, decomposed, and polymerized, resulting in a rich carbon solid residue known as biochar, a condensable organic liquid known as bio-oil or tar, and a fuel gas containing hydrogen, carbon oxides, light hydrocarbons, and some other reaction-dependent compounds (Giudicianni *et al.*, 2013).

Biochar has been identified as a promising technology for carbon (C) sequestration, energy production, enhanced soil and environmental quality, and soil and environmental quality improvement (Hua *et al*., 2009; Clough and Condron, 2010; Qian *et al*., 2015). The numerous benefits of biochar illustrate its ability to contribute to the long-term economic feasibility of developing cellulosic bioenergy production systems (Lehmann, 2007; Laird *et al*., 2009; Sohi *et al*., 2010). Depending on the thermochemical working parameters and the underlying essence of biomass, biochar exhibits a variety of physical and chemical properties. Several units and reactors for biomass production were created in order to improve the target product's performance and quality. These reactors are largely identical, although they differ in terms of oxygen consumption, heating rates, and end temperature, all of which can have an impact on final product quality and distribution.

2.5 Processes for biochar production

2.5.1 Slow pyrolysis

Slow pyrolysis is a decomposition technology that decomposes biomass at a low temperature (350–500°C), allowing the pyrolysis vapour to settle and increase the secondary cracking level as much as possible. The term "slow" in the slow pyrolysis method denotes a low heating rate; nevertheless, the "optimum char formation temperature zone" (Prabir Basu 2010) is another important element affecting the quality and production of biochar. Biochar was often generated from various organic and non-organic resources, such as land waste, algal biomass, scrap-pneumatic tyres, and heavy crude oil, which was commonly utilized as a biochar precursor by slow pyrolysis (Liao *et al.*, 2018). The carbon content of biochar created from slow pyrolysis of red cedar wood reached up to 88.88 percent at 500 °C pyrolysis temperature and 6 °C/min heating rate; nevertheless, the larger heating value of biochar attained 32.95 MJ/kg, suggesting good quality of biochar (Yang *et al*., 2016).

2.5.2 Fast pyrolysis

Fast pyrolysis requires very large heating rates at a temperature of some 1000 °C/min at about 500 °C pyrolysis and vapor residence are generally 5 hrs. (Choi *et al*. 2017). Biomass particles are rapidly degenerated into pyrolysis vapors and biochar (10–15 wt. %) in a fast pyrolysis method. In the downstream plant, which is a darker-brown liquid called bio-oil, the condensation composition of the pyrolysis vapors is extracted and collected and this process is based upon biochar. The biomass feedstock is rapidly heated, and the pyrolysis vapors generated are rapidly transferred from the pyrolysis reactor, when the heating rate is high. These pyrolysis vapors spend less time in the high temperature zone, resulting in less carbon deposition. For example, raising the heating rate from 10 to 50 °C/min reduced the yield of safflower seed biochar by 3–8 percent (Angn, 2013).

Due to the release of volatiles from the biomass particle, higher pyrolysis temperatures are good for increasing the carbon content of biochar and its specific surface area. For example, as the pyrolysis temperature climbed from 200 to 700°C, the specific surface area of rapeseed stem biochar increased from 1 to 45 m2 /g a. (Zhao *et al*., 2018). The carbon content of biochar generated from the pyrolysis of pine sawdust increased from 70.68 percent to 78.75 percent as the pyrolysis temperature climbed from 550 to 750 °C (Peng *et al*., 2012).

2.5.3 Gasification pyrolysis

Gasification is a process that involves incomplete combustion of biomass with various gasifying agents such as air, pure oxygen, or steam and oxygen to produce a gas product. In general, researchers in a biomass gasification process focus on how to increase the quality and production of syngas by minimizing pollutants such as fly ash, nitrogen oxides, sulfur dioxide, and tar (Han and Kim, 2008). When the oxygen flow rate was increased from 0.15 to 0.6 kg/h, the carbon content of biochar declined from 89 to 80 percent at 700°C and from 93 to 86 percent at 900°C, according to Muvhiiwa *et al*. (2019). On one hand, it boosts heterogeneous processes, allowing more carbon to be converted from the solid phase to gaseous species, encouraging the creation of micro pores and increasing the specific surface area of biochar (Kumar *et al*., 2017).

2.5.4 Torrefaction pyrolysis

Torrefaction is usually used to create a "charred" product that can be used as a fuel or a soil supplement (Barskov *et al*., 2019). In a typical torrefaction process, biomass feedstock is heated to temperatures between 200 and 300 °C in an inert environment at a low heating rate (i.e., less than 50 °C/min) and a relatively long residence period (20–120 minutes) (Wang *et al*., 2017). During this process, almost 30% of the mass of some highly reactive volatile compounds is transformed into torrefied vapor (Ma *et al*., 2019).

2.6 Biochar quality

The quality of biochar varies based on the feedstock and pyrolysis method utilized. Pyrolysis variables such as heating rate, residence time, and ultimate temperature have a significant impact on biochar quality. The pyrolysis temperature affects biochar properties such as elemental composition, particle size, specific surface area, pore size distribution, thermal capacity, and electrical conductivity. Depending on how biochar is used, some quality parameters are more important than others. Biochar quality parameters include pH, volatile chemical content, ash content, water holding capacity, bulk density, pore volume, and specific surface area (Song a). In carbon sequestration and soil fertility enhancement, carbon stability is a significant quality criterion. Two further important quality markers in increasing soil fertility are surface area and nutrient content. One of the most important biochar characterization characteristics is the molar hydrogen to carbon (H/C) ratio; it is a measure of the degree of carbonization and biochar stability. H/C ratios greater than 0.7 indicate poor biochar quality and pyrolysis deficiencies. Biochar is distinguished from other carbonization products by its molar oxygen to carbon (O/C) ratio (EBC, 2012). When the O/C ratio is more than 0.4, biochar stability suffers.

2.7 Pyrolysis kiln

For the production of biochar, earth kilns or metal kilns are usually employed as fixed bed pyrolysis reactors in which biomass is kept and heated. For several hours or days in an airtight oven (Garcia-perez *et al*., 2010).

A kiln, a type of oven made out of clay or metal, generate enough heat to complete biomass process in a slow pyrolysis. The solid reactants cannot be uniformly heated in these pyrolysis reactors, and the gas-solid contact in a fixed bed reactor is weak. Garcia-Perez *et al*. (2007) compared a batch of pine for slow pyrolysis with a continuous auger reactor. The char yield (30-31 wt. %) for both reactors is essentially the same and indicates that both pyrolytic reactors are extremely similar in reactions leading to carcinogenic formation. Another continuous reactor of pyrolysis (bubbling fluidized bed) was also studied for sluggish biomass pyrolysis, with the exception of the augur reactor.

2.8 Screen house

A screen house is a farm system that protects crops from light, insects, and other pests by covering them with a high-density plastic net (Vitner and Bechar 2011). To assure varying shading levels, decrease heat intensity during the day, and check the light spectrum penetrating the net, the netting can be in various colors such as black, white, red, and so on. The geometrical proportions, panel size, quantity and position of routes, and screen colours can all differ between farms. Plate 2 depicts the screen house in research farm at Landmark University that was used for the study. The screen house has the following dimension; width 8m, length 24m, height from ground 1.5m, total height 6.8m and it is made of transparent Lyon & steel.

Plate 2: A typical screen house for vegetable cultivation at Landmark University

2.9 Substrate

It is a growing medium, which serves to fix plant; to supply air, water, nutrient to the roots; to control the microflora, particularly to be sheltered to the soil-borne pathogens; to have no Phyto-toxicity appearance (Lemaire, 1994). When opposed to soil-based production, soilless culture of plants in containers has a restricted root system and a smaller root zone volume. It is vital to note that the physical and chemical qualities of the growing media must be such that the plant can store enough water and nutrients while maintaining appropriate aeration under these conditions.

2.9.1 Water retention characteristics of substrate

The most significant physical properties of a growing medium are those that govern its capacity to provide water to the root system without cutting off the oxygen supply (Jon E. S. and Jackie F. C., 2015). These characteristics are studied using the volumetric distribution of water and air in the growing media in relation to the water potential, or the water retention energy in the growing medium.

2.9.2 Definition of some Physical characteristics of substrate

i) The total void volume (accessible to water and air) as a percentage of the total volume of the growth medium is called total pore space.

ii) At water potentials between 0 and -1 kPa, air volume content, also known as air-filled porosity, is the volumetric proportion of the water present at saturation (water potential = 0 kPa) in the coarsest pores that is rapidly released and replaced by air.

iii) The volumetric fraction of pore water retained in the growth medium by forces consistent with root extraction capabilities is known as water availability (defined for the range of water potential from -1 kPa to -10 kPa).

iv) Water buffering capacity is the volumetric proportion of water released by the growth medium between -5 and -10 kPa that allows the plant to respond physiologically to changing water potential.

2.9.3 Wettability of substrate

The ability of a material to re-wet itself after drying is described by its wettability. This is a crucial feature of horticultural growing media because it controls the efficiency with which the medium - and thus the plant - absorbs water after it has been removed by evaporation or through roots and evapotranspiration. Fields *et al*. (2014) investigated the wettability (rehydration efficiency) of pine-bark substrates and discovered that the initial substrate moisture content (MC) and the application of wetting agents had a substantial impact on the number of hydration events required to rewet a pine-bark substrate.

2.9.4 Classification of growing media

i) Aerated growth media with high water availability (> 25% v/v) and high-water buffering capacity (air volume content > 20% v/v). Some Sphagnum peat has these qualities, although they're usually achieved by combining many different ingredients. Because it offers the most flexible irrigation requirements and hence is the least restrictive in terms of water management, this is the "optimal" variety.

ii) Less aerated growing media with a moderate to high water availability. The biggest downside is the potential risk of shutting off the oxygen supply to the root system due to their finer pores and thus higher water retention than aerated growth materials.

iii) Highly aerated growing media with low water availability. The poor water supply, if employed alone, would necessitate too-frequent low-dose irrigation.

iv) Aerated growth media with a high-water availability but a fast-depleting water reserve (low water buffering capacity).

2.10 Different types of substrates

2.10.1 Peat

Peat is generated through the gradual decomposition of mosses, reeds, and sedges in wet habitats where biomass accumulates in conditions that are not favourable to microbial activity, such as low pH and low oxygen levels. Because of its unique features, low cost, and widespread availability, peat will continue to be a prominent component of growing substrates in the coming decades (Caron and Rochefort, 2013). These peat layers formed after the ice sheets receded 14,000-11,000 years ago, during the postglacial period. Peat bogs are classed as either ombrogenous (raised and blanket bogs), where rainfall controls the formation of the peat layer, or topographic (basin bogs), where topography and the groundwater table regulate the deposition of new peat (Rochefort, *et. al*., 2012). The International Peatland Society (Kivinen, 1980) established the following simplified classification system for peat based on its botanical content, degree of decomposition, and nutrient status:

i. Botanical composition

- **a.** Moss peat (predominantly sphagnum and other mosses)
- **b.** Sedge peat (sedges, grasses, herbs)
- **c.** Wood peat (remains of trees and woody shrubs)

ii. Degree of decomposition/humification (H)

- **a.** Weakly decomposed (H1-H3)
- **b.** Medium decomposed (H4-H6)
- **c.** Strongly decomposed (H7-H10)

iii. Trophic status

- **a.** Oligotrophic (low in nutrients)
- **b.** Mesotrophic (moderate in nutrients)
- **c.** Eutrophic (high in nutrients)

The nature of the plant remnants and their degree of decomposition determine the qualities of peat. Peats vary in age and are typically characterized using the simple but effective von Post scale (von Post, 1922) that distinguishes three types of peat: younger, undecomposed of low humification (H1-H3), partly decomposed (H4-H6), and older, extensively decomposed (H7-H10). H1 to H4 peats are commonly referred to as "white peat," whereas H4-H6 peats are referred to as "dark peat," and H7 and above peats are referred to as "black peat" (Bunt, 1988). Dark peats also have a higher lignin/humic concentration than white peats, making them less biodegradable. In the winter, black peats are frequently frozen, which increases their air and water-holding capacity. It is light, but shipping it to Africa is highly expensive. Finally, when employed as a growing medium, peat is relatively stable.

2.10.1.1 Physical properties of peats

The particle size distribution and degree of decomposition of peats are determined by the species makeup of the bogs where they were formed (Kitir *et al.*, 2018; Corradini *et al.*, 2020). Plate 3 shows the arrangement of peat sods that can be used as substrate. It is because peat-based growing media may be well aerated while still containing an appropriate reservoir of water for plants, high porosity is the single most significant physical attribute. The physical nature of the elements, as well as the extraction, processing, and preparation methods, influence the porosity of growth media. Sphagnum peat moss has pores that allow water to enter and exit. Quantitative data on size, shape, connectivity, surface roughness, and anisotropy of the pore spaces (Tang *et al.*, 2013; Rezanezhad *et al.*, 2009, 2016) are currently available on the porous structure of sphagnum peat in situ and these data may have relevance to harvested peat used as a component of growing media. Peat's total porosity includes both very large interparticle pores that can actively convey water and relatively small, closed, and dead-end pores generated by plant cell remnants (Hayward and Corradini *et al.*, 2020; Kremer *et al.*, 2004). Both relatively large interparticle macropores and smaller deadened pores are visible using scanning electron microscopy (SEM). Rezanezhad *et al.* (2009) discovered that a single pore dominated the pore distribution in a near-surface sample of sphagnum peat, an area with little decomposition, pores in deeper peat layers, which are anticipated to be more degraded, were substantially smaller and had fewer interconnections, accounting for 94 percent to 99 percent of the total interparticle pore volume.

Plate 3: Peat moss (Source: Colman Hynes)

2.10.1.2 Pore sizes

Although the pore size of undecomposed peat may surpass 5 mm, substantial shrinking happens during dewatering, compression, and decomposition (Rezanezhad *et al.*, 2016). Pore structure and size are related to the kind and degree of decomposition of peat, but the super hydrophilic quality of peat is preserved even after extraction and processing, and peat media can absorb 10-20 times their own weight in water (Koch and Barthlott, 2009).

2.10.1.3 Pore structure

The molecular structure and arrangement of molecules in pores are not well known. Drying sphagnum peat moss to moisture contents below 40% – 50% (depending on the degree of humification) causes it to become very hydrophobic, which could be owing to changes in pore structure (Michel, 2015).

2.10.1.4 Particle size

When developing growing media, particle size is an important factor, and in the case of peat, it is influenced by the degree of decomposition, extraction, and processing (Michel, 2010). Peat produced by milling or cutting (to form sods) can be mechanically broken down and sieved to yield fractions of varying particle sizes, allowing for a wide range of physical qualities in peat growing media (Prasad and Maher, 1993). Milling peat on the bog or creating sod peat and breaking these sods into the necessary fractions are two options for manufacturing peat fractions. There are two sorts of sods: bin sods and sod moss. Sod moss refers to sods cut directly from bogs of moderately decomposed peat, while bin sods are made by extrusion of peat with a high degree of decomposition (H6-H7) (H5-H6). Before being used, both types of sods are dried on the bog. Bin sod fractions have a larger bulk density than sod moss fractions, as expected. When compared to milled peat fractions, sod fractions are more consistent and stable (Prasad *et al.*, 2017). The use of fractioned peats allows for the retention of water and ease of filling in media meant for plant propagation, as well as the augmentation of air content inside media in big containers for nursery stock development. Plants that require more aeration, such as those maintained in big containers for months or even years, will benefit from peat fractions.

2.10.1.5 Chemical properties and pH

i) pH of peat-based media for most plants other than calcifuges needs to be in the range 5.5-6.5 (Lucas and Davis, 1961). In general, the pH values for raw sphagnum peat (untreated, as harvested from a bog) range from 3.5 to 4.1, and desirable pH levels for most growing media are easily achieved with peat through addition of lime, commonly as dolomitic limestone (which also provides calcium and magnesium) at 2-3 kg/m^3 for less decomposed (H2-H3) and 3-7 kg/m3 for more decomposed (H4-H6) peats (Maher and Prasad, 2004). The acidic nature of sphagnum peat makes it an almost indispensable component of media for growth of calcifuges such as Azalea, Camellia, and Rhododendron spp., where, typically, peat-based media receive a dressing of 1-1.5 kg m^3 of lime (Maher *et al.*, 2000).

ii) Cation exchange capacity

(CEC) of growing media constituents is frequently reported on a weight basis, since plants grow in a limited volume of media, and in the case of peat-based media, low bulk density, it is more appropriate (as with nutrient concentrations) to express CEC on a volume basis. If the bulk density of materials is known, then conversion from cmol (1)/kg (meq/100 g) to meq/L is straightforward (Handreck and Black, 2010). The CEC of peat has been recorded at 130 cmol (1)/kg for undecomposed sphagnum peat, 80 cmol (1)/kg for sedge peat, and 150-250 cmol (1)/kg for decomposed H4-H6 peats (Puustjarvi and Robertson, 1975). These values approximate to 150-250 meq/L (Landis, 1990), and endow many peats, particularly H4-H6, with good buffering capacity, being resistant to pH changes brought about by alkaline water supplies and minimizing checks to plant growth from fertigation. Further, the high CEC values mean that peat has a good capacity to retain cationic nutrients. However, the anion exchange capacity is very low (Bunt, 1988). This means, for instance, that, unlike in most soils, phosphate can easily be leached from peat-based growing media as will N present in nitrate form. The low pH and very low basic level of fertility of sphagnum peat requires the addition of nutrients as well as lime to support good plant growth.

iii) Micronutrients

This must be included in peat-based growing material as well. Individual inorganic salts, components of compound fertilizers, or slow-release forms, such as fritted trace elements, can be added (FTE).

2.10.1.6 Biological characteristics and stability

Weed seeds originating from plants growing on peat bogs or bog borders may contaminate peat (Keijzer and van Schie, 1997). Rushes (*Juncus spp.*) and sheep's sorrel are the two main species involved (*Rumex acetosella L.*). Manual inspection and removal are frequently used to control these on site, with drainage ditches around peat extraction regions receiving special care. Despite the low pH of peat, self-heating is a serious issue with stored peat, whether on the bog or in transit, and is thought to be microbially mediated (Tahvonen & Kemppainen, 2008). Self-heating has been linked to thermophilic fungi (Wever and Hertogh-Pon, 1993) and bacteria (including some unusual species such as the genus Alicyclobacillus—Ranneklev and Ba°a°th, 2003). Phytotoxic chemicals may be released during self-heating (Wever and Hertogh-Pon, 1993); in addition, changes in the physical, chemical, and microbiological properties of self-heated peats may occur (Cattivello, 2009), and plant germination and growth may be harmed in media obtained from such peats. Peats that have experienced self-heating are, in most situations, unsuitable for the manufacture of growth media.

As measured by oxygen uptake rate, biological stability suggests O2 consumption rates as low as 1.9 mol/kg/h (Blok *et al*., 2017). According to Grunert *et al*., (2016), Irish peat (10-30 mm) had the lowest rate of respiration with 16.163.1 mg CO2-C/kg/day, followed by sod peat (10-30 mm) with 25.261.5 mg CO2-C/kg/day and coconut fiber with 82.664.0 mg CO2-C/kg/day. The number of lignin-like compounds found in different peats has been connected to the poor pace of decomposition (Freeman *et al*., 2001; Prasad and Maher, 2004).

2.10.2 Coir

Coir is the substance that makes up the middle layers of coconut fruits, known as the mesocarp (Cocos nucifera L.). Fibers imbedded in the so-called coir pith, also known as coir dust in its dry form, make up these layers. In many tropical and subtropical countries, coir is one of the most plentiful plant-derived organic waste products. After soaking, long fibers are removed from the mesocarp and used to make matting, brushes, and insulating materials. Short fibers and coir pith make up the rest of the material. This material was traditionally abandoned and piled up as a waste product, and it is still considered a concern in some locations (Indian Coir Board, 2016). Prior to preparation for horticultural use, coir pith is washed with water and/or solutions, such as Ca (NO3)2 (the so-called buffered coir), to remove excessive salt levels (mostly Na, Cl, and K) (Poulter, 2014). Coir has a high porosity, excellent aeration, and a large water-holding capacity. Coir pith, like peat, is virtually devoid of weeds, pests, and plant pathogens, with most major exporters working with organizations like the RHP (Regeling Handels Potgronden) in the Netherlands to certify products as pest-free. Typical coir substrate from coconut fruit is shown in plate 4.

Plate 4: Coir substrate (Source: Field survey, 2021)

2.10.2.1 Composition and physical properties of coir

The macromolecule composition and structure within coir pith may explain its advantageous qualities as a plant development substrate. The main elements of coir differ depending on its age and treatment (especially composting). The main macromolecular ingredient of coir pith is lignin, which is primarily a p-hydroxyphenyl-guaiacyl-syringyl lignin in coir fiber (Rencoret *et al*., 2013). The lignin concentration of coir pith has been reported to range from 30% to 50% by weight (Israel *et al*., 2011; Muthurayar and Dhanarajan, 2013), and the lignin structure may degrade with age, especially in stored/composting piles (Priya *et al*., 2016).

Both peat and coir are renowned for their ability to absorb and retain not only water but also air, due primarily to their microporous nature (Tsuneda *et al*., 2001; Fornes *et al*., 2003) allowing internal retention of both water and air.

2.10.2.2 Electrical conductivity and pH of substrates

Coir is less acidic than peat, but the acidity varies greatly depending on the source. Coir's EC varies greatly depending on its age, processing, and whether or not it was washed and buffered. The differences in methodologies used to assess EC of growth media and their components around the world make it difficult to compare published EC results. McLachlan *et al*., (2004), on the other hand, discovered a substantial link between saturated extract values and various water extract ratios, such as 1:1, 1:2, 1:5, and so on.

2.10.2.3 Biological characteristics and stability

Raw coir has two orders of magnitude more microbial content than raw peat (Prasad, 1997a), with TVCs of around 105 (cfu) bacteria, 104 actinomycetes, and 103 fungus per gram of raw coir (Paramanandham and Ross, 2016). Although coir-based media have slightly higher microbial activity than peat media (Prasad, 1997a), coir, like peat, is considered a stable substrate component. Prasad (1997a), for example, observed a 24 percent volume reduction as a result of biodegradation over the course of 24 months.

2.10.3 Bark

Bark from both softwoods, primarily coniferous, and hardwood (particularly in North America) species is a major component of growing media, especially in areas where peat is scarce or expensive. Bark is a by-product of sawmills, often categorized as "residue," and bark from both softwoods, primarily coniferous, and hardwood (particularly in North America) species is a major component of growing media, especially in areas where peat is scarce or expensive.

Bark was originally discarded as a by-product of the lumber industry in the United States, but its utility as a decorative mulch and component of growing media was discovered in the 1960s, and its use, especially of pine bark, quickly spread. Plate 5 shows bark substrate from a tree.

Due to a drop in house building and thus sawmill activity after 2008, and an increase in the utilization of wood, including sawmill residues, for pellets used as biomass, bark supplies for growth medium have decreased, particularly in the Southeast United States (Jackson and Fonteno, 2013; IEE, 2016).

2.10.3.1 Physical Properties of wood bark

Bark has a wide range of morphology and composition depending on where it comes from (Shameli *et al., 2012*). Light and electron microscopy reveal a porous structure in Pinus spp. bark, which is linked to the voids within dead cells, primarily phloem, axial, and radial parenchyma (Tulik *et al*., 2019). Bark is hammer-milled or ground, then screened into a variety of particle sizes, enabling for the production of specific air and water capacity combinations (Yap *et al*., 2014; Fields *et al*., 2015).

Plate 5: Tree bark (Source: Field survey, 2021)

2.10.3.2 Chemical Composition, and Properties

The chemical makeup of bark varies by species, growth conditions, tree age, harvest season, and harvesting methods, particularly the effectiveness with which bark is separated from underlying wood (Eberhardt, 2012).

Because the pH of most barks is higher than that of peat, at 4.0-5.0 for pine bark (Wright *et al.*, 1999) and 5.5 for spruce bark (Naasz *et al.*, 2009), lime can be added at lower rates than in peat: in some cases, plant growth in pine bark media at pHs 5 did not respond to liming, and in some species, growth was actually reduced (Wright *et al.*, 1999). Mono- and disaccharide concentrations are also relatively high in bark (Kylliainen and Holmbom, 2004; Naasz *et al.*, 2009).

2.10.4 Wood-Derived Materials:

2.10.4.1 Saw dust

Wood fiber is produced from clean, chipped wood, whereas sawdust is a by-product of the timber industry. Whole tree substrates are often made by shredding and grinding entire trees, as well as leaves, twigs, branches, and needles removed during forest management. The saw dust utilized in the experiment, depicted in Plate 4, was collected from a saw milling center in Omu-aran, Kwara state. Sawdust (Plate 6) is widely available from timber operations around the world and has been utilized as a component of media in many countries, including Australia (Handreck and Black, 2010; Anon, 2016; Asamoah *et al*., 2020; Mwango and Kambole, 2019). (Mirski *et al*., 2020).

Plate 6: Sawdust (Source: Field survey, 2021)

2.10.4.2 Wood fiber

Mechanical defibrillation or, more typically, steam-assisted thermal extrusion of clean wood chips through a thermo-screw press produces wood fiber (Gumy, 2001). Wood fiber (plate 7) can also be manufactured in coarse or fine grades. Wood fiber, like coir, can be compressed for transport (Jackson, 2016).

2.10.4.3 Physical properties

Good aeration but low water-holding capacity are characteristics of wood-based materials; nevertheless, particle shape and size play a big role in this. Because of the low accessible water content (Prasad, 1979), irrigation must be given regularly and in tiny amounts during active plant growth (Allaire *et al*., 2005; Dorais *et al*., 2005). (Favaro *et al*., 2002).

Low bulk density, high total porosity, and very high air content describe wood fiber for use in growing mediums (Gruda and Schnitzler, 2004a; Domeno *et al*., 2010), resulting in a higher oxygen diffusion rate than peat (Clemmenson, 2004).

2.10.4.4 Chemical and microbiological characteristics

The pH of sawdust varies depending on the source, ranging from neutral (6.3-7.7) to more acidic levels of 5.33 (Goh and Haynes, 1977) and 4.71 (Prasad, 1979). (Marinou *et al*., 2013). The pH of wood fibers has been observed to range from 3.8 to 6.6. Furthermore, because sawdust and wood fiber have limited buffering ability, their pH is influenced more by the materials with which they are mixed or the pH of the liquid fertilizer used during plant growth.

Plate 7: Wood fiber (Source: Field survey, 2021)

2.10.4.5 Plant growth in sawdust and wood fiber substrates

Sawdust has been used to grow greenhouse vegetables and strawberries in bag or module culture, either alone or in mixes. While Maree (1994) and Parks *et al*. (2004) found P. radiata sawdust to be suitable for growing tomato and cucumber plants, Allaire *et al*. (2005) discovered that fresh sawdust blends from [White spruce (Picea glauca (Moench) Voss. and fir [Abies balsamea (L.) Mill] were inferior to mineral wool as tomato culture substrates. Several writers advocate combining sawdust with various substrates.

A variety of protected vegetable crops have been successfully grown with wood fiber. Gruda and Schnitzler (2004b) discovered that immature tomato plants grown in wood fiber grew as well as tomatoes grown in "white peat" (H undefined), with the former having more established root systems.

2.10.5 Rice husks

The husk is the outermost coat of the rice grain (*Oryza sativa L.*) and serves as a protective cover for the grain. Milling separates the rice husk from the rice grains after parboiling (soaking, steaming, and drying the grain). Plate 8 shows an image of the substrate (rice husk) utilized in the experiment.

Rice husk is abundant as a waste product from rice processing operations: rice cultivation in Asia generates over 770 Mt of husk each year (IRRI, 2017). The ash is used in construction materials, and much of it is burned as fuel. Rice processing in the United States can produce up to 1.9 million tons of husk per year (Sambo et al., 2008), and rice husk is used in growth media by numerous companies (Anon, 2014a). Professional growers in the Netherlands utilized about 12,000 m3 of rice husk in 2013. (Schmilewski, 2017).

Plate 8: Rice husk (Source: Field survey, 2021)

Evans and Gachukia (2007) found that big particles of parboiled rice husk incorporated at up to 50% (v/v) in peat-based substrates improved drainage and aeration. Fresh parboiled rice husk has water-holding capabilities of 20% and 23% (v/v), total pore space of 89 percent and 93 percent (v/v), and an air-filled pore space of 69 percent and 70%, according to Hanan (1998) and Gomez and Robbins (2011). Evans and Gachukia (2007) found that big particles of parboiled rice husk incorporated at up to 50% (v/v) in peat-based substrates improved drainage and aeration. Fresh parboiled rice husk has water-holding capabilities of 20% and 23% (v/v), total pore space of 89 percent and 93 percent (v/v), and an air-filled pore space of 69 percent and 70%, according to Hanan (1998) and Gomez and Robbins (2011). Rice husk is rarely utilized as the only ingredient in a growth medium. Evans and Gachukia (2004) found that growing impatiens (Impatiens walleriana Hook, f) and pansy (Viola 3 wittrockiana Gams) in peat-based media containing up to 40% (v/v) parboiled rice husk had no negative effects on root or shoot development when compared to growth in pure peat medium.

2.11 Irrigation

Irrigation is the process of supplying water to plants in order to meet their requirements for a variety of essential resources. It is well understood that delivering too little or too much water can lower crop output or, in the worst-case scenario, cause plant death.

2.11.1 Drip irrigation systems

Drip irrigation systems slowly provide water to the base of each individual plant, allowing water to flow laterally in the root zone before it begins to emerge from the bottom of the root zone. Drip systems provide the most precision and regularity, but the high costs of purchasing, installation labour, and maintenance mean that they may not be economical for smaller pots or crops with short production cycles.

2.11.2 Different level of irrigation application

i) Deficit irrigation rate: is the use of water in excess of the ET requirements. Computer models that replicate irrigation performance (Lorite *et al.*, 2005), along with social studies, can help water managers maximize a limited supply of irrigation water, reducing uncertainty and risk.

ii) Actual irrigation rate: reflects the crop's water requirements, which include transpiration and evaporation (Alberto *et al*., 2014; Senay *et al*., 2017; Olivera-Guerra *et al*., 2018).

iii) Surplus irrigation is the word used to describe the use of more water to irrigate plants than is necessary, resulting in water logging and soil damage.

2.12 Drip regimes on yield and water use for pepper

Irrigation scheduling is the method used by irrigation system managers to determine the appropriate watering frequency and duration. It is determined by irrigation equipment precipitation rate, uniformity of distribution, soil infiltration rate, land slope, soil availability, water capacity, and effective rooting depth. It's vital to get the most out of your drip irrigation system since too much irrigation diminishes output while too little irrigation creates water stress and lowers production (Ya-dan *et al.,* 2017).

2.12.1 Irrigation use efficiency

Irrigation efficiency is a means of expressing the effective utilization of irrigation water. (Lameck *et al*., 2011) defined from three factors that is irrigation system performance, uniformity of water application, response of crop to irrigation.

This irrigation efficiency measures are interrelated and vary on spatial and temporary scale. The spatial scale being defined as for a single field or a larger scale up to a whole irrigation district or watershed.

Field application efficiency is defined by the amount of water stored in the Root zone, available for crop production, divided by the amount delivered to the farm field. Irrigation systems performance is described as the effectiveness of the physical system and operating decisions to deliver water from a water source to the crop (Lameck *et al*., 2011). Other terms used to evaluate irrigation efficiency which include water conveyance efficiency, water application efficiency, soil water storage efficiency, overall irrigation efficiency and effective irrigation efficiency.

2.13 Water quality

Irrigated agriculture relies on a sufficient supply of high-quality water. Because good quality water sources have been plentiful and widely available, water quality concerns have often been overlooked (Ayers and westcot, 1985). Irrigation water is made up of a variety of naturally occurring salts. A similar mix will be present in irrigated soils, although at a higher concentration than in the applied water. The amount of salt that accumulates in the soil is determined by the irrigation water quality, irrigation management, and drainage capacity. If salt levels reach too high, yield will suffer. When sprinklers are employed, irrigation water having a high proportion of somewhat soluble salts such as calcium, bicarbonate, and sulphate causes white scale to form on leaves and fruit (Grieve *et al*., 2012). Despite the fact that there is no toxicity, the deposits frequently accumulate on the leaves and fruit, and are especially problematic when flowers, vegetables, or fruits are cultivated (Ryan *et. al*., 2013).

2.14 Fertigation

Fertigation is the process of using injection equipment to dissolve soluble nutrients that are regularly dissolved in irrigation water. Fertigation is the preferable method of delivering nutrients in some soilless systems, particularly when the substrate is incapable of retaining (bonding) nutrient ions (e.g., due to limited cation-exchange capacity) (CEC). It should also be noted that dissolved components can travel by diffusion or bulk (mass) movement. Plate 9 depicts the experiment's fertigation setup (Mathias A. 2021).

Plate 9: Fertigation setup

2.15 Water movement in plants

Plants absorb water mostly through their roots, while CO2 enters the plant through pores in the leaves known as "stomata." Temperature, light, relative humidity, wind speed, leaf area, and the degree to which the plant's stomata are open all influence the potential rate of water removal by plants from the root zone. Water and solute transport in soils research (Beven and Germann, 2013; Mohammadi *et al*., 2009; Russo, 1993) is a suitable starting point for understanding soilless systems. Integrating this rate over time yields the potential amount of water removed.

The transfer of water from the earth, through the plant, and into the air surrounding the leaves is driven by transpiration, which is the transport of water into the atmosphere.

Selker (1996) discussed preferential flow in the field and identified three types of preferential flow: I fingered flow (i.e., fingers or channels create uneven flow paths through coarse textured soils); ii) macropore flow (i.e., large pores dominate small pores); and iii) funnel flow (i.e., water flow is dominated by large pores over small pores) (i.e., different textural layers redirect the flow of water). These flow types could reveal how applied irrigation water travels via soilless substrates.

2.15.1 Water potential

The hydraulic forces of water within plants and substrate have a significant influence in water management. These forces can be described in terms of energy potentials such as matrices, osmotic potentials, and gravimetric potentials. When it comes to irrigation, such potentials are expressed as negative quantities in kilopascal units (kPa), (Leith *et. al*., 2019).

2.16 Root zone

Root zone denotes the area (usually filled with substrate) that has been made accessible in a production system for plant roots to occupy. Because of harsh conditions at various times or because the plant has not yet filled the root zone with roots, there may be patches inside the root zone with few roots.

2.17 Research gap

In literature, cultivation of *Capsicum chinense* from different substrate has been conducted. However, research publication on the combined effects of substrate with biochar and water application for pepper production is very scarce and this form the basis for the research.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of study area

The study was carried out at Landmark University Omu-Aran in Kwara state, Nigeria. Omu-Aran is located in the humid agro-ecological zone of southern Guinea savannah, Nigeria, in latitude 8°7'30''N and longitude 5°5'0'' E, and at an elevation of 564 m above the mean sea level. It is situated in a location characterized by a long rainy season, tropical marine environment, resulting in mild weather with daily air temperatures 19°C, Wind N at 3 km/h, 43% Humidity. Omu-aran is the closest place in Kwara state to the rainforest, originating in Nigeria's north central (middle belt) and hence forming the state's wettest zone. The study map is shown in Plate 10.

The typical depth of rainfall is 500-1500 mm and is spread out across 6-8 months of the year, depending on the variation of temperature and weather as the seasons change (Raphael *et al*., 2018). In the region, the rainy and dry seasons constitute different seasons of the year. The region has fertile soil that can support several crops like as maize, sorghum, millet, legumes, roots and tubers, rice, locus beans, and so on, as well as cash crops such as cocoa, kola-nut, and oil palm (omuaran.com, 2015).

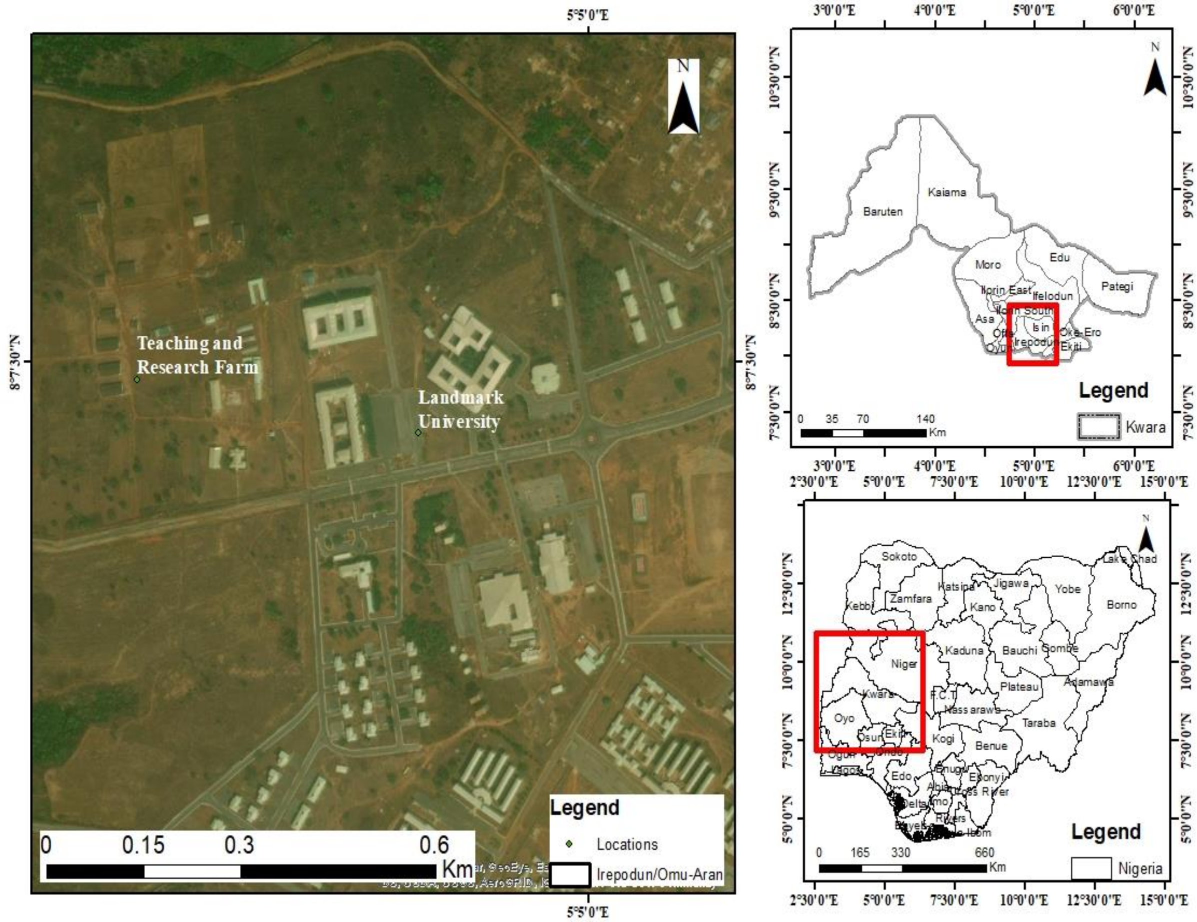

Plate 10: Map of the study area

3.2 Materials

The substrate for the study was obtained from a rice milling factory in Ire-Ekiti, Ekiti State, Nigeria. The poultry litter was taken from Landmark University's Teaching and Research Farm, sun dried on a plat form for two days, then transformed to char at a temperature of 300°C using a locally constructed pyrolysis kiln at 6-hour intervals, and crushed to a small particle using mortal and pistol. The burnt poultry particles were allowed to cool then mixed into rice husk and saw dust at different percent and was poured into the planting bucket. Some of the mixed substrates were collected into a clean white Lyon then transferred to a laboratory for analysis. The hybrid pepper seeds were obtained from an agro-allied merchant in Ibadan, and the black planting bucket was obtained from the Omu-aran local market.

3.2.1 Equipment used

Cabinet dryer, oven, weighing machine, spectrometer, standard flask, beaker, drip irrigation system, grow container, rice husk, saw dust, poultry droppings, and pepper seed.

3.3 Sample preparation

The poultry liter (PL) in Plate 11a was obtained from the Landmark University Teaching and Research Farm in Omu-Aran, Kwara State, Nigeria (8°7’30’’ N, 5°5’0’’ E). The material was air-dried to a maximum moisture content of 20% after sampling. The liter was then burnt in a 300 ml constructed kiln at 300°C under normal atmospheric pressure (Plate 11b). There was still residual air in the system at first. Once the reaction began, oxygen was consumed, and pyrolysis continued under anoxic conditions.

Plate 11a: Dry poultry liter (Source: Field survey, 2021)

Plate 11b: Char poultry liter (Biochar) (Source: Field survey, 2021)

3.4 Potted plants preparation

Planting was accomplished using black plastic buckets. To eliminate extra water during irrigation, a drainage hole was constructed on the sides and bottom of the bucket, especially towards the start of the experiment. These buckets were filled with substrate (Rice husk and Saw dust) mixed with biochar (poultry litter) at a 2:1 ratio, (5kg of substrate to 2.5kg of biochar) for 50% and (5kg of substrate to 1.5kg of biochar) for 30%, then left to mineralize for around four weeks before transplanting. Water was also added to encourage proper mineralization.

3.5 Experimental methods

3.5.1 Determination of drip emission uniformity

To determine the drip setup's emission uniformity, discharge via all emitters was measured for 10 minutes at a steady operating pressure (pressure compensating emitters). The Equation 1 was used to calculate emission uniformity. (Zamaniyan *et al.*, 2014).

$$Eu = 100\,\frac{\bar{q}_{25\%\,min}}{\bar{q}} \tag{1}$$

Where:

EU = emission uniformity (%)

$\bar{q}_{25\%\,min}$ = average of 25% of the lowest values of flow rate (l/h)

$\bar{q}$ = average flow rate (l/h)

The evaluated system was classified according to the EU values, following Capra and Scicolone, (1998) and Merriam and Keller (1978) (Table 3.1).

Table 3.1: System classification according to emission uniformity (EU) values

EU (%)	Classification	
	MERRIAM and KELLER (1978)	CAPRA and SCICOLONE (1998)
<66	poor	low
66 – 70	poor	means
80 - 84	acceptable	
80 - 83	good	
84 - 90	good	high
> 90	excellent	

3.5.2 Scheduling of irrigation

Raphael *et al* (2018) method of daily irrigation scheduling for *Capsicum chinenses* was adopted, which was on growth-stage-specific crop coefficient and consumptive use of *Capsicum chinense* using hydraulic weighing lysimeter. The crop factor for the three growth stages of *Capsicum chinense* was used in the calculation of daily evapotranspiration (ETc) the crop water requirement (CWR) was estimated using the crop coefficient according to Equation 2 below;

$$ETc = ETo * Kc \qquad (2)$$

Where:

ETc= crop water requirements (mmd^{-1})

Kc= crop coefficient.

ETo= reference evapotranspiration (mmd^{-1}) for the planting month using mean weather data obtained from the Campbell scientific weather station. The data generated by the weather station were used as input into the Crop Water Model (CROPWAT 8) in order to estimate the reference evapotranspiration, ETo (Raphael *et al*., 2018a). The crop water use was related to the specification of the drip tape emitter precipitation rates to obtain the duration for running of the drip system for the different level of water application rates (0.6 ETc, 0.8 ETc, 1 ETc and 1.2 ETc).

3.5.3 Duration of irrigation

The quantity of water to apply was computed every day as explained above. For the known discharge rate of emitters (0.4 lph), the duration of irrigation water was calculated using the following Equation 3 and Equation 4.

$$\text{Duration of Irrigation} = \frac{Emitter\ discharge\ (lh^{-1})}{Emitter\ spacing\ \ x\ Inline\ spacing} \qquad (3)$$

$$\text{PR} = 231\,\frac{Q_e\ x\ Eff}{Row_x\ \ x\ Emit_y} \qquad (4)$$

Where; PR = precipitation rate (in/hr.), Q_e = Drip emitter flow rate (gal/hr.), Eff = irrigation efficiency (decimal) uses 0.95 for drip systems, Row_x = Distance between drip rows (lines) (in), $Emit_y$ = emitter spaces (in)

For the study set up, $PR = 231 \frac{0.11 x 0.95}{23.6 x 12}$ (5)

Using, Qe= 0.4 l/h (0.11), Row_x = 60 cm (23.6 in), $Emit_y$ = 30 cm (12 in)

= 0.09 in/hr = 2.28 mm/hr

Depth of irrigation calculation was obtained using equation 6

Q x time = Area x Depth (6)

Where Pot surface area, = 49,093.75 mm^2, from diameter of 250 mm,

Flow rate Q = 0.4 l/h = 9,600,000 mm^3/d, for t= 1 hr, Depth d = 8.15 mm

3.6 Experimental detail and layout

The experiment was laid out in split system in a randomized complete blocks design with three reapplications; the irrigation water application levels were assigned main plots while the treatments were made the sub-plots. The following are the facts of the irrigation scheduling,

- ➢ Factor A: irrigation levels (schedule)
- ○ 60% of ETC (I60)
- ○ 80% of ETC (I80)
- ○ 100% of ETC (I00)
- ○ 120% of ETC (I20)
- ➢ Factor B: Treatment
- ○ 30% A, Saw dust (Aa)
- ○ 30% A, Rice husk (Ab)
- ○ 50% B, Saw dust (aB)
- ○ 50% B, Rice husk (Bb)

Table 3.2: Treatment details

S/N	Treatments	Name	Description
1	T1 (I_{60})	Aa	30% A, Saw dust (A-30% Biochar, a-Saw dust)
2	T2 (I_{60})	Ab	30% A, Rice husk (A-30% Biochar, b-Rice husk)
3	T3 (I_{60})	aB	50% B, Saw dust (B-50% Biochar, a-Saw dust)
4	T4 (I_{60})	Bb	50% B, Rice husk (B-50% Biochar, b-Rice husk)
5	T5 (I_{80})	Aa	30% A, Saw dust (A-30% Biochar, a-Saw dust)
6	T6 (I_{80})	Ab	30% A, Rice husk (A-30% Biochar, b-Rice husk)
7	T7 (I_{80})	aB	50% B, Saw dust (B-50% Biochar, a-Saw dust)
8	T8 (I_{80})	Bb	50% B, Rice husk (B-50% Biochar, b-Rice husk)
9	T9 (I_{100})	Aa	30% A, Saw dust (A-30% Biochar, a-Saw dust)
10	T10 (I_{100})	Ab	30% A, Rice husk (A-30% Biochar, b-Rice husk)
11	T11 (I_{100})	aB	50% B, Saw dust (B-50% Biochar, a-Saw dust)
12	T12 (I_{100})	Bb	50% B, Rice husk (B-50% Biochar, b-Rice husk)
13	T13 (I_{120})	Aa	30% A, Saw dust (A-30% Biochar, a-Saw dust)
14	T14 (I_{120})	Ab	30% A, Rice husk (A-30% Biochar, b-Rice husk)
15	T15 (I_{120})	aB	50% B, Saw dust (B-50% Biochar, a-Saw dust)
16	T16 (I_{120})	Bb	50% B, Rice husk (B-50% Biochar, b-Rice husk)

3.7 Experimental Design

These were four irrigation treatments (I_{60}, I_{80}, I_{100} and I_{120}) and four biochar and substrate amendments (30% biochar + rice husk; 50% biochar + rice husk; 30% biochar + saw dust; 50% biochar + saw dust). All the treatments were replicated three times on each irrigation line to make a total of 48 treatment points in a split plot design as shown in Figure 1.

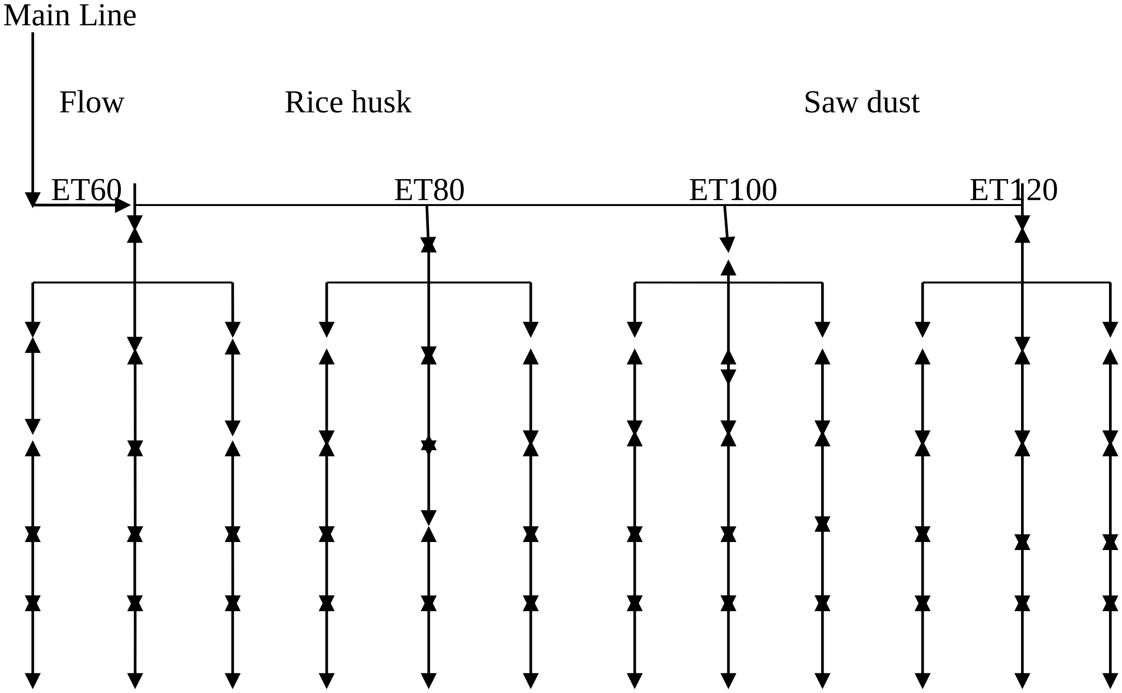

Fig. 1: Outline of drip irrigation

2 Factors

- Irrigation regime

- Biochar amendment

So, the experimental will be;

4 * 4 * 3 = 48

48 Experimental units.

Note: PL (Poultry litter)

3.8 Fertigation

The macro and micro nutrients were produced separately as A and B stock solutions at 100x dilution for the study. Calcium nitrate and iron were in solution A, whereas the rest of the ingredients were in solution B. The irrigation solutions were prepared in a 200-litre tank. Stock A and stock B were added into the tank at 1:1 ratio until the needed electric conductivity (EC) was achieved. The EC of the fertigation solution was between 1.5 mS cm^{-1} and 2.5 mS cm^{-1}. The duration of irrigation varies due to different rate of water application and an identical amount of fertilizer solution was applied to all plastic buckets. All components were added one by one to ensure that they dissolved completely in the water.

3.9 Drip irrigation specification

The drip irrigation system is of the following specification:

i. Dripper flow rate -0.8 L/H
ii. Distance between dripper-0.3 m
iii. Distance between lateral -1.85 mm/hr.
iv. Total flow rate (1 ha) 6000m dripper line be used -20m^3/hr

3.10 Construction of drip system

The drip systems were constructed from a 16mm drip tapes connected to a main line from 38 mm PE pipe with a collector attached to it as a collecting point for the drip lines. This drip system was gravity fed from a reservoir located at a head of about 2 meters above the ground level. The drip tapes were designed to have a pressure compensating emitters that allows the system to maintain uniform discharge under variable water head in the holding tank, the irrigation system setup is shown in plate 12.

Plate 12: Irrigation setup in a screen house (Source: Field survey, 2021)

3.11 Crop details

Crop: Hot pepper (*Capsicum chinense*)

Family: Solanaceae

Variety: Rodo variety- NH Ca(R) 429) (NIHORT)

Spacing: 3 m x 0.6 m

3.12 The fabrication of pyrolysis kiln for carbonization of poultry litter.

A kiln, metal fabricated in the University was used to generate enough heat to complete biomass process in a slow pyrolysis. It is shown in Plate 13 and the heating source for the kiln shown in Plate 14.

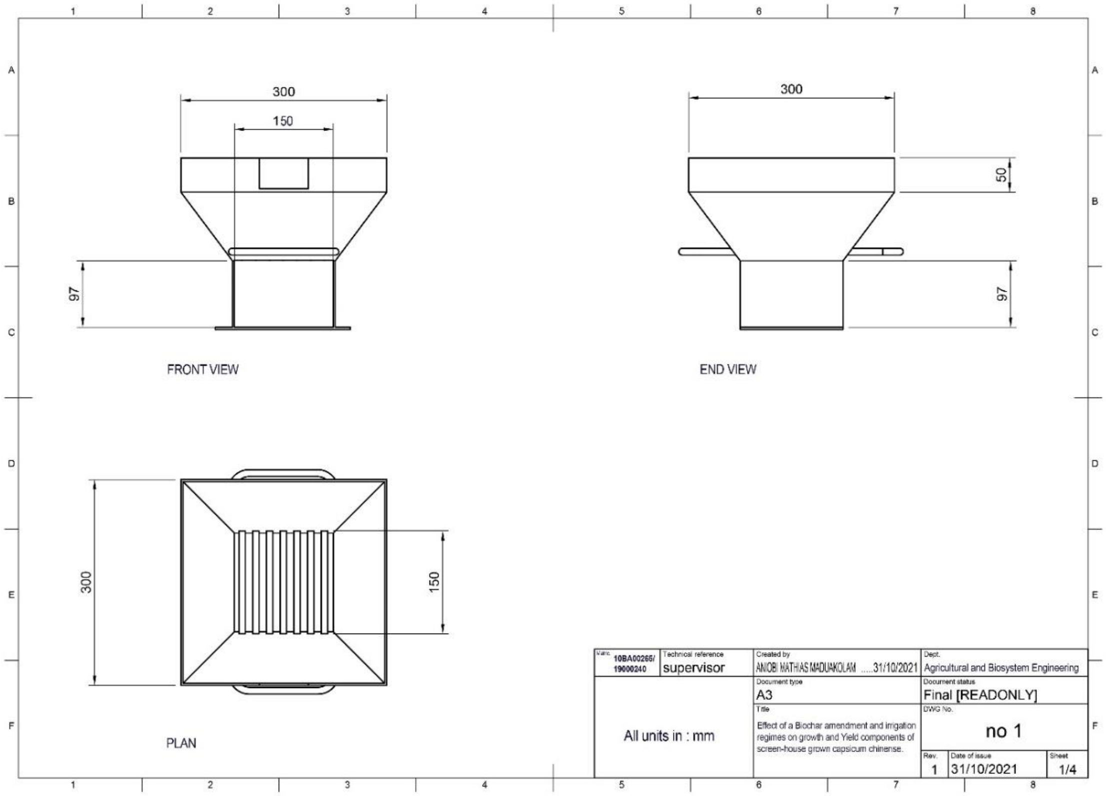

Figure 2: Dimensions of fabrigated pyrolysis heating source

Plate 13: **Biochar kiln heat source**

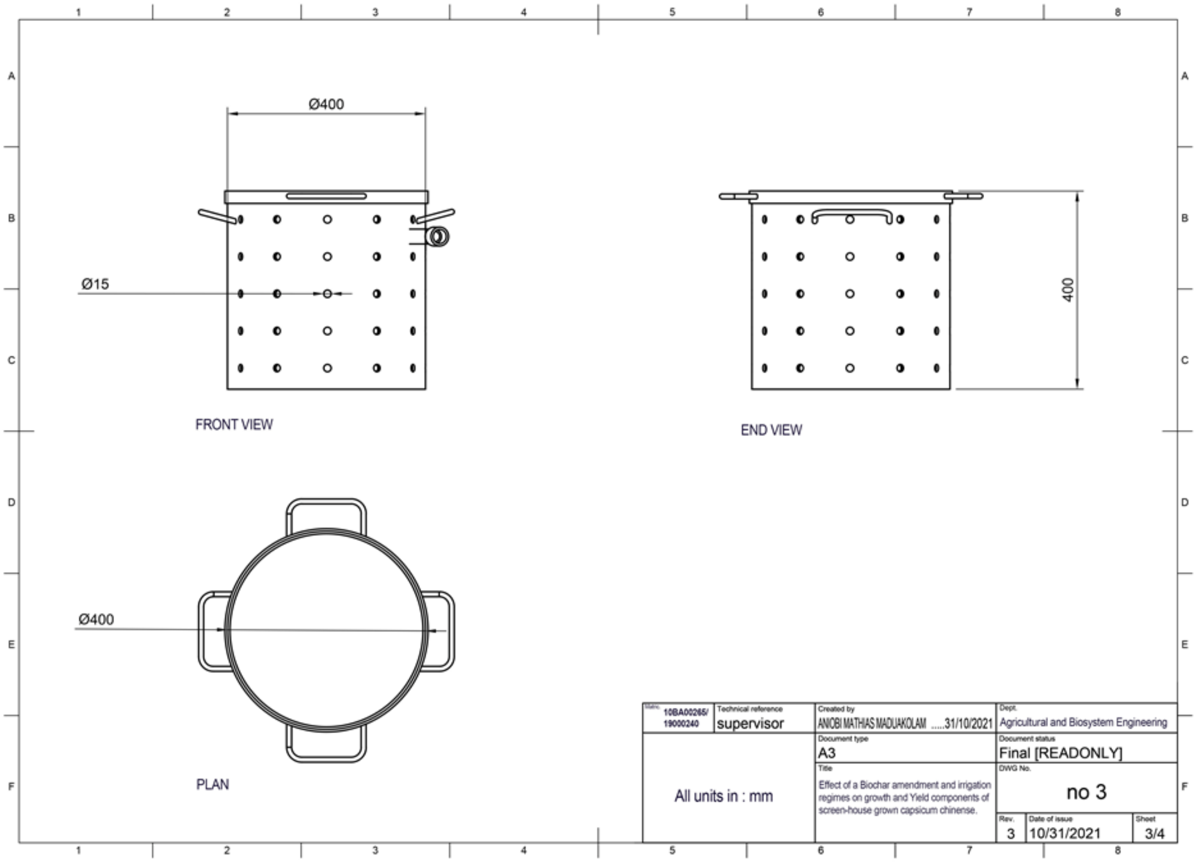

Figure 3: Dimensions of fabricated pyrolysis kiln

Plate 14: Biochar kiln

3.12 Effect of temperature and material preparation on preparation

The qualities of biochar are governed by two key factors: temperature and parent material. The surface area of biochar increases as the pyrolysis temperature rises, allowing for greater sorption of chemical such as pesticides. Charcoal created from tree residue at 500-700°C was produced, and then the charcoal was used as source of heat to char the poultry into biochar using the fabricated kiln with thermometer to know temperature at which the poultry charred. Moreover, it was observed that the required temperature for charring the litter is 300°C for 12kg dried poultry.

3.13 Laboratory analysis

Some physiochemical characteristics of the culture media including media temperature, air filled porosity (AFP), bulk density (Shammary *et al*., 2018), organic carbon (% OC) (Stockmann *et. al*., 2015), total porosity (Shammary *et al*., 2018) and water holding capacity (WHC) (Olorunfemi *et. al*., 2016), cation exchange capacity (CEC) (Olorunfemi *et. al*., 2016) were measured.

3.14 Procedures for substrate analysis

3.14.1 Bulk density calculation

Rice husk and saw dust were separately put into a 200ml beaker up to the 100ml mark. The sample of the rice husk and saw dust were reweighed separately, while the area and height of the beaker containing the rice husk and saw dust were calculated from which eventually the volume of the materials were measured. The bulk density was calculated from the ratio of the mass of rice husk and saw dust to the volume of the materials following the equation described by (Shammary *et al*., 2018) an indicated in Equation 7.

$$\rho_{\mathrm{b}} = \frac{M_S}{V_S} \tag{7}$$

Where;

ρb is in Mg m–^{3},

Ms is the weight of the dry soil sample in Mg,

Vs is the volume of the dry soil sample in m^3

3.14.2 Solid density

The solid density ρ_s (kg/m^3) was calculated by filling a 100-ml beaker with 50 ml of distilled water and then adding three grams of rice husk and saw dust. The amount of water displaced (the volume of the grains) is measured. The measurement is carried out three times (Shittu, *et al*., 2012). Equation 8 was used to calculate solid density.

$$P_s = \frac{M_{gs}}{V_{dw}} \tag{8}$$

3.14.3 Porosity

Total porosity is the volume of the empty spaces occupied by fluids in the total volume; porosity in substrates is between 75 and 90 percent, compared to 50 percent in natural soils. Porosity (percent) was estimated using the above-mentioned analysis results for solid density and bulk density. (Shammary *et al*., 2018) described the porosity mathematically as shown in Equation 9:

$$\varepsilon = 100 \times \left(1 - \frac{\rho_\mathrm{b}}{\rho_\mathrm{s}}\right) \tag{9}$$

3.14.4 Moisture content

Moisture content of any substrate is also controlled by physical qualities of the substrate (particle size distribution, particle surface properties, pore space, etc.), each of which affects the various potentials and was estimated using Equation 10. Moisture tension and moisture content have a relationship for every substrate. This association might be viewed as a "signature" for a specific substrate. The gravimetric approach was used to determine this. Two (2g) fresh samples were dried at 105℃ for 24 hours. The final weights were then measured after drying to constant weight and the % moisture content determined using the Equation 10 (Orth and Seneviratne, 2021).

$$\%\,Moisture = \frac{Initial\ weight - final\ weight}{Initial\ weight} \times 100 \qquad (10)$$

Were

W_1 = Weight of crucible,

W_2 = Initial weight of crucible with sample

W_3 = Final weight of crucible with the sample.

3.14.5 Water holding capacity

Water holding capacity represents the maximum quantity of water held in the soil and depicts the soil's ability to supply water for plant growth. Changes in land use that occur during vegetation restoration have been recognized as one of the most important forces driving environmental change, accounting for more than half of the variability in water quantity. (Zhao *et al*., 2015.) Equation 11 was used to compute water storage capacity.

$$WHC = (M_w - M_d) \div V \times 100 \qquad (11)$$

3.14.6 Cation exchange capacity

Cation exchange capacity is a measure of the ability of a soil to hold and exchange cations (Saidi, 2012). Determining soil quality requires identification of soil properties that are important in a soil's ability to carry out its various functions as well as being responsive to changes in land use and land management (Paz-Ferreiro and Fu, 2016, Zolfaghari *et al*., 2016). CEC plays an important role in soil quality (Brevik, 2009, Khaledian *et al*., 2016a, Taghizadeh-Mehrjardi, 2016). CEC can be influenced by soil physical (e.g., soil texture), chemical (e.g., pH, mineralogy), and biological (e.g., soil organic matter) characteristics (Mukherjee and Zimmerman, 2013); therefore, CEC integrates aspects of all three of the indicator groups commonly used to determine soil quality (Brevik, 2009) and there are strong positive relationships between CEC and the soil colloidal fraction (Kweon *et al*., 2013).

3.14.7 Volatile matter

Equation 12 was used to determine the amount of volatile matter, an adsorbent mass of 1.0 g was weighed into a crucible and allowed to heat for 10 min to a temperature of 500°C (Nworie *et. al* 2018).

$$volatile\ matter\ \% = \frac{weight\ of\ volatile\ component}{oven\ dry\ weight} \times 100 \tag{12}$$

3.14.8 Ash content

The % ash content was determined by Equation 13 using the procedure as described by Dada *et al*., (2013). Measurement was done in triplicate. One gram of the sample was placed in crucibles and heated in a furnace ast 500°C for 1 h 30 min. After which, it was allowed to cool in a desiccator and then reweighed.

$$\%\ Ash = \frac{wt.of\ crucible + ash\ wt.of\ crucible}{Wt.\ of\ sample} \times 100 \tag{13}$$

3.14.9 pH

One gram of the sample was placed in a beaker and 100-mL water was added to it. It was placed on a heating mantle and allowed to boil for 5 min. The content was left to cool and made up to the 200 mL mark with distilled water. The pH was then measured using a pH meter.

3.14.10 Characterization of the produced biochar

The C, H, and N contents of biomass and biochar were determined in accordance with EN 15104 by combustion, followed by gas-phase chromatographic separation and measurement in an elemental analyser. The Cl content was be determined in accordance with EN 15289, using a digestion step based on bomb combustion in oxygen and absorption in NaOH (0.05 M), followed by ion chromatography measurement.

3.14.11 Nitrogen determination for substrates in combination with treatment

The total Nitrogen was calculated using Equation 14 and determined by Kjeldahl digestion and distillation method as described by Partey (2010). 1 gram of grounded oven dried substrate sample was placed in a Kjeldahl flask and added 0.7g of copper sulphate, 1.5g of $\mathrm{K_2SO_4}$ and $\mathrm{H_2SO_4}$. The solution was heated gently until frothing ceases and later boils until the solution was clear which was allowed to digest for 30 minutes. After cooling, 50 ml of water was added and transferred to the distilling flask. Twenty milliliters of standard acid (0.05M $\mathrm{H_2}SO_4$) was placed in the receiving conical flask with 2 drops of methyl red indicator and water added. Thirty milliliters of 35% NaOH was added in the distilling flask in a way that the content will not mix up. Contents were heated for 30 minutes to distil ammonia excess acid in the distillate was titrated with 0.1M NaOH and the Nitrogen content of the sample was calculated as;

$$\%N = \frac{1.401(V_1M_1 - V_2M_2) - (V_3M_2 - V_4M_2) \times df}{W} \quad (14)$$

V_1= volume of acid put in receiving flask for samples
V_2= volume of NaOH used in titration
V_3= volume of acid in receiving flask for blank
V_4= volume of NaOH used in titrating for blank
M_1= molarity of acid
M_2= molarity of NaOH
W= weight of sample
Df= dilution factor of sample.

3.15 Specific surface area

Surface areas of biochars were measured from N_2 isotherms at 77 K using a gas sorption analyzer (NOVA-1200; Quanta chrome Corp., Boynton Beach, FL, USA). The N_2 adsorbed per gram of biochars was plotted versus the relative vapor pressure (P/Po) of N_2 ranging from 0.02 to 0.2, and the data were fitted to the Brunauer–Emmett–Teller (BET) equation to calculate the surface area. Total pore volume was estimated from N_2 adsorption at P/Po -0.5. The Barrett–Joyner–Halenda method was used to determine the pore size distribution from the N_2 desorption isotherms.

3.16 Nutrient content

Hydroponic fertilizer was applied in the process called fertigation and the nutrient was supplied as water to the substrate where the crop was planted through the process of drip irrigation which was setup in the screen house.

3.17 Agronomic practices

3.17.1 *Capsicum chinense* nursery

Capsicum chinense seeds were planted in plotted tray and placed under a shed at the Engineering building of Landmark University, Omu-aran. The seeds were planted on December 21, 2021 and watered twice daily (i.e., morning and evening). The seedlings were transplanted to the different container according to the irrigation and substrate treatment on 8th February, 2021. The plastic buckets containing the seedling were filled with amended substrate.

3.17.2 Sowing and transplanting

The transplanting was done to ensure a spacing of 0.3 X 0.6m with two seedlings per pot. All pots were arranged in a screen house at the Research farm Landmark University, Omu-aran. Drip irrigation system was setup for water supply to plants according to the irrigation treatment as shown in plate 12. The irrigation treatment; $I_{60,}$ $I_{80,}$ I_{100} and I_{120} were carrying out with some calculations to determine the amount of water needed for each drip line.

Plate 15: ***Capsicum chinense*** **in the nursery**

Plate 16: Transplanting process

3.18 Agronomic measurements

These include growth parameters which were observed in the field work and measurement was taken from 4th week. The following parameters were measured from the 4th week, because the plant was allowed from week 1 to week 3 to establish and have a firm anchor root to the substrate.

a) Plant height (cm): - The height of the representative plants from the two plants per plot were measured across the three replicates at 4,5 and 6 weeks after transplanting using measuring tape from ground level to the tip of the highest growing point and the mean recorded and sane was repeated for other parameters.

b) Plant leaf length (cm): - The plant leaf length was measured from the tip of the leaf base where it joined the stalk by using measuring tapes and averages were calculated.

c) Plant leaf width (cm):- The plant leaf width was measured from there widest part end to end by means of measuring tape and averages where calculated.

d) Number of leaves: - This was determined at interval of 4, 5 and 6 weeks after transplanting by counting the number of the leaves from each of the three tagged plants per plot and the mean recorded.

e) Stem diameter (Mm): - This was determined at interval of 4, 5 and 6 weeks after transplanting by measuring the diameter of the representative plant per plot using a vernier calliper and the mean recorded.

f) Leaf Area Index (LAI)

Two leaves from the plant were measured from each plant pot and their leaf area was obtained from data of leaf width and length multiplied by the quotient of 0.85 then LAI was obtained from the ratio of leaf area and surface area of the pot. LAI is estimated according to equation 14, (Dong *et. al.*, 2019).

$$LAI = (LA * N) / A \qquad (14)$$

Where

LA is the leaf area = L*B*0.85

L= leaf length

B= leaf width

N is the number of leaves on the plant (N was taken as 12)

A is the area occupied by one plant in the cropped area.

d) Number of Branches: - This was determined at interval of 4, 5 and 6 weeks after transplanting (WAT) by counting the number of branches on each representative plant per plot.

f) Number of Fruits per Plant: - This was determined by counting the number of fruit (if any) per representative plant per plot.

g) Total biomass: - This was determined by weighing the representative plant per plot immediately after harvesting using the weighing balance of to determine the whole weight.

h) Total yield (Kg/ha)

Fruits were harvested constantly for 5 weeks (1 month), and a total value for each treatment was recorded. The weight of fruits collected from each pot in each treatment was recorded at each harvesting, and the total yield per treatment plot in kg was calculated.

3.19 Data analysis

The experiment was laid out in a split-plot design. The data obtained on various parameters under study were analyzed statistically using the method of analysis of variance for split-plot design (Scott and Kevin, 2003). The standard error (S.E.) of the mean was worked out. Duncan’s Multiple Range Test (DMRT) was performed to separate means. Wherever the results were significant, the critical difference (C.D) or LSD at $P \leq 0.05$ level of probability. The data is suitably illustrated with graphs and figures at appropriate sections.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Climatic condition

During the growing phases of *Capsicum chinense*, data on climatic variables such as minimum and maximum daily air temperature, relative humidity, wind speed, sunlight, and radiation were acquired from a weather station located at Landmark University. In Appendix I, the data is presented with monthly reference evapotranspiration, ETo, was estimated using the Penman-Monteith method (Allen *et al*., 1998). The results showed that the peak values obtained throughout the growing season of December to May showed no significant difference. This is due to the ongoing effect of climate change on all meteorological factors, including those employed in the Penman-Monteith method for ETo determination.

4.1.1 Measured crop coefficient Kc for *Capsicum chinense*

The Kc values for initial, mid and end stages of growth of *Capsicum chinense* were adopted from the Kc curve provided in Raphael *et al.* (2018a). The crop coefficient values were found to be 0.32-0.7, 1.02-1.45 and 0.76-0.9 respectively. These values were slightly different from the values suggested by FAO-56 (Allen *et al.*, 1998) which are 0.6, 1.05 and 0.9 for Kc_{ini}, Kc_{mid} and Kc_{end} respectively for Bell pepper (not *C. chinense*). The values for crop evapotranspiration shown in Table 4.1.

Table 4.1 Value of the crop evapotranspiration.

Parameter	**Months**				
	January	***February***	***March***	***April***	***May***
ETo (mm day^{-1})	4.26	4.84	4.96	4.88	5.19
Growth Stage (GS)	Initial	Development	Dev/Mid	Mid	Late/end
Kc for GS	0.7	0.5	1.4	1.5	0.9
ETc (mm day^{-1})	2.98	2.42	6.94	7.32	4.67
ETc (mm month^{-1})	89.4	72.6	208.2	2.19.6	140.1

4.2 Physio-chemical properties of the substrate in the study area

The results of the substrate physiochemical properties of experimental planting media were analysed prior before planting. The amended substrate are as follows; 30% biochar & rice husk and 30% biochar & saw dust each, then 50% biochar & rice husk and 50% biochar & saw dust each and also materials that are not amended are rice husk, saw dust, and biochar which were used for the study are shown in Tables 4.2. The result obtain from the characterised substrate shows that they will be a good impact on the plant grown due to air content and retained volume of accessible water, as well as nutrient retention in the substrate (Dueitt 1994). From past studies has been proven that rice husk and saw dust has low nutritional content and was later increased by adding hydroponic nutrients. In a procedure known as fertigation, the hydroponic fertilizer was dissolved in water. Water holding capacity, porosity, and bulk densities vary greatly which depends on the treatment mix, the bulk densities of substrate media ranged from 0.18 to 0.23 g cm^{-3}. Also, bulk densities of 0.1 to 0.3 g cm^{-3} are regarded as suitable for hydroponic seedlings and vegetables (Kampf *et al*. 1999). From the results substrate with the highest total porosity was 50% biochar & rice husk (37.47 percent), followed by 30% biochar & rice husk (32.97 percent), while substrate with the lowest total porosity was 30% biochar & saw dust (20.4 percent). On average, 10 to 30% of the container volume should be air space, while the remaining 45 to 65% should be water (Altland 2006). On the other hand, bulk density of 50% biochar & saw dust was higher than the other media treatment, but the lowest bulk density (0.228) and highest porosity was closely related to 50 BC & RH (69%), therefore root media aeration in this treatment was better than the other media.

Table 4.2: Substrate properties prior experimentation

SAMPLE NAME	Moisture Content (%)	pH	Bulk Density (Kg/m^3)	Solid Density (Kg/m^3)	Porosity	WHC (%)	Ash Content (%)	Volatile Matter (%)	CEC	Nitrogen
SAW DUST	5.5	5.48	0.183	0.47	54.97	78.69	3.67	18.23	7.56	0.24
RICE HUSK	5.83	5.64	0.306	0.61	49.5	49.34	12.67	18.04	4.77	0.83
BIOCHAR	1.83	9.28	0.324	0.39	16.83	42.67	72.67	3.08	2.36	1.91
30% BC & SD	3.17	6.24	0.228	0.29	20.4	73.2	11.3	14.68	7.52	0.49
30% BC & RH	2.5	6.49	0.238	0.33	32.97	59.54	21.33	12.5	3.58	1.09
50% BC & SD	15.33	6.62	0.288	0.31	24.23	78.99	17.67	15.42	7.03	0.77
50% BC & RH	1.83	7.07	0.229	0.5	37.47	63.57	32	16.09	4.17	1.27

4.3 Drip irrigation scheduling

Table 4.3 displays the irrigation scheduling statistics of the drip irrigation system. Despite the fact that it was a fresh drip tape that had never been used before, the approximate discharge per emitter was found to be 0.4 l/h. This differs somewhat from the manufacturer's specification of 1.0 l/h. The drip irrigation system discharge, which was based on the recorded emission rate of 0.4 l/h, was utilized in the depth of irrigation calculation, which was the same as the value of emission rate of 0.4 l/h acquired during season1. The IS value for the emitter was assessed to be 75.2%. The value indicates that there was no uniformity issue caused by hydraulics, and it is fully satisfactory (Zamaniyan *et al*., 2014). The measured precipitation rate was 2.28 mm/h.

Table 4.3: Drip irrigation scheduling data during evaluation (measurement in 10 ml)

	L1	***L2***	***L3***	***L4***	***L5***	***L6***	***L7***	***L8***	***L9***	***L10***	***L11***	***L12***
1	67	65	66	67	67	67	64	61	67	61	62	60
2	65	66	65	65	66	66	64	59	65	47	61	61
3	64	67	65	65	64	66	63	54	48	61	62	61
4	56	64	66	64	64	65	63	57	61	59	64	61
ave, Q	**63**	**65.5**	**65.5**	**65.25**	**65.25**	**66**	**63.5**	**57.75**	**60.25**	**57**	**62.25**	**60.75**
Q (ml/min	6.3	6.55	6.55	6.525	6.525	6.6	6.35	5.775	6.025	5.7	6.225	6.075
Q(ml/H)	378	393	393	391.5	391.5	396	381	346.5	361.5	342	373.5	364.5
Q(L/H)	0.378	0.393	0.393	0.3915	0.3915	0.396	0.381	0.3465	0.3615	0.342	0.3735	0.3645
approx, L/H	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.3	0.4	0.4
Average	0.4											

4.4 Calculation of water quantity for irrigation

I_{60} Treatment

Number of lines 3 (4 emitters on each line)

So, 3*4 = 12

Emitter discharge = 1.1L/Hr

$Q_{I60} = 1.1 * 12$

$= 13.2$ L/Hr

Irrigation for $1\frac{1}{2}$ Hr

Half of 13.2 L/Hr added to same value

= 19.8 L/Hr

I_{80} Treatment

$Q_{I80} = 13.2$ L/Hr

Irrigation for 2 Hrs

= 26.4 L/Hr

I_{100} Treatment

$Q_{I100} = 13.2$ L/Hr

Irrigation for $2\frac{1}{2}$ Hrs

= 33 L/Hr

I_{120} Treatment

$Q_{I120} = 13.2$ L/Hr

Irrigation for 3 Hrs

= 39.6 L/Hr

Total Quantity of water needed per irrigation time

$I_{60} + I_{80} + I_{100} + I_{120}$

$19.8 + 26.4 + 33 + 39.6$

= 118.8 L/Hr

4.5 Freshwater quality evaluation

Table 4.4 displays the physical, chemical, and biological parameters of the untreated borehole used for drip irrigation in the research region. All parameters were discovered to be below the permissible limit. Turbidity, as an indicator of water clogging potential, was also found to be very low, as did TSS. The absence of Fe, H_2S, Mn, and Bacterial count suggests that bacterial slimming, which causes precipitation, sedimentation, and clogging, is improbable. These results also show that borehole water was cleaner and contained fewer dissolved contaminants, which is a very good value. Despite being adequate for agricultural purposes, the somewhat acidic pH level of borehole water was not strong enough to avoid clogging, especially after extensive accumulations of suspended particles and mineral precipitation.

Table 4.4: Clogging potential constituents of freshwater samples in the study area

Parameters					***Level of concern**		
	Max	**Min**	**Avg**	**SD**	**Low**	**Moderate**	**High**
Turbidity (NTU)	0.01	0.001	0.01	0.00	-	-	-
EC (ms/cm) x 10^2	3.4	2.75	3.00	0.23	-	-	-
pH	5.57	5.68	5.72	0.00	< 7.0	7.0-8.0	> 8.0
TSS (mg/l)	0.73	0.16	0.37	0.24	< 50	50-100	> 100
TDS (mg/l)	0.34	0.15	0.23	0.07	< 500	500-2000	> 2000
Zn (mg/l)	0.29	0.02	0.11	0.11	-	-	-
Fe (mg/l)	ND	ND	ND	ND	< 0.2	0.2-1.5	> 1.5
Ca (mg/l)	7.05	1.90	3.67	2.36	-	-	-
Na (mg/l)	12.95	2.25	7.24	4.36	-	-	-
Mg (mg/l)	0.94	0.75	0.84	0.07	-	-	-
H_2S (mg/l)	ND	ND	ND	ND	< 0.2	0.2-2.0	> 2.0
BOD_5 (mg/l)	9.5	9.1	9.3	0.30	-	-	-
Mn (mg/l)	ND	ND	ND	ND	< 0.1	0.1-1.5	> 1.5
Bacterial count(#/ml)	ND	ND	ND	ND	< 10,000	10-50,000	> 50,000

source: Sojobi, (2016); * sourced from smart-fertilizer.com, ND- Not Detected

The increased BOD_5 level, which was beyond the FAO permitted limit of 6 mg/l, showed severe levels of organic pollution. This could be due to the boreholes' inadequate placement at a relatively low elevation, which allows non-point pollutants to accumulate.

4.6 Agronomic parameters of *Capsicum chinense*

4.6.1 Plant height

The data reported in Table 4.5 on the influence of several treatments on plant height of *Capsicum chinense* over a 5-week period reveal that plant height rose significantly with weeks after transplanting (WAT). It was discovered that the growth rate of Ab and Bb across I_{60}, I_{80}, I_{100}, and I_{120} in terms of height was higher than other treatments during the 5-week development period, while I_{100}Bb and I_{120}Ab had the highest height growth at week 5.

Table 4.5: Trend in height (cm) of *Capsicum chinense* plant as response to different treatment factors

Treatments	Notation	10WK	11WK	12WK	13WK	14WK
T1	$I_{60}Ab$	6.7	10	12.4	15.6	20.3
T2	$I_{60}Aa$	3.3	5.7	7.4	11.1	16.1
T3	$I_{60}Bb$	7.1	11	12	15.5	19.5
T4	$I_{60}aB$	3.5	5.8	7.2	9.7	12.1
T5	$I_{80}Ab$	7.0	8.1	13.2	17.1	21.0
T6	$I_{80}Aa$	4.7	6.3	12.5	16.5	20.0
T7	$I_{80}Bb$	7.9	8.6	13.7	17.7	19.7
T8	$I_{80}aB$	3.3	4.6	10.9	14.6	16
T9	$I_{100}Ab$	7.1	7.2	10	14.6	18.5
T10	$I_{100}Aa$	4.3	5.1	7.6	10.9	13.3
T11	$I_{100}Bb$	8.1	5	10.2	17.5	21.9
T12	$I_{100}aB$	4.3	4.6	7.2	10.3	12.8
T13	$I_{120}Ab$	7.1	8	12.5	16.9	21.9
T14	$I_{120}Aa$	3.7	4.1	5.9	7.8	10.1
T15	$I_{120}Bb$	7.4	7.9	12.3	16.8	21.4
T16	$I_{120}aB$	3.7	4.1	8.5	11.9	13.8
S.E m±		0.46	0.53	0.64	0.81	0.98

4.6.2 Stem diameter

The data regarding the effect of different treatment across the 5 weeks on stem diameter of *Capsicum chinense* as presented in the Table 4.6 shows that the stem diameter increased significantly with weeks after transplanting (WAT). It was observed that Ab, Aa and Bb across I_{60}, I_{80}, I_{100}, I_{120} growth rate in term of stem diameter was higher than other treatment throughout the growth period of 5 week, but I_{80}Bb has the highest stem diameter at week 5 and the least value at I_{60} Aa & aB, I_{80} aB and I_{120} Aa, aB at week 1 and 2. Biochar application also enhanced stem diameter, plant fresh and dry weights and yield components of tomato plant (Gamareldawla Agbna, *et. al*., 2017).

Table 4.6: Trend in stem diameter of *Capsicum chinense* plant as response to different treatment factors

Treatment	Notation	10WK	11WK	12WK	13WK	14WK
T1	I_{60}Ab	0.4	0.4	0.6	0.7	0.9
T2	I_{60}Aa	0.2	0.2	0.3	0.5	0.5
T3	I_{60}Bb	0.3	0.5	0.6	0.7	0.8
T4	I_{60}aB	0.2	0.3	0.4	0.4	0.5
T5	I_{80}Ab	0.3	0.4	0.5	0.6	0.7
T6	I_{80}Aa	0.3	0.4	0.4	0.6	0.7
T7	I_{80}Bb	0.4	0.4	0.6	0.8	1
T8	I_{80}aB	0.2	0.3	0.4	0.5	0.5
T9	I_{100}Ab	0.4	0.5	0.5	0.6	0.7
T10	I_{100}Aa	0.3	0.3	0.4	0.4	0.5
T11	I_{100}Bb	0.3	0.3	0.5	0.7	0.9
T12	I_{100}aB	0.3	0.4	0.4	0.5	0.5
T13	I_{120}Ab	0.4	0.5	0.5	0.6	0.7
T14	I_{120}Aa	0.2	0.3	0.3	0.4	0.4
T15	I_{120}Bb	0.4	0.5	0.6	0.7	0.8
T16	I_{120}aB	0.2	0.3	0.3	0.4	0.4
		0.02	0.02	0.03	0.03	0.05

4.6.3 Leaf area index

The leaf is an important plant organ that is associated with photosynthesis and evapotranspiration therefore leaf area measurements are required in most physiological and agronomic plant measures in plant growth. Pandey and Singh (2011). the data on the leaf area index is shown in Table 4.7, the data revealed that LAI increase gradually across the treatment for the five weeks of measurement but has higher values at I_{60} (Ab, Bb), I_{80} (Aa, Bb), I_{100} (Aa, Bb, aB) and I_{120} (Ab, Bb) while it has the highest at I_{80} (Aa), I_{120} (Ab) respectively but has least value at I_{60} (Aa).

Table 4.7: Trend in leaf area index (LAI) of *Capsicum chinense* plant as response to different treatment factors

Treatment	Notation	10WK	11WK	12WK	13WK	14WK
T1	I_{60}Ab	0.7	1	1.4	2.1	2.2
T2	I_{60}Aa	0.2	0.3	0.5	1.2	2.5
T3	I_{60}Bb	0.9	1.2	1.7	1.8	2
T4	I_{60}aB	0.3	0.5	0.6	1.2	2.1
T5	I_{80}Ab	0.5	0.9	1.2	1.8	2.3
T6	I_{80}Aa	0.7	0.9	1.2	1.9	2.7
T7	I_{80}Bb	0.8	1.1	1.4	1.8	2.4
T8	I_{80}aB	0.6	0.8	1.1	1.8	2.3
T9	I_{100}Ab	0.5	0.8	0.9	1.4	2.1
T10	I_{100}Aa	0.6	0.8	1	1.5	2
T11	I_{100}Bb	0.7	1	1.1	1.7	2.4
T12	I_{100}aB	0.6	1.1	0.9	1.5	2
T13	I_{120}Ab	0.8	0.8	1.2	1.9	2.7
T14	I_{120}Aa	0.4	1.3	0.7	1.2	1.8
T15	I_{120}Bb	0.7	1.2	1.1	1.5	2
T16	I_{120}aB	0.4	0.7	0.7	1.1	1.5
		0.05	0.07	0.08	0.08	0.08

The results of the multivariate test indicated that the intercept, water, biochar as well as water and biochar were significant predictors of the design using the Pillars' Trace and Largest root statistics. Specifically, the computed F and associated significant probabilities for the test of significance of water irrigation on mean yield using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root were 1.874 (0.042), 3.007 (0.005), 6.197 ($p < 0.01$) and 29.333 ($p < 0.01$). The implication is that based on the four test statistics, water irrigation has a significant influence on mean yield of screen house grown *Capsicum chinense* in a soilless media. However, while the effect of water irrigation on mean yield was significant at five percent (5%) using Pillai's Trace statistic, it was significant at one percent (1%) using Wilks' Lambda, Hotelling's Trace, Roy's Largest Root.

Furthermore, the computed F and associated significant probabilities for the test of significance of biochar on mean yield using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root were 2.289 (0.012), 2.409 (0.017), 2.509 (0.028) and 31.826 ($p < 0.01$). The implication is that based on the four test statistics, biochar has a significant influence on mean yield of screen house grown *Capsicum chinense* in a soilless media. However, while the effect of biochar on mean yield was significant at five percent (5%) using Pillai's Trace, Wilks' Lambda, Hotelling's Trace statistics, it was significant at one percent (1%) using Roy's Largest.

The results of the multivariate test also indicated that the computed F and associated significant probabilities for the test of significance of the effect of the interaction between the irrigation and biochar amendment treatments on mean yield using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root were 1.270 (0.067), 1.466 (0.028), 1.312 (0.158) and 28.091 ($p < 0.01$). The implication is that based on the Wilks' Lambda and Roy's Largest Root, the interaction between the irrigation and biochar amendment treatments has a significant influence on mean yield of screen house grown *Capsicum chinense* in a soilless media. The effect of the interaction between the irrigation and biochar amendment treatments on mean yield was significant at five percent (5%) using Wilks' Lambda statistic but significant at one percent (1%) using Roy's Largest root statistic. It is important to note that all the factors were significant at one percent (1%) using Roy's largest root statistic.

Table 4.8: Water level and biochar combination effect on plant height

Water Level	**PH1**	**PH2**	**PH3**	**PH4**	**PH5**
I_{60}	5.16^a	8.08^a	9.75^b	12.94^b	17.01^a
I_{80}	5.74^a	6.88^{ab}	12.56^a	16.46^a	19.16^a
I_{100}	5.83^a	5.48^b	8.75^b	13.32^{ab}	16.60^a
I_{120}	5.48^a	6.03^{ab}	9.78^b	13.33^{ab}	16.15^a
Biochar					
Ab	5.21^a	6.67^a	10.13^a	13.14^a	15.68^a
Aa	6.37^a	6.60^a	10.69^a	14.79^a	17.98^a
Bb	4.58^a	5.74^a	9.18a	13.28^a	16.63^a
aB	6.05^a	7.47^a	10.84^a	14.83^a	18.63^a
Response					
Water	0.882	0.076	0.026	0.088	0.44
Biochar	0.206	0.419	0.531	0.526	0.48
Water * Biochar	0.997	0.994	0.892	0.606	0.622

Table 4.8 shows the data on the effect of water level and biochar combinations on plant height. Considering water level as a single factor, there were no significant differences between water levels (I_{60}, I_{80}, I_{100}, I_{120}) at week 1 and week 5. However, at week 2 & 3 I_{60} & I_{80} has the highest water level respectively and I_{100} has the least values. At week 4, I_{80} has the highest plant height whereas I_{60} has the least value. When biochar is considered as a single factor, there were no significant difference between all biochar combination at week 1, 2, 3 and 4.

The interaction of biochar and water was not significant for all the weeks for plant height of pepper.

4.8. Mean comparison of plant height from the combinations of variables.

The corrected model in the test for between subject means of plant heights revealed that the computed F and the asymptotic significant probabilities were 0.456 (0.946), 0.812 (0.658), 1.13 (0.371), 1.117 (0.381) and 0.841 (0.629) for PH1, PH2, PH3, PH4 and PH5 respectively. The implication is that there were no significant differences between the subject means of plant heights for the five weeks studied.

The test for between subject mean for the water (irrigation) treatment showed that the computed F and the asymptotic significant probabilities were 0.220 (0.882), 2.515 (0.076), 3.529 (0.025), 2.381 (0.088) and 0.914 (0.881) for PH1, PH2, PH3, PH4 and PH5 respectively. The implication is that there were no significant differences between the subject means of plant heights for the week’s one, two, four and five but there were significant differences between the plant leaves for week three due to the water treatment.

The test for between subject mean for the Biochar treatment showed that the computed F and the asymptotic significant probabilities were 1.610 (0.206), 0.970 (0.419), 0.750 (0.531), 0.758 (0.526) and 0.904 (0.450) for PH1, PH2, PH3, PH4 and PH5 respectively. The implication is that there were no significant differences between the subject means of plant heights due to biochar treatments for weeks one, two, four and five but there were significant differences between the plant leaves for week three due to the water treatment.

The test for between subject means of plant heights due to the interaction between water and biochar treatments also revealed that the computed F and the asymptotic significant probabilities were 0.149 (0.997), 0.191 (0.994), 0.458 (.892). 0.816 (.606) and 0.796 (0.622) for PH1, PH2, PH3, PH4 and PH5 respectively. The implication is that there were no significant differences between the subject means of plant heights due to the interaction between water and biochar treatments for the period studied.

Table 4.9: Effects of water level and biochar combination on stem diameter

Water Level	**SD1**	**SD2**	**SD3**	**SD4**	**SD5**
I_{60}	0.27^a	0.34^a	0.48^a	0.57^a	0.67^a
I_{80}	0.31^a	0.37^a	0.49^a	0.62^a	0.73^a
I_{100}	0.35^a	0.44^a	0.46^a	0.56^a	0.65^a
I_{120}	0.33^a	0.42^a	0.44^a	0.51^a	0.59^a
Biochar					
Ab	0.29^a	0.37^a	0.42^a	0.50^a	0.58^b
Aa	0.33^a	0.41^a	0.48^a	0.56^a	0.66^{ab}
Bb	0.31^a	0.37^a	0.46^a	0.54^a	0.59^b
aB	0.33^a	0.40^a	0.51^a	0.65^a	0.81^a
Response					
Water	0.259	0.26	0.846	0.452	0.42
Biochar	0.897	0.825	0.506	0.187	0.047
Water * Biochar	0.916	0.989	0.998	0.948	0.824

Table 4.9 shows the data on the effect of water level and biochar combinations on stem diameter. Considering water level as a single factor, there were no significant differences between water levels (I_{60}, I_{80}, I_{100}, I_{120}) at week 1, 2 and week 3. However, at week 4 & 5 ET80 has the highest water level respectively and I_{60} has the least values. At week 5, I_{80} has the highest stem diameter whereas I_{60} has the least value. When biochar is considered as a single factor, there were no significant difference between all biochar combination at week 1, 2, 3 and 4 but it was significant at week 5.

The interaction of biochar and water was not significant for all the weeks for stem diameter of pepper.

4.9 Mean comparison of stem diameter from the combination of variables.

The test for between subject means of stem diameter revealed that the computed F and the asymptotic significant probabilities were 0.571 (0.875), 0.472 (0.938), 0.302 (0.992), 0.732 (0.736) and 1.118 (0.381) for SD1, SD2, SD3, SD4 and SD5 respectively. The implication is that there were no significant differences between the subject means of stem diameters for the five weeks studied.

The test for between subject means of stem diameter revealed that the computed F and the asymptotic significant probabilities were 1.408 (0.259), 1.401 (0.260), 0.271 (0.846), 0.900 (0.542) and 0.967 (0.420) for SD1, SD2, SD3, SD4 and SD5 respectively. The implication is that there were no significant differences between the subject means of stem diameters because of water treatment for the five weeks studied.

The test for between subject means of stem diameter due to biochar treatments revealed that the computed F and the asymptotic significant probabilities were 0.198 (0.897), 0.300 (0.825), 0.794 (0.506), 1.697 (0.187) and 2.961 (0.047) for SD1, SD2, SD3, SD4 and SD5 respectively. The implication is that there were no significant differences between the subject means of stem diameters because of biochar treatment for the first four weeks studied. However, biochar treatment had a significant impact on the stem diameter in the fifth week.

The test for between subject means of soil diameters due to the interaction between water and biochar treatment also revealed that the computed F and the asymptotic significant probabilities were 0.417 (0.916), 0.220 (.989), 0.148, (0.998), 0.354 (0.948) and 0.553 (0.824) for SD1, SD2, SD3, SD4 and SD5 respectively. This indicates water and biochar treatments did not have any significant influence on the soil diameters.

Table 4.10: The effects of water level and biochar combination on leaf width

Water Level	**LW1**	**LW2**	**LW3**	**LW4**	**LW5**
I_{60}	3.51^{a}	4.23^{a}	4.97^{a}	6.33^{a}	7.06^{a}
I_{80}	3.86^{a}	4.48^{a}	5.49^{a}	6.50^{a}	7.06^{a}
I_{100}	3.54^{a}	4.08^{a}	4.68^{a}	6.06^{a}	7.10^{a}
I_{120}	3.60^{a}	4.07^{a}	4.61^{a}	5.81^{a}	6.83^{a}
Biochar					
Ab	3.22^{a}	3.86^{a}	4.51^{a}	5.93^{a}	6.98^{ab}
Aa	3.57^{a}	4.04^{a}	4.77^{a}	5.89^{a}	6.52^{b}
Bb	3.76^{a}	4.36^{a}	4.99^{a}	6.35^{a}	7.33^{a}
AB	3.97^{a}	4.58^{a}	5.48^{a}	6.52^{a}	7.64^{a}
Response					
Water	0.825	0.784	0.241	0.352	0.328
Biochar	0.322	0.394	0.225	0.336	0.15
Water * Biochar	0.977	1	1	0.842	0.042

Table 4.10 shows the data on the effect of water level and biochar combinations on left width. Considering water level as a single factor, there were no significant difference between water levels (I_{60}, I_{80}, I_{100}, I_{120}) at week 1, 2, 3, 4 and 5. However, at week 4 & 5 I_{80} and I_{100} has the highest water level respectively and I_{60} has the least values. At week 5, I_{80} has the highest stem diameter whereas I_{60} has the least value. When biochar is considered as a single factor, there were no significant difference between all biochar combination at week 1, 2, 3, 4 and 5.

The interaction of biochar and water was not significant for weeks 1, 2, 3, and 4 but was significant at week 5 for leaf width of pepper.

4.10 Mean comparison of leaf width from the combination of variables.

The test for between subject means of stem diameter further revealed that the computed F and the asymptotic significant probabilities were 0.467 (0.941), 0.328 (0.987), 0.657 (0.805), 0.778 (0.691) and 2.416 (0.018) for LW1, LW2, LW3, LW4 and LW5 respectively. The implication is that there were no significant differences between the leave widths for the first four weeks studied. However, the leave width studied differed significantly at the five percent level in the fifth week.

The test for between subject means of stem diameter further revealed that the computed F and the asymptotic significant probabilities were 2.096 (0.120), 0.328 (0.987), 0.657 (0.805), 0.778 (0.691) and 2.416 (0.018) for LW1, LW2, LW3, LW4 and LW5 respectively. The implication is that there were no significant differences between the leave widths for the first four weeks studied. However, the leave width studied differed significantly at the five percent level in the fifth week.

The test for between subject means of stem diameter due to biochar treatment further revealed that the computed F and the asymptotic significant probabilities were 1.209 (0.322), 1.027 (0.394), 1.533 (0.225), 1.170 (0.336) and 4.036 (0.015) for LW1, LW2, LW3, LW4 and LW5 respectively. The implication is that there were no significant differences between the leave widths due to biochar treatment for the first four weeks studied. However, the leave width studied differed in the fifth week.

Table 4.11: Biochar combination and water level effect on leaf length

Water Level	**LL1**	**LL2**	**LL3**	**LL4**	**LL5**
I_{60}	5.17^{b}	6.16^{a}	7.23^{a}	9.43^{a}	10.65^{b}
I_{80}	6.36^{a}	7.28^{a}	8.48^{a}	10.32^{a}	12.16^{a}
I_{100}	6.13^{ab}	6.92^{a}	7.57^{a}	9.38^{a}	11.13^{ab}
I_{120}	5.18^{ab}	6.57^{a}	7.22^{a}	8.92^{a}	10.73^{b} `
Biochar					
Ab	5.28^{a}	6.24^{a}	7.05^{a}	8.73^{a}	10.82^{a}
Aa	5.63^{a}	6.43^{a}	7.17^{a}	9.93^{a}	10.83^{a}
Bb	6.16^{a}	6.86^{a}	7.92^{a}	9.50^{a}	11.38^{a}
AB	6.39^{a}	7.39^{a}	8.36^{a}	9.88^{a}	11.64^{a}
Response					
Water	0.12	0.284	0.234	0.256	0.11
Biochar	0.139	0.229	0.194	0.304	0.523
Water * Biochar	0.869	0.987	0.986	0.451	0.11

Table 4.11 shows the data on the effect of water level and biochar combinations on leaf length. Considering water level as a single factor, there were no significant differences between water levels (I_{60}, I_{80}, I_{100}, I_{120}) at week 1, 2, 3, 4 and 5. However, at week 4 & 5. I_{80} has the highest water level respectively and I_{60} has the least values. At week 5, I_{80} has the highest leaf length whereas I_{60} has the least value. When biochar is considered as a single factor, there were no significant difference between all biochar combination at week 1, 2, 3, 4 and 5.

The interaction of biochar and water was not significant for all the weeks for leaf length of pepper.

4.11 Mean comparison of leaf length from the combination of variables.

The test for between subject means of leave lengths also revealed that the computed F and the asymptotic significant probabilities were 1.108 (0.388), 0.708 (0.758), 0.775 (0.694), 1.143 (0.361) and 1.660 (0.112) for LL1, LL2, LL3, LL4 and LL5 respectively. The implication is that there were no significant differences between the subject means of leave lengths for the five weeks studied.

The test for between subject means of leave lengths due to water treatment also revealed that the computed F and the asymptotic significant probabilities were 2.096 (0.120), 1.322 (0.284), 1.497 (0.234), 1.417 (0.256) and 2.176 (0.110) for LL1, LL2, LL3, LL4 and LL5 respectively. The implication is that there were no significant differences between the subject means of leave lengths for the five weeks studied.

The test for between subject means of leave lengths due to the interaction between water and biochar treatment also revealed that the computed F and the asymptotic significant probabilities were 0.149 (0.997), 0.191 (0.994), 0.458 (0.892), 0.816 (0.606) and 0.796 (0.622) for LL1, LL2, LL3, LL4 and LL5 respectively. The implication is that there were no significant differences between the subject means of leave lengths due to the interaction between water and biochar treatment for the five weeks studied.

The test for between subject means of the leave length due to the interaction between water and biochar treatments also revealed that the computed F and the asymptotic significant probabilities were 0.493, (0.869), 0.234 (0.987) 0.237 (0.986), 1.012 (0.451) and 1.787 (0.110) for LL1, LL2, LL3, LL4 and LL5 respectively. This indicates that water and biochar treatments did not have any significant influence on leave length.

Table 4.12: Effects of water level and biochar combination on number of branches

Water Level	**NB4**	**NB5**
I_{60}	1.58^a	2.50^a
I_{80}	1.58^a	3.17^a
I_{100}	1.42^a	2.42^a
I_{120}	1.83^a	2.92^a
Biochar		
Ab	1.67^a	2.50^a
Aa	1.75^a	3.00^a
Bb	1.25^a	2.33^a
Ab	1.75^a	3.17^a
Response		
Water	0.628	0.354
Biochar	0.349	0.256
Water * Biochar	0.518	0.45

Table 4.12 shows the data on the effect of water level and biochar combinations on number of branches. Considering water level as a single factor, there were no significant differences between water levels (I_{60}, I_{80}, I_{100}, I_{120}) at week 4 and 5. However, at week 5 I_{80} has the highest water level and I_{100} has the least values. When biochar is considered as a single factor, there were no significant difference between all biochar combination at 4 and 5.

The interaction of biochar and water was not significant for all the weeks for number of branches of pepper.

4.12 Mean comparison of number of branches from the combination of variables

The test for between subject means of the number of branches also revealed that the computed F and the asymptotic significant probabilities were 0.899 (0.573) and 1.117 (0.381) for NB4 and NB5 respectively. The implication is that there were no significant differences between the subject means of the number of branches for the two weeks studied.

The test for between subject means of the number of branches also revealed that the computed F and the asymptotic significant probabilities were 0.586 (0.628) and 1.125 (0.354) for NB4 and NB5 respectively. The implication is that there were no significant differences between the subject means of the number of branches due to water treatment for the two weeks studied.

The test for between subject means of the number of branches also revealed that the computed F and the asymptotic significant probabilities were 1.138 (0.349) and 1.417 (0.256) for NB4 and NB5 respectively. The implication is that there were no significant differences between the subject means of the number of branches due to biochar treatment for the two weeks studied.

The test for between subject means of the number of branches due to the interaction between water and biochar treatments also revealed that the computed F and the asymptotic significant probabilities were 0.923 (0.518) and 1.014 (0.450) NB4 and NB5 respectively. This shows that the interaction between water and biochar treatment did not have any significant influence on number of leaves.

4.13. Effects of different treatment on growth and yield parameters of *Capsicum chinense*

Biochar amendment can change substrates (RH and SD) chemical and physical properties, as Dumroese *et al*. (2011) demonstrated that a mixture of 75% peat and 25% pellets biochar has been found to enhance hydraulic conductivity and increase water availability at lower matric potential. Biochar application also enhanced plant height, stem diameter, plant fresh, weights and yield components of tomato plant. Moreover, biochar application improved the irrigation water use efficiency

Table 4.2 shows that high quality substrate has low pH, high cation exchange capacity (CEC), low inherent fertility, proper balance of aeration and water-holding capacity, porosity, and sufficient rigidity to support the plant to be used alone, and is similar to (Landis *et al*., 1990). Due to the high pH of biochar, it could be added to substrates at a concentration of up to 75% (vol.) for nursery production of plants (Steiner and Harttung, 2014). In the research study, *Capsicum chinense* plants grown in substrate (RH and SD) mixes with higher biochar incorporation had higher substrate pH as shown in table 4.2, while there was no significant difference of substrate pH among the biochar treatments in *Capsicum chinense*. The proper percentage of biochar mixed with substrate could have a positive impact on plant performance. The biochar could replace commercial peat moss and perlite-based substrate from 5-30% (vol.) without negative impact on plant growth of gomphrena (Gu *et al*., 2013). Similarity between physical properties of the biochar used in this study and substrate tested in this experiment will contributed to the fact that replacing peat moss at substantially high rate (>50%) did not negatively affect plant growth. According to Graber *et al*., (2010) the biochar amendment has effect on plant height and leaf size but not on flower and fruit in tomato but the study carried out on *Capsicum chinense* showed that biochar amendment increased plant height and leaf size, also has effect on flower and fruit yield. The positive impact of biochar amendment on *Capsicum chinense* plants height was only found on substrate mixes (Ab, Bb) with ET80 and I_{100} water supply, which may be due to the lower fertility (indicated by lower EC level). The addition of Bb (50% A, Rice husk) with ET_{80} water supply to *Capsicum chinense* shows that the stem diameter and leaf area of the pepper increased by 60% which is in-line with Facella (2015) that reported the stem diameter and leaf area of Euphorbia x lomi increased by adding 60% (vol.) conifer wood biochar to peat substrate. The present study had different incorporation rate of biochar in rice husk and saw dust substrate. The positive impact of biochar amendment on *Capsicum chinense* plants stem diameter was only found on substrate mixes (Ab & Bb) with I_{80} and I_{100} water supply, which may be due to the lower fertility (indicated by lower EC level). The improved plant productivity by biochar can be directly due to its nutrient content and release characteristics (Graber *et al*., 2010), and it can be indirectly due to improved nutrient retention (Lehmann *et al*., 2003), soil pH (Rondon *et al*., 2007), and increased soil carbon exchange capacity (Liang *et al*., 2006).

Based on the results from the four different amended substrate and levels of water regimes tested in this experiment, incorporating biochar in container substrate could have positive effect on plant growth at low (plant height: I_{120}Aa, stem diameter: I_{120}Ab & aB, LAI: I_{120}aB) or very high rate (plant height: I_{100}Bb & I_{120}Aa, stem diameter: ET_{80}Bb, LAI: I_{80}Aa & I_{120}Ab), and no negative effect on plant growth was observed in mixes incorporating biochar as high as 60% compared to amended substrate. Therefore, the biochar used in this study could substantially (>50% by volume) replace peat-based substrate for horticulture plant growth in containers.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be drawn from this research:

i. The growth of *Capsicum chinense* in the study was influenced by substrate amendment method under different treatment. After the 6 weeks of monitoring the plants under the various treatments, the highest plant height (PH) of 20.3 m was recorded in treatment I_{60} Ab with the least record of 12.1 m in I_{60} aB. Under I_{80} Ab, PH of 21.0m was recorded as the highest value of PH against the least record value of 16.0 m for aB. In the case of 100% ETc treatment (I_{100}), the highest and the least values of 21.9 m and 12.8 m was recorded for Bb and aB respectively. For the surplus irrigation application of I_{120}, Ab recorded the highest plant height of 21.9 m with the least record for Aa experiment. Generally, the PH were in the order (Ab> Bb > aB > Aa).

ii. The data revealed that LAI increase gradually throughout the growing period and varied with irrigation application regimes. In all water application rates, Bb was found to be consistently in the runners up position compared with other substrate amendment types. Bb treatment also recorded the highest LAI for I_{80}, I_{100} and I_{120}. This is an indication that Bb is suitable for both actual, deficit and surplus irrigation. The Bb maintained its leading values from the beginning to the end of the study for actual and deficit (I_{80}) irrigation treatments. The Bb treatment recorded the highest values of SD throughout the growth period for the I_{80} treatment.

iii. The yield for the experiment on crop (*Capsicum chinense*) were affected by some infections (fungi and bacteria) due to unsterilized substrate used as a planting media.

iv. These shows that biochar application enhanced plant height, stem diameter, plant fresh, weights and yield components of pepper plant. Moreover, biochar application improved the efficiency of irrigation water usage.water irrigation has a significant influence on mean yield of screen house grown *Capsicum chinense* in a soilless media.

v. However, ANOVA results were not significant, but using four test statistics were significant at 5% and significant at 1% respectively.

5.2 Recommendations

This study should be repeated for sterilized substrate specifically the char poultry liter process effluents to investigate the influence of combined treatment of regimes irrigation levels and cultivation of *Capsicum chinense* and other vegetables in the study greenhouse conditions.

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