UNIVERITY FOR DEVELOPMENT STUDIES

EFFECT OF DIFFERENT IRRIGATION REGIMES AND SOIL AMENDMENT STRATEGIES ON GROWTH AND YIELD OF GARDEN EGG (*Solanum aethiopicum)*

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BY

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2023

DECLARATION

DECLARATION BY CANDIDATE

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere. The work of others which served as sources of information for this study, has been duly acknowledged in the form of references.

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DECLARATION BY SUPERVISOR

I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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ABSTRACT

In Northern Ghana, water required for food production has decreased due to land degradation and climate change. The increased demand for water and drought condition affects water required for food production and poor soil fertility and directly influenced food production Therefore, improved soil amendment strategies together with water management are required for improved crop production, especially in drought prone areas. The aim of this study was to evaluate the effect of soil amendment techniques and different irrigation regimes on garden egg growth and yield. The research was conducted at the WACWISA experimental field at the University for Development Studies, Nyankpala Campus. The study was a 3 × 4 factorial pot experiment laid out in a split-plot design with 3 replications. The treatments comprised three (3) irrigation regimes namely, full irrigation (FI_{100}), regulated deficit (RD_{70}) and sustained deficit (SD_{70}) on the main plots and three (3) soil amendments techniques namely; biochar (B), Poultry manure (PM) and combination of biochar and poultry manure (PMB) and the control on the sub-plots. The physicochemical properties of the soil were determined at the laboratory before and after the experiment. The results showed that the soil of the area was sandy loam with dry bulk density ranged from 0.94 - 1.43 g/cm^3, field capacity (FC) ranged from 18-25 %, permanent wilting point (PWP) ranged from 7 -10%, organic carbon (OC), 2.71 – 4.1% and pH and electrical conductivity (EC) were between 4.9- 6.8 and 1.23 – 6.23 dsm^{-1} respectively before and after amending the soil. The crop water requirement was 699.36 mm/season, 593.31 mm/season, and 490.05 mm/season for FI_{100}, and SD_{70} respectively. Application of FI_{100} with soil amended with B and PM combined resulted in the tallest plant height (79.33 cm) and stem diameter (14 mm) whereas the application of SD (70 %) in soil without B or PM resulted in lowest plant height (23 cm) and stem diameter of (4.0 mm). Yield ranged from 10.54 to 27.27 ton/ha with the highest yield recorded in the pot treated with the combination of B and PM under FI_{100}. The highest WUE was recorded in the pot treated with the combination of B and PM under RD_{70} (4.82 kg/m^3) while lowest WUE (0.98 kg/m^3) was recorded in soil without PM or B application under FI_{100} condition (100 % CWR). The study indicated that, combination of biochar and poultry manure improved soil physical and chemical properties compare to single application. No significant difference observed in application of organic fertilizer (B and PM) under (FI_{100}), and RD_{70} on growth and yield of garden egg while, application of (B and PM) under RD_{70} improved WUE compare to other treatment.

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DEDICATION

I dedicate this work to the Almighty God for the gift of life and wisdom to carry out this thesis also to my lovely Mum and Mr. Terah Alaazi for the great support and patience throughout this thesis writing. May God bless you abundantly.

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LIST OF ABBREVIATIONS AND ACRONYMS

AWC	Available Water Content
B	Biochar
BD	Bulk Density
DP	Days After Planting
EC	Electrical Conductivity
CWR	Crop Evapotranspiration
ETo	Reference Crop Evapotranspiration
FC	Field Capacity
GDP	Gross Domestic Product
GS	Groundnut shell
GSS	Ghana Statistical Service
HDPE	High Density Polyethylene
IWUE	Irrigation Water Use Efficiency
Kc	Crop coefficient
MAD	Management Allowed Depletion
MoFA	Ministry of Food and Agriculture
NPMB	No Poultry Manure-Biochar
PM	Poultry Manure
PMB	Poultry Manure and Biochar
PRD	Partial Root Zone Drying
PWP	Permanent Wilting Point
SBDI	Stage Based Regulated Deficit Irrigation
SCS	Soil Characteristic Software
SI	Supplemental Irrigation
SDI	Sustained Deficit Irrigation
UDS	University for Development Study
USDA	United State Department of Agriculture
WACWISA	West African Center for Water, Irrigation and Sustainable Agriculture
WAT	Week after Transplanting

CHAPTER ONE

INTRODUCTION

1.1 Background

Global warming caused by changes in precipitation brought water availability problems in some parts of Africa, particularly in sub-Saharan African countries where agriculture is considered the main driver of economic growth (Emediegwu *et al.,* 2022). Also, global warming has caused climate variability which has a significant impact on agriculture and affects food security and farm incomes for households (Wossen *et al.*, 2014; Fanzo *et al.*, 2018; Pickson and Boateng, 2022).

Socioeconomic sector of Ghana is based on agriculture which is primary source of livelihood in majority of rural people in Ghana (Nyamekye *et al.*, 2021). In the year 2019, the agricultural sector contributed about 20 % to Ghana's gross domestic product (GDP) (Nyamekye *et al.*, 2021). Between 2016 and 2019 the average share of agriculture in total GDP growth was 5.2 % (Pauw, 2021). Other typical example is in fourth quarter of 2021 (October - December) where gross domestic product of the agriculture sector recorded the highest growth rate of 8.2 %, followed by the services sector with a growth rate of 8.1 %, but the industry sector increased only 4.8 % (Ghana statistical service, 2022). This demonstrates how agriculture serves as the foundation of the Ghanaian economy and agriculture transformation strategies can help in reducing poverty in Ghana (Adomako and Ampadu, 2015).

Water is one of the important components in agricultural production hence crop yields are reduced when natural rainfall is not available at the right time (Meena and Dotaniya, 2022). Due to the agricultural restriction of not being able to manage this natural input, farmers are unable to produce efficiently, which leads the majority of farmers achieving low yields (Dakpalah *et al.*, 2018). Irrigation is a major technique for mitigating this unpredictable rainfall condition in Ghana

(Baldwin and Stwalley, 2022). In 2000, the estimated water management coverage in the country was only 30,900 hectares which was just 1.7% of the possible area. However, by 2007, the irrigated area had grown to 33,800 hectares (Namara *et al.*, 2011). In 2022, the Ministry of Food and Agriculture (MoFA) published a report stated that the rehabilitation and modernization of numerous irrigation projects where at their completion that will make available a total irrigation area of 6,766 ha (MOFA, 2022). The Kpong Irrigation Scheme (2,176 ha), Tono Irrigation Scheme (2,490 ha), and Kpong Left Bank Irrigation Project (2,100 ha) are currently in the stages of 93%, 97%, and 90% completion respectively. These projects will contribute a combined area of 375 hectares (ha) for rice and vegetable production (MOFA, 2022). To reach 28 % of the potential of country, the government ultimately plans to increase the irrigated land by 500,000 ha (Baldwin and Stwalley, 2022). There are a total of 22 official irrigation schemes in the country, categorized by their covered land size. These include 13 small-scale districts, covering about 60% of all districts and with an area of 100 hectares or less. There are also 5 medium-scale districts spanning between 100 and 500 hectares, and 4 large-scale districts encompassing 500 hectares or more (Baldwin and Stwalley, 2022). Pressurized irrigation system such as sprinkler and drip irrigations are demonstrated as superior performance efficiencies compared to surface irrigation methods (Ahmed, 2018). Drip irrigation is the best irrigation systems that conserves water because it has been examined and selected as one of the irrigation systems that minimizes water losses due to slow water application, This irrigation method is particularly beneficial for fruit and vegetable crops because it delivers water directly to the roots, resulting in reduced fertilizer and water usage (Biswas *et al.*, 2015). Drip irrigation enables precise control of soil moisture by delivering water directly to the root zone at low application rates and pressure. This method ensures that water is applied in close proximity to the roots, thereby facilitating accurate soil moisture management. (Nikolaou *et al*., 2020).

Drip irrigation has the capacity to enhance crop yield even when using reduced amounts of irrigation water. (Shareef *et al*., 2019). This irrigation system also increases crop productivity while using less water with high application efficiency of 90 % and above especially in vegetable crops in arid and semi-arid regions (Biswas *et al.,* 2015; Nikolaou *et al.,* 2020). In order to maximize crop yield per cropped area and per unit of water utilized, drip irrigation also includes various irrigation deficits that change from full irrigation to reduced crop water delivery and maximize the amount of fruit produced per unit of water consumed while also improving irrigation water efficiency (Fereres and Soriano, 2007). The deficit irrigation techniques include various approaches such as stage-based or regulated deficit irrigation (SBDI), sustained deficit irrigation (StDI), partial root zone drying (PRD), and supplemental irrigation (SI) (Nikolaou *et al*., 2020, Ghafari *et al.,* 2020). Due to the high capital costs of installing a drip system and maintaining the system, it is mainly used on high value crops (banana, coconut, grapes) and vegetables are taken into consideration in this system and many farmers preferred to plant row crops (vegetables and soft fruit) with drip irrigation since they are high-value crops and are healthy (Ali *et al.,* 2020).

Application of soil amendment techniques under irrigated land increase water holding capacity of the soil due to the increase in organic matter content and yield production (Solomon & Lehmann, 2019). A new technology of soil fertility management known as biochar that was introduced in Ghana as a by-product of biomass pyrolysis, a process that occurs in an oxygen-depleted environment (Ding *et al.,* 2016). Poultry manure fertilizer also has been assessed as best quality fertilizer to contain nutrient required to improve soil quality and crop yield (Masocha and Dikinya, 2022). Applying biochar with manure fertilizer has a greater impact on water conservation, soil water retention, soil temperature, and reducing water evaporation and reduce water stress in crops (Li *et al.*, 2018; Kader *et al.*, 2019).

1.2 Problem Statement and Justification

In Ghana, water required for food production has decreased due to land degradation and climate change (Yaro, 2013) . The increased demand for water and drought condition affect water required for food production and this have a direct influence on food production (Varga, 2021, Siwar *et al.,* 2022).

Northern Ghana also has a short period of rainfall due to the effects of climatic change resulted by a prolonged dry season and impact food security in country (Gbangou, 2020). The percentage of the population experiencing food insecurity varies depending on where people live, rural areas experiencing 78 % more food insecurity than urban areas which have 22 % (Peprah *et al.*, 2020). According to Bawa (2019), the Upper West Region has an approximate food insecurity rate of 34 %, while the Upper East Region has a rate of 15%, and the Northern Region has a rate of 10%. Due to the heavy reliance on rain-fed agriculture, which is severely characterized by the unimodal rainfall pattern and frequently insufficient to meet year-round household food needs and food insecurity continues to become a challenge in northern Ghana for almost four to five months each year (Adongo *et al.*, 2015).

Soil fertility in Ghana is currently at low level and is deteriorating quickly as result of improper soil management techniques (Issaka et al., 2021). Actively adopting and enhancing strategies to preserve soil and water resources, such as implementation of soil conservation techniques aimed at maintaining or enhancing soil fertility to boost crop production (Ren et al., 2023). These techniques encompass improved water, crop, and soil management practices to ensure sustainable agricultural practices (Diop *et al.*, 2022). The utilization of advanced farming techniques, such as controlled irrigation, appropriate fertilizer application, effective mulching, and the implementation of water retention methods like resistant varieties and optimal planting and harvesting timings, has resulted in higher yield per acre of irrigated land compared to rain-fed agriculture on equivalent land size (Ren et al., 2023). These technological advancements have not only increased agricultural production but have also enhanced food security and improved the livelihoods of farmers in northern Ghana (Dakpalah *et al.,* 2018). Improvement of water productivity or crop yield per cubic meter of water used is a key technique to combat the problem of water scarcity for future water demand.

Water productivity are required to develop better water management strategies. These strategies include using techniques like sustained deficit irrigation, stage-based deficit irrigation, partial root zone drying, and supplemental irrigation to manage water deficits. Sustained deficit irrigation involves maintaining a water shortage throughout the entire crop growth period. Stage-based deficit irrigation applies a water shortage only during specific growth phases while providing full water requirements for the rest of the phases. Partial root zone drying involves irrigating only half of the root-zone area, allowing the other half to dry out, and alternating the irrigation between the two halves. Supplemental irrigation adjusts the amount of water applied based on the soil moisture from rainfall to meet the crop water needs where irrigation applied according to the rain water available in the soil to meet crop water requirement (Nikolaou *et al*., 2020).

The use of deficit irrigation water, in combination with other irrigation and water management strategies, can impact different factors of crop yield such as fruit size, weight, and number. It also improves the efficiency of irrigation water usage and enhances the quality of the fruit. This is achieved by minimizing water loss through transpiration, improving the control of stomatal function to maximize the ratio of photosynthesis to transpiration, and reducing the surface area available for evaporation. As a result, the amount of water needed for crop production is reduced while still maintaining and improving crop productivity (Nikolaou *et al*., 2020).

Applying regulated deficit irrigation, which involves intentionally inducing water stress during specific stages of crop growth, can have various effects on crop characteristics. These effects include an increase in the root to shoot ratio, improved nutrient uptake and recovery, enhanced physiological traits such as stomatal closure, reduced leaf respiration, and sustained photosynthesis. Additionally, regulated deficit irrigation can lead to biochemical changes, such as an increase in antioxidation enzymatic activity (Chai *et al.*, 2016).

Soil amendment with biochar is possible to promote garden egg growth , agricultural yield, and soil quality (Pandian *et al.*, 2016). In additional biochar combined with organic fertilizer such as poultry manure, cow dung or compost can utilize to improve crop productivity and enhance soil quality. where Research done in 2022 resulted that the field production of garden eggs is greatly affected by biochar-based (BF) fertilizers (Chun *et al.*, 2022). Application of deficit irrigation (70 % CWR) on development stage and late season stage (regulated deficit) and application of deficit irrigation (70 % CWR) throughout growth period (sustained deficit) was conducted to examine response of garden egg under amended soil with groundnut shell biochar and poultry manure compared to full irrigation application.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of the study was to assess how different irrigation regimes and soil amendment techniques affect the growth and productivity of garden eggs (*Solanum aethiopicum)* in a field experiment carried out in northern Ghana.

1.3.2 Specific Objectives

The specific objectives of the study were:

1. To determine effect of amendments on physico-chemical properties of the soil.
2. To determine the crop water requirement of garden egg.
3. To examine the effects of different irrigation methods and soil amendments on the growth and yield of garden egg.
4. To assess the impact of different irrigation regimes and soil amendment techniques on the water use efficiency of garden egg.

1.4 Structure of the Thesis

The thesis is structured into five main chapters. Chapter One introduces the study, including the background, problem statement, justification, and research objectives. Chapter Two reviews relevant literature on garden egg characteristics, drip irrigation, deficit irrigation, irrigation water requirements, irrigation scheduling, biochar and its applications, poultry manure, and its impact on crop water requirements. Chapter Three describes the materials and methods employed, including study area descriptions, fieldwork procedures, data collection methods, and indicators used to assess soil properties. The fourth chapter presents the results and discussions, while the fifth and final chapter provides conclusions and recommendations of the study.

1.5 Conceptual framework

The conceptual framework of this study aims to clarify ow tee y variables affected growth, yield of garden egg and water use efficiency under different irrigation regimes namely regulated deficit irrigation at 70 %, sustained deficit irrigation at 70 % and control full irrigation and application of different soil amendment techniques namely biochar, poultry manure and combination of biochar and poultry manure on soil physical and chemical properties, growth parameters, yield parameters and water use efficiency. This framework drawn to achieve the main principles which are garden eggs production and water use efficiency.

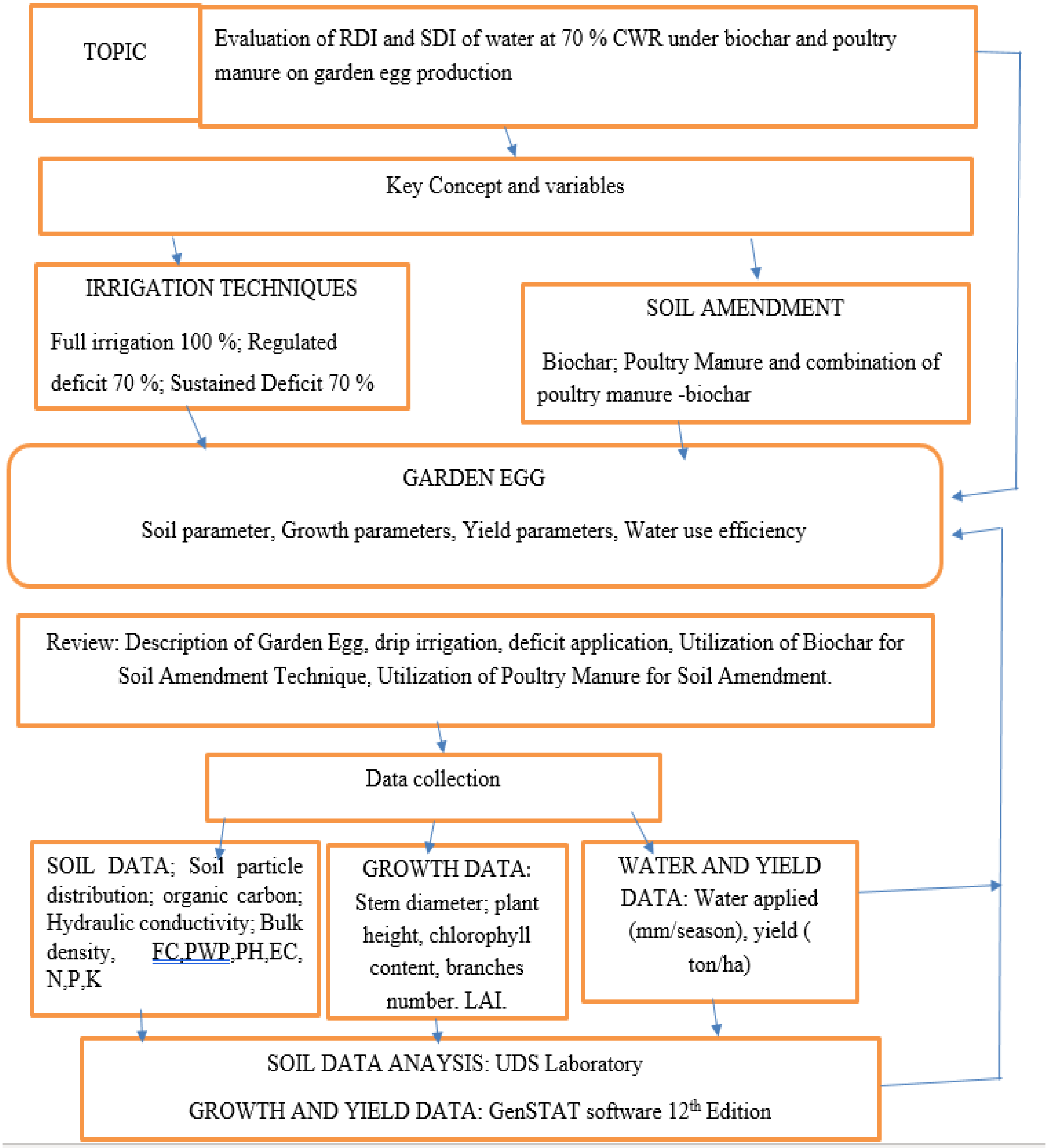


Figure 1.1: Conceptual framework of the study

CHAPTER TWO

LITERATURE REVIEW

2.1 Description of Garden Egg

A plant species known as garden egg (Solanum aethiopicum) is categorized as a short-lived perennial herb. It belongs to the genus Solanum and the family Solanaceae (Darko *et al*., 2019). African eggplant, also known as garden egg, is a popular vegetable crop grown in many warm regions of Africa. It comes in various varieties with different fruit shapes such as pear-shaped, round, long, or cylindrical (Mpanga *et al*., 2021).

There are four main groups of garden egg plants: Gilo, Kumba, Shum, and Aculeatum. Gilo and Kumba are important in Africa because they are mainly grown for their fruits, while Shum cultivars are primarily cultivated for their leaves (Daniela *et al*, 2007). The Gilo variety in mostly produced by African farmers and originated in tropical Africa as local variety (Olubunmi *et al*., 2017), The cultivation of Gilo variety has significantly increased across Africa, especially in West and East Africa where they are grown extensively (Horna and Gruère, 2006). The Gilo variety in Ghana is more genetically diverse than the Kumba variety due to increased cross-pollination but also the Kumba variety is also present in the Ghanaian market (Solberg *et al*,. 2022).

2.1.1 Nutritional Values of Garden Egg

In Ghana, garden egg fruits are commonly utilized in the preparation of soups and stews, serving as a vegetable ingredient. Additionally, they can be consumed raw on certain occasions. Some people eat the leaves in a cooked form (Han *et al*., 2021). Garden eggs are highly nutritious and contain a wide range of essential vitamins and minerals, making them comparable to other common vegetables in terms of nutritional value. In terms of fresh weight composition, they consist of approximately 92.7% moisture, 1.4% protein, 1.3% fiber, 0.3% fat, 0.3% minerals, and the remaining 4% comprises various carbohydrates, as well as vitamins A and C. Additionally, garden eggs contain approximately 92.5% water, 1% protein, 0.3% fat, and 6% carbohydrates. Similarly, eggplants are rich in nutrients such as dietary fiber, folate, ascorbic acid (vitamin C), vitamin K, niacin, vitamin B6, pantothenic acid, potassium, iron, magnesium, manganese, phosphorus, and copper (Olubunmi *et al.*, 2017). Garden eggs are a good source of calcium, phosphorus, and iron, which are essential for bone health and the formation of blood cells. These minerals play vital roles in various bodily functions, including maintaining heart rhythm, muscle contraction, bone and teeth formation, acid-base balance, regulation of cellular metabolism, and facilitation of enzymatic reactions (Han *et al.*, 2021)**.** As presented in Table (2.1), Chinedu *et al.*, (2011) conducted a study on garden egg fruits and found and recorded the presence of different nutrients and mineral elements.

Table 2.1: Proximate Composition of Garden Egg (*Solanum aethiopicum*)

Nutrient	**Composition (per 100 g of Fresh Fruit)**
Moisture content	91.20 ± 0.34 %
Crude protein	1.07 ± 0.01 %
Crude fat	0.38 ± 0.03 %
Crude fiber	2.44 ± 0.04 %
Ash content	0.73 ± 0.03 %
Carbohydrate	4.18 ± 0.08 %
Dry matter	8.80 ± 0.19 %
Mineral	**Element Concentration (mg/g Dry Weight Basis)**
Calcium	0.310± 0.360
Iron	0.025± 1.125
Potassium	4.475± 9.525
Sodium	0.865± 1.005
Manganese	0.005
Copper	0.007± 0.008
Zinc	0.077± 2.938
Phosphorus	1.091± 1.245
Vitamins	**Content (mg/100 g Fresh Fruit)**
Vitamin A (retinol)	53.550 ± 0.55
Vitamin B1 (thiamine).	0.037
Vitamin B2 (riboflavin)	0.03

Vitamin B (niacin)	0.700
Vitamin C (ascorbic acid)	2.300
Vitamins D (calciferol)	0.010
Vitamin E (tocopherol)	0.310

Source: Chinedu *et al.*, (2011)

2.1.2 Distribution and Market Level of Garden Egg in Ghana

Garden egg is a popular fruit vegetable in tropical Africa and is one of the most commonly consumed. in quantity and value probably is the third after tomato and onions and before okra (Horna and Gruère, 2006; Olubunmi *et al.*, 2017). Garden eggs are a common food in Ghana, consumed by both rural and urban families. They are prepared in a similar way to tomatoes, but are often used together with tomatoes rather than as a replacement. Furthermore, growing garden eggs is an important source of income for many rural households in Ghana (Darko *et al*., 2019) . In Ghana, the Gilo variety is widely cultivated and is the most common group. However, it has been observed that fruits with characteristics resembling the Kumba group are also found in the markets of Ghana (Daniela *et al*., 2007) .

Garden egg production is widespread across the entire country, but commercial cultivation is primarily concentrated in the forest zone area, in comparison to other regions of Ghana. Garden egg is grown as a commercial crop to meet domestic demand as well as for export purposes (Of *et al*., 2012). Garden egg has an established marketing network in Ghana and beyond, facilitating the connection of various stakeholders across different geographical locations. This network connected from rural communities to national, regional, and international markets **(**Daniela *et al.*, 2007)**.**

2.1.3 Agronomy of Garden Egg

The African eggplant, commonly known as garden egg, is primarily cultivated as an annual plant, although it can exhibit perennial characteristics with persistent woody stems, enabling it to withstand hot climates, particularly in northern Ghana. It prefers in deep, well-drained, and fertile soils. While the cultivation of garden egg largely relies on rainfall, irrigation can be applied during dry seasons. Required conditions for garden egg growth include a pH level of 5.5-6.8 and daytime temperatures ranging from 32°C to 21°C at night. It can tolerate temperatures between 10°C and 40°C but does not tolerate a very cold or waterlogged conditions (Han *et al*., 2021).

2.1.4 Crop Water Requirement Estimation for Garden Egg

The growth of garden eggs is influenced by amount of water applied. Roots hair of garden eggs absorb water from the soil and moves through the stem up to the leaves and water lost through the pore space on the surface of the leaves as transpiration. Water is lost from the soil through various processes, including evaporation from the soil surface and other exposed surfaces. The combined loss of water through transpiration from plants and evaporation from the soil is referred as evapotranspiration (Rai *et al.*, 2017). The use of the FAO CROPWAT computer program has become prevalent for estimating crop water requirements. This program requires input of climatic data, soil data, and crop data in order to generate accurate estimations (Allen *et al*., 1998).

$$\text{CWR} = ETo \times kc \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 2.1}$$

Where:

CWR = Crop water requirement (mm),

Eto - Reference evapotranspiration (mm) and

Kc - Crop coefficient.

FAO penman montheith method used to calculate reference evapotranspiration is as follows (Equation 2.2):

$$\text{ET}= \frac{\left(0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}\text{U}_2(es-ea)\right)}{\Delta+\gamma(1+0.34U_2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 2.2}$$

Where:

ETo - Reference evapotranspiration in mm/day,

Rn- Net radiation at the top surface (MJm^2/day),

G - soil heat flux density (MJm^{-2}/day),

T - Mean daily air temperature (°C)

U2 - Wind speed at 2 m height (m/s),

es – ea - Saturated vapor pressure deficit (kPa),

Δ - Slope vapor pressure curve (kPa/°C), and

Y - Psychrometric constant (kPa/°C).

ETo used for crop water requirements and irrigation scheduling is calculated according crop coefficient (Kc) of crop growth stage. Approximate duration of growth stage and crop coefficient of garden eggs is 130 days with 30 days in initial stages, 40 days for crop development stage, 45 days for mid-season stage, 25 days for late season stage with Kc values of 0.45, 0.75, 1.15 and 0.80 respectively (Singh, 2012). Garden egg maximum rooting lies between 0.7-1.2 m and management allowed depletion (MAD) of 45 % when garden egg is planted in deep, uniform, well-drained soil profiles (USDA, 2016).

2.1.5 Pests and Diseases of Garden Egg

Most of pests that affect garden eggs includes shoot and fruit borer (*Leucinodes orbonalis*), Pyralid moth larva (*Euzophra villova*), Thrips and eggplant skeletonizer (*Selepa docilis*) Leafhopper commonly known as cotton jassid, aphid, whitefly, and spidermites are the major pest of garden egg and they can be controlled by regular sprays of recommended insecticide (Sudhanshu *et al.*, 2022). Eggplant is susceptible to several common diseases, including bacterial wilt, verticillium wilt, fusarium wilt, and brinjal little leaf. Other problematic diseases and pathogens include alternaria rot, anthracnose fruit rot, damping-off disease, phytophthora blight, mosaic viruses, and viroids. Bacterial wilt, caused by *Ralstonia solanacearum*, is particularly detrimental and is more severe in high-temperature conditions. The characteristic symptom of bacterial wilt is wilting, resulting from damage to the roots and stems of the plant (Mcavoy *et al*., 2019). Effective management of pests and diseases in garden eggs can be achieved by selecting crop varieties that are well-adapted to the local climate and soil conditions. Additionally, maintaining a healthy crop through cultural practices such as appropriate fertilization and irrigation is crucial. Early detection and removal of pests, as well as weed control, are important in preventing minor infestations from becoming major issues. Regular monitoring and earlier elimination of pests and diseases contribute to the success of pest and disease management strategies (Amengor *et al*., 2017).

2.2 Drip Irrigation System

Drip irrigation, also called micro irrigation, is a technique where water is carefully and slowly delivered to plant roots. It involves using small water drops, usually less than 12 liters per hour, through emitters connected to pipes where water can be sprayed or released in a steady flow near the plants (Singh, 2012). Micro irrigation focuses on delivering the necessary amount of water to plants by targeting a specific area of soil rather than watering the entire surface.

2.2.1 Merits of Drip Irrigation System

According to Kumar (2015), the drip irrigation system offers several advantages, including the following:

- Enhanced water use efficiency
- Conservation of water leading to improved growth and yield
- Uniform production and better quality of crops
- Efficient and cost-effective use of fertilizers
- Control of weed growth

- Energy savings due to reduced water requirements
- Potential for automation
- Suitable for cultivation on undulating terrain
- Prevention of soil erosion due to slow water application
- Operational flexibility
- Labor savings
- Reduced risk of disease and pest infestation

2.2.2 Challenges of Drip Irrigation System

Kumar (2015) outlined the challenges of drip irrigation system as follows; clogging of drip emitters by particulates, chemicals and biological materials and technical skill is required for design and installation. Clogging problem mostly caused by dissolved salt like carbonate, bicarbonate, iron, calcium, and manganese salts that accumulate or precipitate inside the drip line and stop water from passing in dripline. Clogging also can delivered from microorganism like algae and bacteria that can be treated either by chloride injection or sulfuric acid injection in water supply.

2.2.3 Deficit Irrigation Techniques

Water is an essential component for plant growth and of photosynthesis by water uptakes from root-zone and carbohydrates production, plant growth and vigor with proper managing of available water with respecting optimum soil moisture (Gavrilescu, 2021). Methods that prevent excessive water application and increase water usage efficiency (WUE) are essential for water conservation. In this situation, deficit irrigation has been proposed as strategies that can significantly contribute to increasing WUE and reducing irrigation requirements (Alomran and Louki, 2011; Zhao *et al*., 2019). The implementation of deficit irrigation, which involves applying water below the crop evapotranspiration rate or providing a volume of water lower than the plant water requirement, has been recognized as a sustainable irrigation strategy. This approach aims to optimize net returns, particularly in situations where water availability is limited, as compared to conventional irrigation practices (Capra and Consoli, 2015). Drip irrigation commonly employs various irrigation strategies, including full irrigation and different variations of deficit irrigation. Deficit irrigation can be further categorized into regulated deficit irrigation (such as stage-based or regulated deficit irrigation), sustained deficit irrigation, partial root zone drying deficit irrigation, and supplemental irrigation. These approaches are widely utilized in practice (Egea *et al*., 2017).

Agronomically, effect shows that deficit irrigation reduces total flesh mass and total productivity but also increase water use efficiency in term of application efficiency increase because all water applied remain in root-zone with no deep percolation or runoff and consumptive efficiency as ratio of evapotranspirated water to the water available in the root-zone increase because water are forced to be extracted from the soil (Capra and Consoli, 2015). Drought condition also result in plant uptakes of less moisture and nutrient to carry optimum growth and reproduction function which reduce vigor and smaller leaves which decrease area for photosynthesis and carbohydrates production decrease and result in less food production in quality and quantity (David *et al*., 2013).

Sustained deficit irrigation involves maintaining a water deficit throughout the entire crop growth period. In stage-based or regulated deficit irrigation, the water deficit is applied only during specific growth phases, while 100% of the crop water requirement (CWR) is provided during the remaining phases. Partial root zone drying (PRD) is a technique where half of the root-zone area is irrigated while the other half is allowed to experience drying soil conditions, and this is alternated. Supplemental irrigation (SI) is practiced by applying irrigation water based on the availability of rainfall in the soil, in order to meet the crops water requirement (Nikolaou *et al*., 2020). According to Nikolaou *et al.* (2020) the level of water deficit can be determined by the percentage reduction in soil field capacity as presented in table (2.2):

Table 2.2: The relationship between water deficit level and the percentage reduction

Water Deficit Regimes	Soil Field Capacity (%)
Severe water deficit	<50
Moderate water deficit	50-60
Mild water deficit	60-70
No deficit/ full irrigation	>70
Over irrigation	>100

Source: Nikolaou *et al.* (2020)

2.2.4 Application of Regulated Deficit Irrigation on Vegetable Production.

Regulated deficit irrigation (RDI) involve reducing water supply during the drought-tolerant phase of plant growth while maintaining full irrigation when the plant is more sensitive stage of plant growth (Abdalltif, 2018; Ved Parkash, 2020). Irrigation water deficit in various crop growth stage have an impact on plant growth and ability of crop to produce yield (Bray, 2007). But morphological characteristics of some crop species permit crop to survive in water stress condition by promoting physiological adaptation to water deficit while other may indicate injury due to water stress (Bray, 2007). Compared to various other vegetable crops, eggplant (Solanum groups) and onion (*Allium cepa L.*) have shown better performance under water deficit conditions. In contrast, leafy greens like lettuce (*Lactuca sativa L.*) have consistently experienced yield losses when subjected to deficit irrigation (Singh *et al.*, 2019).Application of deficit irrigation on garden egg reduce crop development by changing physiological process which might influence fruit size and overall yield (Flores-saavedra *et al.*, 2023)

Regulated deficit can be classified as severe water deficit, moderate water deficit, mild water deficit and full water deficit based on percentage of reduction in soil field capacity (Nikolaou *et al*., 2020). But milt water deficit stress does not severely affect the plant and its effect can be reversed when water is re-applied again at 100 % CWR (Imadi *et al*., 2016).

Research conducted showed that regulated deficit of 80 % CWR by alternative timing strategy where deficit applied 2 weeks and full irrigation replenished back again for next 2 weeks at vegetative growth, pre- flowering and fruit ripening stage does not have detrimental impact on eggplant production (Karam *et al*., 2011). A research conducted confirmed that irrigation of 70 % CWR or above maintained crop yield and improve fruit quality of garden egg by using less water (ZHOU *et al*., 2017). while (Darko *et al*., (2019) on analysis of garden eggs growth and yield response under deficit irrigation throughout growth period shows that plant height and diameter decreased on 70 % of water application compare to 100 % CWR.

Regulated deficit irrigation conducted by Valencia (2013) using moderate deficit irrigation and severe deficit irrigation resulted in yield and fruit size reduction compare to the full irrigation. Onion growth stage-based deficit was also conducted by Nurga *et al*., (2020) and the study results indicated that applying deficit irrigation on garden egg during the initial and maturation stages of crop growth was found to be suitable in minimizing yield reduction. Valencia (2013) suggested that Regulated deficit irrigation should be applied to the relation with crop development stage so that application of water deficit applied in non-critical stage and full irrigation also applied at critical stage. Regulated deficit irrigation help to improves crop production and improve crop water use efficiency by enhancing guard cell signal transduction network, optimize stomata control and reduce evaporative surface area (Chai *et al*., 2016). Deficit also can be applied either throughout crop growth period as sustained deficit or on only crop vegetative growth as stage-based deficit irrigation or regulated deficit. David et al. (2013) provided critical stages of different vegetables as presented in (Table 2.3):

Table 2.3: Critical Stages of Different Vegetables

Vegetable Crops	Critical Periods
Asparagus	Spear growth and fern growth
Broccoli	Transplanting and flower bud production
Cabbage	Transplanting and head formation
Cauliflower	Transplanting and curd development
Carrot	Root enlargement
Cucumber	Pollination and fruit enlargement
Eggplant	Transplanting, flowering and fruit development

Source: David *et al.*(2013**)**

2.3 Utilization of Biochar for Soil Amendment Technique

The application of biochar is an innovative approach to managing soil fertility. It is derived as a by-product from the pyrolysis of biomass in an oxygen-depleted environment (Ding *et al.*, 2016). The application of biochar is an innovative approach to managing soil fertility. It is derived as a by-product from the pyrolysis of biomass in an oxygen-depleted environment (Kätterer *et al.*, 2019). Biochar used as great system of integrated soil fertility management agriculture especially in West Africa (Liberia and Ghana) and also in East Africa (Ethiopia) because of its enrichment in Carbon, calcium, magnesium and nitrogen and it is intended used as soil amendment techniques (Solomon and Lehmann, 2019). Biochar plays a crucial role in soil as a soil conditioner by enhancing the humus content. Its presence in the soil promotes a favorable environment for beneficial microorganisms like mycorrhizae, bacteria, and protozoa. Additionally, biochar helps to improve soil structure, resulting in increased oxygen availability in deeper soil layers. This favorable soil environment facilitates nutrient absorption by both microorganisms and plant roots. (Gustafsson, 2013). Biochar aids in land drainage improvement, reduces nutrient leaching, mitigates methane emissions, and raises pH levels in acidic soils. These benefits contribute to improved soil health and agricultural productivity (Gustafsson, 2013).

Laghari *et al*. (2016**)** provided the general importance of biochar in environment sustainability as presented in Figure 2.1:

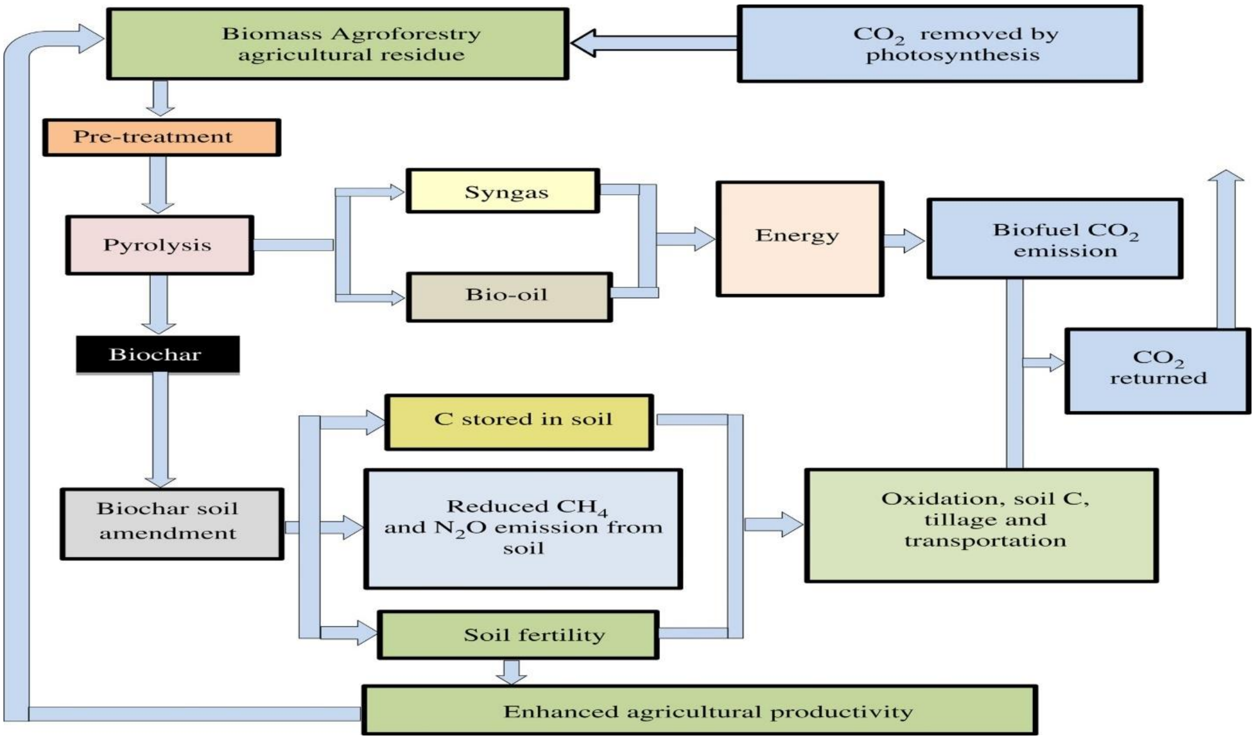


Figure 2.1: General Importance of Biochar in Environment Sustainability

Source: Laghari *et al*. (2016**)**

2.3.1 Biochar Feedstock

Feedstock biomass for biochar production includes all raw materials required for biochar production and depends on local availability of material and cost of acquisition. These feedstocks includes crop residues, agro-processing wastes, manures, municipal solid wastes, aquatic weeds, firewood, forest residues (Gwenzi *et al*., 2015).

2.3.2 Biochar Pyrolysis

Biochar pyrolysis is defined as the process where biochar feedstock materials are burned and result with any chemical or physical change by heat done in an environment with absence of access to oxygen. It involves in termo-decomposition of plant residues at a temperature of 350 ℃ or above 500 ℃ (Özsin, 2017). Biomass particle size modified by pyrolysis mechanism and mass yields influenced by heat applied on biomass (Yang *et al.*, 2021). When feedstock decompose, they release volatile compounds, and the non-volatile parts are collected as biochar. (Ripathi *et al*., 2016; Zhang , 2018). Pyrolysis is categorized into four (4) techniques which include; slow, fast, flash and intermediate pyrolysis.

2.3.2.1 Slow Pyrolysis

Slow pyrolysis involves subjecting the biomass to a gradual or low heating process, typically within the temperature range of 350-550 °C. This method utilizes low heating rates, typically in the range of 0.10-1.0 °C/s, and requires reaction durations of 5 to 30 minutes. Slow pyrolysis promotes increased char formation while reducing the production of bio-oil and biogas (Sun *et al*., 2017)

2.3.2.2 Fast Pyrolysis

Fast pyrolysis is a technique where the biosolids or biochar feedstock is rapidly heated to temperatures between 800-1300 °C within a short timeframe of 1.0 to 10.0 seconds. This process utilizes high heating rates, typically ranging from 10-200 °C/s. The purpose of fast pyrolysis is to maximize the production of bio-oil yield (Mackey *et al*., 2022). In a typical fast pyrolysis process, approximately 60-75% of the output is in the form of liquid products, while 15-25% consists of biochar, and the remaining 10-20% is composed of non-condensable gaseous products (Tripathi *et al*., 2016).

2.3.2.3 Flash Pyrolysis

Flash pyrolysis is an improved form of fast pyrolysis where the biomass feedstock is quickly heated at an extremely high rate, reaching temperatures between 900 and 1200℃. This rapid heating is done for a very short period, typically lasting only 0.1 to 1 second. (Tripathi *et al.*, 2016).

2.3.2.4 Intermediate Pyrolysis

Intermediate pyrolysis is a pyrolysis technique that aims to achieve a balance between the production of liquid and solid products. Unlike slow pyrolysis, which yields a higher amount of char but lower liquid production, and fast pyrolysis, which prioritizes liquid production with reduced char yield, intermediate pyrolysis operates at temperatures ranging from 500 to 650 °C. The heating rate during intermediate pyrolysis ranges from 0.1 to 10 °C/min, and the residence time typically falls between 300 and 1000 sec. In the case of intermediate pyrolysis, the resulting products are typically composed of approximately 40-60% liquid, 20-30% non-condensable gases, and 15-25% biochar. This pyrolysis method offers a balanced approach, generating significant liquid output while still producing a required amount of biochar (Tripathi *et al.*, 2016).

2.3.3 Biochar Properties and Multiple Applications

Biochar production properties such as chemical or physical properties and common elemental composition like carbon, nitrogen, hydrogen, and some lower nutrient element, such as K, Ca, Na, and Mg influenced by various factor such as Biochar feedstock, pyrolysis process and condition (Ding *et al.*, 2016). Biochar produced at different temperatures has different effects on fertilizer nutrients and can act as a carbon sink to reduce CO2 emissions. The structure and pore size of biochar influence its water retention and adsorption capacity. Other factors like pH, cation exchange capacity, surface group functionality, and surface heterogeneity also affect how biochar adsorbs and releases substances. Adding biochar to sandy soils can improve water and nutrient retention and make them more available for plants (Gwenzi *et al*., 2015). When the pyrolysis temperature is increased from 300 to 800 °C, the biochar produced has more carbon and less nitrogen and hydrogen (Ding *et al*., 2016). The use of biochar in soils improves their ability to retain nutrients, leading to increased plant growth and nutrient absorption. Biochar also enhances ability of the soil to absorb and store water, which is an important benefit (Coumaravel *et al*., 2015).

2.4 Utilization of Poultry Manure for Soil Amendment

Poultry manure is organic manure fertilizer produced from poultry farm. Poultry manure has different nutrient contents which depend on poultry ages, types and amount of feedstock applied, amount of water gives to poultry and time and rate of poultry house cleaned but generally Poultry manure is rich in essential nutrients that are crucial for plant growth. These nutrients include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), chloride (Cl), boron (B), iron (Fe), and molybdenum (Mo). By utilizing poultry manure as a fertilizer, plants can benefit from these important elements required for their healthy development (Chastain *et al*., 2010).

Application of poultry manure fertilizer on crop or trees provide portion or all nutrient required for plant growth and Poultry manure performed better that goat manure cow manure. According to the experiment carried out by Maerere (2015) to determine the comparative effect of animal manures on the soil chemical properties and growth of Amaranthus, he was found out that out of the three organic fertilizers applied (i.e., poultry manure, goat manure and dairy cow manure), poultry manure performed well compared from goat and caw manure by poultry manure > goat manure > dairy cow manure. And difference obtained in total N, total P, C/N and C/P ratios of the amendment.

According to experiment carried out by Ahmad (2017) on the impact of organic fertilizer on the growth and yield of coriander using farm yard manure, compost, and poultry, it was discovered that of the three organic fertilizers applied, plants that received poultry manure had the highest number of leaves branch, highest leaf area, and shortest harvest time.. Also, according to the experiment carried out by Abdul-hakim (2021) in Savanna Agriculture Research Institute (SARI) on effect of poultry manure an growth of *zea mays* indicated that productivity increased at rate of 15 % of poultry manure, compare to 5 % and 10 %.

In a derived savanna transition zone of South Eastern Nigeria, Ogbonna and Umar-Shaba (2012) conducted research on the effects of poultry manure application on the growth and yield performance of sesame (Sesamum indicum L.) accessions. The findings revealed that the application of poultry manure significantly promoted sesame growth and yield as it increased from 0 to 5 and 10 tons/ha, respectively.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was carried out at the Experimental Field of the West African Centre for Water, Irrigation and sustainable Agriculture (WACWISA) at Nyankpala Campus. Nyankpala Campus is located in the Northern Region in the Guinea Savanna Agro-ecological Zone of Ghana. It is about 16 km west of Tamale and lies on latitude N 09º 25’ and longitude W 0º 58’and an altitude of 200 m above sea level. Northern Ghana characterized by one rainy season (unimodal) and total annual rainfall of about 1000 -1200mm. In a typical year, a rainy season lasts between 140 and 190 days, with August and September seeing the most precipitation. Other months namely from November to May are extremely dry, making it difficult for the household and agricultural sectors to obtain water (SARI, 2014). Figure 3.1 presents the map of the study area.

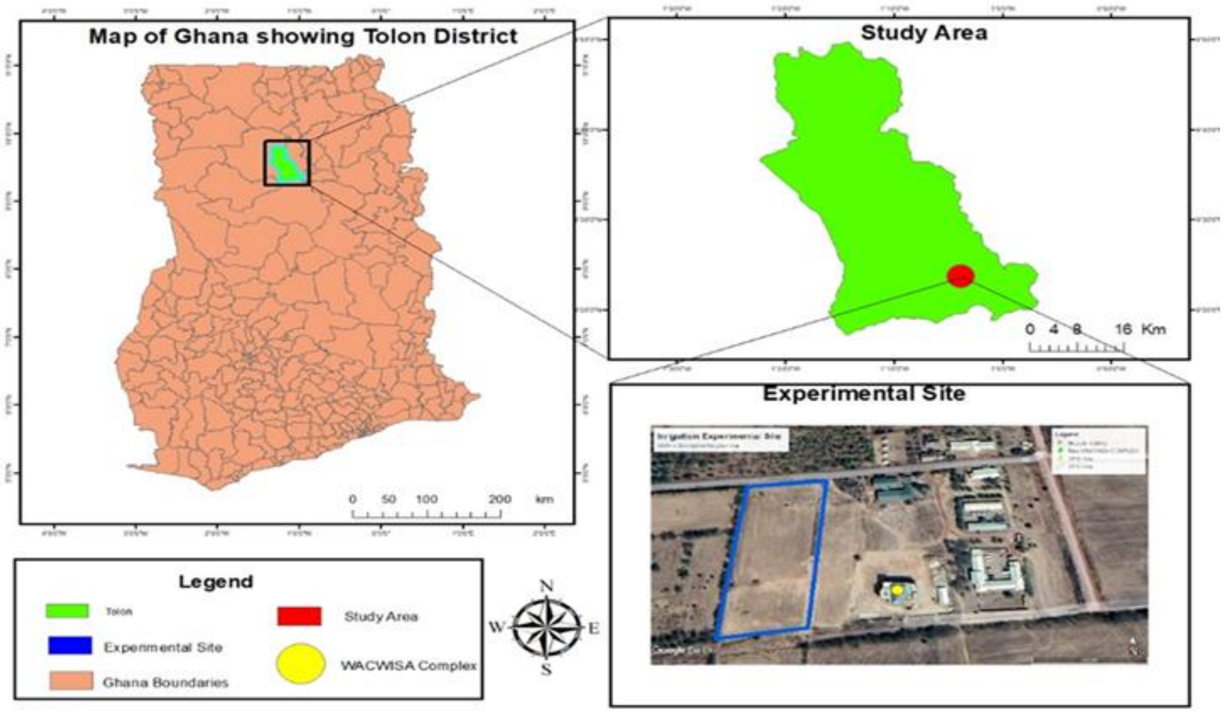


Figure 3.1: Map of WACWISA Experimental Field

3.2 Experimental Design and Layout

The experiment was conducted in pots using one of the local varieties of garden eggs known as Gilo Variety with four (4) different soil amendment techniques namely; groundnut shells biochar, poultry manure, combination of poultry manure -groundnut shells biochar and control under three (3) different irrigation regimes namely; water application at 70 % CWR (regulated deficit), 70 % CWR (sustained deficit) and 100 % CWR (full irrigation). Regulated deficit irrigation at milt deficit of 70 % CWR was applied where water deficit was applied only on no-critical stage of garden eggs which are crop development and fruit enlargement stages while full irrigation (100 % CWR) was applied at critical stages which are seedling establishment after transplanting, flowering and fruiting stages. Sustained deficit irrigation at milt deficit of 70 % CWR was applied where water deficit was applied through all growth stages of garden eggs either critical or no-critical stages. The full irrigation at 100 % CWR was used to compare the performance of the two (2) different deficit irrigation regimes on growth and yield of the garden eggs.

The main treatments were three (3) drip irrigation regimes (70 % CWR regulated deficit, 70 % CWR sustained deficit and full irrigation 100 %) whilst the sub-treatments were four (4) soil amendment techniques (biochar, fertilizer, combination of fertilizer and biochar and no-biochar no poultry) and each pot was filled with 12 kg of soil. The combination of the four (4) soil amendment treatments and the three (3) irrigation regimes resulted in 12 treatments which replicated 3 times in split-plot design and total number of experiments used in experimental were 36 pots. The experimental treatments are presented in Table 3.1 whilst the field experimental layout is present in Figure 3.2.

Table 3.1: Experimental Treatments

Treatment	Irrigation Regime	Biochar (B)+Soil	Poultry Manure (PM) + Soil	Combination
T1	Regulated water deficit- 70 % CWR	0.5:5 (v:v)/pot	0.5:5 (v::v)/pot	RDI and PMB
T2	Regulated water deficit- 70 % CWR	0:5 (v:v)/pot	0:5 (v:v)/pot	RDI and NPMB
T3	Regulated water deficit- 70 % CWR	0:5 (v:v) /pot	1:5 (v:v)/pot	RDI and PM
T4	Regulated water deficit -70 % CWR	1:5 (v:v)/pot	0:5 (v:v)/pot	RDI and B
T5	Sustained water deficit 70- % CWR	1:5 (v:v)/pot	0:5 (v:v)/pot	SDI and B
T6	Sustained water deficit- 70 % CWR	0:5 (v:v)/pot	0:5 (v:v)/pot	SDI and NPMB
T7	Sustained water deficit -70 % CWR	0:5 (v:v)/pot	`1:5 (v:v) /pot	SDI and PM
T8	Sustained water deficit -70 % CWR	0.5:5 (v:v)/pot	0.5:5 (v:v)/pot	SDI and PMB
T9	Full irrigation -100 % CWR (FI)	0:5 (v:v)/pot	0:5 (v:v)/pot	FI and NPMB
T10	Full irrigation -100 % CWR (FI)	0:5 (v:v)/pot	1:5 (v:v)/pot	FI and PM
T11	Full irrigation- 100 % CWR (FI)	1:5 (v:v)/pot	0:5 (v:v)/pot	FI and B
T12	Full irrigation- 100 % CWR (FI)	0.5:5 (v:v) /pot	0.5:5 (v:v)/pot	FI and PMB

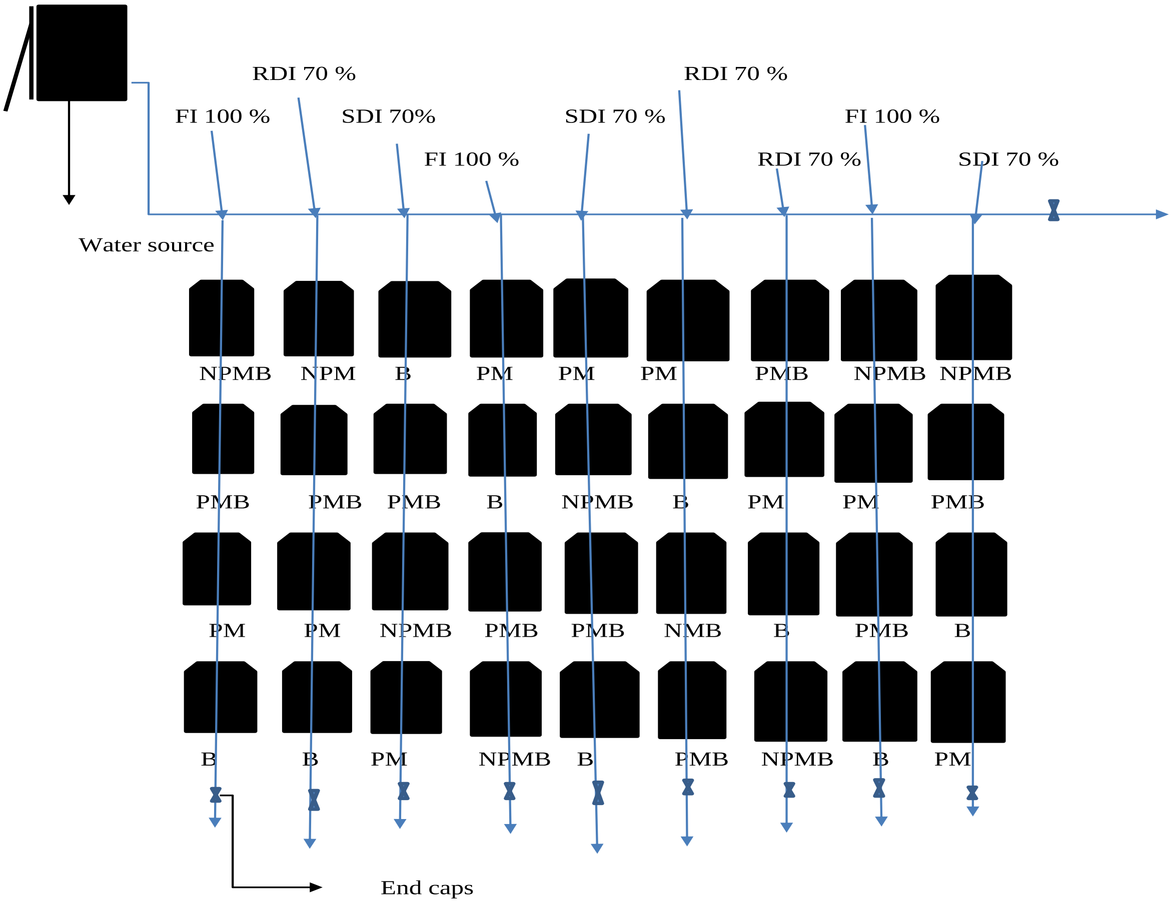


Figure 3.2: Field Experimental Layout

3.3 Agronomic Practices

3.3.1 Variety of Garden Egg

For this experiment, one of the local garden eggs varieties known as *Solanum aethiopicum* var. Gilo from the Gilo group was selected and used due to their availability and adaptability to the local weather of Tamale. It is the most common variety cultivated in northern Ghana.

3.3.2 Nursery Preparation

Nursery beds were prepared on 6th February, 2023 where 20 g of garden egg seeds were sowed and covered with a thin layer of straw mulch to retain soil moisture and regulate soil temperature for effective and uniform seed germination. Garden eggs seedlings emerged 7 days after planting (DAP), after which the mulch material was removed from the surface and raised to allow the 36 seedlings to be well established. Shade was constructed by using grasses and hanging sticks in a period of 4 weeks with row spacing of 1.5 m × 1 m and everyday watering was done by using watering cans morning and evening until the seedling reached the stage of three (3) true leaves indicating they seedlings were ready for transplanting.

3.3.3 Groundnut Shell Biochar Preparation

Groundnut shells were collected at Nyankpala Groundnut Shelling Unite and charring was done by using a cuntan-charring apparatus obtained from UDS- soil laboratory where Hard sticks were used to start the fire beneath the apparatus, and the temperature needed for charring was held between 250 and 300 ^{o}C. For complete charring to take place, raw groundnut shells were uniformly distributed around the apparatus while turning the groundnut shells around it. After charring, hot biochar were spread using a shovel for cooling. Groundnut shells were selected because their biochar have been noted to high performance in crop production. Camara-williams (2019) conducted a pot and field experiments Ghana on the effect of rice straw biochar, groundnut shell biochar, rock phosphate and calcium carbonate with two soybeans varieties (Jenguma and Quarshie) and groundnut shell biochar produced the highest number of 126 nodules and production on Quarshie variety. Plate (3.1) represented production of biochar used in experiment.

Plate 3.1: Biochar Production Using Cuntan-charring Apparatus

3.3.4 Poultry Manure

Poultry manure were obtained from UDS Poultry Farm and mixed with soil and allowed for 2 weeks for decomposition before transplanting. Poultry manure is considered as an essential organic fertilizer and it has increased soil productivity and growth of crops compared to goat manure or cow dung. Poultry manure was also selected based on their performance among other organic manures.

3.3.5 Field Preparation

Land was prepared by cleaning the field and drip-lines were laid across the field and pots were arranged in the field by digging holes of depth 0.4 m to flatten pots to the level of drip-lines and each hole directed under emitter and garden egg planting distance was taken according to emitter distance as 60 cm between plant and 60 cm between rows.

3.3.6 Transplanting

Bucket pots of 40 cm depth, 35 cm top diameter, 20cm bottom diameter were used for the experiment. Holes were perforated at the bottom of the pots to drain excess water. Pots were prepared 2 weeks before transplanting and different soil composition were weighted at 12 kg according to the depth of the pots and kept watered for 4 days to obtained moisture content at field capacity before transplanting. Pots were placed according the split-plot design. One seedling was transplanted in each pot. After transplanting, water was applied at 100 % CWR until seedlings established and straw mulch were used to keep soil moisture in the soil and regular hand picking of weeds was done to control weeds. Crop monitoring was regularly carried out to examine adaptability of seedlings in the pots and replacement of weaker seedlings was done in a week after transplanting. After establishment of seedlings, different irrigation regimes were implemented to achieve the objectives of the study.

3.4 Layout of Drip Irrigation System in Experimental Field

Drip irrigation system is one of the three (3) irrigation systems installed in the WACWISA Experimental Field which is operated by two (2) elevated tanks with a total capacity of 6 m^3 mounted on metallic stand of 3 m height to create pressure. The drip irrigation system has a main and sub-main pipe of same diameter of 32 mm diameter and drip-lines of 16 mm and all drippers were connected on the laterals.

Elevated tanks were filled with water with the help of water pump and amount of water released was calculated according the crop water requirement using CROPWAT (12th edition) Software. The irrigation system has three (3) manually control valves attached to mainline, sub-mainline and each drip line control water distribution in the field. Mainline was made-up of high-density polyethylene (HDPE) with 32 mm internal diameter and its fitting included elbows, tees, reducers and end cups. The mainline was also connected to a disk filter for filtration purpose. The laterals were 16 mm diameter of high-density polyethylene (HDPE) pipes with emitter distance of 30 cm and a maximum flow-rate of 1.6 l/hr.

The drip-lines were placed on the pots and kept straight with pegs at the ends as represented by plate (3.2). After the irrigation system has been installed, water distribution unit was tested in the field with catch cans and 36 catch cans were used according to the number of pots and system operated in period of 30 minutes to determine the distribution uniformity.

Plate 3.2: Layout of Drip Irrigation System at the Field

3.4.1 Calculation Emitter Discharge Rate in Experimental Field.

Dripper discharge was varied according to the regimes of water in tank and average discharge rate of drippers was taken after emitter discharge uniformity and after testing system uniformly water distribution, volumetric method was used to measure emitter discharge where five graduated disposables plastic cups were arranged under each dripper and discharged water were collected in hour. Experiment was repeated 3 times i.e., when tanks were full, when tanks were half-full and when tanks were about to finish because water level in tank affected dripper discharge. The average emitter discharge (Qa) was obtained by using Equation 3.1 as given by Darimani *et al.*(2021).

Qa=$\frac{1}{n}\sum_{i-1}^{n} qi$……………………………………………Eqn 3.1

Where:

Qa = emitter discharge(l/hr),

qi = flow rate of the emitter(l/h), and

n = total number of emitters.

3.4.2 Amount of Water Applied at experimental Field

Water was applied according to the initial soil moisture data that were obtained from soil moisture measurement kits which recorded soil moisture status in every morning. Amount of water applied was calculated bases on various crop growth stages of garden eggs, its rooting depth, manageable allowable depression and wetted Area (Abubaker Jamal, 2001).

Available water content (AWC) = $(FC - PWP)$ …………………………... Eqn 3.2

Total available water (TAW) = $AWC \times Rd$……………………………………. Eqn 3.3

Soil readily available water = $AWC \times Bd$…………………………………… Eqn 3.4

Irrigation depth (Id) = $RAW(mm) \times Rd(cm) \times MAD \times A(cm)$……. Eqn 3.5

Where:

FC - Field capacity,

PWP - Permanent wilting point,

Rd - Root depth (cm),

Bd - Bulk density,

MAD – Manageable allowable depletion,

RAW -Readily available water content, and

A -Wetted area (cm).

3.4.3 Crop Water Requirement at Experimental Field

The daily reference crop evapotranspiration (ETo) was determined using weather data collected from the weather station situated in the WACWISA experimental field. To adapt the crop water requirement (CWR) for localized drip irrigation systems, the equation proposed by Keller and Bliesner in 1990 was applied. This conversion equation takes into account the ground cover (Pd) of the specific crop, which typically ranges from 70% to 100% depending on the crop type and its expected ground cover but most researcher prefer to use of 95 % (PNS, 2017; Rodrigo *et al.*, 2021). The adjusted CWR was calculated using the formula given in Equation 3.6.

$Td = Ud \times [0.1\,(Pd)^{0.5}]$ ……………………………………......................................Eqn 3.6

Where:

Td - CWR-localized,

CWR (localized) - Estimated CWR-crop at peak demand for localized irrigation,

Ud - Conventionally estimated peak CWR-crop, and

Pd - Percentage ground cover (%).

The crop coefficient (Kc) values for garden eggs were considered to determine the crop water requirement at different stages of growth. The Kc value for the initial stage was 0.45, for the crop development stage it was 0.75, for the mid-season stage it was 1.15, and for the late harvesting stage it was 1.10. These Kc values were utilized to calculate the water requirement for each specific growth stage of the garden egg crop.

Crop water requirement: $ETcrop = ETd \times kc \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..$ Eqn 3.7

Where:

CWR-crop refers to the crop water requirement, which represents the amount of water needed by the crop on a daily basis, measured in millimeters per day (mm/day).

Kc-is a factor that accounts for the water needs of a particular crop compared to the reference evapotranspiration (ETo).

Eto- represents the overall evapotranspiration in a given area, also measured in millimeters (mm).

By using the appropriate Kc value and combining it with the reference ETo, the CWR-crop was calculated to determine the daily water requirement for garden egg.

Irrigation requirement to meet daily crop evapotranspiration was calculated with consideration of effective rainfall in the entire growth period and net irrigation was calculated using equation 3.8

$\text{NIR} = \text{CWR (localized)} - Pe$……………………Eqn 3.8

Where:

NIR - Net irrigation requirement, and

Pe - Effective rainfall.

Effective rainfall was taken from weather station located in WACWISA experimental field and rainfall less than 5 mm was considered as ineffective while rainfall greater than 5 mm, 50 % of it was considered as effective rainfall (Abubaker Jamal, 2001). Equation 3.9 was used to calculate effective rainfall.

$\text{Pe} = (P - 5) \times 0.5$……………………………………. Eqn 3.9

Where:

Pe - Effective rainfall, and

P - Total rainfall in given day.

Gross irrigation requirement was obtained by using the following equation 3.10:

Gross irrigation requirement (GIR) = $\frac{\text{net irrigation requirement}}{\text{Application efficiency}}$………… Eqn 3.10

Calculation of gross irrigation requirement for each pot was based on crop evapotranspiration (CWR 100 %; CWR 70 %) on both regulated and sustained deficit and running time were also calculated based on emitter discharge by using formula given by Darimani *et al.* (2021).

3.4.4 Efficiency of WACWISA Drip Irrigation System

The efficiency of the drip irrigation system varies between 90 % and 95 % when properly designed, installed and managed (Darimani *et al*., 2021). Data obtained from 36 catch cans were used to test performance of irrigation system installed in the field experiment by considering Uniformity of water distribution and uniformity coefficient.

3.4.5 Uniformity of Water Distribution

Drip irrigation performance were tested based on previous researchers to obtained performance of drip irrigation installed in WACWISA Experimental Field. The coefficient of uniformity and distribution uniformity of water indicate how water is evenly distributed in the field.

The formulas (Equations 3.11 and 3.12) developed by Keller and Karmeli (1974) were used to determine the distribution uniformity of the drip irrigation system.

DU (%) = $\frac{The\ average\ volume\ of\ the\ lowest\ quater\ of\ catch\ can\ measurement}{The\ average\ volume\ of\ catch\ can\ measurement}$×100....Eqn 3.11

DU (%) = 100 [Q^{25} / Qav] ....Eqn 3.12

System classification developed by Merriam and Keller (1978) was used to examine the performance of the drip irrigation system.

Table 3.2: Classification of Uniformity of Water Distribution

Uniformity of Water Distribution (%)	Classification
<66	Poor
66-70	Poor
70-79	Acceptable
80-84	Good
84-90	Good
>90	Excellent

Uniformity Coefficient was also calculated by using equation 3.13:

$$UC = 100\left[1 - \frac{1}{nqa}\sum_{i-1}^{n}|qi - qa|\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 3.13}$$

Where:

q_a - average of emitter flow tested during experiment (l/h),

n - number of emitters under consideration, and

qi -each flow-rate measured in catch can (l/h).

Table 3. 3: Uniformity of Coefficient

Uniformity of coefficient (%)	Classification
<60	Unacceptable
60-70	Poor
70-80	Fair
80-90	Good
>90	Excellent

3.5 Data Collection on Soil Properties

3.5.1 Soil Infiltration

Tension mini-disk infiltrometer known as mini-disk infiltration was used for soil infiltration measurement at the suction tension of 2 cm as represented by table and plate (3.3).

For calculation of soil infiltration values, equation developed by Zhang (1997) and (Genuchten, 1980) were used as given in equations 3.14 and 3.15 as follows:

$I = c2t + c1\sqrt{t}$ ……………………………………………Eqn 3.14

$K = \frac{C1}{A}$……………………………………………………Eqn 3.15

Where:

I - soil infiltration capacity (cm/sec),

k – Hydraulic conductivity of the soil

C1 ($cm.s^{-1}$) and C2 ($cm.(s^{-1})^{-0.5}$)- are parameters

C2 - is a parameter that is associated with the hydraulic conductivity of the soil

C1- represents the soil sorptivity value, which is a parameter used to describe the ability of soil to absorb water

C1 is obtained from the slope of the cumulative infiltration curve versus the square root of time

A- The parameter A is associated with the Ganuchten equation and is used to relate soil properties to the suction rate and the radius of the infiltrometer disk for specific soil types.

and The Van Genuchten equation involves the determination of parameters specific to 12 different soil texture classes. Table (3.4) represent A value from the 2.25 cm disk radius and suction value from 0.5 to 6 cm.

Table 3.4: A-value from 12 Different Soil Texture

Soil Texture	Suction						
	-0.5	-1	-2	-3	-4	-5	-6
Sand	2.84	2.40	1.73	1.24	0.89	0.64	0.46
Loamy sand	2.99	2.79	2.43	2.12	1.84	1.61	1.40
Sand loamy	3.88	3.89	3.91	3.93	3.95	3.98	4
Loam	5.46	5.72	6.27	6.87	7.53	8.25	9.05
Silt	7.92	8.18	8.71	9.29	9.90	10.55	11.24
Silt loam	7.10	7.37	7.93	8.53	9.19	9.89	10.64
Sandy clay loam	3.21	3.52	3.24	5.11	6.15	7.41	8.92
Clay loam	5.86	6.11	6.64	7.23	7.86	8.55	9.30
Silt clay loam	7.89	8.09	8.51	8.95	9.41	9.90	10.41
Sand clay	3.34	3.57	4.09	4.68	5.36	6.14	7.04
Silt clay	6.08	6.17	6.36	6.56	6.76	6.97	7.18
clay	4.00	4.10	4.30	4.51	4.74	6.98	5.22

Source: (MDI-Decagon, 2012)

Plate 3.3: Mini-Disk Infiltration Test

3.5.2 Soil Bulk Density

Dry bulk density of the soil (BD) was determined by using oven-dry method at 105 °C. Core sampler was used to collect soil in the field where core samplers were driven vertically into the experimental soil until enough soil filled the core and were removed carefully without disturbing soil particles and directly transferred into oven dry in 24 hours period. Weight of core sample before and after drying was taken to compute soil bulk density by using equation (3.16). The higher value of bulk density, means the more compacted the soil and this resulted in roots penetration problems (Blake, 2016).

$$\text{Bulk Density } = \frac{\text{weight of oven}-\text{dry soil in gram with its contoiner(after 24hrs) }-\text{mass of container in gram}}{\text{volume of the container in } cm^3} \text{.......Eqn 3.16}$$

3.5.3 Determination of Soil Particle Distribution

Hydrometer method were used for soil particle distribution where sample were collected in field experimental units and analyzed for gravel, clay, sand percentages. Soil was sieved in 2 mm sieve.

51 g of soil was transferred into plastic beaker and mixed with 100 ml of distilled water and mixed to wet the soil thoroughly after mixture, 20 ml of 30 % H_2O_2-H_2O_2 were added to destroy soil organic matter, 50 ml of 5 % Sodium Hexamethaphosphate $(NaPO_3)_6$ were also added for soil particle separation and shake well by using mechanical shaker and solution was transferred again in beaker and 1000 ml of distilled water were added. Thermometer was used to measure temperature whiles the hydrometer readings were taken from the hydrometer instrument in 40 second. The same reading procedure were repeated after 3 hours period. Finally, clay, silt and sand percentage were obtained by using equation 3.17,3.18 and 3.19.

% Sand = $100 - [H1 + 0.2\ (T1 - 20) - 2] \times 2$………. Eqn 3.17

% Clay= $[H2 + 0.2\ (T2 - 20) - 2] \times 2$………………. Eqn 3.18

% Sand= $100 - (\ \%\ clay + \%\ sand$…………………. Eqn 3.19

The value obtained were used to classify soil texture by using soil textural triangle (Phogat *et al.*, 2016).

3.5.4 Determination of Organic Carbon and Organic Matter Content

Soil organic carbon content of the samples was also carried out by walkley-black wet oxidation method. Weight of 1 g soil sample as transferred into 250 ml Erlenmeyer flask and a burette of 10 ml of 1.0 $K_2Cr_2O_7$ solution followed by 20 ml of H_2SO_4 and shake well to ensure that the solution is in contact with all soil particles then solution cooled in 330 min period. 100 ml of distilled water combined with 10 ml of H_3PO_4 acid was also added and 2 ml of diphenylamine indicator was used to indicate soil organic carbon. The procedure ended by titrating solution with 10 ml ferrous sulphate solution until the color changed to blue then green as end point as presented by plate (3.4) The record of titrate value and black solution were used to determine soil organic carbon using equation 3.20.

% OC in soil =$Blank\ value - Titrate\ value(0.003 \times f \times 100)$……….. Eqn 3.20

Where;

% OC-Organic carbon and

f- correction factor (f) = 1.33

Plate 3. 4: Analysis of Soil Organic Carbon

Organic matter mass percentage was determined by finding the percent of organic carbon present in the sample and was converted to organic matter (Blake, 2016) by using this formula

$OM\ (\%) = 1.724 \times OC\ (\%)$……………………………………………….…Eqn 3.21

Soil fertility were classified according to organic matter obtained in the soil after amendment with poor organic soil less than 10 %, medium organic soil lies between 10 to 30 % and high organic soil which is greater than 30 % (Huang *et al*,. 2009).

3.5.5 Field Moisture Status and Water Holding Capacity

Water characteristics hydraulic properties software developed by Keith Saxton in conjunction with department of biological system engineering as stated by Oyeogbe and Oluwasemire (2013) was used to determine permanent wilting point and field capacity using value obtained from soil particle distribution which (clay, sand, silt and soil organic matter content).

3.5.6 Soil Chemical Properties

Samples of soil were collected for being analyzed. soil before amendment application and in soil with amendment and were tested for N, P, K, Ca, Mg, pH, EC, and organic carbon at CSIR-SARI soil laboratory**.** Electric conductivity (EC) is a function of its chemical decomposition and salinity is quantified in term of the total concentration of the solute salts as measured by the EC of the soil in Ds/m (Corwin, 2003). Electrical conductivity (EC) is a parameter used to assess the conductivity of a solution or the concentration of soluble salts within a sample. It indicates the ability of a solution to conduct an electric current and is commonly measured using a combination of pH and electric conductivity meters (FAO, 2020). Total nitrogen available in the soil was examined by Kjeldahl method while the Bray-P solution method was used to determine phosphorus (P). Flame photometer method was used to measure potassium (K). The ammonium acetate method was used to determine calcium (Ca) and magnesium (Mg) content (Buurman *et al.*, 1996; Bélanger *et al.*, 2007; Abukari *et al.*, 2018).

3.5.7 Garden Egg Growth Parameters Data

To evaluate the impact of irrigation regimes and soil amendment techniques on the growth and yield of garden egg plants, various parameters were measured at two-week intervals, starting from two weeks after transplanting. These parameters included height, stem girth, number of branches, leaf area index and crop water requirement (CWR).

3.5.7.1 Plant Height

The height of the plant was measured from the base of the stem to the top of apical meristem by using folding long rule during growth period, flowering and fruiting stage.

3.5.7.2 Stem Girth

Stem girth was measured from the base of the stem by using automated vernier caliper during growth period, flowering and fruiting stage.

3.5.7.3 Number of Branches

Number of branches were counted during growth period, flowering and fruiting stage.

3.5.7.4 Plant Chlorophyll

During the growth period, flowering, and fruiting stages, the chlorophyll content of the leaves was assessed using an SPAD Chlorophyll meter manufactured by KONICA MINOLTA INC in the USA. For each pot, four leaves per plant were selected for measurement.

3.5.7.5 Leaf Area Index

Portable leaf area index (PAR/LAI) Ceptometer was used to measure the leaf area index during growth period, flowering and fruiting stage.

3.5.7.6 Yield Data

36 pots were harvested and weighted in (kg) after harvest from each pot and each replication, the weight of fresh garden egg was measured by using a sensitive electronic balance and expressed in ton/ha.

3.5.7.7 Crop Water Use Efficiency (WUE)

Water use efficiency (WUE) was determined by calculating the ratio of the yield obtained to the amount of water utilized as represented by equation (3.22). This measurement used to assess the efficiency with water utilized in relation to the crop yield. By quantifying the relationship between water consumption and crop productivity, and expressed in kilograms per cubic meters (m^3).

$$\text{WUE} = \frac{YLD}{ETc} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.22}$$

YLD-Total yield (ton/ha).

CWR-Seasonal crop water consumption (kg/m^3).

3.6. Statistical Data Analysis

General analysis of variance (ANOVA) for a split-plot design were used to analyze data. The mean values the treatments were compared for significant difference at 5 % using P-value and least significant difference (LSD) IN GenSTAT statistical package and significantly treatments means were separated by using Duncan Multiple Comparison.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physio-chemical Properties of the Experimental Soil

4.1.1 Soil Physical Properties

Soil physical properties of the experimental field was tested before and after experiment to examine soil physical characteristic caused by application of amendment techniques.

4.1.1.1 Soil Textural Classification and Organic Carbon Content

Walkley-black wet oxidation method was used for soil organic carbon and hydrometer method was for soil particle size distribution in this study. As presented in Table 4.1, the soil particle size distribution before the experiment were determined as 72.16 %, 5.88 % and 21.96 % for % sand, % clay and % silt respectively. The soil was classified as sand loamy according to the textural triangle (source). The organic carbon content from different soil amendments were also calculated and used to calculate soil organic matter content before and after experiment. The soil organic carbon content before the experiment was calculated as 2.21 % whereas the organic matter content was 4.67 %. Please provide data and calculation of these parameters.

After the experiment, soil amended with combination of poultry manure and biochar produced the highest carbon content (5.71 %), followed by biochar (5.11 %) and poultry manure (4.31 %) but the least was recorded in is soil without any amendment techniques (2.71 %). The % clay content was increased by application of poultry manure and biochar combined (5.88-7.92 %). It also decrease % sandy content from 72.16- 67.16 % whereas % silt content was increased up to 24.92 % by the application of poultry manure and biochar combination. Effect of application of poultry manure only increased % clay up to 5.92 %, while the biochar only also increased % clay content from 5.88 - 5.92 %. % Sand content observed in biochar amendment was decreased from 72.16 %

to 68.12 %. Poultry manure also decreased % sand to 68.16 %. Biochar amendment improved % silt content to 26.11 % whereas poultry manure amendment increased % silt to 25.92 %.

Results obtained indicated that the decreased % sand content and increased % clay content was as a result of the presence of organic carbon and organic matter as indicated by (Ning et al., 2022). This was also in line with Yandong *et al*. (2023) who revealed that, combination of biochar and conventional fertilizer increased % clay content, % silt content, decreased % sand content and also enhanced soil organic carbon and soil organic matter. This was also in line with Blanco-Canqui (2017) who showed that, biochar reduced tensile strength and soil particle density by increasing % clay content and decreasing % sand content. (Nath, 2014) indicated that soil organic matter has a positive relationship with % clay content and negative relationship with % sand content.

The application of a combination of biochar and poultry manure resulted with high change in particle distribution compared to using biochar or poultry manure alone. The combined application of these organic amendments enhanced the distribution of soil particles. This was caused by transient organic binding agents provided by poultry manure which caused it to bind with biochar particles to ensure an aggregate stability (Blanco-Canqui, 2017). Presence of organic matter and carbon sequestration obtained from application of biochar and poultry manure influenced the presence of soil organic carbon in the soil and influenced % clay, % sand and % silt, improved aggregate stability, reduce bulk density and increased plant available water content in the soil (Agbede, 2021; Masocha and Dikinya, 2022).

Table 4.1: Soil Particle Distribution and Organic Carbon from different Soil Amendment

Soil Sample		% OC	% OM	% Sand	% Clay	% Silt	Texture
Soil Before Amendment		2.71	4.67	72.16	5.88	21.96	Sand loamy
After Amendment	Combination of Biochar and PM	5.71	9.83	67.16	7.92	24.92	Sand loamy
	Biochar	5.11	8.80	68.12	5.92	25.96	Sand loamy
	Poultry manure	4.31	7.42	68.16	5.92	25.92	Sandy loamy

4.1.1.2. Available Moisture Content for Plant Use

Soil characteristic software (SCS) were used to estimate field capacity, permanent wilting point and plant available water content by using data obtained from soil particle size distribution analysis (Clay content, sandy content, and silt) and organic matter obtained from soil organic carbon analysis and result obtained were represented by table 4.2.

Table 4.2: Plant Available Water Content from Different Soil Amendment.

Soil Sample	Field capacity (%)	Permanent wilting point (%)	Plant available water content (%)	Soil texture
Soil Before amendment	18	7	11	Sandy loamy
Combination of Poultry manure and Biochar	25	10	15	Sandy loamy
Biochar only	23	10	13	Sandy loamy
Poultry Manure only	22	10	12	Sandy loamy

Combination of poultry manure and groundnut shell biochar gave the highest plant available water content (15 %) compare to the other soil amendments. PM gave the least plant available water content (12 %). This variation was as a result of the high soil fertility and organic carbon increase which impacted soil water retaining capacity and soil.

The FC and PWP obtained after application of soil amendment indicated that, % of clay, % sand and % silt can be changed without modifying soil texture. The values obtained were in the range of the estimated values obtained by FAO (1998) on available volumetric water content at field capacity and permanent wilting point for different soil textures. Soil chemical, physical and biological properties change mostly as a result of incorporating organic matter. Sandy loamy soil had FC ranging from 18-28 % while PWP ranges from 6 - 16 % (Richard *et al.*, 1998). Available water content was influenced by soil organic matter increase. This was in line with the findings of Yu *et al.* (2021) discovered a positive correlation between soil water holding capacity and soil organic carbon content. Their study indicated that an increase in soil organic carbon resulted in a corresponding increase in the ability of the soil to retain water. A study conducted by Smith (2016) reported that available water content increase significantly with an increasing soil organic matter. Smith (2016) also revealed that, a change of nature of soil matrix from mineral dominated to the carbon dominated surface has positive influence on plant available water content which can be increased from 2.4 to 5 % per only 1 % of organic carbon in poorly soil which has carbon less than 2.5 % and less than 40 % of clay. Mishra *et al*. (2017) demonstrated that, soil amended by biochar and manure increased the saturated water content, plant available water and FC.

4.1.1.3 Soil Bulk Density.

Soil bulk density was determined after the application of groundnut shell biochar and poultry manure. Soil bulk density is mostly related to soil compaction since compacted soil leads to high value of bulk density. As presented in figure 4.1, bulk density measured from pot before amendment techniques was 1.43 g/cm^3. The pots amended with poultry manure gave a bulk density of 1.23 g/cm^3. This therefore, demonstrated how soil fertility ability to decrease soil compaction and reduce bulk density. Soil amended with groundnut shell biochar produced low bulk density of 0.94 g/cm^3 whereas biochar combined with poultry manure gave a bulk density of 1.02 g/cm^3. This was influenced by carbon content presented in biochar which reduced soil compaction and hence reduced bulk density. Bulk density was also influenced by application of soil amendment because of the change in soil texture by the modification of clay, sand content, soil carbon content, and gravel content. High presence of organic carbon increase soil organic matter in the soil which leads to a substantial increase in biological activity down the soil profile resulting in a reduction in bulk density. The value of bulk density ranges from 0.5 -3.0 g/cm^3 which is different from the soil bulk density of most soils in Northern Ghana which range from 0.8 to 1.8g/cm^3. The work of Sesay (2021) revealed that, soils with bulk density greater than 1.8 g/cm^3 can limit water infiltration.

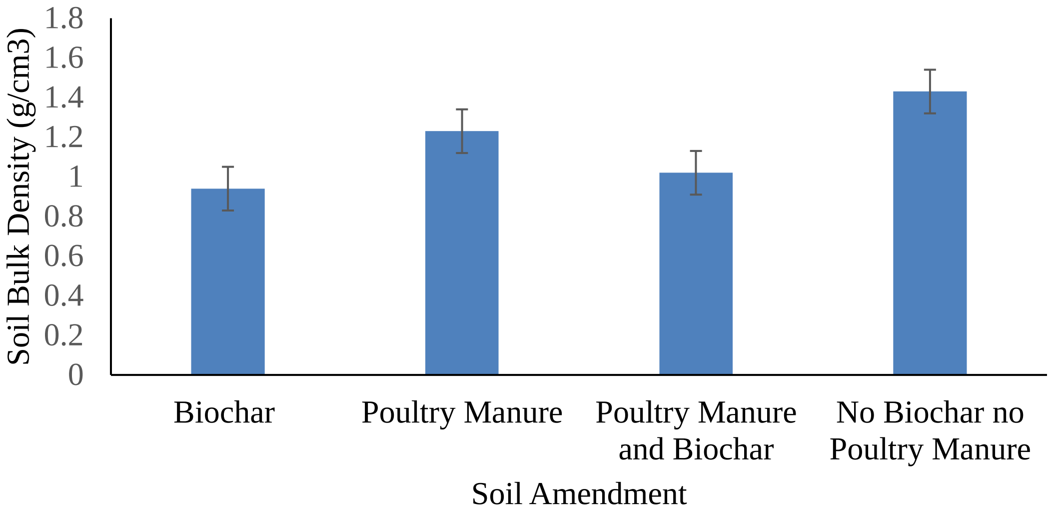


Figure 4. 1: Soil Bulk Density

4.1.1.4 Soil Hydraulic Conductivity (SHC)

Equation developed by Zhang, (1997) and Genuchten, (1980) was used to calculate unsaturated soil hydraulic conductivity on mini-disk infiltrometer data represented in appendix (1).

The Figures (4.2; 4.3; 4.4 and 4.5) represented that unsaturated hydraulic was influenced by biochar and poultry manure application whereas, soil without amendment recorded 7×10^{-3} cm/sec, poultry manure only recorded SHC of 13×10^{-3} cm/sec as SHC the groundnut shell biochar amendment resulted in a SHC of 26×10^{-3} cm/sec and combination of groundnut shell biochar and poultry manure gave a SHC of 22×10^{-3} cm/sec. The values obtained in this study indicated that SHC in biochar amended pots were the highest compare to the pot without amendment. This demonstrated the impact of biochar to increase SHC. Study conducted by Yang *et al*. (2020) reported that the application of biochar improve soil infiltration and reduce soil runoff. Wang *et al*. (2017) and Gholamahmadi *et al*. (2023) reported that, biochar increase soil infiltration and improve soil structure by decreasing soil erodibility dramatically and improved soil aggregate stability. The combination of groundnut shell biochar and poultry manure fertilizer in enhance soil physical properties, thereby facilitating the development and stability of soil structure. This combination likely stimulated increased microbial growth and enhanced soil aggregation that influenced the increase in SHC (Adekiya *et al*., 2020).

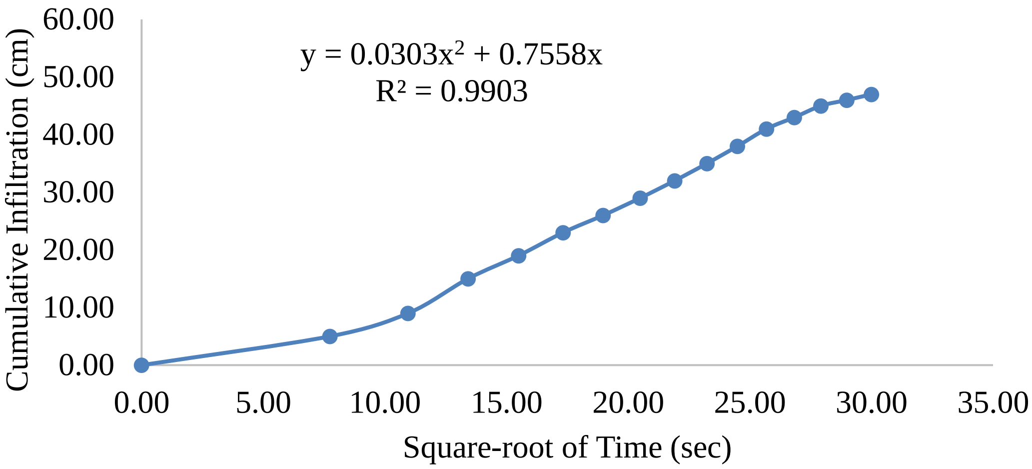


Figure 4. 2: Cumulative Infiltration vs Square Root of Time in no Poultry Manure no Biochar Amended Soil

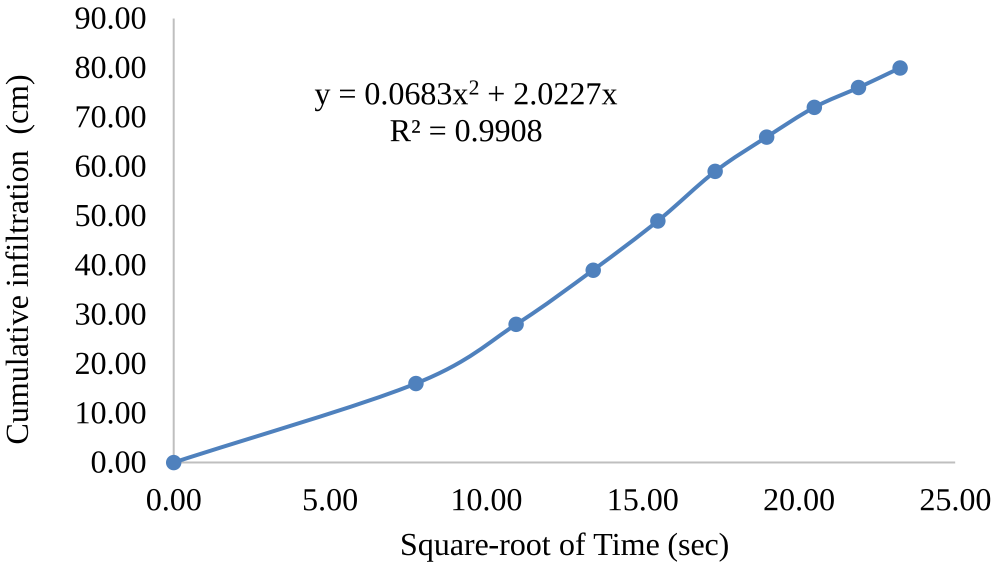


Figure 4.3: Cumulative Infiltration vs Square Root of Time in Poultry Manure Amended Soil

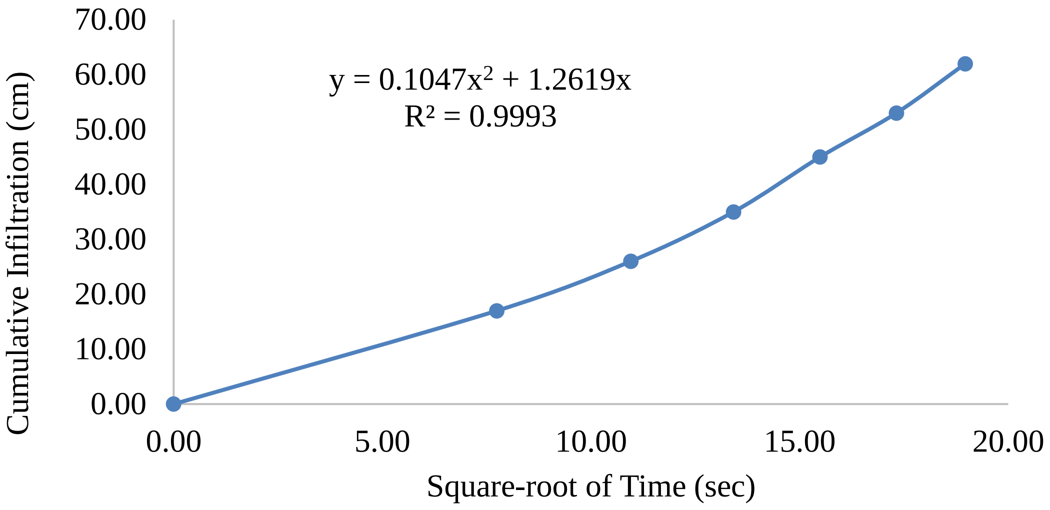


Figure 4.4: Cumulative Infiltration vs Square Root of Time in Biochar Amended Soil

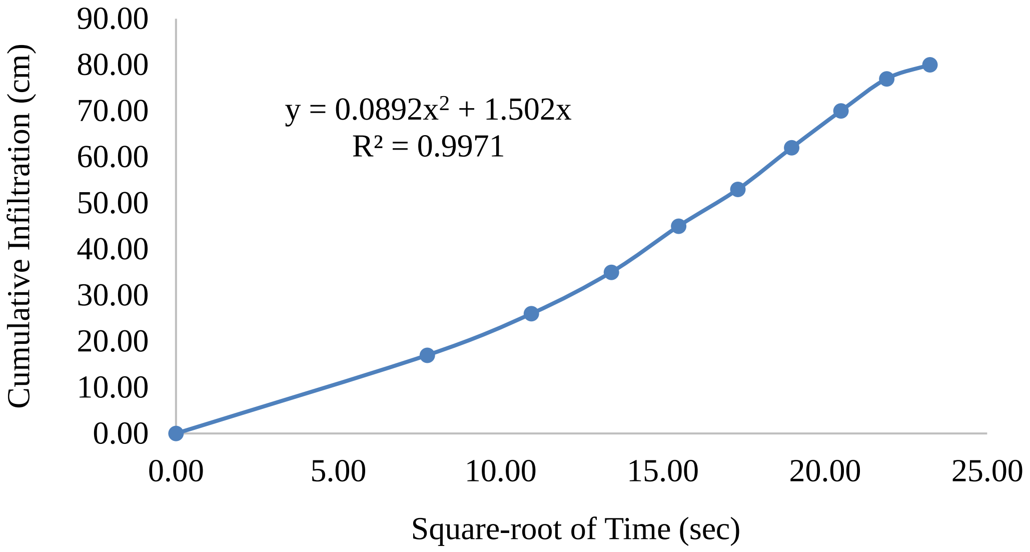


Figure 4. 5: Cumulative Infiltration vs Square Root of Time in Combination of Biochar and Poultry Manure Amended Soil

4.1.2 Soil Chemical Properties

The chemical properties of the soil were also carried out before and after experiment and result showed that, the soil pH before application of amendment was 5.6 and pH tested at harvesting time indicated that, the application of soil amendment techniques affected soil PH. The combination of groundnut shell biochar and poultry manure resulted in a pH of 6.8. The application of poultry manure fertilizer also increased PH (6.19) whereas biochar only also recorded soil pH of 5.71. The results indicated that, the application of different amendment techniques has improved soil pH to the level required for garden egg production which has been reported by Han *et al*. (2021) to be between 5.5-6.8. Agbede *et al.* (2020) also reported that, biochar or poultry manure applied to soil can significantly increase soil pH, reduced bulk density and increased porosity and moisture.

Electrical conductivity was influenced by application of soil amendment. Soil electrical conductivity conducted before soil amendment was 3.23×10^{-2} dsm^{-1} and increased up to $6.23\times 10^{-2} dsm^{-1}$ after the application of biochar and poultry manure. Poultry manure only and biochar only increased soil electric conductivity to 5.60×10^{-2} dsm^{-1} and 4.38×10^{-2} dsm^{-1} respectively. The results was in line with previous studies which revealed that, the application of groundnut shell biochar and poultry manure fertilizer can increased soil pH and EC compare to the control (Chathurika *et al.*, 2016; Shah *et al.*, 2017). There is a relationship between plant growth, yield biomass and electric conductivity and pH. Pots with higher EC and PH in addition with biochar and poultry manure combined produced plant vigor, longer plant height and high fruit yield.

Total nitrogen content (TNC), Potassium (K), Phosphorus (P), calcium (Ca) and magnesium (Mg) of the soil were influenced by the application of soil amendment. Soil macro and micro nutrient measured after soil amendment indicated how combined poultry manure and biochar influenced soil chemical properties as presented in Table 4.3.

Table 4.3: Soil Chemical Properties of Experimental Site

Soil Sample	Total nitrogen content (%)	Potassium (mg/kg)	Phosphorus (mg/kg)	Calcium (Cmol+/kg	Magnesium (Cmol+/kg)
Soil Before amendment	0.045	1.28	42	3.5	0.4
Combination of Poultry manure and Biochar	1.28	4.72	79	7.2	2.2
Biochar only	0.63	3.59	62	5.8	1.6
Poultry Manure only	0.86	3.06	65	6	1.8

Soil chemical properties was increased by biochar and poultry manure combination compare to the soil without amendment. The results were supported by Carmo *et al.* (2016) who indicated that concentration of ions such as F^-, Cl^-,NO_3^-,Br^-,SO_4^-, Mg^+,Ca_2^+ and Na^+ have greater relationship with EC that is obtained from soils made up higher clay content and organic matter content. Neina (2019) reported that, soil biochemical properties was influenced by pH and EC which affects plant growth and biomass yield due to the presence of Ca, Mg, Na. Adekiya *et al*. (2020) reported that, the application of biochar alone did not result in an increase in nitrogen levels. However, when biochar was combined with poultry manure, it led to improvements in soil pH, as well as increased levels of calcium (Ca) and magnesium (Mg) and promoted the yield of ginger. Result obtained from different studies revealed that, the influence of biochar, poultry manure and combination of poultry manure and biochar on soil pH and SHC.

4.2 Crop Water Requirements and Irrigation Regimes of Garden Egg

4.2.1 Weather Parameters of the Experimental Site during Experimental Period

Appendix (2.A and B) indicated weather parameters such as solar radiation, wind speed, dairy temperature; Dairy reference crop evapotranspiration of the experimental site recorded in garden eggs growing period started in march to June indicated that maximum solar radiation was obtained in march (517.46 W/m^2) and minimum obtained in June with 116.72 W/m^2. Maximum wind speed was recorded in June (2.47 m/s) while minimum was in march (0.41 m/s). Maximum daily temperature was recorded in March (33.49 ℃) and minimum recorded in May (24. 24 ℃). The temperature recorded was in line with the required temperature for growing garden eggs which range from 21 ℃ −29 ℃ and tolerate between 10 to 40 ℃ as reported by Han *et al*.(2021). Temperatures above 30 ℃ slowed down eggplant growth parameters and yield (Adamczewska-Sowińska *et al.*, 2016). Research conducted by Annah (2020) stated that, garden eggs can tolerate temperatures below 17 ℃ and above 35 ℃ but high temperature affect garden eggs especially during growth and pollination.

Garden egg was affected by high temperature where temperature increased has become a primary limiting factor for plant development and yield (Santhiya *et al*., 2019). Weather parameters such temperature, wind speed, wind direction, vapor pressure, atmospheric pressure, sunshine hours and radiation influenced daily reference crop evapotranspiration (mm/day) in the experimental field. Minimum, maximum and monthly mean was represented respectively. In March, minimum and maximum were 4.2 mm/day and 9.2 mm/day respectively. April recorded 4.8 mm/day and 8.9 mm/day for minimum and maximum respectively. May recorded 3.1 mm/day and 8.8 mm/day for minimum and maximum respectively with a mean of 6.1 mm/day and in June recorded 4.6 mm/day and 8.5 mm/day for minimum and maximum respectively with a mean of 6.8 mm/day. Figures (4.6; 4.7; 4.8 and 4.9) represented climatic condition during field experiment.

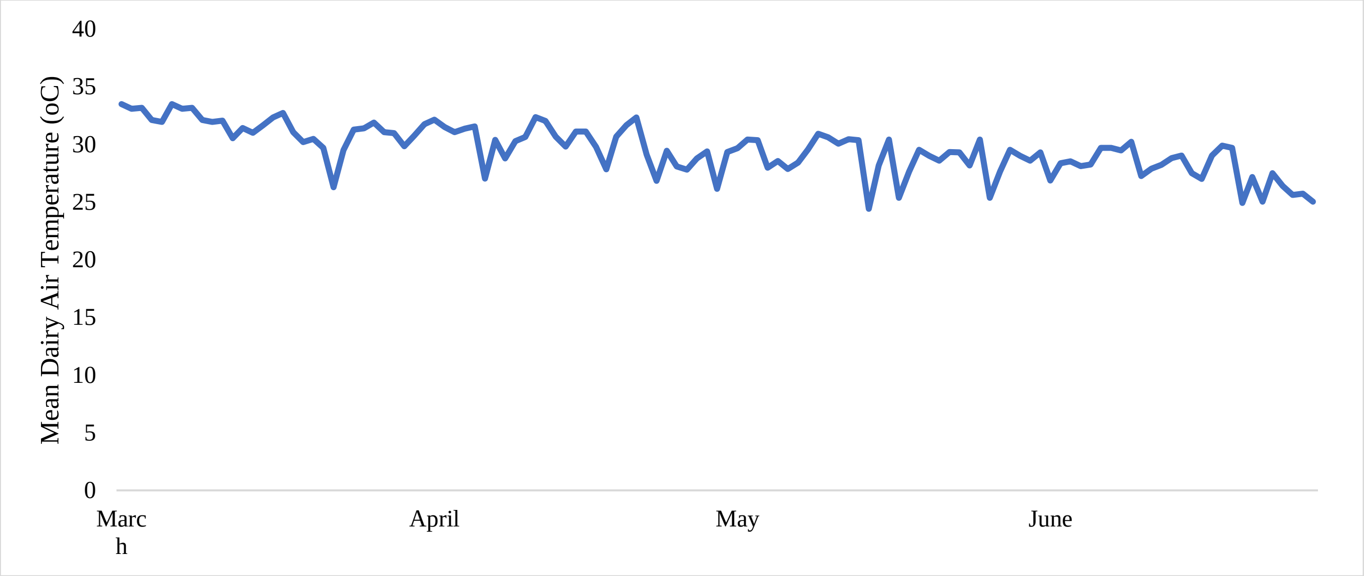


Figure 4.6: Daily Mean Temperature at the Experimental Site

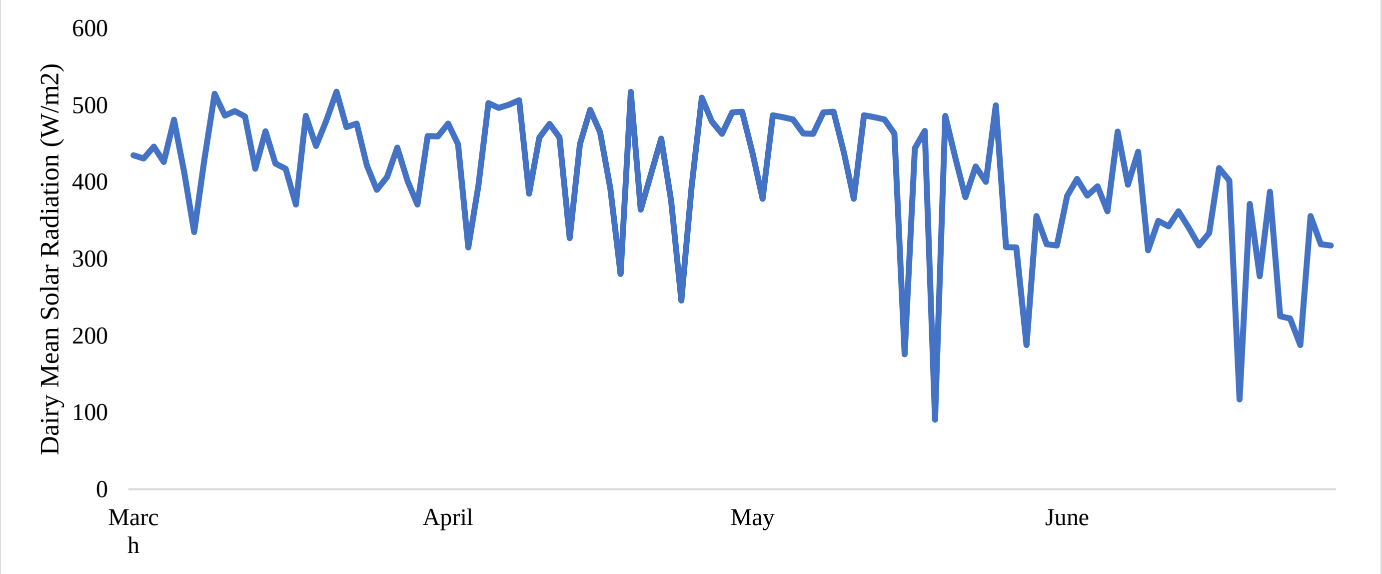


Figure 4.7: Daily Mean Solar Radiation Recorded at the Experimental Site

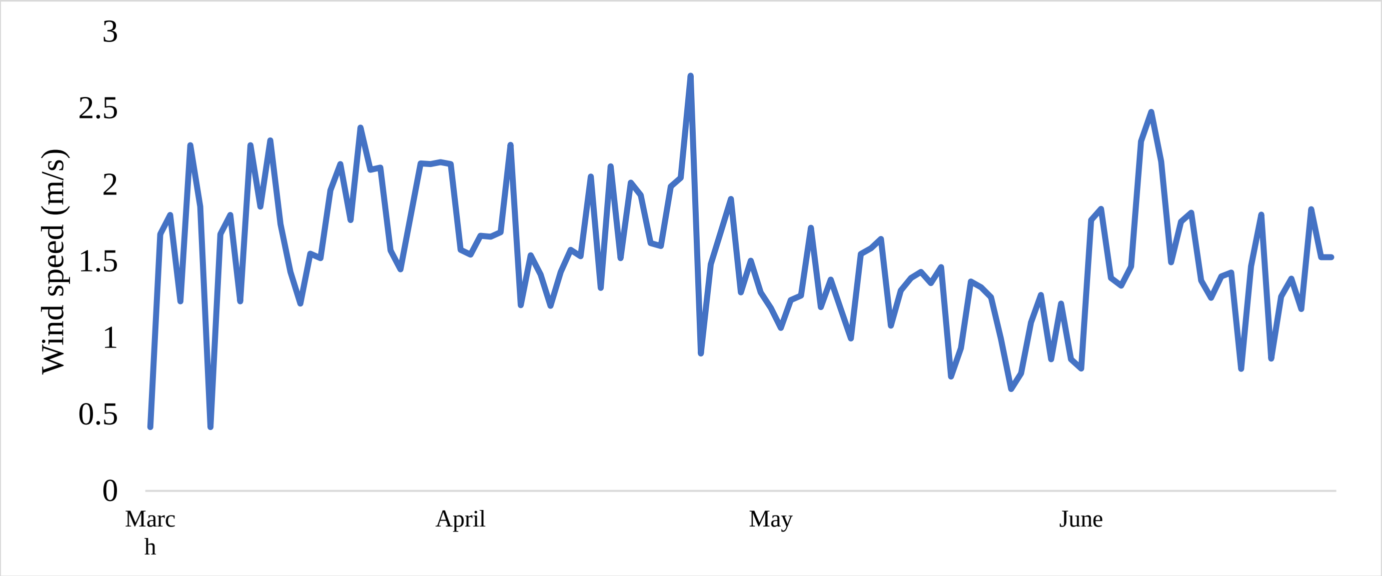


Figure 4.8: Daily Mean Wind Speed at the Experimental Site

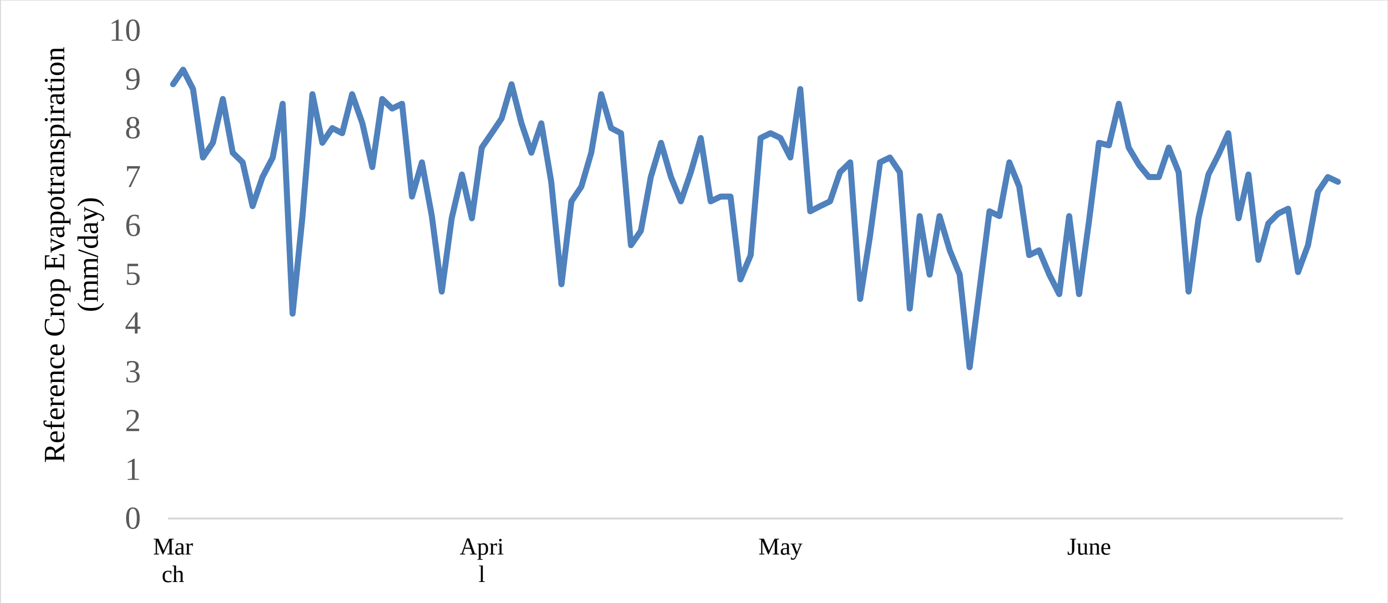


Figure 4. 9: Daily Reference Crop Evapotranspiration at Experimental Site

4.2.2 Crop Water Requirement of Garden Egg and Irrigation Regimes

Crop water requirement were calculated based on daily crop evapotranspiration (ETo) and crop coefficient (KC) value as represented in table (4.4). For regulated deficit irrigation, 70 % CWR was applied based on crop growth stage whereas 70 % CWR applied at non-critical stage and 100 % CWR applied at full irrigation. Maximum water was applied at full irrigation (100 % CWR) and minimum water was applied at sustained deficit irrigation (70 %).

Table 4.4: Seasonal Crop Water Consumptions

Month	Growth stage	duration	Kc-value	Number of days	100% CWR (mm)	70%-CWR Regulated (mm)	70%-CWR sustained (mm)
February-March	initial	6h -7th	0.45	30.00	107.25	107.25	75.08
March-May	Development	8th -6th	0.75	60.00	276.80	206.18	194.91
May-June	Flowering and fruiting stage	7th -5th	1.15	30.00	199.38	199.38	139.56
June	Late season stage	6th-26th	0.80	20	115.93	80.5	80.5
Total				**140.00**	**699.36**	**593.31**	**490.05**

4.2.3 Testing of Drip Irrigation System WACWISA Demonstration in Field

The performance of drip irrigation system after its installation was tested using uniformity of water distribution and coefficient of uniformity to illustrate how water is evenly distributed on the field. Highest water discharged obtained in catch can was 418 ml for a period of 30 min and lowest water discharged from drip line recorded as 340 ml at a period of 30 minutes. The uniformity coefficient obtained was 95 % which was in line with value recorded by Merriam and Keller (1978) who reported that, the uniformity coefficient was found to be greater than 90 % which was scored as excellent performance of the system in terms of water distribution. Keller and Karmeli (1974) also stated that uniformity of water distribution of 86.9 % indicate good performance. This excellent performance of drip irrigation system was due to regular flushing and regular checking of system leakage before the start of the experiment. Drip irrigation test was also done by many researchers such as Darimani *et al.* (2021) to examine drip irrigation performance in the Upper West Region of Ghana and results obtained shown that, the uniformity of water application was 90 % which indicated good water application of the system. Drip performance also was tested by Pranav *et al.* (2017) the hydraulic performance of a drip irrigation system was evaluated based on various parameters such as emitter discharge, coefficient of variation, emission uniformity, statistical uniformity coefficient, variation of emitter flow, emitter flow uniformity, and absolute uniformity. The findings of the study indicated that the performance of the drip system was rated as excellent and efficient. This suggests that the drip irrigation system effectively delivered water to the plants with high uniformity and minimal variation in emitter flow rates. The results indicated the effectiveness and reliability of the drip irrigation system in providing precise and efficient water distribution, which is crucial for optimizing water use and promoting crop growth.

4.3 Effect of Deficit Irrigation and Soil Amendment Techniques on Growth of Garden Egg

The analysis of variance indicated different treatment effect on growth and yield of garden egg. Parameter such as plant height, stem diameter, chlorophyll content, leaf area index and number of branches were measured and recorded.

4.3.1 Stem Diameter

There was significant difference in stem diameter at 2 weeks after transplanting (WAT) ($p<0.001$), 4 WAT ($p<0.001$), 6 WAT ($p<0.001$), 8 WAT ($p<0.001$) and 10WAT ($p<0.001$) as represented by figure (4.10). At 2WAT, full irrigation measured the highest stem diameter (9.97 mm), followed by regulated deficit (70 % CWR) (8.77 mm) and sustained deficit irrigation performed the lowest

(5.86 mm). Stem diameter also followed the same trend at 4 WAT, 6 WAT and 8WAT and 10 WAT.

For all the weeks, Appendix (4.a) indicated that full irrigation indicated high stem diameter whereas sustained deficit gave the lowest stem diameter. Impact of water deficit were also assessed previous research conducted in 2019 revealed that, plant height and diameter of garden egg decreased with 70 % CWR of water application compare to 100 % CWR (Darko *et al*., 2019). Tomato morphological traits such as plant height, stem diameter, leaf area, chlorophyll content as well as nitrogen uptake were also decreased due to dificit irrigation application (Ullah *et al*., 2021).

Soil amendment also significantly influence stem diameter at 2WAT ($p<0.006$), 4 WAT ($p<0.004$), 6WAT ($p<0.003$), 8WAT ($p<0.001$) and 10 WAT as indicated by figure (4.11). Combination of poultry manure and biochar recorded the highest stem diameter (9.54 mm) whereas the smallest stem diameter (6.42 mm) recorded in soil without biochar or poultry manure.

At harvest, table (4.5) represented no statistical interaction effect observed in irrigation regimes and amendment techniques on stem diameter ($p= 0.51$)

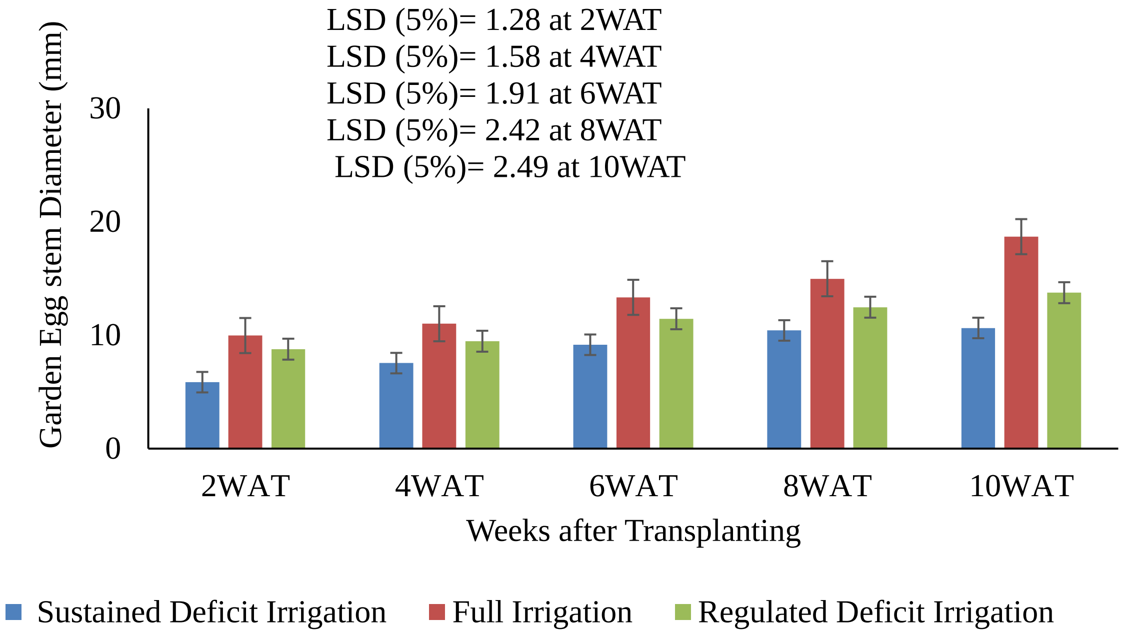


Figure 4.10: Effect of Irrigation Regimes on Stem Diameter of Garden Egg

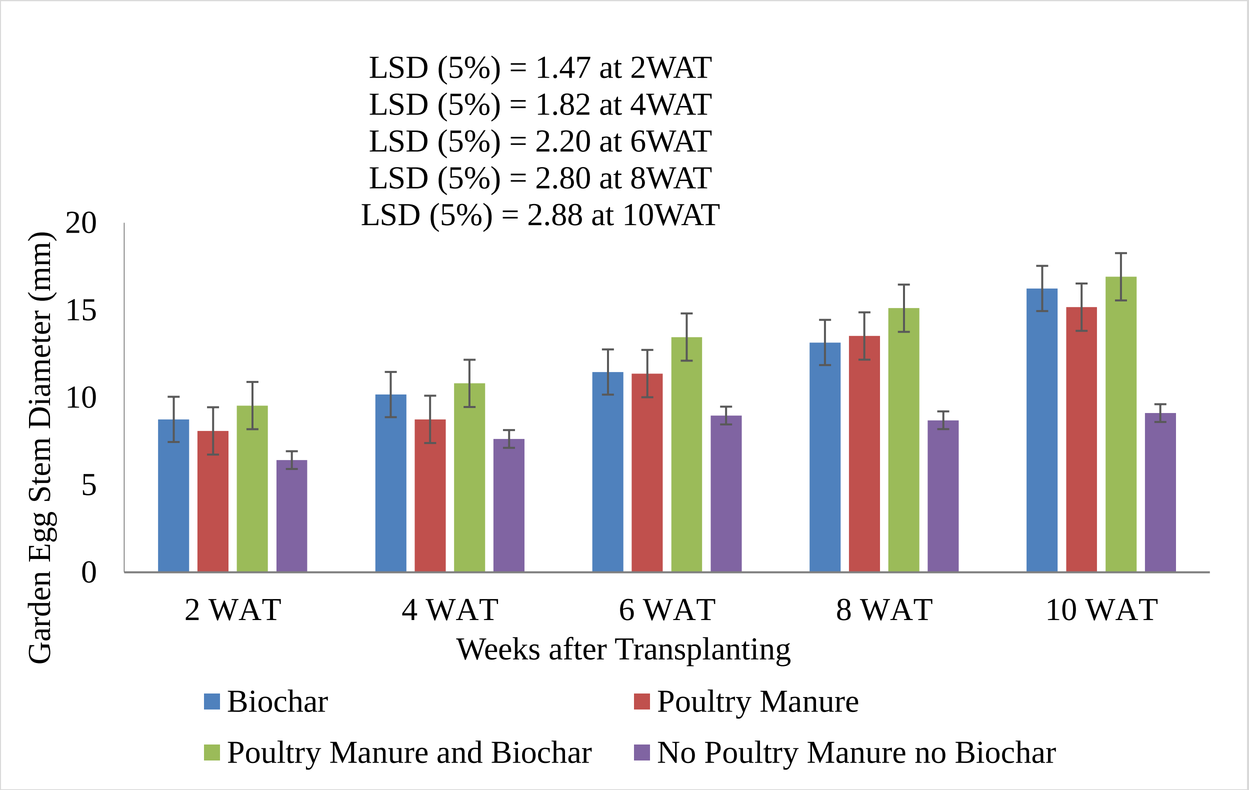


Figure 4.11: Effect of Soil Amendment on Stem Diameter of Garden Egg

Table 4.5: Interaction Effect of Soil Amendment Techniques and Irrigation Regimes on Stem Diameter of Garden Egg at Havest

Fertilizer / **Irrigation**	**No Biochar No Poultry manure**	**Biochar**	**Poultry Manure**	**Poultry Manure and Biochar**
Sustained deficit at 70 % CWR	4.97a	12.3bc	12.62bc	12.65bc
Regulated deficit at 70 % CWR	7.95ab	13.75cd	15.43cd	17.85cde
Full irrigation at 100 % CWR	14.41cd	18.55de	19.14de	22.64e
LSD (0.05)		4.99		
P-Value		0.51		

(Means that do not share same letter are significant difference)

4.3.2 Plant Height

There was significant difference in plant height at 2 WAT ($p<0.001$), 4 WAT ($p<0.001$), 6 WAT ($p<0.001$), 8 WAT ($p<0.001$) and 10WAT ($p<0.001$) as indicated by figure (4.12).

At 2 WAT, full irrigation resulted in the highest plant height (17.08 cm), while sustained deficit irrigation performed less in terms of plant height (14.83 cm). At 4, 6, 8 and 10WAT plant height followed the same trend as in the case of 2WAT (Appendix 4.b) where full irrigation resulted in higher plant height and sustained performed less. Each irrigation level performed differently from each other. Finding obtained from research carried out by Darko *et al.* (2019) revealed that, the eggplant plants exhibited the greatest height when grown in pots receiving 100% of the crop water requirement (CWR). The height observed in this treatment was significantly different from the heights observed in pots receiving 80% and 70% of the CWR. A similar results were observed from a research conducted by Medyouni *et al.* (2021) who showed that, the application of water deficit at crop development stages decreased plant height and stem diameter compare to full water application.

Soil amendment also indicated significant difference at 2WAT (p<0.001), 4 WAT (p<0.001), 6 WAT (p<0.001), 8WAT (p<0.001) and 10WAT (p<0.001) as also represented by figure (4.13). At 2 WAT, the results indicated that combination of biochar and poultry manure resulted in the highest plant height (17.11 cm) and lowest was observed in soil without biochar or poultry manure (12.22 cm). The 4th, 6th, 8th and 10th WAT followed the same trend as in the case of week 2. Table (4.6) represented no interaction effect between the irrigation regime and soil amendments (p=0.21).

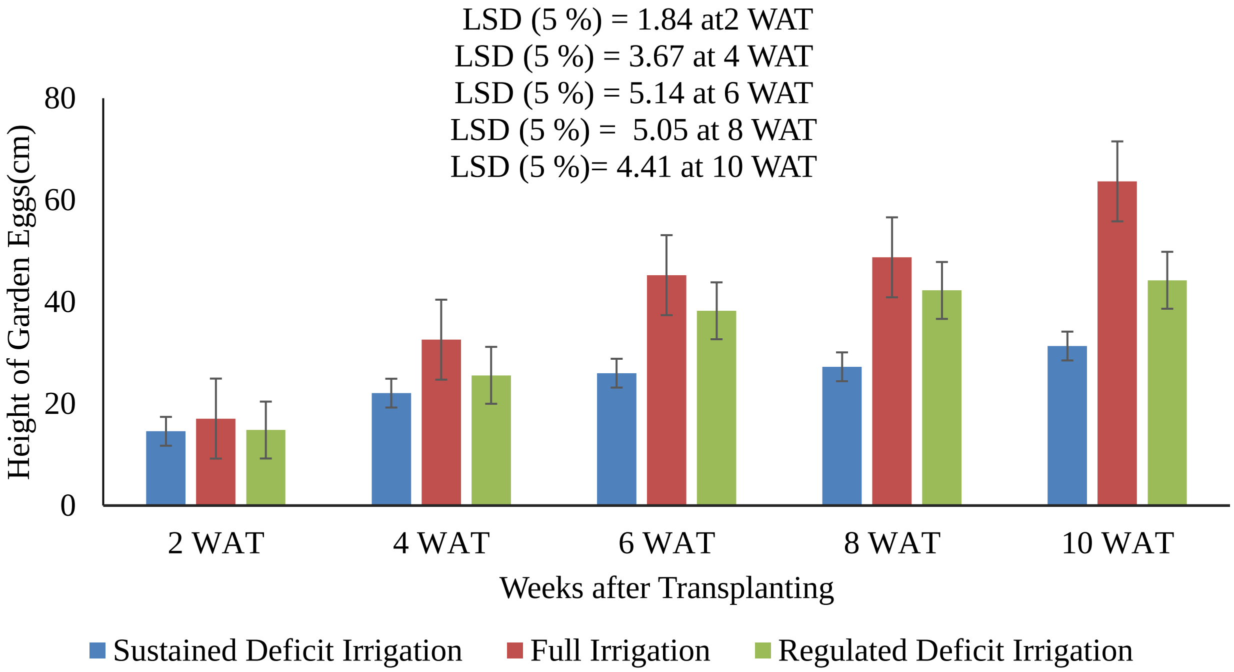


Figure 4.12: Effect of Irrigation Regimes on Plant Height

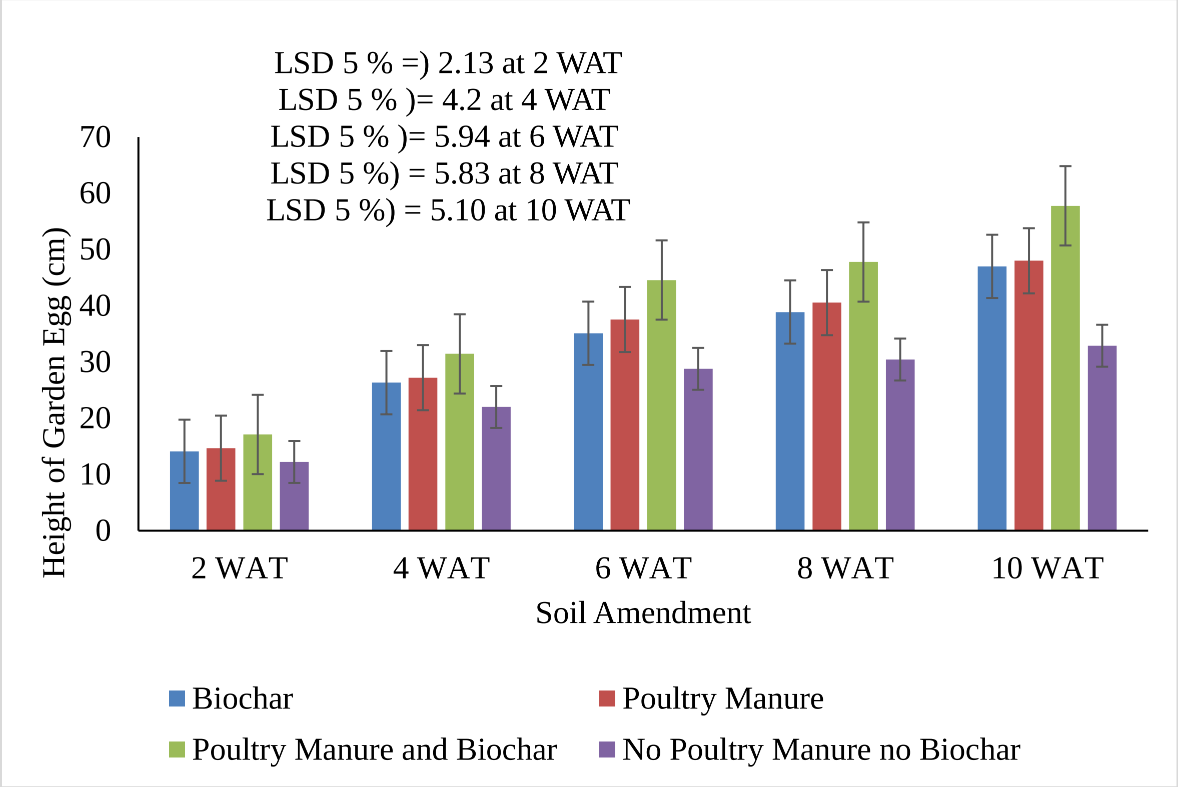


Figure 4.13: Effect of Soil Amendment on Plant Height

Table 4.6: Interaction Effect of Soil Amendment Techniques and Irrigation Regimes on plant height

Fertilizer **Irrigation**	**No Biochar no Poultry manure**	**Biochar**	**Poultry Manure**	**Poultry Manure and Biochar**
Sustained deficit at 70 % CWR	23g	31.65fg	32.33fg	38.33ef
Regulated deficit at 70 % CWR	28.33g	46.33de	46.67de	55.67cd
Full irrigation at 100 % CWR	47.33de	63bc	65b	79.33a
LSD		8.83		
P-Value		0.21		

(Means that do not share same letter are significant difference)

4.3.3 Number of Branches

Garden egg started branching at 4 WAT ($p<0.006$). Figure (4.14) indicated that, the highest number of branches were observed at full irrigation (100 %) (3.16), followed by regulated deficit (70 % CWR) (3.08). The lowest branches number was observed in sustained deficit (70 % CWR) (2.08). This response of garden eggs at at 6 WAT ($p<0.004$), 8WAT ($p<0.003$) and 10 WAT ($P<0.04$) followed the same trend as in 4WAT where each irrigation regime performed differently from one another with the highest number of branches observed in full irrigation (100 %) and the lowest in sustained irrigation level (70 %) CWR (Appendix 4.c).

At 4 WAT ($P<0.036$), 6 WAT ($P<0.005$), 8 WAT ($p<0.001$) and 10 WAT ($p<0.001$), the number of branches were significantly affected by soil amendment techniques as represented by figure (4.15). Highest branches number counted was observed at the pots treated with biochar and poultry manure combination (4.0) while the lowest number of branches counted was observed at pots containing no poultry manure or biochar (1.2). This trend continuous from 6WAT to 10WAT where combination of biochar and poultry resulted in higher branches number and the lowest branches number counted in soil without biochhar or poultry manure.

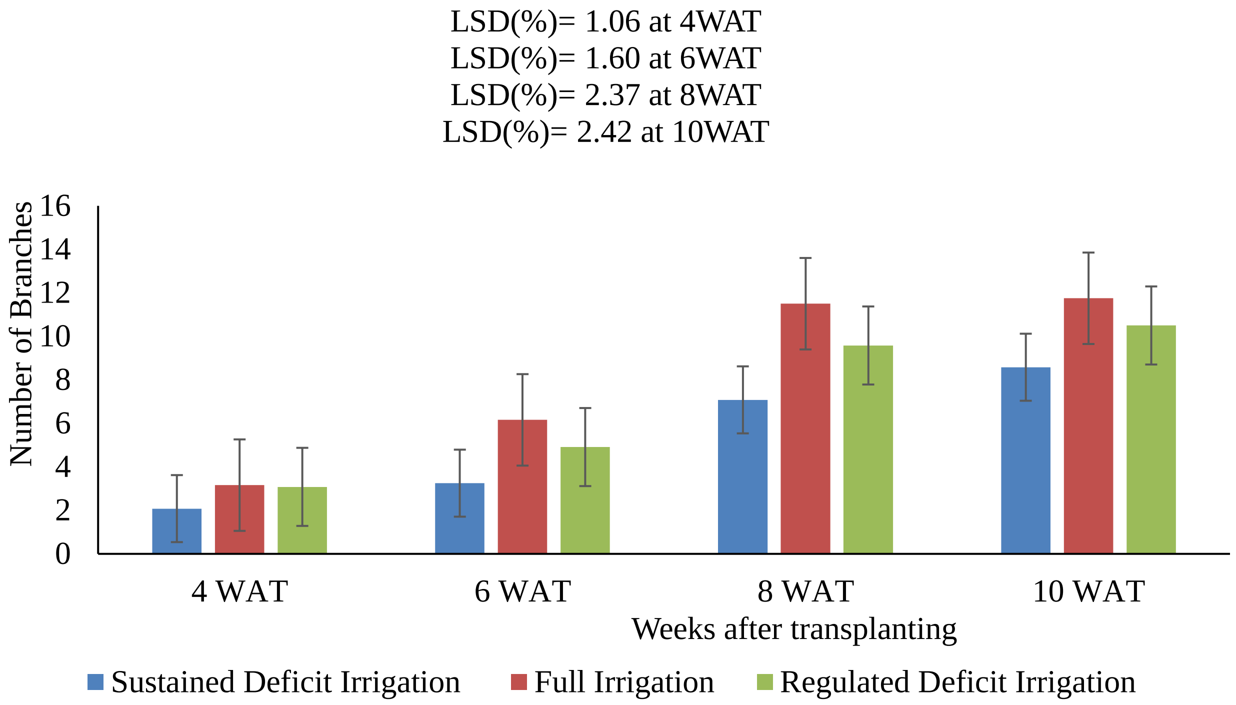


Figure 4.14: Effect of Irrigation Regimes on Number of Branches

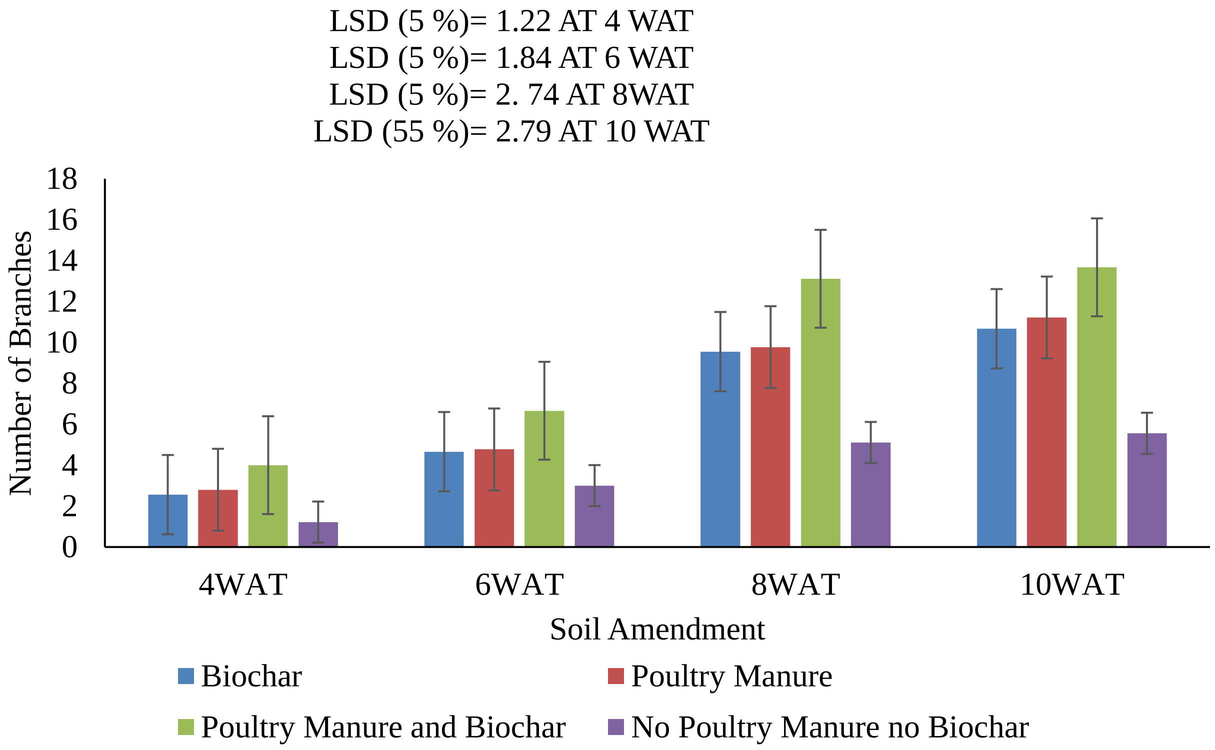


Figure 4.15: Effect of Soil Amendment on Number of Branches

Interaction effect observed in irrigation regimes and amendment techniques on number of branches at harvesting period as indicated by table (4.7). Highest branches number was recorded in full irrigation combined with poultry manure and biochar (14), followed by regulated deficit combined with poultry manure only (13.67) whereas the lowest number of branches counted was seen in sustained deficit (70 % CWR and soil without biochar combination (4.0).

Table 4.7: Interaction Effect of Soil Amendment Techniques and Irrigation Regimes on branches number.

Fertilizer / Irrigation	No Biochar No Poultry Manure	Biochar	Poultry Manure	Poultry Manure and Biochar
Sustained deficit at 70 % CWR	4c	8b	8b	9bc
Regulated deficit at 70 % CWR	4.6c	11.6ab	12.ab	13ab
Full irrigation at 100 % CWR	12.ab	13.33ab	13.67a	14a
LSD		4.84		
P-Value		0.81		

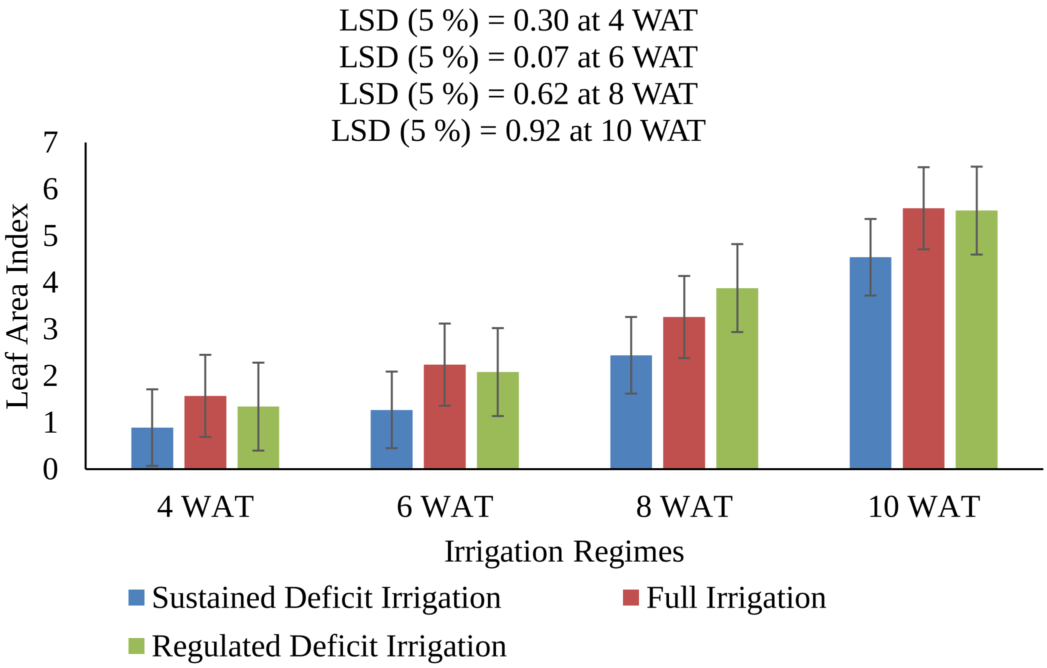
(Means that do not share same letter are significant difference)

4.3.4 Leaf Area Index

Leaf area index (LAI) was significantly affected by irrigation. At 6th week ($p<0.001$), the highest LAI was observed in full irrigation (100 % CWR) (2.24), followed by regulated deficit (70 % CWR) (2.08) while the lowest LAI was recorded in sustained deficit (70 % CWR) (1.27). LAI continued to respond in same way at 8 WAT ($p<0.001$) and 10 WAT ($p< 0.048$) with full irrrigation recorded highest LAI whereas the sustained recorded the least LAI. As represented by Figure (4.16) and Appendix (3.d).

Deficit irrigation was found to decreased LAI of Tomato and also resulted lower plant height, stem diameter, leaf area, chlorophyll content and tomato nitrogen uptake (Ullah *et al*., 2021). Parkash *et al* (2021) observed that deficit irrigation decreased cucumber stomata conductance, transpiration rate, photosynthesis rate, leaf area compare to full irrigation (100 % CWR).

Figure (4.17) indicated that, soil amendment also performed differently at 6WAT (P <0.001) where combination of biochar and poultry manure gave the highest LAI (2.06) whereas the lowest value was observed in pot without biochar or poultry manure (1.29). Similar responses were observed at 8 WAT (p<0.012) and 10 WAT (p<0.003) where the combination of biochar and poultry manure resulted in higher LAI and the lowest observed in pot without biochar or poultry manure provided.



LSD (5 %) = 0.30 at 4 WAT
LSD (5 %) = 0.07 at 6 WAT
LSD (5 %) = 0.62 at 8 WAT
LSD (5 %) = 0.92 at 10 WAT

Figure 4.16: Effect of Irrigation Regimes on Leaf Area Index

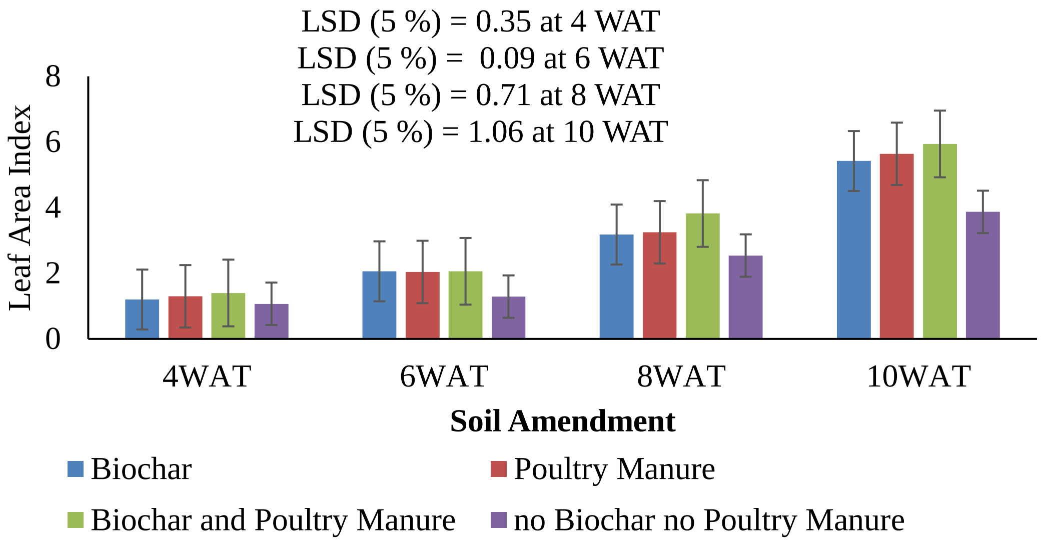


Figure 4.17: Effect of Soil Amendment on Leaf Area Index

Interaction effect observed in irrigation regimes and amendment techniques on leaf area index at harvesting period revealed that, the highest LAI recorded was in full irrigation (100 % CWR) combined with poultry manure and biochar combination (6.46) and less LAI was observed in sustained deficit (70 % CWR) combined with soil without poultry manure and biochar (2.95) as represented by table 4.8.

Table 4.8: Interaction Effect of Soil Amendment Techniques and Irrigation Regimes on branches number.

Fertilizer **Irrigation**	**No Biochar No Poultry Manure**	**Biochar**	**Poultry Manure**	**Poultry Manure and Biochar**
Sustained deficit at 70 % CWR	2.95c	4.46abc	4.90abc	4.96abc
Regulated deficit at 70 % CWR	4.21bc	5.36ab	5.69ab	7.4ab
Full irrigation at 100 % CWR	5.68ab	6.02ab	6.23ab	6.46a
LSD		1.85		
P-Value		0.98		

(Means that do not share same letter are significant difference)

4.3.5 Chlorophyll Content

Effect of irrigation regimes on plant chlorophyll content was significantly different at 2 WAT ($P < 0.001$). The results showed that, full irrigation produced the highest chlorophyll content (51.37 SPAD unit) and the regulated deficit irrigation produced the second highest chlorophyll content (45.93 SPAD unit). The least chlorophyll content was recorded in sustained deficit irrigation (34.95 SPAD unit). Week 4 ($P<0.008$), 6 ($P<0.002$), 8 ($P<0.001$) and 10 ($P<0.001$) followed the same trend as week 2 where full irrigation resulted in higher chlorophyll content than the other treatments as indicated by figure (4.18) and Appendix (3.e). The results of this study were in line with the study of Faghih *et al.* (2019) who reported that, deficit irrigation caused a reduction in garden eggs relative growth indices including shoot length, stem diameter, chlorophyll content compare to full irrigation.

Soil amendment also performed differently in chlorophyll content during the experiment as presented by figure (4.19). At 2 WAT ($p>0.05$), 4 WAT ($p<0.027$), 6 WAT ($p<0.014$), 8 WAT ($p<0.006$) and 10WAT ($p<0.001$).

At 4WAT, biochar recorded 34.95 SPAD unit, poultry manure recorded 42.16 SPAD unit and combination of biochar and poultry manure recorded 45.90 SPAD unit and lowest chlorophyll content was recorded in pots without biochar or poultry manure (34.62 SPAD unit). 6WAT ($p<0.014$), 8WAT ($p<0.006$) and 10WAT ($p<0.001$) followed the same trend.

Poultry manure and biochar combination produced the highest leaf chlorophyll content and no-poultry manure no-biochar performed less in all the weeks observed. (Mpanga et al., 2021) reported that, best result observed in combination of biochar and poultry manure on growth parameters was caused by poultry manure decomposition which provided different nutrient such as p, K Ca, Mg, Zc, Mn with reduction in NO_2, Fe, Cu and carbon sequestration obtained from biochar. Adekiya *et al.*, (2019) indicated that interaction effect of biochar and poultry manure improved the ability of the biochar to increase the efficiency of the utilization of the nutrients in the poultry manure and influenced crop growth development, yield production and water use efficiency as well.

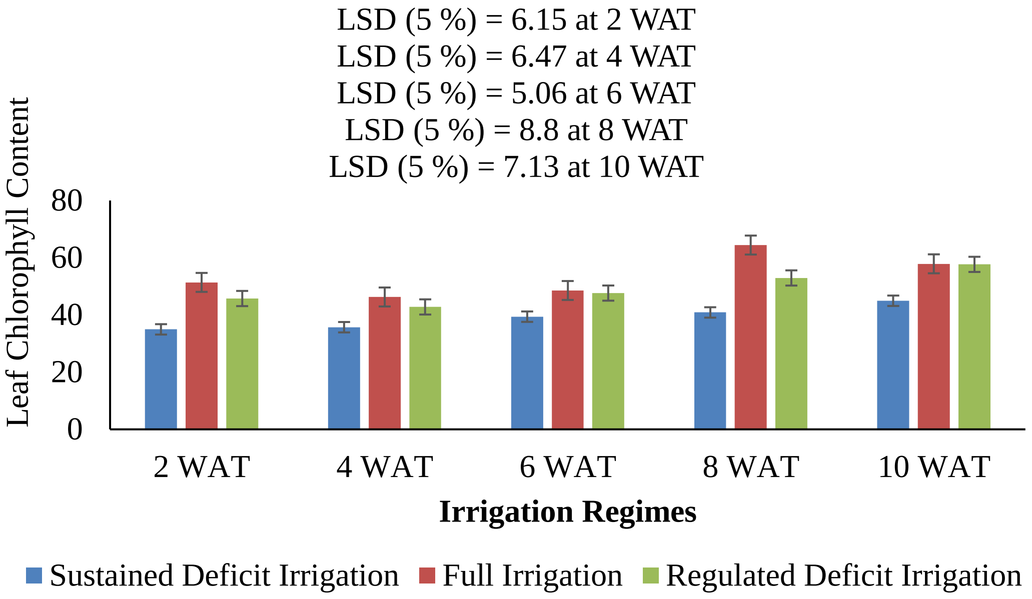


Figure 4.18: Effect of Irrigation Regimes on Leaf Chlorophyll

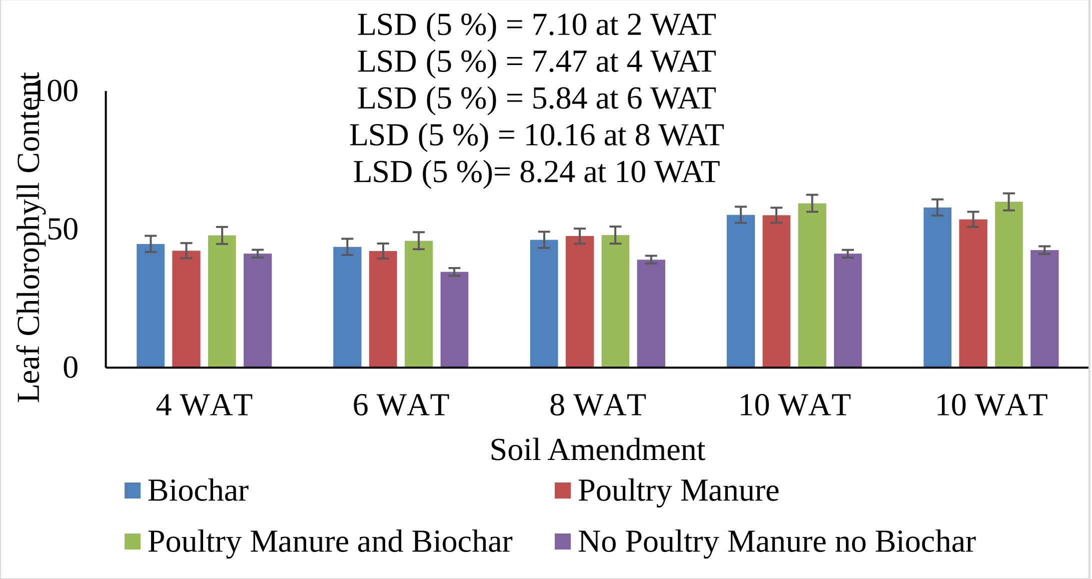


Figure 4.19: Effect of Soil Amendment on Leaf Chlorophyll

4.4 Effect of Deficit Irrigation and Soil Amendment on Yield Production of Garden Egg

Irrigation regimes and amendment techniques had significance difference on yield obtained from the experiment. Figure (4.20) indicated that, the highest yield production was recorded in full irrigation (100 % CWR) (16.39 ton/ha) which was followed by yield recorded in regulated deficit (70 % CWR) (16.31 ton/ha). The lowest yield harvested was observed in sustained deficit irrigation (70 % CWR) (11.57 ton/ha). The yield of garden egg in this study was in the range of Darko *et al.* (2019) who stated that garden egg yield in Ghana varies between 5 to 8 ton/ha under rainfed while yield production also varies between 12 to 30 ton/ha when local variety is used and may go up to 50 to 80 ton/ha when improved cultivars are cultivated under supplemental irrigation. The percentages of yield reduction indicated that sustained deficit resulted (70 % CWR) in the highest yield reduction compare to regulated deficit (70 % CWR). This results were confirmed by findings of Wahb-Allah and Al-Omran (2012) whose work showed that, there was significant reduction in tomato applied with deficit irrigation during the reproductive stages. A similar findings on the effectiveness of regulated deficit were obtained by Abiyu and Alamirew (2015) where application of 75 % CWR during entire growth stage had yield reduction of 53 % but water deficit applied on no-critical stage gave a yield reduction of 6.16 %. Regulated deficit irrigation is recommended as an essential irrigation technology compare to sustained deficit since it boosted the production and quality of garden eggs when applied in combined with other effective management measures such as weeding, pest and disease management.

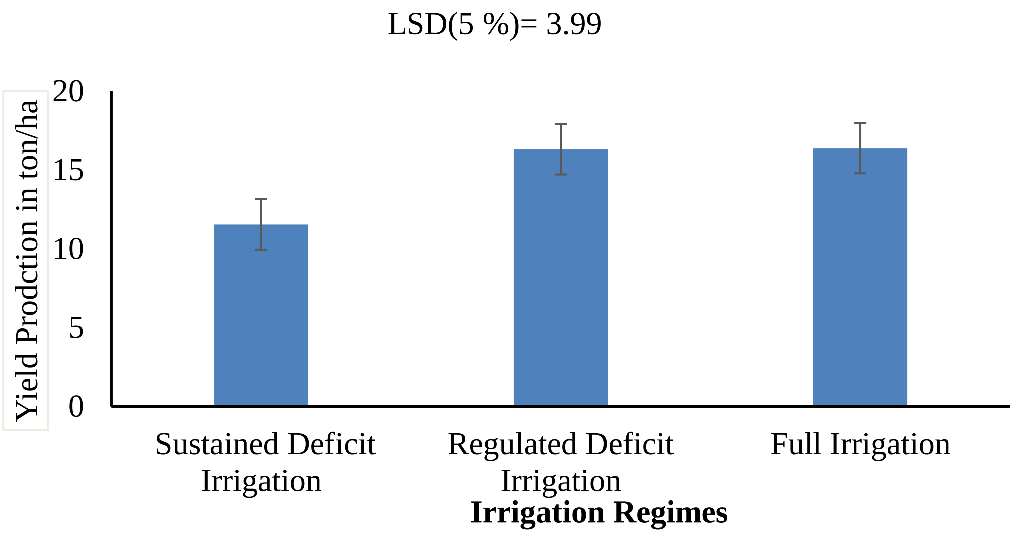


Figure 4.20: Effect of Irrigation Regimes on Yield Production

Soil amendment also had significant effect on garden eggs production ($p<0.001$). The results showed that, the combination of biochar and poultry manure produced the highest yield production (23.34 ton/ha), followed by poultry manure application (15.14 ton/ha) whiles the pot without biochar or poultry manure produced lowest yield (6.14 ton/ha) as represented by figure (4.21). The effect of combined poultry manure and biochar was also conducted by Michael and Oyewumi (2022) and the results showed that, the combination increased sweet potato growth and tuber yield. Dias *et al*. (2010) stated that, the increase in yield production was influenced by the chemical composition of the combination of poultry manure and biochar which promoted crop development, yield and water use efficiency.

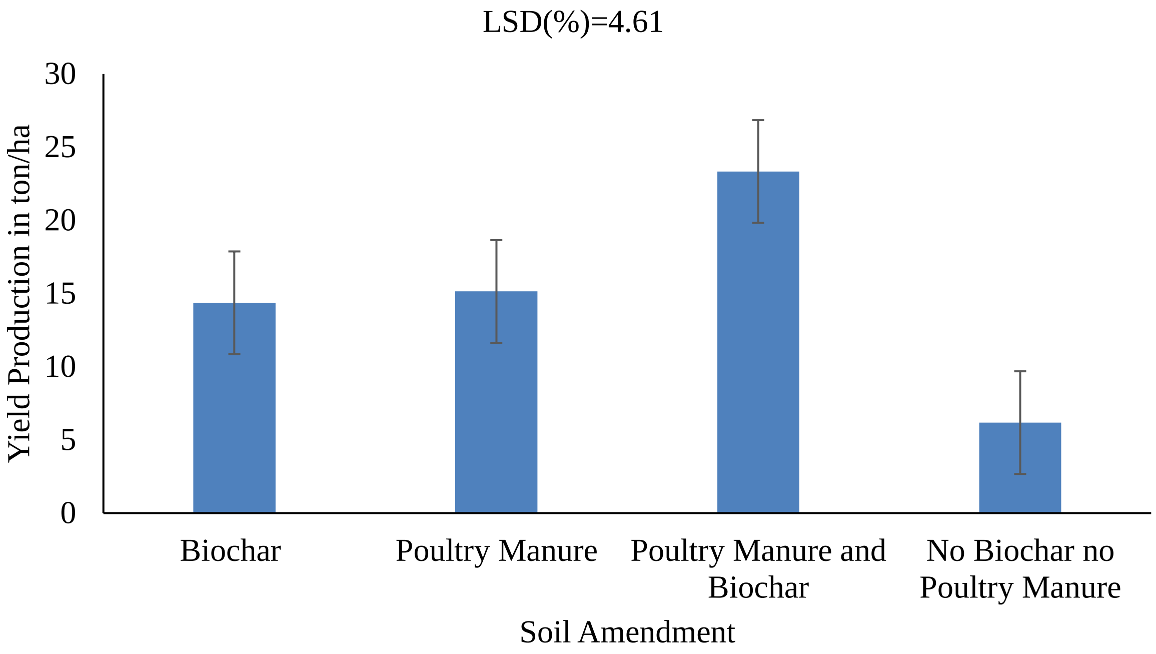


Figure 4.21: Effect of Soil Amendment on Yield Production

Interaction effect between irrigation regimes and soil amendment techniques on yield indicate that, highest yield production was observed in full irrigation combined with biochar and poultry manure (27.79 ton/ha), followed by regulated deficit irrigation (27.75 ton/ha) and the lowest yield was observed in sustained deficit irrigation combined with soil without biochar or poultry manure (5.42 ton/ha). Table (4.9) represented that, the results obtained indicated how combination of irrigation regimes and soil amendment techniques can influence yield production. Research conducted by Ikeh and Akpan (2018) revealed that, the highest yield (26.80 ton/ha) in garden egg was obtained from an interaction between full irrigation and mulching while less yield of 4.16 ton/ha was obtained from no irrigation and no mulching techniques.

Table 4. 9: Interaction Effect of Soil Amendment Techniques and Irrigation Regimes

Fertilizer / **Irrigation**	**No Biochar no Poultry manure**	**Biochar**	**Poultry manure**	**Poultry Manure and Biochar**
Sustained deficit at 70 % CWR	5.41d	12.88bcd	13.53bcd	14.48bc
Regulated deficit at 70 % CWR	6.55cd	15.07bc	15.87bc	27.75a
Full irrigation at 100 % CWR	6.57cd	15.15b	16.03b	27.79a
LSD		7.99		
P Value		0.23		

(Means that do not share same letter are significant difference)

4.5 Effect of Deficit Irrigation and Soil Amendment Techniques Crop Water Use Efficiency

Water applied per crop was estimated. The amount of water applied at sustained deficit was 490.05 mm, the amount of water applied at the regulated deficit irrigation was 593.31 mm and full irrigation applied utilized an amount of 699.36 mm. There was no significant difference in water use efficiency (p=0.48) as represented by figure (4.22). However, at harvesting, the highest water use efficiency recorded was regulated deficit (70 % CWR) (2.83 kg/m^3), followed by sustained deficit (70 % CWR) (2.47 kg/m^3) and lowest water use efficiency recorded was observed in full irrigation (100 % CWR) (2.44kg/m^3). WUE recorded in regulated deficit (70 % CWR) saved 17.5 % of water applied at full irrigation (100 % CWR) whiles WUE recorded in sustained deficit (70 % CWR) saved 0.86 % of the amount of water applied at full irrigation (100 % CWR). These results were in-line with previous research which revealed that, the regulation of water deficit by applying water stress at timing deficit strategy of 80 % during vegetative growth, pre- flowering and fruit ripening stage does not have detrimental impact on eggplant (Karam *et al*., 2011). Zhou *et al.* (2017) confirmed that irrigation deficit at 70 % maintained peach yield and improve fruit quality. Regulated deficit was also conducted on Onion growth in previous research and the results obtained showed that, the deficit irrigation applied at initial and maturation stage where crop is not under critical stage was the right time of practicing deficit irrigation which will not affect yield significantly (Nurga *et al.*, 2020). Water productivity and income of fruit and vines trees increased by application of regulated deficit irrigation (Fereres and Soriano, 2007). Other finding revealed that, regulated deficit increased water use efficiency. From these studies, regulated deficit irrigation should be applied at crop phenological stage so that deficit will be applied in non- critical stage while full irrigation applied at critical stage.

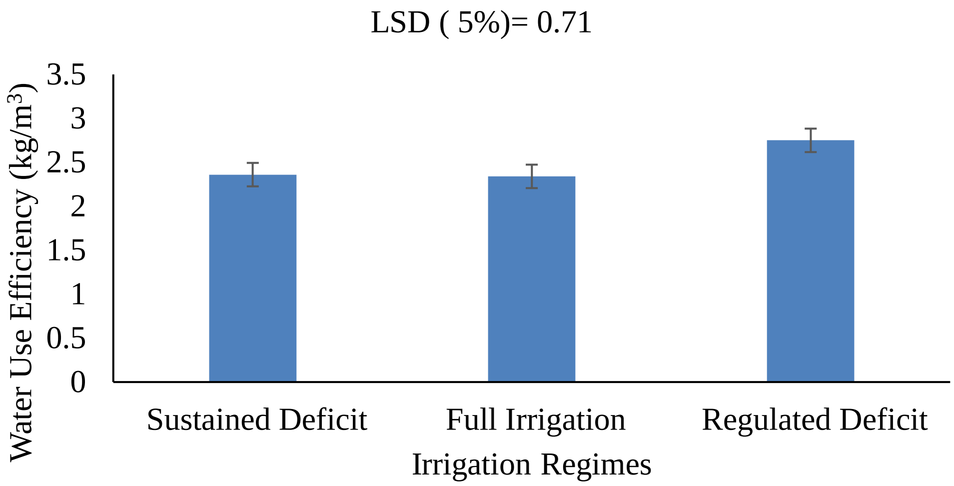


Figure 4.22: Effect of Irrigation Regimes on Water Use Efficiency

The WUE was significantly affected by soil ammendment techniques ($p<0.001$). Higher WUE was observed in pot amended with biochar and poultry manure combination (4.02 kg/m^3), followed by poultry manure amended pot (2.68 kg/m^3) and biochar amended pot (2.54 kg/m^3). Lowest WUE observed in pot without biochar or poultry manure (1.09 kg/m^3) as indicated by figure (4.23). Improved WUE was influenced by increasing soil organic matter in amended pots (Ma *et al.*, 2016). Increase in available water content influenced high yield production and WUE. This was caused by soil amendment techniques such as application of biochar and poultry manure (Sujatha *et al*., 2016). Findings from studies carried out by Yu *et al.* (2021) indicated that higher levels of soil organic carbon contribute to increased crop productivity. Moreover, increase of soil organic carbon content has the potential to enhance the soil-water retention capacity while also improving crop water use efficiency (WUE).

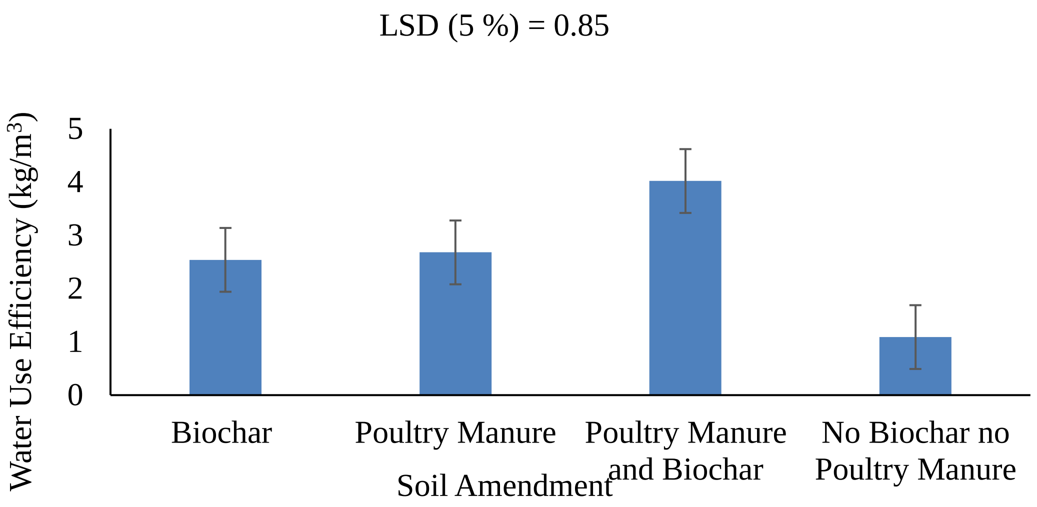


Figure 4. 23: Effect of Soil Amendment on Water Use Efficiency

Interaction effect between irrigation regimes and soil amendment techniques on WUE revealed that, the highest WUE was observed in regulated deficit (70 % CWR) combined with biochar and poultry manure (4.82 kg/m^3), followed by application of full irrigation (100 % CWR) in combination with biochar and poultry manure (4.15 kg/m^3) whereas the lowest WUE observed was full irrigation (100 %) combined with soil without biochar or poultry manure (0.9 kg/m^3) as represented by table (4.10).

Table 4.10: Interaction Effect of Soil Amendment Techniques and Irrigation Regimes

Fertilizer / **Irrigation**	**No Biochar no Poultry manure**	**Biochar**	**Poultry manure**	**Poultry Manure and Biochar**
Sustained deficit at 70 % CWR	1.158de	2.75bcd	2.88bc	3.091bc
Regulated deficit at 70 % CWR	1.14de	2.75bcd	2.76bcd	4.82a
Full irrigation at 100 % CWR	0.98e	2.26cde	2.39cde	4.15ab
LSD		0.84		
PValue		0.52		

(Means that do not share same letter are significant difference)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In summary, the findings of the study revealed that:

- Combination of poultry manure and groundnut shell biochar in soil at the ratio of 0.5:0.5:5 (v:v:v) improved soil particle distribution by increasing clay content from 5.88-7.92 %, decreasing sand content from 72.16 to 67.16 % which made an increase of organic matter and soil chemical properties over single application at the ratio of 1:5 (v:v).
- Estimated crop water requirements of garden egg applied in full irrigation, regulated deficit at 70 % and sustained deficit were 699.36, 593.31 and 490.05 mm/ season.
- Interaction indicated that full irrigation (100 % applied in PMB resulted with highest plant growth parameters such as plant height (79.33 cm), stem diameter (22.64 mm) and lowest observed in sustained deficit applied in NPMB (23 cm) plant height, (4.97mm) stem diameter.
- No significant difference in Fruit yield obtained in Full irrigation (100 % CWR) and regulated deficit 70% (CWR) applied in PMB gave results with 27.79 and 27.75 tons/ha respectively.
- Highest WUE was observed in regulated deficit (70 % CWR) applied in PMB (4.82 kg/m^3) and lowest observed was full irrigation applied in NPMB (0.98 kg/m^3).

5.2 Recommendations

Based on the findings of the study, it is therefore recommended that;

- Combination of Biochar and poultry manure at ratio 0.5:0.5 should be adapted for improvement of soil physical and chemical properties.
- Regulated deficit at 70% (CWR) should be applied in combined biochar and poultry manure increased WUE without significant yield reduction.
- Further researchers should work on other amendment techniques to compare the to the finding of this study.
- Water use efficiency should also evaluated by application other deficit irrigation techniques such as partial root zone dry on garden egg.
- To validate the research findings, the experiment should be repeated under different environmental conditions with other deficit irrigation techniques such as partial root zone drying deficit irrigation.

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APPENDICES

Appendix 1. Infiltration by Mini-disk Infiltrometer

Time (min)	NPMB (ml)	PM (ml)	PMB (ml)	B (ml)
0min	80	80	80	80
10min	78	63	59	52
10min	75	54	48	38
10min	73	45	39	27
10min	71	35	28	15
10min	69	27	19	6
10min	67	18	10	
10min	65	10	7	
10min	63	5	3	
10min	61			
10min	59			
10min	57			
10min	56			
10min	55			
10min	54			
10min	53			

Appendix 2.A: Daily Mean Temperature and Solar Radiation at the Experimental Site

Mean dairy Temperature (°C)				**Mean Dairy Solar Radiation (W/m^2)**			
March	**April**	**May**	**June**	**March**	**April**	**May**	**June**
33.49	32.13	29.67	26.87	434.573333	475.941333	438.525974	382.034177
33.08	31.5	30.43	28.37	430.432877	448.756757	378.118182	403.784416
33.16	31.05	30.35	28.54	446.006667	314.792	486.882051	382.258904
32.1	31.36	27.98	28.1	426.012	396.566667	484.309091	394.482278
31.94	31.56	28.57	28.24	480.960274	502.572727	481.531579	361.858442
33.49	27.04	27.87	29.7	412.325333	496.350667	462.931169	465.358228
33.08	30.38	28.41	29.7	334.891892	500.388158	462.437662	396.321519
33.16	28.77	29.55	29.46	429.186667	506.588158	490.352055	439.452564
32.1	30.29	30.93	30.22	514.565333	384.742105	491.253846	311.055128
31.94	30.63	30.6	27.25	486.344	457.822667	438.525974	349.297436
32.06	32.37	30.07	27.9	492.306667	475.560526	378.118182	342.120513
30.53	32.03	30.45	28.21	484.945946	458.057534	486.882051	361.949367
31.43	30.67	30.37	28.81	417.336	326.780263	484.309091	340.710256
31	29.81	24.41	29.03	465.996	449.442105	481.531579	317.244872
31.65	31.11	28.17	27.51	424.014667	493.752632	462.931169	333.444872
32.33	31.12	30.41	26.99	417.132432	464.868831	175.577632	418.049351
32.73	29.78	25.35	29.04	370.731507	391.207792	444.091026	402.009091
31.05	27.84	27.64	29.88	486.105479	280.15	466.237662	116.722078
30.2	30.68	29.53	29.7	446.778667	517.242105	90.5302632	371.332051
30.46	31.68	28.99	24.93	479.517333	364.062667	486.03038	277.263636
29.7	32.34	28.59	27.16	517.461333	410.185135	430.388462	387.391026
26.29	29.12	29.33	25.03	471.217333	456.345455	380.102597	225.15
29.51	26.84	29.31	27.51	475.829333	375.523684	420.215584	222.328947
31.28	29.44	28.17	26.4	421.260811	245.593421	400.308974	187.65641
31.4	28.09	30.41	25.6	389.708108	393.402564	499.555	355.759494
31.9	27.81	25.35	25.72	406.266667	509.631169	315.224675	318.861538
31.07	28.79	27.64	25.02	444.688718	478.825974	314.755128	317.058442
30.97	29.4	29.53		401.470667	462.437662	187.65641	
29.84	26.13	28.99		370.504	490.352055	355.759494	
30.76	29.33	28.59		459.537333	491.253846	318.861538	
31.74		29.31		459.372		317.058442	

Appendix 2.B: Daily Mean Wind Speed and Reference Crop Evapotranspiration at the Experimental Site

Wind speed (W/m^2)				**Reference Crop Evapotranspiration (mm/day)**			
March	April	May	June	March	April	May	June
0.416667	1.573916	1.193542	0.799444	8.9	7.6	7.8	6.1
1.676294	1.54375	1.064167	1.768472	9.2	7.9	7.4	7.7
1.802153	1.667241	1.246944	1.843264	8.8	8.2	8.8	7.65
1.238958	1.659653	1.275278	1.391748	7.4	8.9	6.3	8.5
2.258958	1.689375	1.719524	1.339701	7.7	8.1	6.4	7.6
1.857708	2.259653	1.200278	1.465556	8.6	7.5	6.5	7.25
0.416667	1.212667	1.38	2.282431	7.5	8.1	7.1	7
1.676294	1.539265	1.184653	2.475694	7.3	6.9	7.3	7
1.802153	1.412958	0.995972	2.151667	6.4	4.8	4.5	7.6
1.238958	1.208889	1.546667	1.493611	7	6.5	5.8	7.1
2.258958	1.429653	1.584931	1.759167	7.4	6.8	7.3	4.65
1.857708	1.574861	1.645694	1.817639	8.5	7.5	7.4	6.15
2.289444	1.5325	1.079861	1.374722	4.2	8.7	7.1	7.05
1.741528	2.053613	1.309375	1.260625	6.2	8	4.3	7.45
1.430694	1.326111	1.390486	1.401932	8.7	7.9	6.2	7.9
1.223819	2.120903	1.431528	1.427292	7.7	5.6	5	6.15
1.549167	1.519514	1.356875	0.796597	8	5.9	6.2	7.05
1.519931	2.013819	1.462373	1.467639	7.9	7	5.5	5.3
1.964444	1.931727	0.745952	1.805486	8.7	7.7	5	6.05
2.134792	1.618472	0.932847	0.864074	8.1	7	3.1	6.25
1.76875	1.598819	1.36875	1.268732	7.2	6.5	4.7	6.35
2.374375	1.989097	1.329583	1.387426	8.6	7.1	6.3	5.05
2.097986	2.044861	1.264306	1.188819	8.4	7.8	6.2	5.6
2.112986	2.712308	0.993889	1.841049	8.5	6.5	7.3	6.7
1.570486	0.897079	0.66473	1.527655	6.6	6.6	6.8	7
1.448125	1.481277	0.767917	1.527655	7.3	6.6	5.4	6.9
1.787361	1.689028	1.09941		6.2	4.9	5.5	
2.138611	1.908087	1.280764		4.65	5.4	5	
2.134167	1.297708	0.860278		6.15	7.8	4.6	
2.148403	1.502986	1.223264		7.05	7.9	6.2	
2.134167	1.297708	0.860278		6.15		4.6	

Appendix 3: Field photo

Plate 1: Field Data Collection

Plate 2: Disease and Pest Control at the Field

Plate 3: Garden Eggs at Harvesting Stage

Appendix 4.A: Field Data Collection Stem Diameter

rep	Irrigation Regimes	Soil Amendments	SD 2WAT	SD 4WAT	SD 6WAT	SD 8WAT	SD 10WAT
1	DI	FB	6.53	8.23	9.14	10.15	10.41
1	DI	NFB	4.22	5.5	5.85	5.93	6.01
1	DI	F	4.16	5.93	9.99	9.64	10.96
1	DI	B	5.33	8.71	9.8	10.5	11.61
1	SBDI	FB	10.11	10.91	12.85	14.07	15.22
1	SBDI	NFB	6.45	7.62	9.13	10.06	11.14
1	SBDI	F	10.03	10.25	11.99	14.42	13.37
1	SBDI	B	10.05	9.99	12.76	12.91	16.7
1	FI	FB	11.62	13.26	16.16	19.58	23.79
1	FI	NFB	10.12	11.32	13.41	14.18	17.36
1	FI	F	10.19	10.41	12.8	15.69	21.661
1	FI	B	12.21	13.47	15.67	17.84	20.3

2	DI	FB	5.88	9.39	10.15	11.73	13.23
2	DI	NFB	4.25	5.82	7.02	8.83	8.91
2	DI	F	5.39	5.24	7.43	9.5	14.75
2	DI	B	8.34	10.38	13.44	12.49	13.26
2	SBDI	FB	10.11	10.89	13.55	17.06	15.7
2	SBDI	NFB	6.89	5.89	6.4	0	0
2	SBDI	F	6.57	7.41	9.05	12.76	13.48
2	SBDI	B	8.2	9.85	9.67	12	19.75
2	FI	FB	9.64	9.18	14.29	15.57	23.19
2	FI	NFB	7.63	6.69	9.56	9.36	10
2	FI	F	7.15	7.54	10.37	12.99	17.45
2	FI	B	10.15	10.48	12.03	14.12	17.08
3	DI	FB	9.06	9.76	14.01	14.3	14.3
3	DI	NFB	4.46	4.3	4.6	4.1	0
3	DI	F	8.59	10.45	13.03	17.63	12.15
3	DI	B	4.06	6.78	5.48	10.19	12.04
3	SBDI	FB	10.25	10.89	14.79	15.42	15.37
3	SBDI	NFB	6.25	10	11.18	11.87	12.71
3	SBDI	F	10.29	9.62	13.29	13.8	14.41
3	SBDI	B	10.09	10.34	12.69	15.22	17.11
3	FI	FB	12.68	14.78	16.21	18.09	20.95
3	FI	NFB	7.48	11.55	13.61	14	15.88
3	FI	F	10.43	11.92	14.36	15.27	18.31
3	FI	B	10.33	11.57	11.6	13.12	18.27

Appendix 4.B: Field Data Collection on Plant Height

Reps	Irrigation Regimes	Soil Amendment	PH 2 WAT	PH 4 WAT	PH 6 WAT	PH 8 WAT	PH 10 WAT
1	DI	FB	12	25	30	32	37
1	DI	NFB	8	17	20	21	21
1	DI	F	10	22	28	30	32
1	DI	B	13	19	20	25	33
1	SBDI	FB	15	29	45	50	57
1	SBDI	NFB	12	20	28	30	35
1	SBDI	F	15	26	36	40	45
1	SBDI	B	17	23	30	39	48
1	FI	FB	19	40	52	57	80
1	FI	NFB	13	30	40	48	50

1	FI	F	15	34	45	48	65
1	FI	B	13	38	50	50	63
2	DI	FB	15	26	30	32	38
2	DI	NFB	10	19	20	20	22
2	DI	F	14	20	25	25	30
2	DI	B	13	27	30	32	28
2	SBDI	FB	19	33	50	58	60
2	SBDI	NFB	10	21	30	30	30
2	SBDI	F	12	23	40	47	50
2	SBDI	B	17	29	41	46	48
2	FI	FB	22	40	55	56	80
2	FI	NFB	18	35	53	57	60
2	FI	F	22	38	52	56	65
2	FI	B	11	23	35	42	63
3	DI	FB	16	23	29	32	40
3	DI	NFB	10	16	18	18	26
3	DI	F	13	30	36	36	35
3	DI	B	14	21	26	24	34
3	SBDI	FB	16	37	60	62	50
3	SBDI	NFB	12	15	20	20	20
3	SBDI	F	13	24	40	43	45
3	SBDI	B	12	27	39	42	43
3	FI	FB	20	30	50	51	78
3	FI	NFB	17	25	30	30	32
3	FI	F	18	28	36	40	65
3	FI	B	17	30	45	50	63

Appendix 3.C: Field Data Collection on Number of Branches

Reps	Irrigation Regimes	Soil Amendment	NB 2 WAT	NB 4 WAT	NB 6 WAT	NB 8 WAT	NB 10 WAT
1	DI	FB	1	3	6	14	15
1	DI	NFB	0	0	0	0	3
1	DI	F	0	0	3	7	8
1	DI	B	1	2	1	7	8
1	SBDI	FB	2	4	8	14	14
1	SBDI	NFB	1	0	3	7	8
1	SBDI	F	3	3	5	12	11
1	SBDI	B	0	2	4	10	13

1	FI	FB	2	4	7	14	14
1	FI	NFB	3	4	7	11	13
1	FI	F	1	3	6	13	13
1	FI	B	2	4	7	13	13
2	DI	FB	1	2	4	14	12
2	DI	NFB	0	0	2	3	6
2	DI	F	0	0	0	1	6
2	DI	B	0	3	6	10	11
2	SBDI	FB	2	3	6	14	14
2	SBDI	NFB	2	2	4	8	6
2	SBDI	F	0	2	5	9	11
2	SBDI	B	2	3	5	9	10
2	FI	FB	2	4	8	14	14
2	FI	NFB	2	4	7	10	11
2	FI	F	2	4	7	13	13
2	FI	B	1	3	6	11	11
3	DI	FB	1	2	9	12	13
3	DI	NFB	0	0	0	1	3
3	DI	F	2	4	7	13	13
3	DI	B	0	0	1	3	5
3	SBDI	FB	0	2	7	10	13
3	SBDI	NFB	0	0	0	0	0
3	SBDI	F	1	2	5	9	13
3	SBDI	B	2	2	7	13	13
3	FI	FB	1	3	5	12	14
3	FI	NFB	1	1	4	6	0
3	FI	F	0	0	5	11	13
3	FI	B	1	4	5	10	12

Appendix 4.D: Field Data Collection on Leaf Area Index

Reps	Irrigation regimes	Soil Amendment	LAI 4 WAP	LAI 6 WAP	LAI 8 WAP	LAI 10 WAP
1	DI	FB	0.96	1.42	3.91	5.11
1	DI	NFB	0.46	0.65	0.86	1.02
1	DI	F	0.66	1.35	2.49	4.83
1	DI	B	1.59	1.68	1.35	5.17
1	SBDI	FB	1.73	2.83	3.88	5.98
1	SBDI	NFB	1.1	1.56	3.3	5.87
1	SBDI	F	1.72	2.58	3.1	6.2
1	SBDI	B	1.37	2.2	3.05	6.04
1	FI	FB	1.6	1.95	4.35	5.65
1	FI	NFB	1.86	1.85	3.98	4.95
1	FI	F	1.41	2.21	4.3	7.31
1	FI	B	1.82	2.32	4.08	5.1
2	DI	FB	0.8	1.42	4.12	4.44
2	DI	NFB	0.73	0.65	0.86	4.02
2	DI	F	0.7	1.35	0.9	5.72
2	DI	B	0.84	1.68	3.59	4.57
2	SBDI	FB	1.55	2.83	3.45	7.54
2	SBDI	NFB	1.66	1.56	3.7	3.97
2	SBDI	F	1.54	2.58	3.68	6.37
2	SBDI	B	1.71	2.2	3	5.47
2	FI	FB	1.86	1.95	3.86	6.91
2	FI	NFB	1.57	1.85	4.08	4.22
2	FI	F	1.66	2.21	3.88	4.71
2	FI	B	1.35	2.32	3.78	7.53
3	DI	FB	1.21	1.42	3.55	6.53
3	DI	NFB	0.44	0.65	0.86	3.83
3	DI	F	1.43	1.35	4.08	4.34
3	DI	B	0.97	1.68	2.79	4.98
3	SBDI	FB	1.05	2.83	3.27	4.56
3	SBDI	NFB	0.64	1	1.5	2.81
3	SBDI	F	1.04	2.58	3.66	6.13
3	SBDI	B	1.08	2.2	3.62	5.55
3	FI	FB	1.36	1.95	3.99	6.82
3	FI	NFB	1.2	1.85	3.79	4.22

3	FI	F	0.89	2.21	2.55	5.22
3	FI	B	2.35	2.32	4.02	4.45

Appendix 3. E. Field Data Collection on Chlorophyll Content

Reps	Irrigation Regimes	soil amendment	LC 2 WAT	LC 4 WAT	LC 6 WAT	LC 8 WAT	LC 10 WAT
1	DI	FB	40.8	47	49.7	50.4	53.9
1	DI	NFB	26.9	29.2	33.6	33.8	38.6
1	DI	B	37.8	46.1	46.1	47.9	50.1
1	DI	F	38.4	47.5	47.5	47.8	50.7
1	SBDI	FB	48.8	48.2	48.7	56.7	69.7
1	SBDI	NFB	51	49.4	48.3	32	46.7
1	SBDI	F	49	40.7	47.4	75.3	68.1
1	SBDI	B	57.4	48.4	50	60.5	69.1
1	FI	FB	57	45	49.9	87.8	61.1
1	FI	NFB	51	45.6	48.7	58.8	57.9
1	FI	F	44.4	47.5	49.3	78.1	53.6
1	FI	B	49.1	47.9	48.4	70.7	57.3
2	DI	FB	35.8	41.8	41.6	56.2	58.7
2	DI	NFB	24.6	0	0	0	0
2	DI	F	33.3	24.9	40.8	42	47.8
2	DI	B	29.8	29.6	41.9	40	44.9
2	SBDI	FB	45.3	45.2	46.3	55.6	52.5
2	SBDI	NFB	39.4	38.3	47.6	45.2	48
2	SBDI	F	21.3	39.2	49.8	50.1	54
2	SBDI	B	49.1	46.9	49.1	52.6	57.6
2	FI	FB	51	49.3	46.8	58.9	63
2	FI	NFB	39.1	46.2	48.8	49.4	49.5
2	FI	B	51.4	47.6	43.8	64.2	57.3
2	FI	F	47	45.1	48.9	47.4	54.6
3	DI	FB	42.1	46	49.6	52.4	57.6
3	DI	NFB	32.6	21.7	32.3	36.9	38.5
3	DI	F	40.1	46.2	48.6	41.2	50.4
3	DI	B	37.2	48.4	41	41.8	48.2
3	SBDI	FB	48.3	48.3	48.9	52.2	66.3
3	SBDI	NFB	47.6	35.1	48	51	50.8
3	SBDI	F	53	44.9	49.5	52.3	50.4
3	SBDI	B	38.6	28.9	48.9	51.6	61.2

3	FI	FB	61.1	42.3	49.9	64.6	56.7
3	FI	NFB	58.8	46.1	44.2	63.5	52.5
3	FI	F	54.2	43.4	46.1	61.7	53.1
3	FI	B	52.3	49.2	46.8	68	75.5

Appendix 3. F. Field Data Collection on Yield

Reps	Irrigation Regimes	Soil Amandment	ton/ ha
1	DI	FB	17.98
1	DI	NFB	11.9848
1	DI	F	20.46
1	DI	B	18.44
1	SBDI	FB	20.4284
1	SBDI	NFB	5.8324
1	SBDI	F	12.8018
1	SBDI	B	13.2598
1	FI	FB	20.4512
1	FI	NFB	5.8674
1	FI	F	12.98
1	FI	B	13.2914
2	DI	FB	12.782
2	DI	NFB	2.46
2	DI	F	12.6942
2	DI	B	13
2	SBDI	FB	30.4132
2	SBDI	NFB	4.1168
2	SBDI	F	14.4062
2	SBDI	B	13.0036
2	FI	FB	30.466
2	FI	NFB	4.133
2	FI	F	14.56
2	FI	B	13.0846
3	DI	FB	12.6828
3	DI	NFB	1.8028
3	DI	F	7.4376
3	DI	B	7.2274

3	SBDI	FB	32.4132
3	SBDI	NFB	9.7168
3	SBDI	F	20.4062
3	SBDI	B	19.0036
3	FI	FB	32.466
3	FI	NFB	9.733
3	FI	F	20.56
3	FI	B	19.0846

Appendix 3. G. Field Data Collection on Water Use Efficiency

Reps	Irrigation Regime	soil Amendment	Water Use Efficiency (kg/m^3)
1	DI	FB	3.669
1	DI	NFB	2.446
1	DI	F	4.175
1	DI	B	3.763
1	SBDI	FB	3.443
1	SBDI	NFB	0.983
1	SBDI	F	2.158
1	SBDI	B	2.235
1	FI	FB	2.924
1	FI	NFB	0.839
1	FI	F	1.856
1	FI	B	1.901
2	DI	FB	2.608
2	DI	NFB	0.502
2	DI	F	2.590
2	DI	B	2.653
2	SBDI	FB	5.126
2	SBDI	NFB	0.694
2	SBDI	F	2.428
2	SBDI	B	2.192
2	FI	FB	4.356
2	FI	NFB	0.591
2	FI	F	2.082
2	FI	B	1.871
3	DI	FB	2.588

3	DI	NFB	0.368
3	DI	F	1.518
3	DI	B	1.475
3	SBDI	FB	5.463
3	SBDI	NFB	1.638
3	SBDI	F	3.439
3	SBDI	B	3.203
3	FI	FB	4.642
3	FI	NFB	1.392
3	FI	F	2.940
3	FI	B	2.729

Appendix 4: Analysis of Variance

Variate 1: Plant Height (cm) at 10 Week after Transplanting

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Irrigation regimes	2	6357.17	3178.58	115.58	<.001
Soil amendment	3	2834.31	944.77	34.36	<.001
Irrigation regimes&soil amendment	6	249.28	41.55	1.51	0.217
Residual	24	660.00	27.50		
Total	35	10100.75			

Variate 2: Stem Diameter (mm) at 10 Week after Transplanting

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Irrigation regimes	2	395.596	197.798	22.54	<.001
Soil amendment	3	343.804	114.601	13.06	<.001
Irrigation regimes&soil amendment	6	46.993	7.832	0.89	0.516
Residual	24	210.646	8.777		
Total	35	997.038			

Variate 3: Leaf Area Index (LAI) at 10 Week after Transplanting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation regimes	2	8.325	4.162	3.45	0.048
Soil amendment	3	23.007	7.669	6.36	0.003
Irrigation regimes&soil amendment	6	1.127	0.188	0.16	0.986
Residual	24	28.937	1.206		
Total	35	61.395			

Variate 4: Number of Branches (NB) at 10 Week after Transplanting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation regimes	2	61.056	30.528	3.69	0.040
Soil amendment	3	313.444	104.481	12.62	<.001
Irrigation regimes&soil amendment	6	24.056	4.009	0.48	0.813
Residual	24	198.667	8.278		
Total	35	597.222			

Variate 5: Chlorophyll Content (CC) at 10 Week after Transplanting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation regimes	2	1315.21	657.61	9.17	0.001
Soil amendment	3	1638.06	546.02	7.62	<.001
Irrigation regimes&soil amendment	6	605.57	100.93	1.41	0.252
Residual	24	1720.39	71.68		
Total	35	5279.23			

Variate 6: Yield Production (Ton/Ha)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Irrigation regimes	2	182.36	91.18	4.05	0.031
soil_amendment	3	1327.68	442.56	19.65	<.001
Irrigation_regimes.soil_amendment	6	195.35	32.56	1.45	0.239
Residual	24	540.59	22.52		
Total	35	2245.98			

Variate 7: Water Use Efficiency (Kg/m^3)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Irrigation regimes	2	1.2627	0.6313	0.88	0.427
Soil amendment	3	35.8536	11.9512	16.68	<.001
Irrigation regimes&soil amendment	6	4.0280	0.6713	0.94	0.487
Residual	24	17.1972	0.7166		
Total	35	58.3414			