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OPTIMIZATION OF VEGETABLE PRODUCTION USING IRRIGATION REGIMES AND ORGANIC FERTILIZERS

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 SUPERVISORS

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

Vegetable farming is one of the most profitable activities in agriculture, in both the wet and dry season's cultivation period. It does not only provide farmers with a source of revenue, but it also constitutes an essential source of food for many kinds of households. The objective of the study was to optimize vegetable production using organic fertilizers and irrigation regimes. Three (3) vegetable crops namely, lettuce, beetroot, and okra were used for the study. The experiment was conducted at Nyankpala Campus of the University for Development Studies in Ghana for two (2) seasons i.e., dry and rainy seasons. A 3 × 4 factorial pot experiment was laid out in Randomized Complete Block Design (RCBD) with three (3) levels of irrigation regimes (50, 75, and 100 % based on crop water requirement (CWR) consumed through evapotranspiration (ETc) and three (3) organic fertilizers i.e., compost (CMT), sheep droppings (SHD), cow dung (CWD) applied at 0.5 kg per pot; and no organic fertilizer treatment (CTR) with three (3) replications each. The physicochemical properties of the soil and organic fertilizer used was analyzed before and after the experiment. The experimental soil was sandy loam with dry bulk density between 1.28 - 1.32 g/cm^3, field capacity (FC) at the time of the experiment was calculated as 19.6 %, permanent wilting point (PWP) as 9.1 %, organic carbon (OC) ranged from 1.18 - 1.19 %, pH ranged from 6.15 - 6.21 and electrical conductivity (EC) of 79.5 – 80.3 µS/cm. The crop water requirement of the study vegetables at 100% for lettuce, beetroot and okra was 371.8 mm/dec, 341.6 mm/dec and 257.2 mm/dec respectively. Lettuce weight ranged from 48.7 to 96.7 g with the highest recorded in the pot treated with SHD at 100 % CWR, the leaf number ranged from 15 to 22, yield ranged from 5.01 – 7.38 t/ha with the highest recorded in the pots treated with CWD at 50% CWR respectively. For beetroot, the plant height ranged from 31 – 36 cm with the highest observed in the control pot with 75 % of CWR, the number of leaves ranged from 13 – 15, bulb weight was from 100 - 160 g with the highest recorded in the pots treated with CMT at 100 % CWR respectively and yield of 7.06 – 12 t/ha, with the highest in the pots treated with CMT at 100 % CWR. For okra, the pot treated with CWD at 75 % CWR had the most positive result with plant height from 27.5 – 30.5 cm, the plants with SHD at 100 % CWR resulted in high number of leaves ranging from 23.2 – 27.5, while the plants with CWD at 100 % CWR resulted in highest fruit weight of 12.5 – 13.6 g. In terms of fruit diameter and length, the pots treated with SHD recorded the highest measurements in the three irrigation regimes. The highest number of fruits was recorded in the plants treated with SHD at 50 % CWR with 13 pods per plant. The study revealed that organic fertilizer application enhances the growth and development of vegetables and can help increase water use efficiency by conserving soil moisture. Hence, in water scares areas, deficit irrigation with organic fertilizer can be adopted in the production of high valued vegetables and improvement in soil properties.

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DEDICATION

This work is dedicated to God and my late Dad, Mr. Joseph A. Olaniyan.

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LIST OF ACRONYMS AND ABBREVIATIONS

AWC	Available Water Content
Ca	Calcium
CMT	Compost
CSIR	Council for Scientific and Industrial Research
CTR	Control (No organic fertilizer treatment)
CWD	Cow Dung
CWR	Crop Water Requirement
DBD	Dry Bulk Density
EC	Electrical Conductivity
ETc	Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
HDPEP	High Density Polyethylene Pipe
IRg	Gross Irrigation Requirement
IRn	Net Irrigation Requirement
K	Potassium
Kc	Crop Factor
MAD	Manageable Allowable Depletion
MoFA	Ministry of Food and Agriculture
N	Nitrogen
OC	Organic Carbon
P	Phosphorus
PWP	Permanent Wilting Point
RAW	Readily Available Water
RCBD	Randomized Complete Block Design
SARI	Savanna Agricultural Research Institute

SEM	Standard Error of Means
SHD	Sheep Droppings
TAW	Total Available Water
TIPCEE	Trade and Investment Project for a Competitive Export Economy
UNESCO	United Nation Educational Scientific and Cultural Organization
USAID	United State Agency for International Development
USDA	United State Department of Agriculture
WAP	Weeks After Planting
WUE	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background

Everybody eats vegetables; hence they are cultivated by a substantial proportion of farmers all over the world. Vegetables produce high income per hectare. There are many short duration vegetables that allow the farmers to cultivate multiple times as possible all year long, especially if irrigation is available during the dry season. Fertile land, significant investment in inputs, and an adequate amounts of labour for establishing nurseries, transplanting, and harvesting are all necessary for profitable production (Nair, 2018). The average land size devoted to the commercial production of vegetables is small, it is mostly not up to a hectare for most commercial farmers (DFID, 2014). The incomes from these small plots play a vital role in livelihood strategies with dry season vegetables providing the cash to pay for additional staples, invest in the main rainy season crop, and pay for basic household essentials such as school fees and medical expenses.

Vegetable farming is one of the most profitable activities in agriculture in both the wet and dry season's cultivation period. It does not only serve as a source of income for farmers, but also constitutes an important source of food consumption for all types of households. Women of poorer households grow vegetables in their gardens as a source of ingredients for soup, selling whatever excess they have left over for cash (DFID, 2014).

Vegetable is the popular name for plants that collectively refer to edible plant materials, which includes the flowers, fruits, stalks, leaves, roots, and seeds. Vegetables are edible plants that do not include trees, bushes, vines, or vascular plants. There are two slightly different botanical definitions for vegetables as it relates to food. In one definition, a vegetable is a plant grown for its edible parts; in another, it is any edible part of a plant, such as celery stems and stalks, carrot, potato, and onion roots, spinach and lettuce leaves, globe artichokes flowers, apples, cucumbers, pumpkins, strawberries, and tomatoes seeds, or bean and pea seeds (FAO, 2021). In the second definition, fruits are classified as a subset of vegetables. Definition of fruit and vegetables applicable in epidemiological studies. These studies define fruits as edible parts of plants that contain the seeds and pulpy surrounding tissue, they can have a sweet or tart taste; generally consumed as beverages, breakfast, lunch, side-dish snacks, or desserts. Vegetable definition according to epidemiological studies is the edible plant parts including stems and stalks, roots, tubers, bulbs, leaves, flowers and fruits; usually includes seaweed and sweet corn; may or may not include pulses or mushrooms, they are generally consumed raw or cooked with a main dish, in a mixed dish, as an appetizer or in a salad (IARC Handbook, 2003)

Fertilizer is any material of natural or synthetic origin that is applied to soil or to plant tissues to supply plant nutrients. Historically fertilization came from natural or organic sources: compost, animal manure, human manure, harvested minerals, and byproducts of human-nature, industries such as fish processing waste and blood meal from animal slaughter (Roy *et al.,* 2006). However, starting in the 19th century, innovations in plant nutrition, and the agricultural industry developed around synthetically created fertilizers. The development of synthetic nitrogen fertilizer has significantly supported global population growth (Gonar, 2021).

Fertilizers enhance the growth of plants. They might be distinct from living materials or other non-nutrient soil amendments. Many sources of fertilizer exist, both natural and industrially produced. For modern agricultural practices, fertilization focuses on three (3) main macronutrients namely, Nitrogen (N), Phosphorus (P), and Potassium (K) with the occasional addition of supplements like rock dust for micronutrients. The study of plant nutrition established these macro and micro nutrients essential for plant growth and development. Nitrogen (N) is essential for leaf growth, Phosphorus (P) is essential for the development of roots, flowers, seeds, and fruit; Potassium (K) is essential for strong stem growth, movement of water in plants, promotion of flowering and fruiting; these nutrients required in a substantial amount for healthy plant life are classified according to the elements, are called the macronutrients.

Farmers apply these fertilizers in a variety of ways, through dry, pelletized, or liquid application processes, using large agricultural equipment or hand-tool methods. Fertilizers, however, are made from compounds containing the required element needed by the plant. The goal of fertilizer application is to increase crop yield and this goal is achieved in two ways. The traditional one being additives that provide nutrients whilst the second mode by which some fertilizers act is to enhance the effectiveness of the soil by modifying its water retention and aeration (Ahmad *et al.*, 2016).

1.2 Problem Statement and Justification

Farming profitably while minimizing damage to the environment is termed “sustainable agriculture”, but it is not easily practiced. Soils rarely have sufficient nutrients to enable crops to reach their potential yield (Tuğrul, 2020). Applying fertilizers without prior knowledge of their properties may cause a reduction in the yield of the plant, underutilization of fertilizers and low supply of required nutrients, while excessive application can pollute the environment. Understanding the nutrient variability and release pattern of fertilizers is crucial to supplying plants with sufficient nutrients to achieve optimum productivity, while also rebuilding soil fertility and ensuring protection of the environment and natural resources (Ahmad *et al.*, 2016). In meeting the higher food demand as population increases there is a conflict to recommend fertilizer quantity use and sustaining the soil for the future, as it is reflected as a risk of reduced yield (FAO, 2017). It has been estimated that almost half the people on the earth are currently fed as a result of synthetic nitrogen fertilizer use (Dawson and Hilton, 2011). Phosphate fertilizer use has also increased from 9 million tonnes per year in 1960 to 40 million tonnes per year in 2000 (FAO, 2017).

Excessive fertilizer use could result in lowering the efficiency of fertilizer use, increasing production costs and a higher nutrient loss that could cause serious environmental issues such as greenhouse gas emissions and groundwater nitrate contamination (Martínez-Dalmau *et al.,* 2021). In this present age, extra actions are enormously required to reduce fertilizer loss and alleviate the degradation of soil (Rasool *et al.,* 2020). In agriculture, inorganic and organic fertilizers are conventionally used to increase crop yield, and organic fertilizer is believed to be more effective than inorganic fertilizer in improving soil and vegetable quality. The inorganic fertilizers generally are relatively "high analysis" fertilizers because they are readily available to use by the plant but with few impurities. Organic fertilizers, on the other hand, are relatively "low analysis" fertilizers, the complete effect is in a space of time, but they often contain a wide range of nutrients as well as organic compounds. Both sources of nutrients have a place in farming, and to use them to their best advantage, it is important that their properties be understood (Silva, 2000). The cost of using these fertilizers also varies, a judicious selection of the right fertilizer for a given situation requires consideration of several factors such as properties affecting their use by plants, economic cost, environmental effects both short and long term.

The need to feed a bulging population with declining soil fertility has led to a call for sustainable intensification to boost crop and livestock production in many parts of the world, especially sub-Saharan Africa (Vanlauwe *et al.,* 2013). The change in time and climate continuously also modify the management of soil fertility, and as population pressure increases, intensification of soil fertility depletion increases and suitable land become scarce (Friis-Hansen, 2001). Ghana however is not an exception, the proportion of Ghanaian farmers using inorganic fertilizers is approximately 33 %. Less than 2 % of the farmers use both organic and inorganic fertilizers (MoFA, 2015). Compost, sewage sludge, food processing waste, compost, and municipal biosolids are examples of commonly used organic fertilizers. Organic matter is one of the most important soil-augmenting investments that compliments inorganic fertilizers (Tittonell and Giller, 2013; Vanlauwe *et al.*, 2011). Ghana has one of the highest soil nutrient depletion rates in sub-Sahara Africa, with the lowest rate of annual inorganic fertilizer application of 8 kg per hectare (MoFA, 2015). Compared to other African countries, sustainable forms of agricultural intensification in Ghana require more attention to soil nutrition replacement. The importance of effective management of water cannot be overruled, as water is gradually becoming a scarce resource, with increasing drought due to climate changing conditions, especially in the arid and semi-arid regions (Morante-Carballo *et al.*, 2022). According to Portmann *et al.* (2010), the total harvested cropland produces more than 41 % of yield globally. Increasing use of irrigation systems and effective water management have the capacity to save and redistribute water to underperforming systems and to increase yield (Fishman *et al.*, 2015; Jägermeyr *et al.*, 2016). Therefore, maintaining good fertile soil with the minimum water needed to produce the maximum yield must also be considered.

1.3 Objectives of Study

The main objective of the study was to optimize vegetable production using irrigation regimes and organic fertilizers in a field experimental setup in northern Ghana.

1.3.1 Specific Objectives

The specific objectives of the study were;

1. To determine and evaluate the combined effect of irrigation regimes and organic fertilizers on growth and yield of the selected vegetables.
2. To determine and evaluate the effect of organic fertilizers on the physical and chemical properties of the experimental soils.
3. To estimate the crop water requirement for the study vegetables i.e., lettuce, beetroots, and okra.
4. To evaluate the effect of organic fertilizer on crop water use efficiency of selected vegetables

1.4 Hypotheses of Study

The specific objectives of the study were used to formulate the hypotheses to guide the study.

1.4.1 Null Hypotheses (H_0):

1. Soil does not always have its own sufficient nutrients and organic fertilizer has no nutrients to add to the soil.
2. There is no estimated amount of water for effective growth and yield of vegetables.
3. There is no combined effect of organic fertilizer and irrigation regimes on vegetable growth and yield.
4. Organic fertilizer has no effect on the soil physical and chemical properties.

1.4.2 Alternate Hypotheses (H_1)

1. Soil always has its own sufficient nutrients and organic fertilizer has nutrients to add to the soil.
2. There is an estimated amount of water for effective growth and yield of vegetables.
3. There is combined effect of organic fertilizers and irrigation regimes on vegetable growth and yield.
4. Organic fertilizer affects the physical and chemical properties of soils.

1.5 Thesis Structure

The thesis is organized into five (5) main chapters. Chapter One presents an introduction to the study which include background of the study, problem statement and justification, objectives and hypotheses of the study. Chapter Two presents the literature of the study which comprised of vegetables production and their importance, the history and production of the selected vegetables in the world and in Ghana, soil fertility and fertilizers, fertilizer and environment, animal manure and compost as fertilizers, review of pertinent literature on the effect of organic fertilizers on soil and yield of crop, response of vegetables to deficit irrigation and effect of irrigation and fertilizer on vegetables. Chapter Three outlines the materials and methods used for the study. Chapter Four presents the results and discussions, while Chapter Five presents the conclusion and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Vegetables Production

Vegetables crop production is vital to human health and should be of interest to everyone. The study of vegetable crops is fundamental because it deals with the need of mankind rather than organization. An average adult has an annual capital vegetable consumption estimated to be 102 kg (Welbaum, 2015). The challenges of increasing vegetable productivity against unfortunate diminishing soil fertility, natural resources particularly land, water and the rising cost of vegetables production call for greater technology support (Hazra *et al.,* 2011). Vegetable production with organic farming has been practiced by many farmers. A major problem organic production of vegetables is experiencing is the lower yield than that of chemical farming (Xu *et al.,* 2003).

2.2 Importance of Vegetables

Vegetables are of different classes, cultivars, and species. They are generally classed mostly by the part of the plant by which they are consumed for food. Therefore, we can generally classify vegetables into fruits, seeds, leaves, flowers, stems and root vegetables, few examples are presented in Table 2.1. Vegetables are very good source of human immunity as they contain antioxidants, vitamins, fibre and minerals. However, consuming them in required amount helps fight against diseases, they are also used as strategies for boosting food production (Baidya and Sethy, 2020).

Table 2.1: World Vegetables, Class and Origin

Species	Class/Part used	Origin	Cultivars
Allium cepa	Bulbs, Leaves	Asia	Onions, Spring onion, Scallion, Shallot
Allium sativum	Bulb	Asia	Garlic
Allium ampeloprasum	Leaf sheaths	Europe and the Middle East	Leek, Elephant garlic
Abelmoschus esculentum L.	Fruits	Hong Kong	Okra
Brassica oleracea	Leaves, Axillary buds, Stems, Flower heads	Europe	Cabbage, Brussels sprouts, Cauliflower, Broccoli, Kale, Kohlrabi, Red cabbage, Savoy cabbage, Chinese broccoli, Collard greens
Brassica rapa	Root, Leaves	Asia	Turnip, Chinese cabbage, Nepa cabbage, Bok choy
Beta vulgaris	Root, Leaves	Europe and Near East	Beetroot, Sea beet, Swiss chard, Sugar beet
Cucumis sativus	Fruits	Southern Asia	Cucumber
Cucurbita spp.	Fruits, Flower	Mesoamerica	Pumpkin, Squash, Marrow, Zucchini
Capsicum annum	Fruits	North and South America	Pepper, Bell pepper, sweet pepper
Daucus carota	Root, Leaves, Stems	Persia	Carrot
Ipomoea batatas	Tubers, Leaves, Shoots	Central and South America	Sweet potatoes
Lactuca sativa	Leaves, Stems, Seed oil	Egypt	Lettuce, Celtuce
Pastinaca sativa	Root	Eurasia	Parsnip
Phaseolus vulgaris	Pods, Seeds	Central and South America	Green beans, French beans, Runner beans, Haricot beans, Lima beans

Source: FAO (2013)

In Ghana, a wide range of vegetables are consumed namely, carrots, onions, chilies, tomatoes lettuce, okra, cabbage, beetroots, garden eggs and cucumbers among others. Most of these vegetables are referred to as urban vegetables, because they did not originate from Ghana. The production of vegetables play an important role in human nutrition, ensures food security and improved livelihood through the provision of healthy diet and source of income for households (Hoornweg and Munro-Faure, 2008).

2.3 History, Production and Benefit of Okra

Okra (*Abelmoschus esculentus)*, which is also known as ladies' fingers, with different local names in respect to country and location, it is called quiabo in Portuguese, quingombo in Spanish, it is originally from India and was cultivated by Egyptians in the 12th century AD, it arrived in the US in the 18th century with the slave trade (Badrie, 2016). It is a very popular crop in many countries across the globe. The plant is cultivated in tropical, subtropical, and warm temperate regions around the world. It is related to cotton and hibiscus, it is a tall growing annual summer vegetable and is a notable part of the cuisine of the Southern United States as well as Middle Eastern cuisine, Indian cuisine, Brazilian cuisine, Sri Lankan cuisine and many others (Erez, 2013).

Okra is generally produced worldwide with an average of 9,953,537 tons per year, with India having the largest production with 6,176,000 tons per year. India alone produces 60 % of the world's okra. Nigeria is the second highest producer with 1,819,018 tons yearly production, Mali is the third on the list with 512,855 tons of production per year (Figure 2.1). According to FAOSTART (2020), the total okra produced was 10,548,942 tons, with India having 6,371,000 tons and Nigeria 1,837,904 tons. The world cultivated land was recorded as 2,531,557 ha with the yield of 4,167 kg/ha.

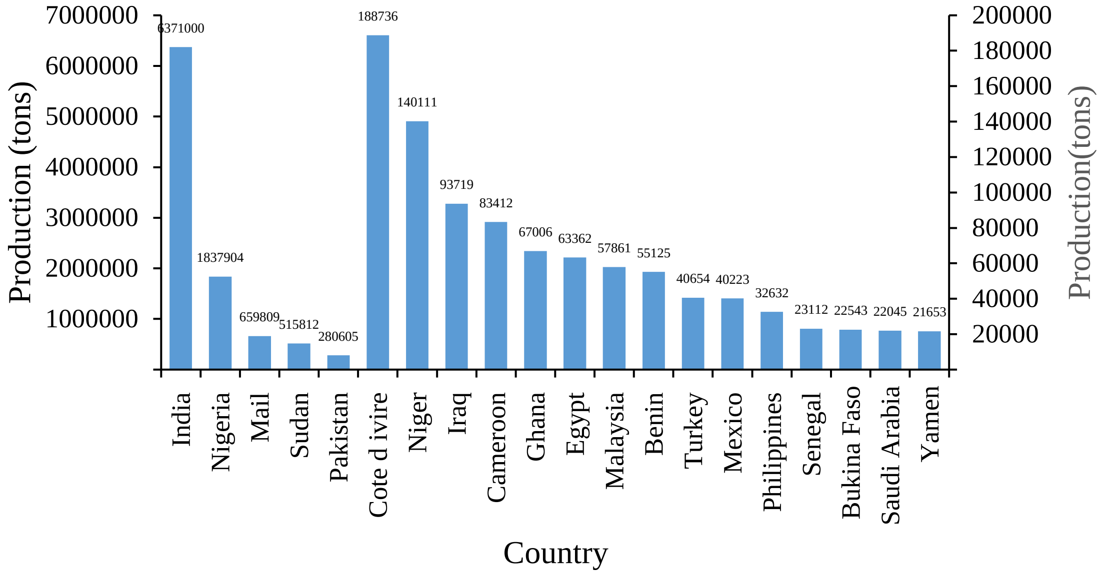


Figure 2.1: World Production of Okra

Source: FAOSTART (2020).

Okra is a vegetable that is eaten in Ghana. It is cooked or fried with other vegetables and eggs from the garden to make stews and soups that are typically served with "banku" and "akple" in most Ghanaian homes. In addition, it is dried and processed into dehydrated okra powder, which is used to flavor food preparations as well as thicken soups and serve as an emulsifier for salad dressing. The Trade and Investment Project for a Competitive Export Economy, funded by USAID, conducted okra trials under irrigation in Northern Ghana. The results showed that okra production is profitable, has a high export potential, and accounts for a significant portion (about 80%) of fresh vegetables exported to the EU market (DFID, 2014).

The irrigable sites in Northern Ghana ensure the availability of water all year round for farming including okra production and provide an opportunity for the crop to be extensively cultivated as a cash crop among smallholder households. Significantly, this help the smallholder farmer who can provide income to procure farm inputs for major season staple crops production, buy other staple food to supplement the main stock, family upkeep, pay school fees, health expenses and build and/or maintain their homes (DFID, 2014). According to FAO (2022), Ghana ranked 10th in the world production of okra in 2020, with 67,006 tonnes produced in 3,175 ha in 2020 (Figure 2.1).

Okra has been called "a perfect villager's vegetable" because of its robust nature, dietary fibre, and distinct seed protein balance of both lysine and tryptophan amino acids. Okra is more a diet food than staple food, it is a good source of dietary fibre, vitamin C and folate, a source of niacin, magnesium and manganese, and it contains a dietary significant amount of potassium, carbohydrates and phytonutrients as phenolics, carotenoids and flavonoids are also found in okra (Baidya and Sethy, 2020; Gemede *et al.*, 2015). Okra fruits are a rich source of iron with some medicinal value, and when preparing the pod in the mucilaginous preparation can be used as a blood plasma replacement or blood volume expander. The young fruits are made up of long-chain molecules made up of sugar units and amino acids (Sami *et al.*, 2013). The pod is also an important fresh fruit, and it can be consumed in different forms, it can be boiled, fried or cooked. Okra leaves are also edible, it contain water, protein, carbohydrates, fibre, calcium, phosphorous, iron, ascorbic acid, β-carotene, thiamin, riboflavin, niacin and with an energy composition of 235.00 kJ (56.00 kcal) (Moyin-Jesu, 2007). Okra seeds are also used on a small scale for oil production (Gemede *et al.*, 2015). The oil contains 47.4 % of linoleic acid, a polyunsaturated fatty acid essential for human nutrition, the seeds are rich in high-quality protein with essential amino acid which also plays a vital role in human diet. The pod skin and seeds are an excellent source of zinc, they are also rich in phenolic compounds with important biological properties like quartering derivatives, catechin oligomers and hydroxycinnamic derivatives. These properties, along with the high content of carbohydrates, proteins, glycol-protein, and other dietary elements enhance the importance of this foodstuff in the human diet (Gemede *et al.,* 2015; Singh and Sharma, 2022).

2.4 History, Production and Benefit of Lettuce

One of the popular fresh-leafy vegetable crops belonging to the Asteraceae family is lettuce (*Lactuca sativa L*.). Ancient Egyptians were the first to cultivate lettuce, turning it from a plant whose seeds were used to make oil into a significant food crop grown for its succulent leaves and oil-rich seeds. The Greeks and Romans introduced lettuce to their cultures and gave it the name lactuca, from which the English word lettuce is derived. By the year 50 A.D., numerous varieties had been documented, and multiple herbals and other medieval works frequently referenced lettuce. In Europe, various variants developed from the 16th to the 18th centuries, and by the mid-18th century, cultivars that are still used in gardens had been identified (Křístková *et al.,* 2008).

Lettuce is generally consumed in salad mixes, and it significantly contributes to the nutritional content of diets, lettuce is eaten raw hence they retain more nutrients compared to other vegetables that are cooked or processed. It has been generally believed that first leaves (cotyledons) or seedlings (baby leaf) have more nutrients, this trend leads to higher profit for the farmers as it leads to shorter cultivation periods with increase in demand as a result of the general belief of higher nutrition in the young ones (Kim *et al.,* 2016). Lettuce comes in different varieties, in colour, shape and size. They are generally classified according to their head formation, leaf shape, size and stem type (Kim *et al.,* 2016; Mou, 2012). In the United States in 2013, California (71 %) and Arizona (29 %) produced nearly all of the country's fresh head and leaf lettuce, with head lettuce yielding $9400 of value per acre and leaf lettuce $8000 per acre (Smith *et al.*, 2011).

In 2020, world production of lettuce (report combined with chicory) was 28 million tons, China produces 52 % of the world’s total production which is about 14.3 million tons, Lettuce is the only member of the genus Lactuca that is grown commercially. Although China is the top world producer of lettuce, most of the crop are consumed domestically. Spain is the world's largest exporter of lettuce, with the US ranking second (Mou, 2008). Western Europe and North America were the region's primary markets to produce vast amounts of lettuce in the beginning. Early in the twenty-first century, the market for bagged salad items surged, particularly in the USA where inventive packaging and transportation techniques preserved freshness.

Lettuce can be cultivated all -round the year if planted in a suitable environment, some varieties of lettuce can be overwintered even in relatively cold climates under a layer of straw, and other heirloom varieties are often grown in cold frames. More sunlight is received by lettuce that is placed wider apart, which enhances the color and nutrient content of the leaves. Few nutrients are found in pale to white lettuce, such as some iceberg lettuce's centers. The crops thrive in full sunlight and loose, nitrogen-rich soils that range in pH from 6.0 to 6.8. Most lettuce varieties grow poorly above 24 °C, which often causes them to bolt (Britannica, 2022). Conversely, chilly temperatures promote better performance, with 16 to 18 °C being favored and as low as 7 °C being tolerated. When given some partial shade during the warmest portion of the day, plants in hot climates will bolt more gradually. The germination of lettuce seeds will typically be poor or non-existent at temperatures over 27 °C. Following harvest, lettuce keeps best at 0 °C and 96% humidity. When lettuce is kept with fruit that releases the ripening agent ethylene gas, such as apples, pears, and bananas, it swiftly degrades. Since lettuce has a high-water content (94.9%), freezing, canning, and drying methods do not work to preserve the plant; it must be consumed fresh. Despite having a high-water content, conventionally cultivated lettuce has a low water footprint, using only 237 liters of water to produce every kilogram (Britannica, 2022).

2.5 History, Production and Benefit of Beetroots

European countries are great consumers of beetroot. In Europe, the main producers are England and France. In Spain, 564 ha of beet are cultivated, standing for 0.14 % of the total area of vegetable cultivation. The culture is usually carried out outdoors on irrigated land (97 %) although a small percentage (0.0 3 %) is cultivated on dry land (Sugar & Cane, 2017). According to La Horticultura Española (2001) the Spanish production in 1995 totaled 12,458 tons intended for fresh consumption (82 %). The average yields were 22.5 t /ha on irrigated land and 10.1 t/ha on dry land. Worldwide, 279,396,160 tons of sugar beet are produced per year, with the Russian Federation being the largest producer in the world with 51,366,830 tons of production volume per year and France comes second with 33,794,906 tons of yearly production (Żarski et al., 2020).

Beetroots are known to be a cold weather crop hence it is not very common in Africa, but because of their health benefit that is getting known to the world we now have hybrid seeds that can withstand heat to an extent and will do well in Africa's weather including Ghana, it has not been fully recognized to be a full commercial crop, but it has been sown in small quantities and sold in various markets. Beetroot is a profitable crop that can easily be grown for profit, with some of its varieties having short maturity periods and good yields. It can be grown in a moderately warm climate; but the best colour, texture, and quality is attained in cool weather conditions. It is a root vegetable with nutritious leaves that are equally edible (Amalia Yunia Rahmawati, 2020). A temperature range of 18 - 21°C is ideal for beetroot cultivation for obtaining good quality, rich in antioxidants sugars and better yield, etc. If the temperature is below 10°C, the crop is prone to bolting. Well-drained soils such as sandy loam is best suited for the cultivation of beetroot. The soil pH should range from 6-7 to get optimum yield. Beetroots have quite a number of varieties but the dark red colour variety is found to be highly nutritious and helps to reduce blood pressure and anti-ageing effects (Liliana and Oana-Viorela, 2020; Mou, 2012).

The root vegetable *Beta vulgaris*, otherwise known as beetroot, has attracted much attention as a health promoting functional food. Scientific interest in beetroot has not only gained momentum in the past few decades, reports of its use as a natural medicine date back to Roman times, Today beetroot is grown in many countries worldwide, it is consumed as part of the normal diet, with the red cultivars as a food colouring agent (Clifford *et al.*, 2015). The recent interest in beetroot has been primarily driven by its health benefits. Discovery has found out that it is a source of dietary nitrate and rich in several bioactive compounds that provide health benefits. They are cardiovascular health-friendly root vegetables and are highly nutritious with certain unique pigment antioxidants in the root. The top green vegetables have been found to offer protection against coronary artery diseases and stroke, it lowers cholesterol levels within the body and also have anti-aging effects. Beetroots offers beneficial physiological effects that translate as outcomes for several pathologies such as hypertension, atherosclerosis, type two (2) diabetes and dementia. Studies have shown that beetroot delivered acutely as a juice supplement or in bread significantly reduce and diastolic blood pressure, it is also referred to as garden beets low in calories with zero cholesterol and very small amount of fat, hence can be used as a very good diet for weight control (Clifford *et al.*, 2015).

2.6 Soil and Fertilizer

Soils in agriculture are of great importance, they can be explained differently according to their uses, and it consists of inorganic particles and organic matter. Soil provides structural support to plants used in agriculture and is also their source of water and nutrients. Due to the role soil takes an important place in crop production and agriculture at large, its fertility is of utmost importance to the plant both vegetative and productivity. Soil fertility and nutrient management is one of the important factors that have a direct impact on crop yield and quality. Plants having the access to the right amount of nutrients at the right time is a key to successful vegetable production, this can be achieved by monitoring the nutrient levels through soil tests. Collecting soils and taking soil test at the beginning of every planting season will help with a continual report on the soil organic matter, pH, electrical conductivity, cation exchange capacity, and levels of the micro and macro nutrients (Nair, 2018).

The major nutrients needed by plants are the three primary nutrients: nitrogen, phosphorus, and potassium, which are usually needed in large quantities. Oxygen, carbon and hydrogen are also essential in plant growth but not in large quantities, however plants obtain the needed quantity directly from air and water. Calcium, magnesium, sulfur and micronutrients are other secondary nutrients which are required in smaller but significant quantities (FAO, 2008). The sources of these plant essential nutrients can be grouped into two general categories, which are inorganic and organic fertilizers, the two sources of nutrients have a place in farming and it is important that their properties be understood to use them to their best advantage. The cost of the two (2) sources also varies, which is also an important factor that is considered when selecting the right fertilizer for the plant, other factors to be considered are the need of the crop and the environmental effects.

2.6.1 Animal Manure and Compost as Fertilizers

In this agricultural age, reducing the synthetic chemical content in food is a priority of some agricultural researchers, this goal can be achieved by reducing the use of chemically synthesized inputs. Generally, chemical fertilizers are expensive for many households, most times crops do not grow well without fertilizer, and hence yield become disappointingly low. Spending hours of work and having effective yield can happen when the soil is fertile (Masarirambi *et al.,* 2012).

Introduction of organic farming and the increase in demands for organically produced crop can play an important role in reducing chemical residue in food crop. The role of organic farming in agriculture is to sustain and enhance the health of ecosystems and organisms from the smallest in the soil to human beings. This is also referred to as sustainable agriculture. Conventional agriculture is considered a practice that has potential to damage the environment, these practices include excessive tilling of the soil, over-applying readily soluble inorganic fertilizers (chemical fertilizers), and over-applying pest-control formulations (herbicides, insecticides, fungicides, etc.) (Hue *et al*, 2000).

Alternative and environmentally friendly method is sustainable agriculture, the practices are economically feasible and have less potential to cause environmental damage. To maintain sustainable agriculture, with the primary goal of profitable farming as well as minimizing damage to the environment. Switching from conventional to sustainable agriculture involves more than substitution, it involves quite a number of tasks such as replacing an insecticide with predator insects, and replacing potassium chloride fertilizer with green sand because it attempts to be more "in tune with nature" than conventional agriculture. Sustainable agriculture requires more information about the environment, its characteristics and the impacts of agricultural practices on the environment. Incorporating environmental consideration into agriculture makes it more complex and information-intensive, at this point it requires a greater level of management effort and skills. Example is cultural and biological pest control; it is important to know the release pattern of organic nitrogen from the manure and how it synchronizes with the crop's nitrogen demand pattern and also a thorough understanding of the pest's life cycle and the economic threshold levels of infestation is necessary to prevent harming the crops. In either sustainable or conventional agriculture, adequate levels of soil fertility and plant nutrients are important to have profitable farming (Hue *et al*., 2000).

The use of animal manure and compost is an alternative use of chemical fertilizer, they are part of the major source of organic fertilizer. Chemical fertilizers have been promoted over the years by some farmers because these fertilizers are more concentrated than manure and easier to handle with mechanized planting equipment (labour saving). Another reason is that the quantity of manure available on large farms is usually insufficient to fertilize all the land that is being planted to crops. Nevertheless, the story is a bit different now with the acceptance of organic manures and agriculture, there are organic fertilizers made from animal droppings and organic wastes which are readily available for the farmers to use. The animal dropping generally contain different minerals that are needed by the plants but they have different concentration depending on the feeds of the animal host.

2.6.2 Fertilizers and the Environment

The surroundings of all living and non-living things occurring naturally can be referred to as the environment, in the plant world the soil is the environment that create their occurrence. Over the years, declining soil fertility has posed a serious challenge to the agricultural sector of the world especially the developing countries, those in sub-Saharan Africa, continuous supply of lost soil nutrients had been found as a step to poverty alleviation, as this will result in increased productivity (Amfo and Baba-Ali, 2021). These activities are paramount and crucial since agriculture is predominantly rural, with vast majority of the household mostly poor with consistently lower crop yields. To meet the higher food demand as the population increases there is a conflict to recommend fertilizer quantity use and maintaining the quality and yield of crops produced. Too much fertilizer use could result in lowering the efficiency of the fertilizer and could cause serious environmental issues. Nitrogen, one of the essential nutrients needed for plant growth can be lost from fields which can pollute water and increase greenhouse gases that contribute to climate change. Likewise, natural and synthetic sources of phosphorus can move out of cropped areas and pollute waterways. Effective application of fertilizers and manures, minimizing erosion, timely and avoiding excess irrigation can help manage their efficiencies as well as the environment.

2.7 Effect of Organic Fertilizer on Soil Chemical Properties

One of the natural nutrient element sources used for improving the health and fertility of soils are organic fertilizers, which ensure growth and sustained crop yield. A study by Abagale *et al.* (2020) on the use of shea waste slurry as an organic soil amendment gave a positive result by increasing the levels of the primary nutrients (N, P, K) and the secondary nutrients (Na, Ca, Mg) in the soil. It also influenced the soil pH, soil electrical conductivity, percentage organic manure and carbon content by increasing their levels and hence recommended its use as an organic amendment material for plant growth as well as soil physical properties improvement. This also agreed with Uwah and Eyo (2014), a study conducted in Calabar, Nigeria, which also reported that the post-harvest soil chemical properties (total nitrogen, available P, K, Ca and Mg) are significantly increased with the increasing rate of organic fertilizer namely goat manure. Similarly, a study in Ghana by Abagale *et al.* (2015) stated that soils taken from active and old kraals are high in organic matter and carbon content due to presence of the cow dung. The study of Zhao *et al.* (2019) in China also reported an increase in the soil organic matter and total nitrogen to the initial values, which are important in sustaining soil fertility (Yu *et al.,* 2017).

2.8 Effect of Organic Fertilizer on Vegetative Growth of Crop

Uka *et al.* (2013) found out that the use of cow dung and poultry droppings improved the growth performance of *Abelmoschus esculentu* seedlings, and hence, its usage should be encouraged in the production of vegetables like okra. The study of Dlamini *et al.* (2020) revealed that organic manure i.e. cattle dung improves the growth performance, quality, and shelf life of beetroot and its usage should be encouraged. This is similar to the findings of Afolabi *et al.* (2021) on lettuce which revealed that organic fertilizers such as cow dung and poultry manure improve lettuce vegetative growth and quality. Uwah and Eyo (2014) also reported in a study in Nigeria, that the effect of goat manure was significant for all vegetative attributes namely; plant height, number of leaves/plant, leaf area index in the performance of sweet maize. Xu *et al.* (2003) in the study of the effect of organic fertilizers on leafy vegetables in Japan, concluded that low nutrient availability of organic fertilizer at the early stage with high nutrient sustainability enhanced plant growth at later stages and maintained higher photosynthetic activity. The study also recorded high quality of leafy vegetables in terms of high sugar concentration and vitamin C and also stated that organic fertilization results in high nutrient sustainability and improved bio micro – environment in the soil.

Similarly, a study in Malaysia by Khandaker *et al.* (2017) reported organic fertilizer (poultry manure) to have shown the best effect in growth parameters namely; plant height, number of leaves, leaf area, chlorophyll content and photosynthesis rate of okra. It was concluded that the application of poultry manure significantly increases the growth performance of *Albemoschus esculentus L. Moench* (okra).

2.9 Effect of Organic Fertilizer on Yield of Crop

Xu *et al.* (2003) found out that organic fertilization (fermented using oil seed sludge, rice bran and fish- processing by- product with microbial inoculant) gives an increase in leafy vegetable quality and a higher yield than that of chemical farming. The study of Zhao *et al.* (2019) in China also reported a beneficial effect on the grain yield of wheat. The improved soil condition is said to stimulate root physiological functions and improve soil, water and nutrient availability for higher yield (Agegnehu *et al.,* 2016). Similarly, a study in Ethiopia Agegnehu *et al.* (2016) also reported a high yield in barley production, with the use of organic soils, and can be doubled when combined with N fertilizer. A study of Jahan *et al.* (2013) carried out to assess the effect of different cattle manure levels on squash production reported that increasing the manure level had a significant effect on both fruits and seed yield, with the 20 t ha^{-1} cattle manure application having the highest yield. Khandaker *et al.* (2017) in Malaysia reported that the application of organic fertilizer (poultry manure) showed the best result in the yield parameters of okra (weight of pod, number of pods, number of seeds). Khandaker *et al.* (2017) study also concluded that application of poultry manure significantly increases the yield performance of okra in the study area.

2.10 Response of Vegetables to Deficit Irrigation

The importance of irrigation in this agricultural age cannot be overemphasized, reducing water use to bring forth optimum yield is also of paramount importance, especially in water-scarce areas. The main physical limitation to the yield and growth of vegetables is usually water stress (Sasani *et al.,* 2004). It has a considerable effect on plant development, growth and quality. Vegetables have different water demand and hence the type of irrigation system adopted also influence their growth and development, deficit irrigation is a way in which water use efficiency is maximized for higher yield (Owusu *et al.*, 2010). A study in Turkey by Topak *et al.* (2011) reported that the effect of deficit irrigation on crop yield, quality and water use demand led to a decrease in root and sugar yield with an increase in water use efficiency as water deficit increases, the study revealed that if water is limited and deficit irrigation is spread over growth season of sugar beet, water use efficiency (WUE) and irrigation water use efficiency (IWUE) may be improved under 25 % and 50 % deficit irrigation schedule and also recommend that up to 25 % water deficit in sugar beet is advantageous to maximizing root yield and net income. Another study in Ghana, Owusu-Sekyere and Annan, (2010), reported that 80 % ETc application of water for okra is considered the best treatment when compared with 60 % ETc water application, with more vegetative stage growth and a better yield. The study concluded that irrigating with 80 % of the estimated water requirement is productive for deficit irrigation of okra.

2.11 Effect of Irrigation and Fertilizer on Vegetables

Climate change has caused substantial uncertainty and farming restriction owing to frequent drought occurrences that has severe negative consequences on livelihood and food security, especially for the rural people (Uka *et al.*, 2021). Water stress is one of the crop growth and yield limiting factors, it reduces leaf size, stem extension, root proliferation and lower plant water use efficiency. It also reduces dry matter production and yield component (Emam *et al.*, 2010: Farooq *et al.*, 2009). Irrigation is a reliable approach to mitigate climatic consequences, drip irrigation can be used for fertigation, when properly designed, the system delivers water and nutrients at a frequency optimizing crop water and nutrient uptake as well as minimizing leaching of nutrients from the root zone (Gärdenäs *et al.,* 2005). Manure application by spreading at a shallow depth or band greatly reduces NH_3 volatilization compared to broad-spread surface application (Oppong Danso *et al.,* 2015). A study in Ghana by Oppong *et al.* (2015) investigated on effect of fertilization and irrigation methods on nitrogen uptake and yield of okra and reported that appropriate irrigation and fertilization management is required in optimizing yield especially in sandy soils with low nutrients and low water holding capacity. The study also reported that compared to sprinkler irrigation systems the drip system with 30 % less water could produce a similar or higher yield of okra. It was also stated that drip irrigation with weekly fertigation significantly improve yield, nitrogen uptake than sprinkler irrigation.

Another study by Uka *et al.* (2021) in Nigeria reported effect of irrigation days on okra growth and yield characteristics. The result showed reduction in the growth parameters as the irrigation intervals day's increases, when irrigated every three days, okra plant had the highest of the yield parameters and the lowest when irrigated every 12 days. Mehanna *et al.* (2017) also researched on the influence of irrigation and fertilizer on growth and yield of two sugar beet varieties. It was reported that fertilizer applications improve growth and yield of the two varieties of sugar beet, and the highest yield was obtained with the highest rate of fertilizer application with moderate water quantity.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was carried out in the Research Field of the West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies (UDS), Nyankpala Campus. It is in Guinea Savannah Ecological Zone of Ghana at latitude 9º24’39’’N and longitude 0º58’52’’W with an altitude of 161 meters above mean sea level as presented in Figure 3.1.

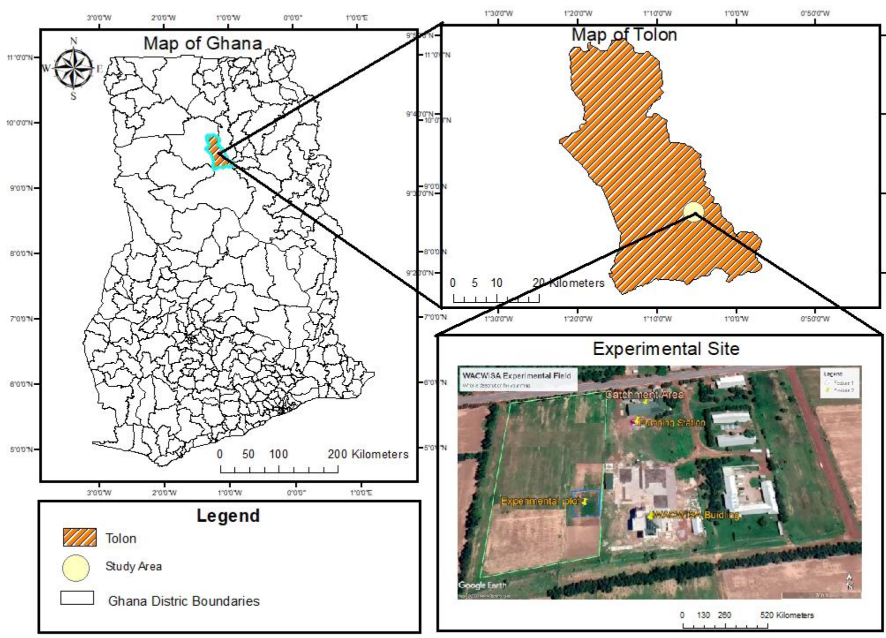


Figure 3.1: Map of Ghana Showing Tolon District and the Experimental Site

The study area has wet and dry seasons, with a monomodal rainfall of approximately 1000 to 1300 mm. The wet season runs for about 140 – 190 days from May to October, with a peak between August and September. The dry season usually lasts from November to March with day time temperatures ranging from 32 - 42 ºC and night time temperatures ranging from 20 – 22 ºC. Indigenous and urban vegetables are cultivated around the study area among which are lettuce, cabbage, spring onions, cauliflower, tomatoes, okro (okra), ayoyo (Corchorus sp.), garden eggs (aubergine) and hot pepper (Danso et al., 2014). The soil in the area according to the Ghana soil classification is savanna ochrosols with granite, sandstone and shale as parent materials with subsoil classification as loamy sandy (Adjei-Gyapong and Asiamah, 2002). According to FAO-UNESCO (1988), the soils in the area are linthic acrisols of Ferric luvisols series, Paleustults with the USDA soil taxonomy.

3.2 Experimental Treatments and Design

The pot experiment was carried out in two (2) seasons (rainy and dry). The first experiment ran from July to October 2022, while the second ran from September to November 2022. The pots were arranged in a 3 x 4 factorial Randomized Complete Block Design (RCBD) experiment with three (3) replications. The treatments were drip irrigation regime of 50 % Crop Water Requirement (CWR), 75 % CWR, and 100 % CWR in combination with three (3) organic fertilizers; cow dung (CWD), sheep droppings (SHD) and organic compost (CMT) and no fertilizer (CTR) as a control. The treatments were applied to three (3) vegetables; beetroots, lettuce and okra. The field was divided into three (3) plots for each vegetable. Treatment patterns and designs are presented in Table 3.1 and Figure 3.2 respectively.

3.3 Nursery Establishment and Management

The seedling was planted in seed trays filled with cocopeat, vermiculite and potting mix and placed in a nursey. Seeds of beetroot and lettuce were nursed on 19th July, 2022 for the rainy season experiment and 24th October, 2022 for the dry season experiment. The beetroot and lettuce seeds were nursed in the seed tray at 2 seeds per hole and covered with a thin layer of media mix and the trays were placed in a plant house. The okra seeds were not nursed but seeded directly in the growth media on the day the beetroot and lettuce seedlings were transplanted (two weeks after planting).

Table 3.1: Experimental Treatments

Treatments	**Irrigation Regimes (% of CWR)**	**Organic Fertilizers**
V_1T_1, V_2T_1, V_3T_1	100	CWD
V_1T_2, V_2T_2, V_3T_2	75	CWD
V_1T_3, V_2T_3, V_3T_3	50	CWD
V_1T_4, V_2T_4, V_3T_4	100	SHD
V_1T_5, V_2T_5, V_3T_5	75	SHD
V_1T_6, V_2T_6, V_2T_6	50	SHD
V_1T_7, V_2T_7, V_2T_7	100	CMT
V_1T_8, V_2T_8, V_3T_8	75	CMT
V_1T_9, V_2T_9, V_3T_9	50	CMT
V_1T_{10}, V_2T_{10}, V_3T_{10}	100	CTR
V_1T_{11}, V_2T_{11}, V_3T_{11}	75	CTR
V_1T_{12}, V_2T_{12}, V_3T_{12}	50	CTR

V_1 - Lettuce, V_2 - Beetroot and V_3 – Okra, CWR- Crop Water Requirement, CWD – Cow dung, SHD – Sheep droppings, CMT – Compost, CTR - Control

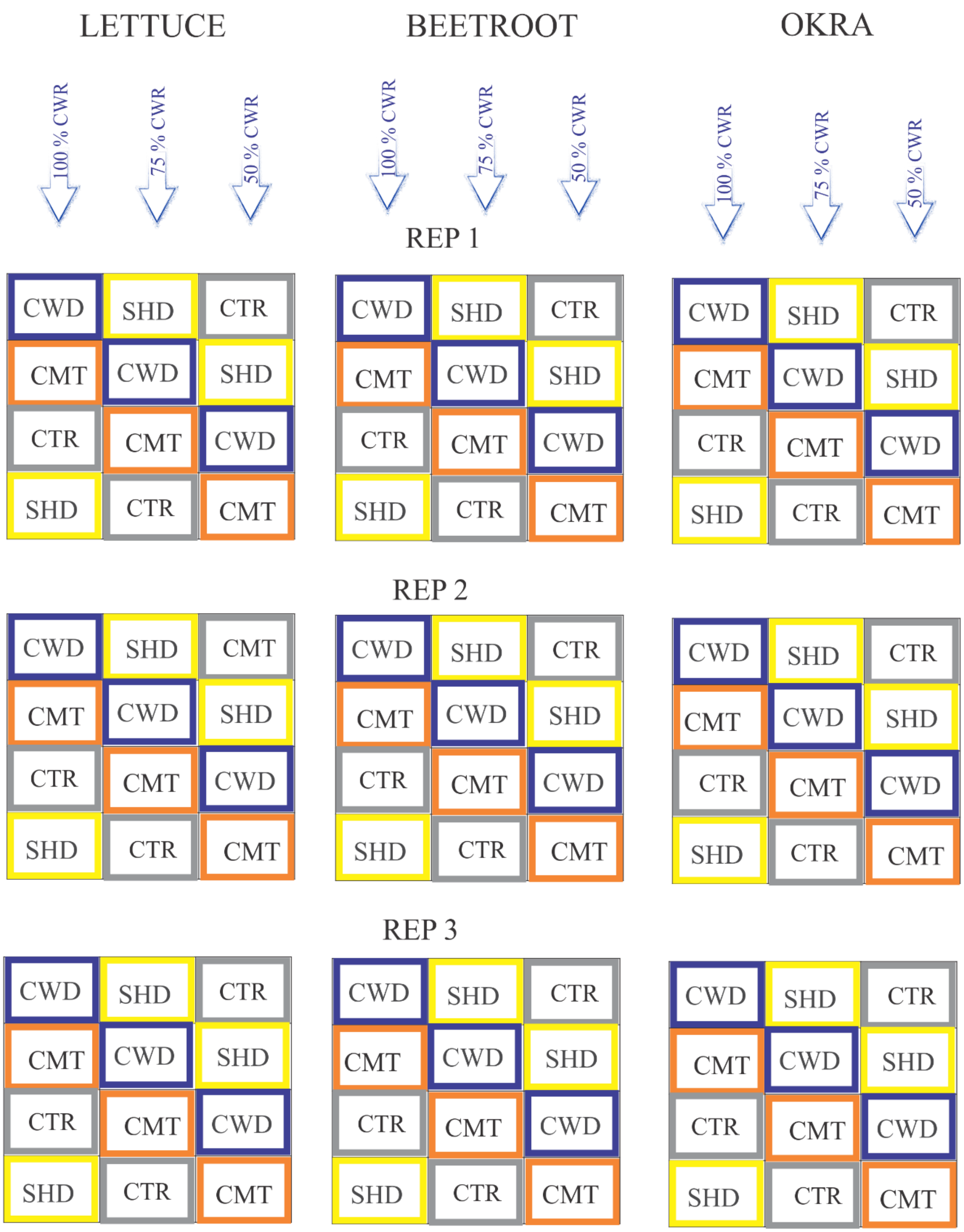


Figure 3.2: Experimental Field Design and Layout

3.4 Soil used for the Experiment

The soil sample used for the experiment was gathered in the WACWISA Research Field, Nyankpala Campus of UDS at a depth of 0 - 20 cm, only the top soil was potted for experiment. To avoid environmental effect the sample was transported to the lab in an air tight clear bag. The physical properties analyzed were soil texture, bulk density, field capacity and permanent wilting point and the chemical properties were total nitrogen, potassium, phosphorus, pH, electrical conductivity, and exchangeable cations.

i. Soil Texture

To determine the soil texture, the hydrometer method for analyzing soil particle size distribution was used (Beretta et al., 2014) and the textural class was assigned using the USDA textural triangle (Nanesa Tufa et al., 2022) and the appropriate texture was obtained based on the particle size distribution (Beretta et al., 2014). 51.0 g of air-dried soil (WT) was weighed into a one-litre screw-top shaking bottle. 100 ml distilled water was added, and the mixture was swirled to completely soak the soil. 20 ml of 30% H2O2 was added to remove soil organic matter and free the different soil classes. 50 ml of 5% sodium hexametaphosphate solution is then added, along with two drops of 95% methanol, and carefully shaken to reduce foaming. The shaking process was moved to a mechanical shaker for approximately 2 hours, the contents were transferred to a 1000 ml sedimentation cylinder, and water was added to wash soil particles into the tube to make up the 1000 ml mark. After 40 seconds, the first hydrometer was read and recorded, followed by the first temperature reading. The sample is left undisturbed for 3 hours in order to obtain the second hydrometer and temperature values.

The % soil particles is calculate using the equations

$\% Sand = 100 - [H1 + 0.2\,(T1 - 20) - 2]\ x\ 2$ ……………………………….. Eqn 3.1

$$\% Clay = [H2 + 0.2 (T2 - 20) - 2] \, x \, 2\% \text{ ………………………………… Eqn 3.2}$$

$$\% Silt = 100 - (\% Sand + \% clay) \text{ ………………………………… Eqn 3.3}$$

Where;

WT= Total Weight of air-dried soil

H1 = 1st Hydrometer reading at 40 seconds

T1 = 1st Temperature reading at 40 seconds

H2 = 2nd Hydrometer reading at 3 hours

T2 = 2nd Temperature reading at 3 hours

– 2 = Salt correction to be added to hydrometer reading

0.2 (T – 20) = Temperature correction to be added to hydrometer reading, and T = Degree Celsius

ii. **Soil Bulk Density**

Dry bulk density is an important measure for characterizing the physical properties of soil. It gives useful information regarding the porosity, compaction, and structure of the soil. The bulk density of the soil was determined using undisturbed soil samples collected with a known volume of core sampler at a depth of 0-20 cm. The soil samples were weighed, and oven dried at 105ºC for 24 hours, and weighed to determine the dry weight of the soil. The bulk density was then calculated by dividing the weight of the dried soil by the volume of the soil in the core sampler.

$$Bd = \frac{M_S}{V_S} \text{………………………………… Eqn 3.4}$$

Where:

Bd - Bulk density (g/cm^3)

M_s - Dry weight of the soil (g)

V_s - Total volume of the soil inside the sampler (cm^3)

iii. **Field Capacity**

The collected sample was saturated for 24 hours, and was drained at 0.33 bar using the pressure plate equipment. The wet sample was weighed after removing it from the plate apparatus (W_1), it was oven dried at 105ºC for 24 hours, and was weighed (W_2) the difference in the weight which is the amount of moisture dried is considered as the field capacity of the soil.

$FC = W1 - W2$ ………………………………………. Eqn 3.5

Where:

FC – Field Capacity

W_1 -Initial weight after leaving the pressure plate (g)

W_2 - Final weight after drying (g)

iv. **Permanent Wilting Point**

The soil sample was saturated for 24 hours like the field capacity, moisture was reduced using the pressure plate device but at 15 bars pressure, the moisture held in the soil at 15 bars was considered to be the Permanent Wilting Point (PWP), the sample was weighed after removing it from the plate apparatus (W_0), it was then oven dried for 24 hours at 105ºC, and measured (W_1) the difference in weight of the samples at each level was determined, which is referred to as the Permanent Wilting Point (PWP).

$PWP = W0 - W1$ ………………………………………. Eqn 3.6

Where:

PWP - Permanent wilting point

W_0 -Initial weight after leaving the pressure plate (g)

W_1 - Final weight after drying (g)

v. **Soil pH**

An electric pH meter (Crimson pH meter Basic 20) was used to evaluate the pH of the soil. 10 g of soil sample was dissolved in 25 ml of distilled water and stirred continuously for 20 minutes before allowing the solution to stand for roughly 30 minutes. The probe was inserted in the partially sample solution after calibrating the instrument with pH solutions of 4 and 7, respectively, and each sample was read and recorded.

vi. **Total Nitrogen**

The total nitrogen available in the soil was determined using the Kjeldal method as described by Jones (1991). After grinding and sieving the sample, 1 g was dissolved in a 900 ml Kjeldal digestion flask with 1.0 g of alundum granules and 20 ml of concentrated H_2SO_4 acid. To prevent overheating, a few boiling stones were placed to the digestion flask. The sample was heated in water for 5-10 minutes at a boil rate to clear dense white fumes from the bulb flask, and the solution was gradually and continuously boiled in water for an additional 40 minutes. The solution was cooled for about 20 minutes by adding 250 ml water at room temperature. A 500 ml titration beaker was filled with 0.5 N HCl standard solution, 250 ml of water, and 3 drops of melty orange indicator. The cooled digestion flask had an additional 1.0 g of alundum granules. 20 ml of H_2SO_4 was neutralized with 60 ml of 45% NaOH. The digestion flask was connected to the distillation apparatus, and the distillate was collected in the beaker after 7.5 minutes of boiling. the process continues until about 180 ml of distillate is collected. For correcting blank determination on reagents, the excess H_2SO_4 in the distillate was titrated against 0.1 N NaOH.

The percentage N is determined using equation 3.7

$$\%N = [(Nacid)(mlacid) - (mlbk)(NNaOH) - (mlNaOH)(NNaOH) \times 1400.67] / mg\ sample \text{ .... Eqn 3.7}$$

Where ml_{NaOH} = the milliliters of standard base required to titrate the sample.

ml_{acid} = milliliters of the sample's standard acid

ml_{bk} = milliliters of standard base required to titrate 1 ml of standard acid minus milliliters of standard base required to titrate the reagent blank distilled into 1 ml of standard acid.

Normality of standard acid = Nacid

N_{NaOH} = standard base normalcy.

vii. **Organic carbon**

This was calculated using the Walkley and Black method. A 500 ml Erlenmeyer flask was filled with 2.0 g of soil sample. 10 ml of 1.0 N potassium dichromate solution was added from a burette, followed by 20 ml of conc. H2SO4; the mixture was swirled while titrating to ensure that the solution was in touch with all soil particles. The flask and contents were cooled for 30 minutes on an asbestos sheet. 200 mL distilled water, 10 mL orthophosphoric acid, and 2.0 mL (of a total of 10 mL) diphenylamine indicator was added. 10 N ferrous sulphate solution was applied for titration and the color changed to blue, then green. The titter value and blank solution correction were recorded, and the percentage organic carbon was computed using equation 3.8

$$\%\ organic\ C\ in\ soil = \frac{(m.e.K2Cr2O7 -- m.e.FeSO4) \times 0.003 \times f\ \times 100}{wt.of\ soil} \text{ .... Eqn 3.8}$$

Where;

m. e. = milli equivalent = Normality of solution x ml of soln. used

0.003 = m. e. wt. of C

f = correction factor = 1. 33

NB: The Wet combustion method is about 76 % efficient in estimating carbon value. Hence a factor of 100/76 = 1. 33 is used to convert the Wet combustion C value to the true C value

viii. **Soil Electrical conductivity**

The procedure is similar to that used to assess soil pH, except the E.C is determined using an electric conductivity meter (Crimson conductivity meter Basic 30). To evaluate the EC of the soil 10 g of soil sample was dissolved in 25 ml of distilled water and constantly stirred for 20 minutes before leaving the solution to stand for approximately 30 minutes. After calibrating the equipment with conductivity standard solutions, the probe was put into the partly sample solution, and each sample was read and recorded.

ix. **Phosphorus**

The amount of phosphorus was calculated using the Bray-P solution method (Sims, 2000). Soil samples were air dried, crushed, and sieved through a 10-mesh sieve. 2. 0g of soil was weighed into a 50 ml shaking bottle, 35 ml of Bray1 P extraction solution was added, and the solution was shaken for 10 minutes before being filtered into a 100 ml conical flask with Whatman no 42 filter paper. Pipette 10 ml of filtrate into a 25 ml volumetric flask. The solution turned blue after 1.0 mL of molybdate reagent and 1.0 mL of dilute reducing agent were added. To reach the 25 ml mark, distilled water was added. Allow the solution to stand for 15 minutes after aggressively shaking it. A spectrophotometer is used to measure and record absorbance at 600 nm.

x. **Exchangeable Cations**

Potassium amount was determine using the flame photometer method (Toth and Prince, 1949). (Grewal *et al.*, 1991) and calcium and magnesium concentrations were determined using the Ammonium acetate technique (Normandin *et al.*, 1998). A quantity of 5 g of air-dried crushed soil was measured and transferred to a 50-ml centrifuge tube. 25 ml of 1.0M sodium acetate solution was added to the tube, a stopper was attached, and the solution was shaken for 5 minutes before being transferred to a centrifuge at 2000 rpm for 5 minutes to clear the supernatant liquid. The liquid is now decanted, and the process is done 3-4 more times. The washing procedure was repeated with ethanol to lower electrical conductivity to less than 40 mS/cm. The washing operation was then repeated with ammonium acetate solution to displace deposited Na, and the decant was collected in a 100 ml volumetric flask fitted with a funnel and filter paper. The sodium concentration is determined by making a series of Na standard solutions ranging from 0 to 10 me/litre of Na. A standard curve is constructed by plotting Na concentration on the x-axis and flame photometric data on the y-axis. In each standard, lithium chloride (LiCl) is added to achieve a final concentration of around 5 me/litre of LiCl. This displaced Na is essentially a measure of the soil's CEC. The method also determined the potassium content. The extract from the washing with ammonium acetate solution was used, together with ethylenediaminetetraacetic acid (EDTA) titration for Ca2+ and atomic absorption spectrometry for Mg2+.

3.5 Field Setup and Preparation

The experimental field was the drip irrigation system section at WACWISA research field. The laterals were monitored for irrigation at 100 % CWR, 75 % CWR and 50 % CWR irrigation regimes. In each plot, 36 filled polyethylene pots were arranged in RCBD according to the percentage water treatment required. There was around 12 kg of soil in each pot, which was filled to a height of 25 cm.

Plate 3.1: Experimental Field with the Layout of the Polyethylene Pots

3.5.1 Drip Irrigation Installation

The drip system was made up of a main line and laterals with their direct emitters. The main line was connected to sub-main, and all laterals also referred to as drippers with 30 cm spacing were also connected to the sub-main. The drip tape lines were 16 mm with a controlling valve. The sub-main pipe was a High-Density Polyethylene Pipe (HDPE) 32 mm size connected to the main line. The pots were spaced according to the drip spacing so that each pot has an emitter in it. The water source for drip irrigation system was a two-unit 3000 liters capacity poly tank mounted at a 3 meters height and with a supply feed from an underground water storage rainwater harvesting reservoir.

3.5.2 Cultural Practices

Seedlings with two to three true leaves were carefully removed from the seed trays and moved from the nursery to the field while adhering to all suggested cultural procedures, including irrigation, fertilizer treatment, weeding, and insect-pest management.

3.5.2.1 Irrigation

The water requirement and irrigation scheduling were estimated including the quantity of water required by each vegetable throughout the growing season.

3.5.2.2 Estimation of Crop Water Requirement

The average climate data from 1990 – 2020 with climatic parameters maximum and minimum temperature, relative humidity, wind speed and sunshine hours were used to calculate CWR. The estimation was done using CROPWAT software. The crop coefficient, critical depletion and yield response parameters were adopted from FAO irrigation and drainage paper 56

$$ETc = ETo \times Kc \quad \text{.. Eqn 3.9}$$

Where:

ETo - Evapotranspiration (mm), and

Kc - Crop constant.

3.5.2.3 Estimation of the Gross Water Requirement (IRg)

Gross Water Requirement accounts for the loss of water which was place during transportation and application in the field. This was computed by adopting an application efficiency (Ea) of 95 % since the method of application was the drip system. According to FAO 1977, application efficiency for drip system varies from 90 % and 95 %. IRg was calculated using Equation 3.10.

$$IRg = \frac{IRn}{Ea} \quad \text{…………………………………. Eqn 3.10}$$

IRg - Gross Irrigation Requirement (mm), and

IRn - Net Irrigation Efficiency (distribution uniformity, %).

$IRn = ETc - Pe$

$IRn = ETc$

Pe - Effective rainfall

Note, Pe = 0, since irrigation was done during the dry season with no rainfall

3.5.2.4 Irrigation Scheduling

To estimate the time and interval for irrigation, some other parameters such as available water in the soil, total available water in the soil and readily available water will be calculated from the soil field capacity, permanent wilting point and the rooting depth of each crop.

3.5.2.4a Estimation of Available Water Content (AWC)

This was estimated by finding the difference between the field capacity and the permanent wilting point.

$AWC = FC - PWP$ ………………………. Eqn 3.11

Where:

AWC - Available Water Content

FC - Field Capacity

PWP - Permanent Wilting Point.

3.5.2.4b Estimation of Total Available Water Content (TAW)

This was estimated using equation 3.7.

$AWC = FC - PWP$ ……………………...Eqn 3.12

Where:

Zr - Root zone depth (mm)

W_{FC}% - Water Content at Field Capacity (%)

W_{wp} % - Water Content at Wilting Point (%).

3.5.2.4c Estimation of Readily Available Water Content of the Soil (RAW)

In this study the readily available water was estimated to multiply the Available Water Content by the management-allowed depletion as presented in Equation 3.13.

$RAW = \text{AWC} \times \text{MAD}$ ………………………. Eqn 3.13

Where:

RAW - Readily Available Water to plant at all times.

It was converted to volume by multiplying by the crop area.

MAD - Management allowable depletion (this was selected concerning soil texture, crop, and climate)

3.5.2.4d Estimation of Maximum Irrigation Interval

This was determined using Equation 3.14:

IRI = $\frac{RAW}{IRn}$ ………………………………. Eqn 3.14

Where:

IRI - maximum irrigation interval or irrigation frequency (days)

RAW - Readily Available Water (litres)

IR_n - Net irrigation requirement in (l/day)

3.5.2.4e Estimation of Irrigation Run Time

This was determined using Equation 3.10:

Ta = $\frac{IRg}{Q}$ …………………………………Eqn 3.15

Where:

Ta - Irrigation run time (hours)

IRg - Gross irrigation requirement (litres)

Q - Emitter discharge (l/h)

3.5.2.4f Estimation of Crop Water Use Efficiency

The yield that can be obtained from the amount of irrigation water is known as water use efficiency (WUE). This was calculated using the formula in Equation 3.16

$$WUE = \frac{Y}{ETc} \quad \text{.....................................Eqn 3.16}$$

Where:

WUE - water use efficiency (kg/ha/L)

Y - Crop yield ($kgha^{-1}$)

ETc -water used (L).

3.5.2.5 Fertilizer Application and Plant Protective Measures

The three (3) organic fertilizers were incorporated into the soil as soil amendment at 0.5 kg per pot (60 t/ha). A portion of the field with termite colony was treated and sprayed with dusfos 48 % (Chlorpyrifos-ethyl solution) before the pots were placed on the field. Weeding was done in each pot as required.

3.6 Data Collection

3.6.1 Agronomic Data

Each plant in the pot was monitored throughout for each growing season. Data collection started two (2) weeks after transplanting when the plants were established and two (2) weeks after okra was seeded. A total of 108 plants were sampled with 36 plants from each vegetable crop. The following dataset were recorded during the experiment:

3.6.1.1 Soil Moisture Content: The amount of moisture present in each pot was monitored and recorded daily, starting from the first week after transplanting for the rainy season and after irrigation during the dry season. Campbell H2S hydro Sense II (CS658) 20 cm rod moisture meters were used in taking the readings. The device was inserted into the soil with the 20 cm rod to record the moisture.

3.6.1.2 Plant Height: The height of each vegetable was measured and recorded weekly with an 80 cm meter rule. Measurement started two weeks after planting for okra and two weeks after transplanting with beetroots and lettuce after they were established.

3.6.1.3 Number of Leaves: The number of leaves of each vegetable was counted and recorded weekly. This started three (3) weeks after sowing for okra and two weeks after transplanting for lettuce and beetroot, to ensure that young plant's root is established.

3.6.1.4 Leaf Size: Three (3) broad leaves were measured in each treatment and the size of the leaves as the length and width were measured and recorded weekly, with a meter rule. The length was measured from the leaf base to the tip, while the broadest part of the leaves blade was measured as the width.

3.6.1.5 Leaf Area: The leaf area for okra was recorded weekly. This was computed by multiplying the leaf length (LL) and the leaf width (LW) and the correction factor according to Musa and Hassan (2016) using the formula given in Equation 3.17.

$$\text{Leaf Area (LA)} = \text{Leaf Length (LL)} \times \text{Leaf Width (LW)} \times 0.62 \ldots\ldots\ldots \text{Eqn 3.17}$$

While for beetroot, leaf area was determined at harvest, calculated using a correcting factor according to Varga *et al*. (2021) using the formula presented in Equation 3.13.

$$\text{Leaf Area (LA)} = \text{Leaf Length (LL)} \times \text{Leaf Width (LW)} \times 0.75 \text{ ………. Eqn 3.18}$$

3.6.1.6 Canopy Diameter: This was measured in lettuce at harvest using the Fiji image App as used by Beckschäfer (2015). A high-quality image of the lettuce canopy was captured using a ruler as the scale bar. The Fiji ImageJ software was launched and calibrated using the ruler scale; each canopy image was then uploaded into the app and analyzed using the calibrated data to convert pixels to real-world units.

3.6.1.7 Leaf Area Index (LAI): This was calculated as the ratio of the leaf area of the plant to the area occupied by one plant as given in Equation 3.19.

$$\text{Leaf Area Index (LAI)} = \text{Leaf Area} \times \left(\frac{\text{Number of leaves}}{\textit{Area occupied by each plant}}\right) \text{…. ….. Eqn 3.19}$$

3.6.1.8 Chlorophyll Content: The chlorophyll content of each crop was determined weekly using the SPAD-502 plus Konica Minolta chlorophyll meter. The device was used on the leaves of each plant and an average of the set calculated by the device was recorded for each treatment.

Plate 3.2: SPAD-502 plus Konica Minolta chlorophyll meter

3.6.1.9 Stem Girth: Stem girth for okra was measured at three weeks after planting while lettuce and beetroot was during harvesting due to the different morphological characteristics using a digital vernier scale.

3.6.1.10 Yield Parameters: At harvest, yield parameters measured. For the okra, the pod length, pod diameter and pod weight were recoded. A visible number of fruits on each plant was also recorded. For beetroot yield parameters measured were bulb weight, dry bulb weight, bulb diameter. For lettuce the parameters measured were individual weight, canopy diameter, above ground biomass fresh weight and dry weight.

3.6.1.11 Root Parameters: The weight of the root of lettuce in each treatment was measured during harvesting and was oven dried at 100 ºC for 48 hours to determine the dry weight. For okra and beetroots, the root lengths were measured and recorded.

3.6.2 Crop Water Use Efficiency (WUE)

This is the response of crop to soil water availability, it is defined as the ratio of total biomass or yield to water supply on a daily or seasonal basis (Sharma *et al.*, 2015).

$$WUE = \frac{YLD}{ETc} \qquad \text{.................Eqn 3.20}$$

Where:

WUE - crop water use efficiency (kg/m^3)

YLD - crop yield (kg/ha)

ETc - seasonal crop water consumption (m^3/ha)

3.6.3 Physical and Chemical Characteristics after Harvest Soil

The physical and chemical characteristics of the amended soil in the polyethylene pots after harvest were analyzed at the laboratory to determine the effect of amendments on the soil. Soil samples were taken with respect to the treatment and variation and was worked on in the laboratory.

3.7 Data Analysis

Collected data (Lettuce: Plant height, stem girth, number of leaves, canopy diameter, above ground biomass, individual weight, chlorophyll content, fresh and dry root weight. Beetroot: plant height, fresh and dry bulb weight, number of leaves, root length, leaf area index, bulb diameter. Okra: Plant height, number of leaves, stem girth, chlorophyll content, fruit length, fruit diameter, fruit weight, no of fruits per plant) were arranged in Microsoft Excel 2019 and subjected to Analysis of Variance (ANOVA) using the 15^{th} edition of the GenStat statistical tool at a significance level of 5 % level probability.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical and Chemical Properties of Experimental Soil before Amendment to Organic Fertilizers

As presented in Table 4.1, the soil used for the experiment had a sandy loam texture. The soil contained 76.2 % sand, 20.3 % silt and 3.5 % clay. The findings of this study agreed with those of Shaibu et al. (2017), who said that the soils in the dry savannah zone vary from sandy to sandy - loam to silt and had low clay contents. The soil's bulk density was found to range from 1.28 - 1.32 g/cm^3 with a mean value of 1.30 g/cm^3 across soil depth 0 – 20 cm, and this was within the range for agricultural soils as indicated by Hillel (2013), who stated that dry bulk density of most sandy loam soil varies within the range of 1.1-1.6 g/cm^3. This is due to the coarse textured nature of the soil. The field capacity was calculated to be 19.6 % and soil moisture content at permanent wilting point was 9.1 % on a dry weight basis. These values are in line with Hillel (2013) and Busscher (2009) which reported that the field capacity of sandy loam soils ranges from 15 - 25 % on weight basis and permanent wilting point ranges from 8.0 - 10 %. Senayah *et al.* (2009) reported that the soils in the study area generally have low water retention capacity due to low clay content and poor organic carbon content. Total available water was found to be 105 mm/m for beetroots, 52.5 mm/m for lettuce and 126 mm/m for okra.

The chemical analysis of the soil was done at the beginning of each experiment and the results are presented in Table 4.1. The pH of the soil ranged from 6.15 to 6.21 and mean was found to be 6.18 and thus slightly acidic. The soil electrical conductivity (EC) was found to range from 79.5 to 80.3 µS/cm with mean of 79.9 µS/cm at the beginning of the experiment. As presented in Table 4.2, the organic carbon of the soil was found to be relatively low, the soil's major and micro nutrients, total

Nitrogen, Phosphorus, Potassium, and others were relatively low. These results were all within the range with the findings of Shaibu *et al.* (2017) for soils within the savannah region.

Table 4.1: Physical Properties of the Experimental Soil before Amendment with Organic Fertilizers

Soil Physical Property	**Values**	**Soil Chemical Property**	**Values**
% Sand	76.2	Organic carbon (%)	1.1895
% Silt	20.28	Total Nitrogen (%)	0.1096
% Clay	3.52	Available P (mg/kg)	7.44
Textural Class	Sandy loam	K (mg/kg)	88
Field Capacity (%)	19.6	Ca (Cmol+/kg)	1.4
Permanent Wilting Point (%)	9.1	Mg (Cmol+/kg)	0.6
Bulk Density (g/cm^3)	1.30	pH (1:2.5)	6.18
Available Water (%)	10.5	EC (µS/cm)	79.9

The chemical properties of organic fertilizers were also analyzed, and the results are presented in Table 4.2. The manure gotten from sheep was noted to be high in the chemical parameters analyzed namely, the pH, organic carbon, total nitrogen, potassium, calcium as well as phosphorous except magnesium where cow dung recorded the highest value. This was attributed to the rice husk that was used as bedding at the kraal where the cow dung was gotten. This agreed with the findings of Korotkova *et al.* (2016) who reported 0.35 % by weight of MgO present in rice husk.

Table 4.2: Chemical Properties of the Organic Soil Amendments

Properties	Cow Dung	Sheep Droppings	Compost
pH (1:2.5)	9.82	10.06	8.11
Total organic C (%)	22.62	31.98	12.48
Total N (%)	2.1038	2.976	1.154
Total P (mg/kg)	2580	4020	2360
Total K (mg/kg)	36100	38100	7000
Ca (Cmol+/kg)	2.6	3.2	1.8
Mg (Cmol+/kg)	1.8	1.6	1.2

4.2 Crop Water Requirement of Experimental Vegetables and Weather Parameters

4.2.1 Crop Water Requirement of Lettuce

As reported by Shaibu *et al.* (2017), lettuce generally matures in 75 – 100 days with 20/25 days for the initial stage, 30/35 days for the developmental stage, 15/30 days for mid-season and 10 days for the late season. The water requirement for lettuce was calculated with CROPWAT 2018 model and the results are presented in Table 4.3. The highest water application was 358.3 mm at 100 % CWR irrigation regime and the minimum water requirement was 179.2 mm at the 50 % CWR irrigation regime. Gross irrigation seasonal requirement with 90 % field application for drip system was obtained at 100 % CWR irrigation regime with the highest value of 413.11 mm and the lowest value of 199.1 mm at the 50 % CWR irrigation regime.

Presented in Table 4.4 is the water use at the field with respect to the CROPWAT model in terms of area and volume of water. The estimated seasonal CWR values for lettuce for the full irrigation in the second experiment was consistent with the study of Gallardo *et al.* (1996). The authors reported that seasonal crop water consumption of lettuce varies from 140 – 400 mm but is depends on climate types, irrigation method and soil properties. The emitter discharge at 0.75 l/hr. was used to calculate the irrigation run time.

Table 4.3: Lettuce Crop Water Requirement and Deficit Irrigation Regimes

Month	Stage	Kc Coeff	CWR/100% Irr Req mm/dec	75% Irr mm/dec	50% Irr mm/dec	CWR/Irr. Req mm/day	75% Irr. Req mm/day	50% Irr.Req mm/day
Sep	Init	0.7	20.2	15.15	10.10	2.89	2.17	1.45
Oct	Init	0.7	30.1	22.58	15.05	3.01	2.26	1.51
Oct	Deve	0.73	32.8	24.60	16.40	3.28	2.46	1.64
Oct	Deve	0.84	42.1	31.58	21.05	3.83	2.87	1.92
Nov	Deve	0.96	44	33.00	22.00	4.4	3.30	2.20
Nov	Mid	1.03	47.7	35.78	23.85	4.77	3.58	2.39
Nov	Mid	1.03	45.5	34.13	22.75	4.55	3.41	2.28
Dec	Mid	1.03	43.2	32.40	21.60	4.32	3.24	2.16
Dec	Late	1.01	39.9	29.93	19.95	3.99	2.99	1.99
Dec	Late	0.95	26.3	19.73	13.15	3.76	2.82	1.88
Total			**371.8**	**278.85**	**185.9**			

Table 4.4: Amount of Water used by the Lettuce Crop

Month	Number of days	CWR (litre/day) A= $0.071m^2$	Irr. Run time at 100% CWR (minutes)	75% CWR (litre/day) A= $0.071m^2$	Irr. runtime at 75% CWR (minutes)	50% CWR (litre/day) A= $0.071m^2$	Irr. Runtime at 50% CWR (minutes)	Total volume of water applied (litres) at 100%CWR	Total volume of water applied (litres) at 75%CWR	Total volume of water applied (litres) at 50% CWR
September	5	0.21	18.67	0.16	14.22	0.11	9.77	1.05	0.8	0.55
October	31	0.27	24	0.20	17.77	0.14	12.44	8.37	6.2	4.34
November	31	0.34	30.22	0.26	23.11	0.17	15.11	10.54	8.06	5.27
December	10	0.31	27.56	0.23	20.44	0.16	14.22	3.1	2.3	1.6
Total								**23.06**	**17.36**	**11.76**

4.2.2 Crop Water Requirement of Beetroot

As presented in Table 4.5, beetroot's maximum net irrigation application, 341 mm, was obtained under a 100% CWR irrigation regime, while its lowest, 171 mm, was obtained under a 50% CWR irrigation regime. Using 90 % field application efficiency, the highest gross irrigation water requirement of 379.6 mm was obtained at the 100 % CWR irrigation regime and the lowest was 190 mm obtained at the 50 % CWR irrigation regime. The calculated water used, irrigation run time in minutes and the amount of water used in litres, in accordance with the CROPWAT model and the irrigated area for the beetroot crop are presented in Table 4.6.

Table 4.5: Beetroot Crop Water Requirement and Deficit Irrigation Regimes

Month	Stage	Kc Coeff	CWR/100% Irr. Req mm/dec	75% Irr.Req mm/dec	50% Irr.Req mm/dec	CWR mm/day	75% Irr. Req mm/day	50% Irr.Req mm/day
Sep	Init	0.5	14.4	10.8	7.2	2.06	1.55	1.03
Oct	Init	0.5	21.5	16.13	10.75	2.15	1.61	1.08
Oct	Deve	0.55	24.7	18.53	12.35	2.47	1.85	1.24
Oct	Deve	0.73	36.4	27.3	18.2	3.31	2.48	1.66
Nov	Deve	0.92	42	31.5	21	4.2	3.15	2.10
Nov	Mid	1.03	47.7	35.78	23.85	4.77	3.58	2.39
Nov	Mid	1.03	45.5	34.13	22.75	4.55	3.41	2.28
Dec	Mid	1.03	43.2	32.4	21.6	4.32	3.24	2.16
Dec	Late	1.01	39.9	29.93	19.95	3.99	2.99	2.00
Dec	Late	0.95	26.3	19.73	13.15	3.76	2.82	1.88
Total			**341.6**	**256.2**	**170.8**			

Table 4.6: Amount of Water used by the Beetroot Crop

Month	Number of days	CWR (litre/day) A = $0.071m^2$	Irr. Runtime at 100% (minutes)	75% CWR (litre/day) A= $0.071m^2$	Irr. Runtime at 75% (minutes)	50% CWR (litre/day) A = $0.071m^2$	Irr. Runtime at 50% CWR (minutes)	Total volume of water applied (litres) at 100% CWR	Total volume of water applied (litres) at 75% CWR	Total volume of water applied (litres) at 50% CWR
September	5	0.15	13.33	0.11	9.77	0.08	7.11	0.75	0.55	0.4
October	31	0.24	21.33	0.18	16	0.12	10.66	7.44	5.58	3.72
November	30	0.34	30.22	0.26	23.11	0.17	15.11	10.2	7.8	5.1
December	10	0.31	27.55	0.23	20.44	0.16	14.22	3.1	2.3	1.6
Total								**21.49**	**16.23**	**10.82**

4.2.3 Crop Water Requirement of Okra

As presented in Table 4.7, the strained 50% CWR irrigation regime produced the lowest irrigation water application of 128.65 mm, and the highest irrigation water application of 257.2 mm was recorded in the 100% CWR irrigation regimes. With 90% field efficiency, 100% CWR yielded the highest gross irrigation season water need (285.78 mm), whereas 50% CWR yielded the lowest (142.94 mm). The water used, irrigation run time and water required in litres per hour were also calculated and presented in Table 4.8. The seasonal water demand of 257.2 mm obtained from 100% CWR agreed with the findings of Aliku and Oshunsanya (2016), who stated that water requirement for okra varies from 1.17 to 3.85 mm for the savannah zone.

Crop water requirements (CWR) are defined as the depth of water [mm] required to meet the water consumed through evapotranspiration (ETc) by a disease-free crop growing in large fields under non-restrictive soil conditions such as soil water and fertility, and achieving full production potential under the given growing environment. While crop evapotranspiration (ETc) is defined as the rate of evapotranspiration [mm d1] of a given crop as impacted by its growth phases, climatic circumstances, and crop management to achieve maximum crop production, the CWR is the sum of ETc during the whole crop growth period (Pereira & Alves, 2004). The values of the CWR obtained for each vegetable in respect to their percentages is the minimum amount of water depth that is required to be consumed through evapotranspiration for each plant survival

Table 4.7: Okra Crop Water Requirement and Deficit Irrigation Regimes

Month	Stage	Kc Coeff	CWR/100% Irr. Req mm/dec	75% Irr.Req	50% Irr.Req	CWR mm/day	75% Irr. Req mm/day	50% Irr.Req mm/day
Nov	Init	0.2	9.2	6.9	4.6	0.92	0.69	0.46
Nov	Deve	0.33	15.5	11.63	7.75	1.55	1.16	0.78
Nov	Deve	0.58	25.5	19.13	12.75	2.55	1.91	1.28
Dec	Deve	0.82	34.5	25.88	17.25	3.45	2.59	1.73
Dec	Mid	0.96	38	28.50	19	3.8	2.85	1.9
Dec	Mid	0.96	41.9	31.43	20.95	3.81	2.86	1.91
Jan	Late	0.95	37.9	28.43	18.95	3.79	2.84	1.90
Jan	Late	0.91	36.2	27.15	18.1	3.62	2.72	1.81
Jan	Late	0.87	18.6	13.95	9.3	3.71	2.78	1.86
Total			**257.2**	**192.98**	**128.65**			

Table 4.8: Amount of Water used by Okra

Month	Number of days	ETc (litre/day) A = $0.071m^2$	Irr. Runtime at 100% CWR (minutes)	75% CWR (litre/day) A = $0.071m^2$	Irr. runtime@ 75% CWR (minutes)	50% CWR (litre/day) A = $0.071m^2$	Irr. Runtime at 50% CWR (minutes)	Total volume of water applied (litres) at 100% CWR	Total volume of water applied (litres) at 75% CWR	Total volume of water applied (litres) at 50% CWR
November	31	0.18	16	0.14	12.44	0.09	8	5.58	4.34	2.79
December	30	0.27	24	0.20	17.78	0.14	12.44	8.1	6	4.20
January	31	0.27	24	0.20	17.78	0.14	12.44	8.37	6	4.34
	Total							**22.05**	**16.34**	**11.33**

4.2.4 Weather Parameters

Weather parameters were monitored during the experiment to understand more about how climate patterns might have impacted the study. ATMOS 41 mini weather station was installed in the experimental field to monitor and record the data. The air temperature averagely varied between 20 – 38 ºC with the least in the rainy season and the highest during the dry season experiment. The Vapour pressure ranged from 0.2 – 3.2 kPa, with the highest in the dry season experiment. The peak of solar radiation ranged from 400 – 900 W/m^2, with the highest recorded during the dry season experiment. Average reference evapotranspiration ranged from 1.5 – 5.5 mm/day with the highest value recorded during the dry season. Precipitation during the rainy season experiment recorded highest in August with 354.3 mm. The data parameters are presented in Figure 4.1 and 4.2.

According to the weather data and crop water demand results, the weather during the experiment's rainy season is highly beneficial, as the data recorded more than adequate water needed by each vegetable with relatively good temperature. During the dry season trial, despite the fact that the water required was delivered in accordance with the crop water need data, the weather appeared harsh to the vegetables. The study goes into greater detail on the effects.

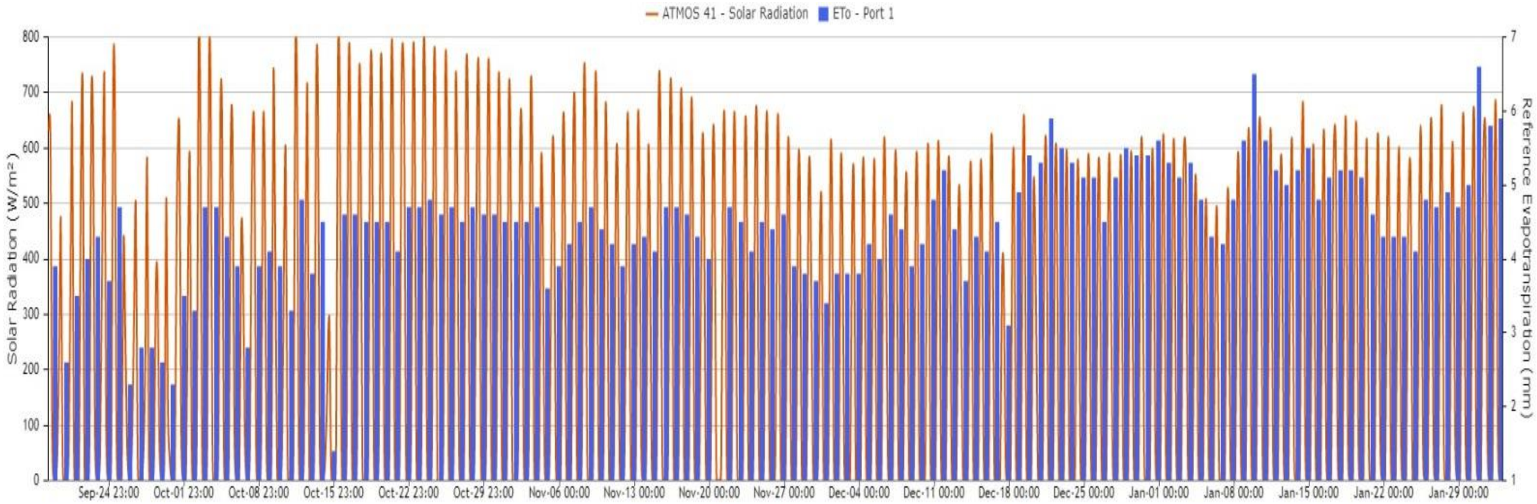


Figure 4.1: Solar Radiation and Reference Evapotranspiration

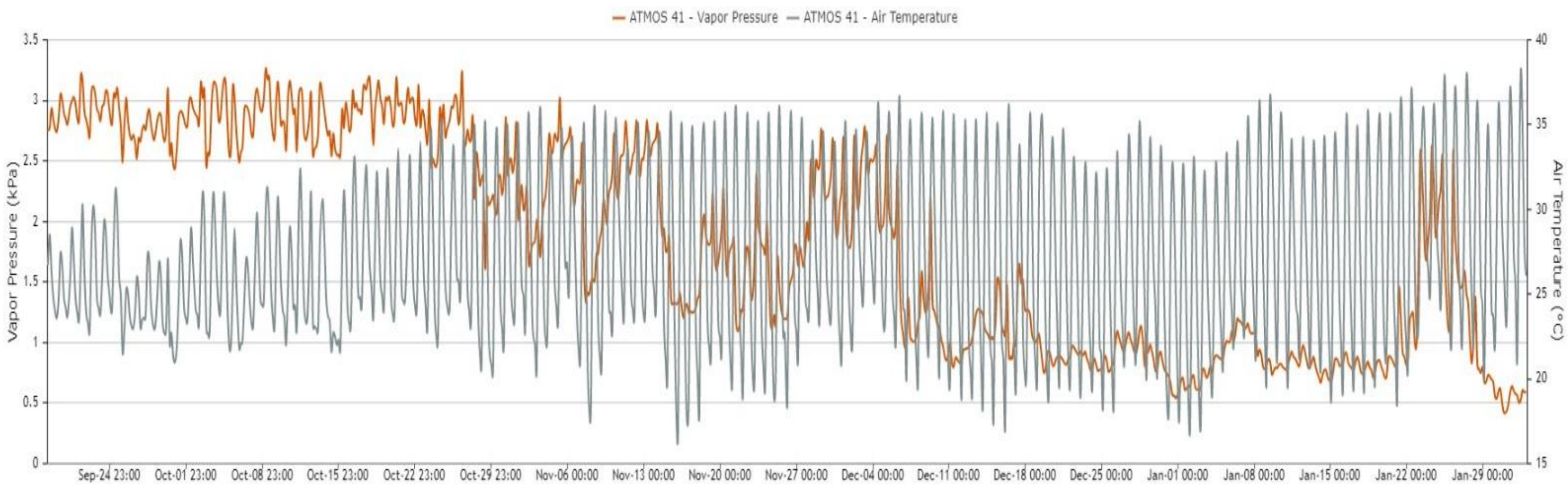


Figure 4.2: Vapour Pressure and Air Temperature during the Experiment

Source: ATMOS 41 Weather Station at Experimental Field (2022)

4.3 Field Soil Moisture Variation in the Production of Experimental Vegetables

4.3.1 Field Soil Moisture Variation during Lettuce Production

As presented in Figure 4.3, the soil moisture during the growth period of lettuce in the rainy season indicated that the volumetric moisture content ranged from 18.9 to 37.9 % with the highest and least observed in the sheep manure amended soils and the compost amended soils respectively.

During the dry season experiment, the soil amendments recorded different levels of soil moisture retention. At 100 % CWR the highest soil moisture content was recorded in the sheep manure amended soils as presented in Figure 4.4a. The soil moisture for lettuce irrigated at 75 % CWR recorded the highest moisture in the soils amended with cow dung (Figure 4.4b) while the soil moisture for lettuce irrigated at 50 % CWR recorded the highest moisture level in the soils amended with sheep manure (Figure 4.4c).

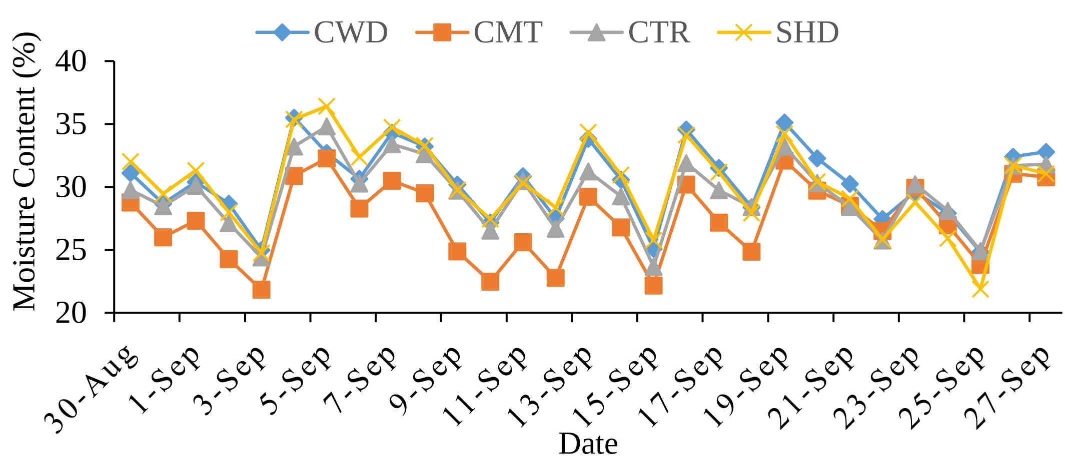
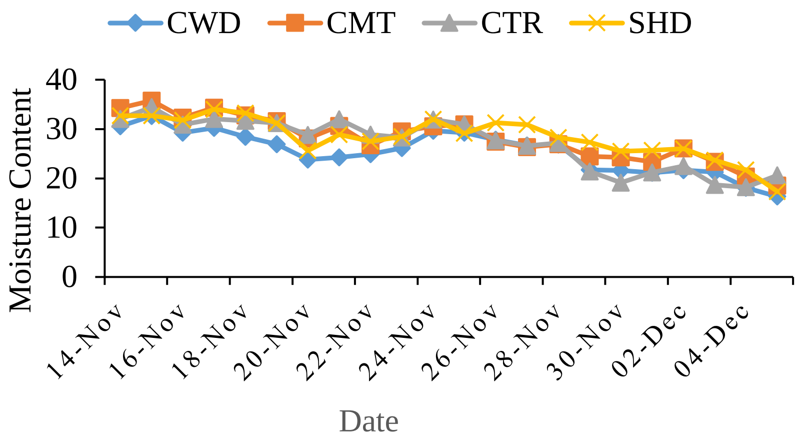
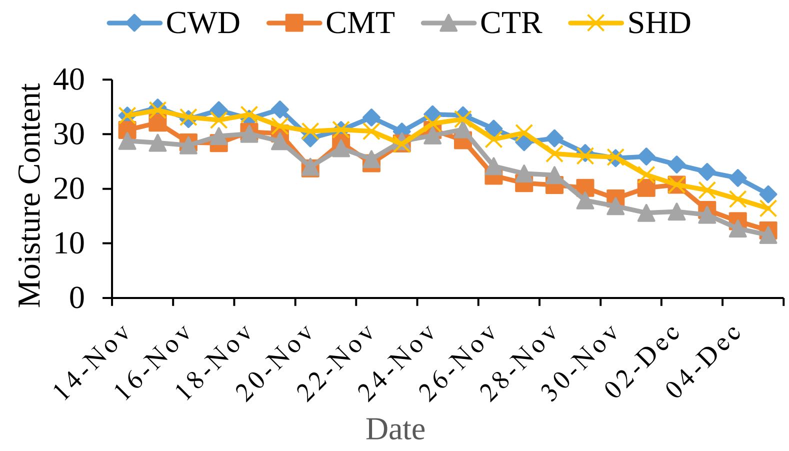


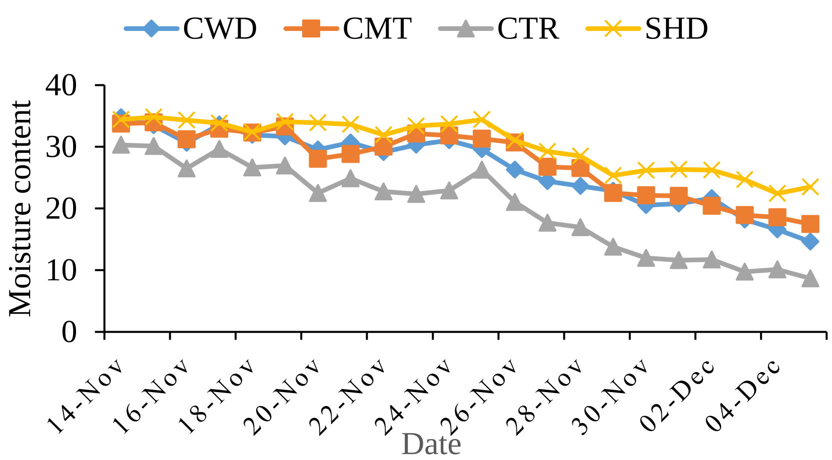
Figure 4.3: Moisture Variation during Lettuce Production in the Rainy Season



(a) Soil Moisture Variation during Lettuce Production at 100 % CWR Irrigation Regime



(b) Soil Moisture Variation during Lettuce Production at 75% CWR Irrigation Regime



(c) Soil Moisture Variation during Lettuce Production at 50 % CWR Irrigation Regime

Figure 4.4: Moisture Variation during Lettuce Production in the Dry Season

4.3.2 Field Soil Moisture Variation during Beetroot Production

Figure 4.5 presents the variation in soil moisture content during the growth period of beetroot in the rainy season experiment. The average highest soil moisture content of 38.3 % was recorded in the sheep droppings amended soils whilst the lowest soil moisture content of 21.5 % was observed in both cow dung and compost amended soils. For the experiment in the dry season, the highest soil moisture content for beetroot irrigated at 100 % CWR was recorded in the soils amended with sheep droppings and however was recorded to have the highest moisture retention capacity (Figure 4.6a). The soil highest moisture content for the beetroot irrigated at 75 % CWR was recorded in the soils amended with sheep droppings (Figure 4.6b). As presented in Figure 4.6c, the soils amended with sheep droppings also recorded the highest soil moisture content for beetroot irrigated at 50% CWR.

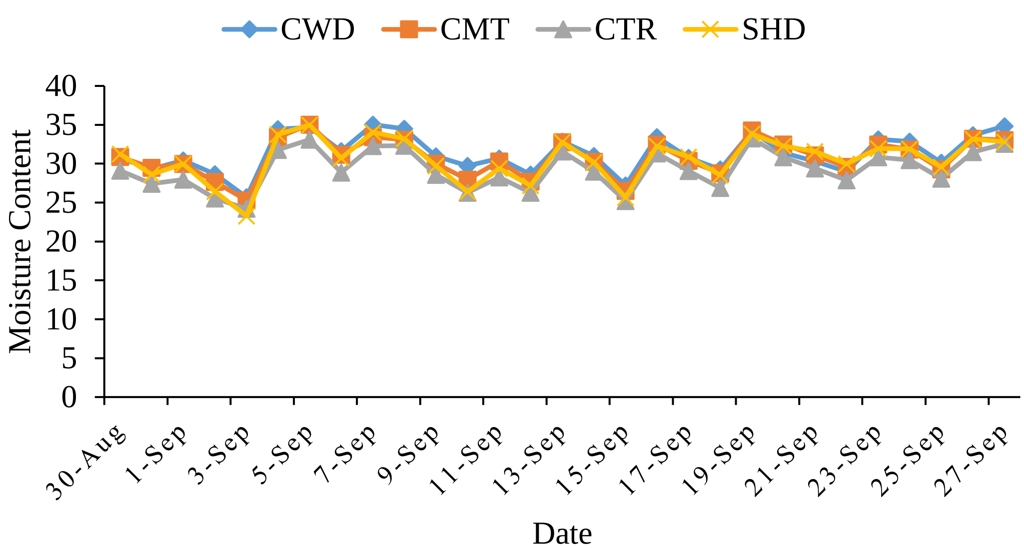
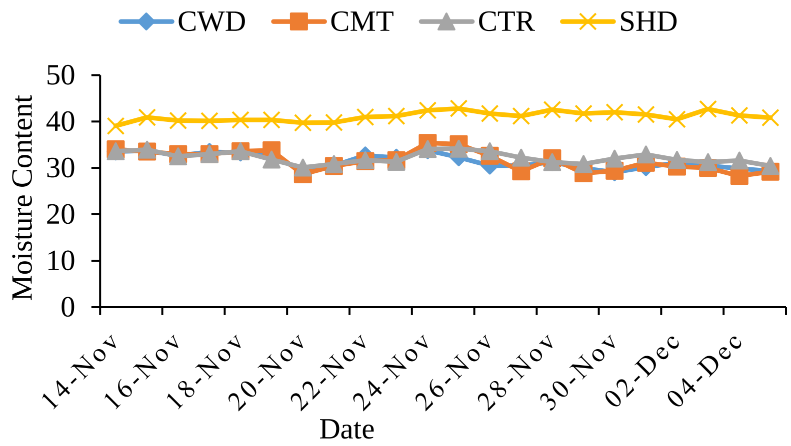
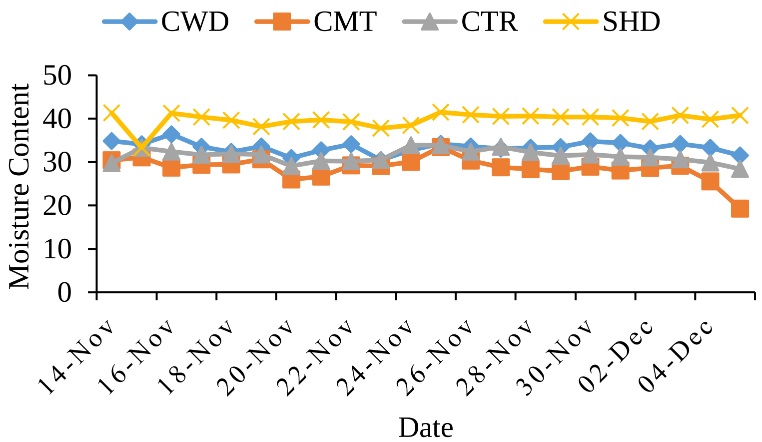


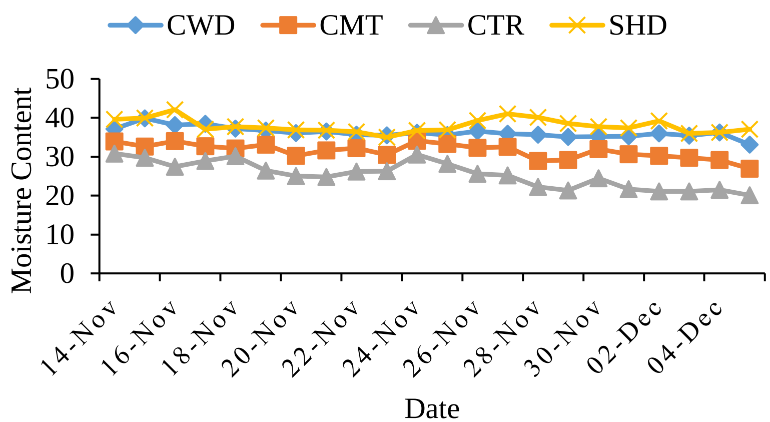
Figure 4.5: Soil Moisture Variation during Beetroot Production in the Rainy Season Experiment



(a) Soil Moisture Variation during Beetroot Production at 100% CWR Irrigation Regime



(b) Soil Moisture Variation during Beetroot Production at 75 % CWR Irrigation Regime



(c): Soil Moisture Variation during Beetroot Production at 50 % CWR Irrigation Regime

Figure 4.6: Soil Moisture Variation during Beetroot Production in the Dry Season Experiment

4.3.3 Field Soil Moisture Variation during Okra Production

Presented in Figure 4.7 is the soil moisture content variation during the growth period of okra in the rainy season experiment. The highest moisture content of 41.2 % was recorded in the cow dung amended soil and the least moisture content of 17.8 % was recorded in the sheep droppings amended soils. For the experiment in the dry season, the highest soil moisture content of 36.27 % was recorded in okra irrigated at 100 % CWR in soils treated with sheep droppings fertilizer as presented in Figure 4.8a. The soil moisture content for okra irrigated at 75 % CWR recorded highest with 32.7 % in soil amended with the sheep dropping fertilizer (Figure 4.8b). Figure 4.8c presents the soil moisture for okra irrigated at 50 % CWR and highest soil moisture content was recorded in soil amended with the sheep droppings fertilizer.

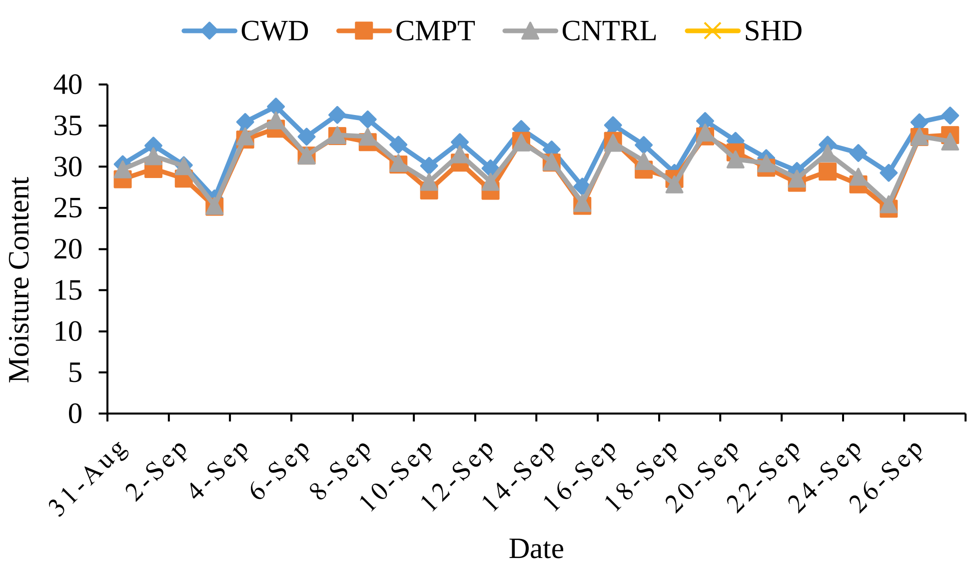
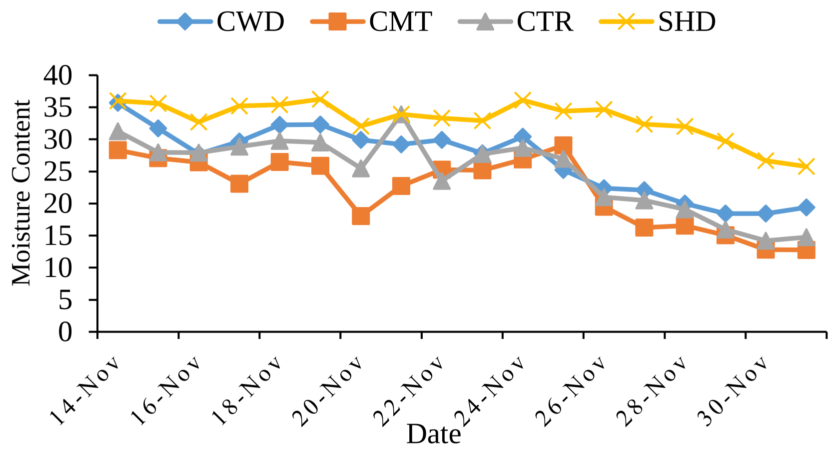
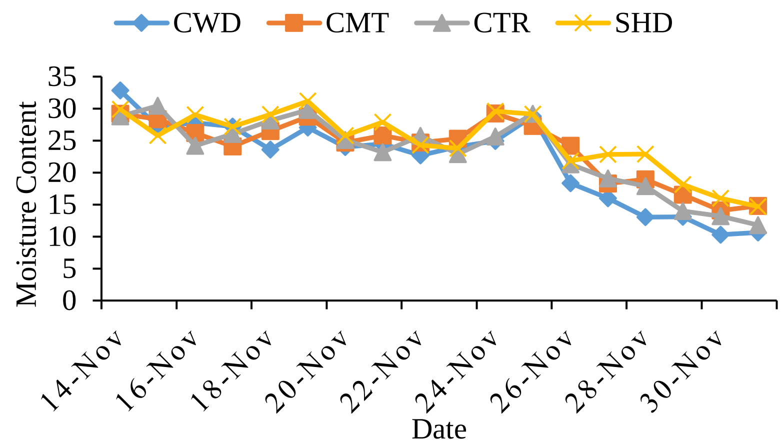


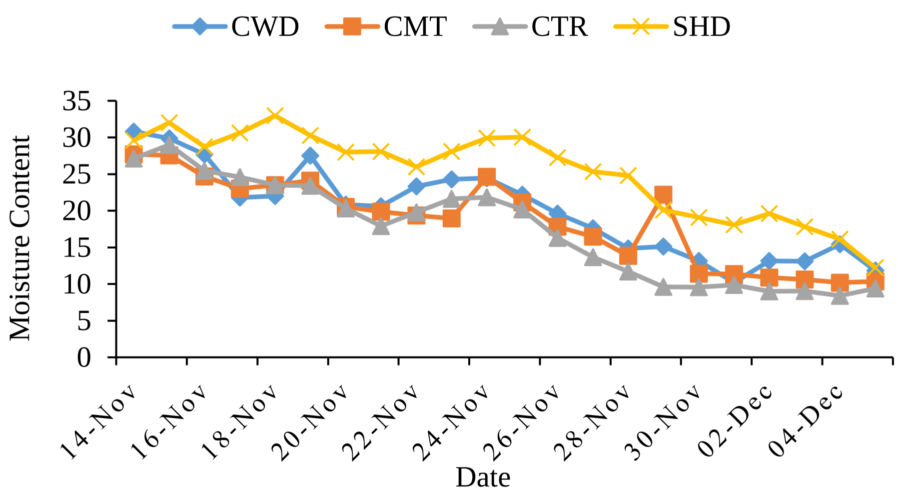
Figure 4.7: Moisture Variation during Okra Production in the Rainy Season Experiment



(a) Soil Moisture Variation during Okra Production at 100 % CWR Irrigation Regime



(b) Soil Moisture Variation during Okra Production at 75 % CWR Irrigation Regime



(c) Soil Moisture Variation during Okra Production at 50 % CWR Irrigation Regime

Figure 4.8: Moisture Variation during Okra Production in the Dry Season Experiment

The results of soil moisture content averagely indicated that the application of organic fertilizers to the soils greatly improved the moisture retaining capacity of the soil in both the rainy and dry seasons' experiments. The moisture content ranged from 20 to 40 %, of which amended soils recorded the highest. The sheep droppings amended soils recorded the highest moisture content in lettuce and beetroot while the cow dung amended soils was highest in the okra production pots. During the dry season experiment with variation in irrigation regimes, the soil moisture content had a similar trend with the rainfed experiment moisture reading. The sheep droppings amended soils had the highest moisture content in the three irrigation regimes for the three (3) vegetables. These can be attributed to the fact that sheep droppings used in the experiment had the highest organic carbon content which makes it more effective compared to the other sources of organic fertilizers. Also, the sheep dropping fertilizer was loose and easily mixed up with the soil after application compared to the other organic soil amenders. These results are in line with the assertion that organic manures help to increase organic matter, and reduce bulk density in the soil, hence conserve soil moisture generally compared to bare or ordinary soil. The findings in this study are in conformity with the results of the study carried out by Vengadaramna and Jashothan (2011) on the effect of organic manures on soil water holding capacity.

4.4 Effect of Organic Fertilizers and Irrigation Regimes on Growth and Development of Lettuce

4.4.1 Plant Height

There was an overall rise in the plant height of lettuce across the organic fertilizer treatments throughout the rainy season experiment. At harvest, the mean plant height ranged from 26.61 to 37.78 cm, with the least recorded in the control pot and the highest in pots treated with cow dung. The results from the ANOVA showed that there was significant difference ($p < 0.037$) in lettuce plant height at harvest as presented in Figure 4.9. During the dry season experiment, the average plant height ranged from 22.11 to 23.09 cm, with the least recorded in the control pots and the tallest recorded in the plants treated with compost. The results from the ANOVA showed that there was no significant difference in the effect of organic fertilizer application on plant height at the end of the dry season experiment ($p > 0.05$). Similarly, there was no significant difference on the effect of irrigation regimes during the dry season experiment ($p > 0.05$). However, the highest height 23.04 cm was recorded at 100 % CWR irrigation regime followed by 22.89 cm which was recorded at 50 % CWR irrigation regime and the least height 21.38 cm was recorded at 75 % CWR irrigation regime. The interaction of organic fertilizers and irrigation regimes at harvest was also not significant ($p > 0.05$), however the highest plant height 24.33 cm was recorded at 100 % CWR irrigation regime with plants treated with sheep droppings while at 75 % CWR irrigation regime, the highest height 22.33 cm was recorded in the plants treated with compost, and at 50% CWR irrigation regime the highest plant height 25.17 cm was recorded in the plant with cow dung treatment.

4.4.2 Canopy Diameter

Canopy diameter was measured on lettuce at 5 WATP and the results ranged from 30.18 to 39.96 cm, with the wideset recorded in the plant treated with sheep dropping fertilizer and least in the control plant. The ANOVA results showed that there was significant difference ($p < 0.001$) in the effect of organic soil amenders on canopy diameter (Figure 4.9). During the dry season experiment, canopy diameter ranged from 25.79 to 28.13 cm, with the least recorded in the plant treated with compost while the widest diameter was recorded in the plants treated with sheep dropping. The ANOVA results showed that there was no significant difference ($p > 0.05$) on the effect of organic soil amenders on canopy diameter at 5 WATP. Similarly, there was no significant difference on the effect of irrigation regimes on canopy diameter of lettuce during the dry season experiment ($p > 0.05$). The 50 % CWR irrigation regime recorded the widest canopy diameter of 29.14 cm followed by 27.64 cm which was recorded in 100 % CWR irrigation regime, while the 75 % CWR irrigation regime recorded the least canopy diameter of 24.32 cm. Also, the interaction between irrigation regimes and fertilizer application did not record significant difference ($p > 0.05$) on canopy diameter, however in the 100 % CWR irrigation regime the plant supplied with sheep droppings had the widest canopy diameter of 30.57 cm while in the 75 % CWR irrigation regime, the widest canopy diameter of 27.43 cm was recorded in the plants treated with cow dung and in 50% CWR irrigation regime the widest canopy diameter of 31.30 cm was recorded in the plants treated with compost.

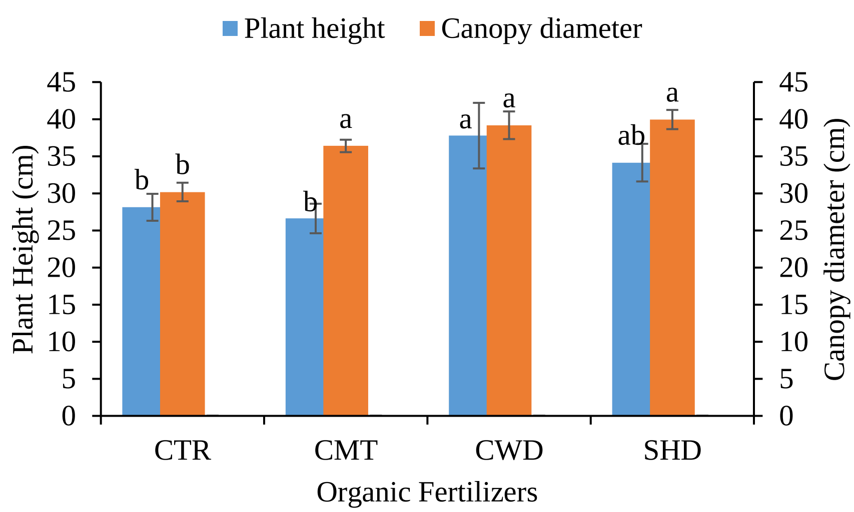


Figure 4.9: Effect of Organic Fertilizers on Plant Height and Canopy Diameter of Lettuce

Bar = SEM (Standard Error of Means), CTR – Control, CMT – Compost, CWD – Cow dung, and SHD – Sheep droppings, *Means that do not share a letter are significantly different*

4.4.3 Number of Leaves

The application of organic fertilizer recorded significant differences on the number of leaves of lettuce at 4 and 5 WATP (Weeks After Transplanting) in the rainy season experiment at $p = 0.050$

and $p = 0.031$ respectively. As presented in Table 4.9, at 4 WATP the number of leaves ranged from 7.67 in control plants to 10.26 in the plants treated with cow dung, while at 5 WATP, number of leaves ranged from 15.03 in the control pots to 22.65 in the plants treated with cow dung. Throughout the dry season experiment, the application of organic soil amenders did not record significant difference on number of leaves of lettuce, however at harvest (6 WATP), the number of leaves ranged from 13.89 to 15.56, with the least recorded in the control pot while the highest leaf number was recorded in the pot treated with sheep dropping. The ANOVA results showed that there was no significant difference ($p > 0.05$) in the effect of irrigation regimes on number of leaves of lettuce throughout the dry season experiment. At harvest, the 100% CWR irrigation regime recorded the highest number of leaves 15.58, followed by 14.27 which was recorded in the 50 % CWR irrigation regimes while the 75 % CWR irrigation regime recorded the least leaf number of 13.14. The interaction between irrigation regimes and fertilizer application on number of leaves was not significant at $p > 0.05$ throughout the season. However, at the 100 % CWR irrigation regime, the plant treated with sheep droppings had the highest leaf number of 19.67 while at the 75 % CWR irrigation regime, the highest number of leaves of 9.67 was recorded in the plants treated with compost fertilizer and on the plant with 50 % CWR irrigation regime the highest leaves number of 16 was recorded in the plants treated with compost.

Table 4.9: Effect of Organic Fertilizer on Number of Leaves of Lettuce at 4 and 5 WATP

Organic Treatments	**Weeks**	
	4 WATP	**5 WATP**
CTR	7.67b	15.33b
CMT	8.66ab	17.71ab
CWD	10.26a	22.50a
SHD	8.67ab	20.75a
P-value	0.054	0.031

CTR – Control, CMT – Compost, CWD – Cow dung, and SHD – Sheep droppings, *Means that do not share a letter are significantly different*

4.4.4 Stem Girth

As presented in Table 4.10, the results of the stem girth during the rainy season ranged from 14.94 mm recorded in the plant treated with sheep droppings and 17.17 mm recorded in the plants treated with compost. The ANOVA results showed no significant difference recorded on lettuce stem girth for both seasons. Also, a stem girth of 5.97 mm was recorded in the cow dung and 6.21 mm recorded in the compost during the dry season. There was no significant difference in the effect of irrigation regimes on the stem girth of lettuce during the dry season from the ANOVA results. However, at harvest the highest irrigation regime 100 % CWR recorded the biggest stem girth of 6.40 mm followed by 6.22 mm recorded in the 50 % CWR irrigation regime, while the 75 % CWR irrigation regime recorded the least stem girth of 5.62 mm. Moreso, the interaction between irrigation regimes and fertilizer application was also not significant on stem girth. At the 100 % CWR, the plant treated with sheep droppings had the largest stem girth of 6.94 mm while at the 75 % CWR the plants without soil amendment recorded the biggest stem girth of 5.82 mm and at 50 % CWR the largest stem girth of 6.65 mm was recorded in the plants treated with compost.

Table 4.10: Effect of Organic Soil Amendment on Stem Girth of Lettuce

Organic Treatments	**Stem Girth (mm)**	
	Rainy Season	**Dry Season**
CTR	15.47a	6.05a
CMT	17.06a	6.21a
CWD	16.93a	5.97a
SHD	14.94a	6.14a
P-value	0.354	0.991

CTR – Control, CMT – Compost, CWD – Cow dung, and SHD – Sheep droppings, *Means that do not share a letter are significantly different*

4.4.5 Chlorophyll Content

As presented in Table 4.11, there was no statistically significant difference at $p > 0.05$ on the effect of organic soil amendment application on chlorophyll level of lettuce throughout the growing seasons. However, at harvest (6 WATP) in the rainy season, chlorophyll content ranged from 17.42 to 20.39 spad with the least in the plant treated with cow dung and the highest recorded in the control pots. Similarly, during the dry season experiment the effect of organic soil amendment was not significant at $p > 0.05$ throughout the season. The highest chlorophyll content of 23.14 spad was recorded in the plants treated with compost followed by 22.61 spad recorded in the plant treated with cow dung while the least chlorophyll content of 21.89 spad was recorded in the plant treated with sheep dropping. There was no significant difference at $p > 0.05$ on the effect of irrigation regimes on chlorophyll content of lettuce throughout the dry season. At harvest, the 100 % CWR recorded the highest chlorophyll content of 23.04 spad, followed by 22.81 spad recorded at 50 % CWR while the 75 % CWR had the least chlorophyll content of 21.45 spad. The interaction between irrigation regimes and soil amendment application on chlorophyll content was also not statistically significant ($p > 0.05$), however at 100 % CWR irrigation regime, plant treated with sheep droppings had the highest chlorophyll content of 24.33 spad while at 75 % CWR the highest chlorophyll content of 22.33 spad was recorded in the plants treated with the compost fertilizer and at 50 % CWR the highest chlorophyll content of 25.17 spad was recorded in the plants treated with cow dung.

Table 4.11: Effect of Organic Soil Amendment and Irrigation Regimes on Chlorophyll Content of Lettuce

Irrigation (% CWR) Levels	At Harvest (spad)			
	Organic Fertilizers			
	CTR	CMT	CWD	SHD
50% CWR	22.33abcd	24.25abc	25.17a	19.5d
75% CWR	20.17cd	22.33abcd	21.5abcd	21.83abcd
100% CWR	23.83abc	22.83abcd	21.17bcd	24.33ab
	P- value		0.101	

Means that do not share a letter are significantly different

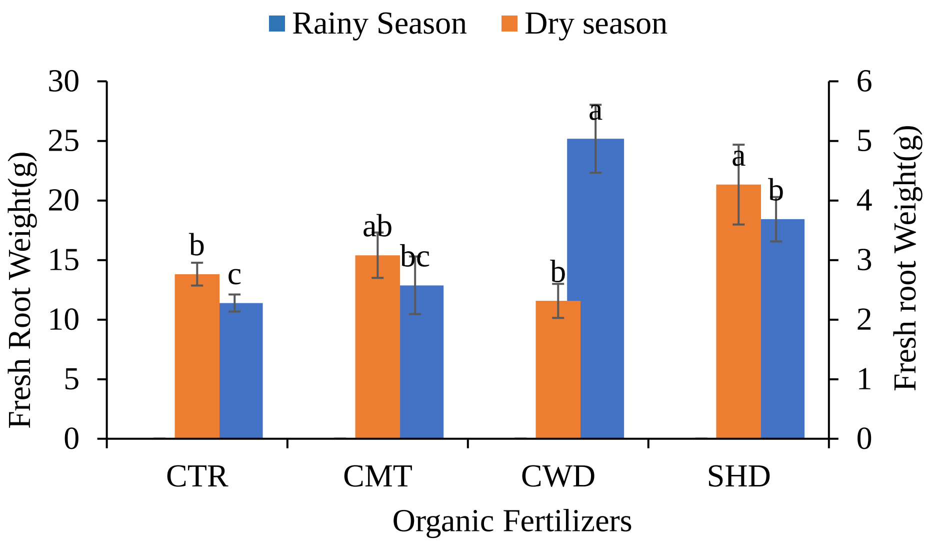
There was a general positive effect on the application of organic soil amenders on the growth parameters of lettuce as the plants treated with cow dung recorded the highest plant height at the end of both the rainy and dry seasons. This results agreed with the findings of Masarirambi *et al.* (2012) on the effect of kraal manure application rates on growth of lettuce. Number of leaves of lettuce was also significantly affected at 4 WATP and the highest number of leaves in the rainy season was recorded in plants treated with cow dung and in the dry season the plants treated with sheep droppings recorded the highest number of leaves. These results revealed that either cow dung or sheep droppings will increase lettuce leaf production which is important in the yield of leafy vegetables. Similarly, the canopy diameter and stem girth also experience general increase with the plants treated with compost recording the highest in the stem girth followed by cow dung treated pots. The pots treated with sheep droppings also recorded the highest canopy diameter followed by the plants treated with cow dung. However, in the dry season, the highest canopy diameter was recorded in plants treated with sheep droppings, cow dung and compost respectively. The plants treated with compost recorded the highest in chlorophyll content in the dry season experiment, and also recorded the second highest at the rainy season. Reis *et al.* (2014) reported that the growth parameters including the SPAD values of lettuce vary in line with the application rate of compost added to the soil. Other sources of organic fertilizer also gave positive results to lettuce growth and can be used alternatively as far as they are available. El-Mogy *et al.* (2020) studied the effect of rabbit manure, chicken manure and compost and recorded general increase with plants treated with chicken manure recording the highest. Reis *et al.* (2014) also recorded increase in growth parameters of lettuce with compost application rate up to 6 kg/m^2.

4.5 Effect of Organic Soil Amendments and Irrigation Regimes on Lettuce Yield Parameters

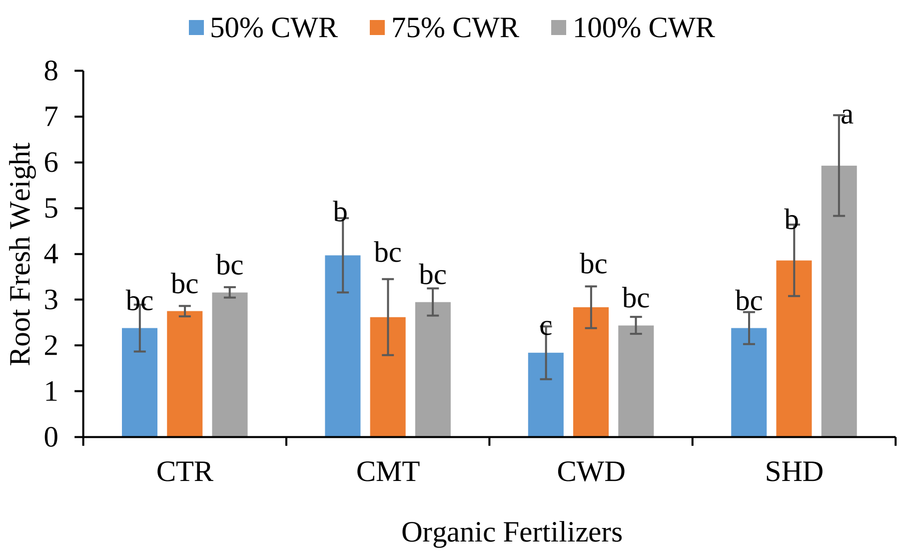
4.5.1 Root Development

Fresh Root Weight

The fresh root weight of lettuce for the rainy season ranged from 11.4 to 25.2 g, with the least recorded in the control pots while the highest weight was recorded in the pot treated with cow dung. The results from ANOVA showed that the effect of organic soil amendment on lettuce fresh root weight was significantly different ($p < 0.001$) at the end of the rainy season (Figure 4.10a). Also, for the dry season, the ANOVA results showed that the effect of soil amendment on lettuce fresh root weight was significantly different with $p = 0.017$ and fresh root weight ranging from 2.37 to 4.06 g, with the least recorded in the pots treated with cow dung and highest weight recorded in the plants treated with sheep droppings (Figure 4.10a). The effect of irrigation regime was not statistically significant at $p > 0.05$ on lettuce fresh root weight, the 100 % CWR irrigation regime has the highest fresh root weight of 3.62 g, 3.02 g by 75 % CWR and 2.64 g by the 50 % CWR. The interactive effect of organic soil amendment and irrigation regimes on the fresh root weight was statistically significant at $p = 0.049$. As presented in Figure 4.10b, at 100 % CWR irrigation regime the highest fresh root weight of 5.93 g was recorded in the pots treated with sheep droppings, at 75 % CWR irrigation regime, the highest fresh root weight of 3.86 g was also recorded in the pots treated with the sheep dropping, at 50 % CWR irrigation regime the highest fresh root weight 3.97 g was recorded in the plants with compost.



(a) Effect of Organic Fertilizer on Fresh Root Weight of Lettuce in both Experiment



(b) Interactive effect of Irrigation Regimes and Organic Fertilizer on Fresh Root Weight of Lettuce in the Dry Season Experiment

Figure 4.10: Effect of Irrigation Regimes and Organic Fertilizer on Lettuce Fresh Root Weight

CTR – Control, CMT – Compost, CWD – Cow dung, and SHD – Sheep droppings
Means that do not share a letter are significantly different

Dry Root Weight

Dry root weight of lettuce during the rainy season ranged from 2.29 to 8.83 g with the least recorded in the control pots and highest in the pots treated with cow dung. The ANOVA results showed that the effect of organic soil amendment on the dry root weight of lettuce was statistically different at $p < 0.001$ (Figure 4.11). For the dry root weight of lettuce in the dry season, weight ranged between 0.67 to 1.16 g with the least recorded in the control pots and the highest recorded in the pots treated with sheep dropping. The ANOVA results showed that the effect of organic fertilizer on the dry root weight of lettuce was statistically different at $p = 0.006$ (Figure 4.11). There was no statistically significant difference in the effect of irrigation regimes as Crop Water Requirements (CWR) on dry root weight of lettuce, the highest dry root weight of 0.95 g was recorded at 75 % CWR irrigation regime followed by 0.844 g recorded at 50 % CWR irrigation regime and the least root dry weight of 0.837 g was recorded at 100 % CWR irrigation regime. Also, there was no statistically significant difference in the effect of irrigation regimes and organic soil amendments application on the dry root weight of lettuce, the 100 % CWR irrigation regime recorded the highest dry root weight of 1.13 g in the plants with sheep droppings treatment, 75 % CWR irrigation regime also recorded its highest dry root weight of 1.22 g in the pots treated with sheep droppings treatment and 50 % CWR irrigation regime which also recorded its highest dry root weight of 1.13 g with the pots treated with the sheep droppings.

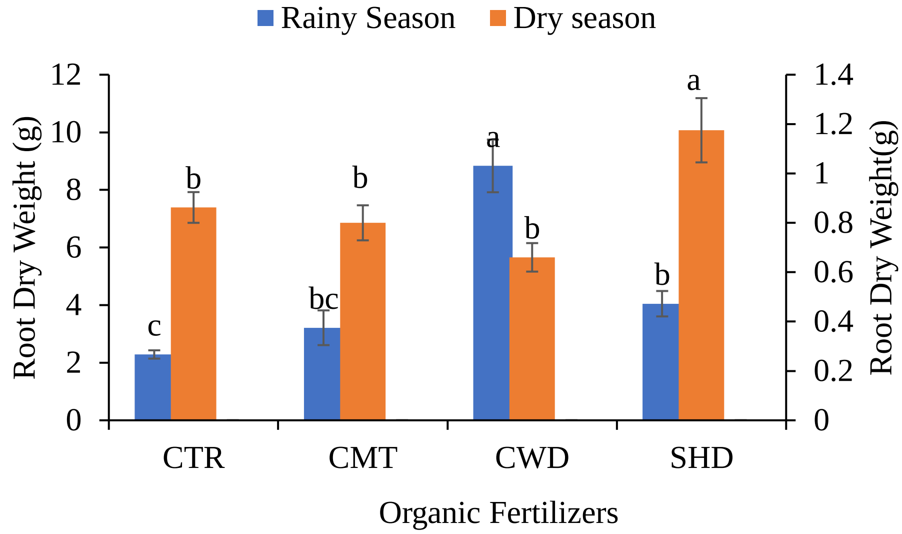


Figure 4.11: Effect of Organic Fertilizer on Dry Root Weight of Lettuce

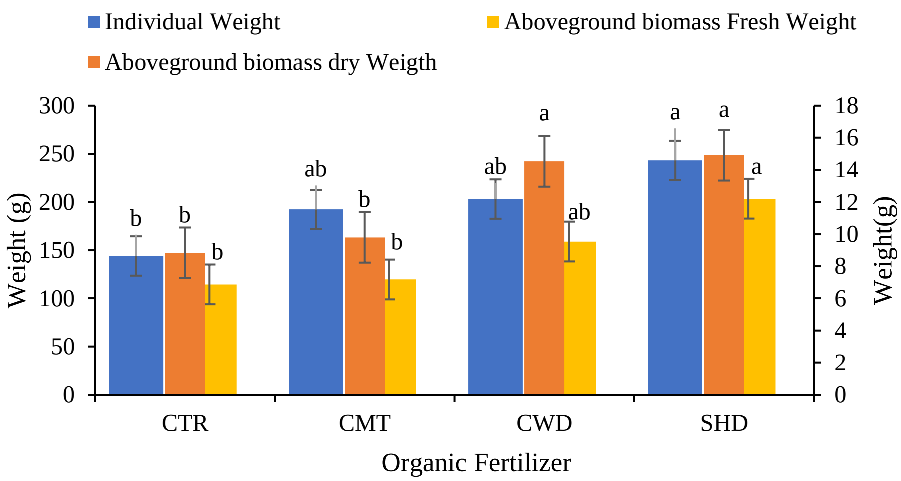
CTR – Control, CMT – Compost, CWD – Cow dung, and SHD – Sheep droppings
Means that do not share a letter are significantly different

4.5.2 Individual Weight of Lettuce

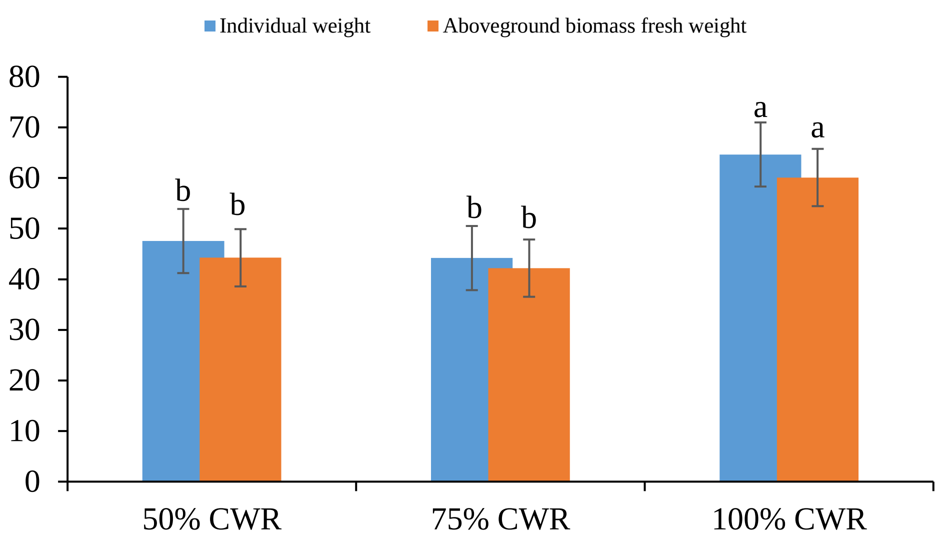
The individual weight of lettuce for all treatments ranged from 144 to 243 g, with the highest recorded in the pots treated with sheep dropping while the least was recorded in the control pots without any treatment. ANOVA results showed that there was significant difference at $p = 0.046$ on the effect of organic soil amendment on the individual weight of lettuce after the rainy season (Figure 4.12a). Results of individual weight of lettuce in the dry season ranged from 48.7 to 58.9 g with the least recorded in the control pots and the highest recorded in the plants treated with sheep droppings. ANOVA showed no significant difference, however, the results showed that there was significant difference in the effect of irrigation regimes on lettuce weight ($p = 0.022$). The highest weight of 64.7 g was recorded at 100 % CWR irrigation regime, followed by 47.9 g which was recorded at 50 % CWR irrigation regime, while the least weight of 44.9 g was recorded at 75 % CWR irrigation regime (Figure 4.12b). The interaction of irrigation regimes and organic soil amendments had no significant difference on lettuce weight, however at 100 % CWR irrigation regime the highest weight of 86.9 g was recorded in the pots treated with sheep droppings, at 75 % CWR irrigation regime the highest weight of 52.2 g was recorded in the pot treated with cow dung and at 50 % CWR irrigation regime the highest weight of 50.1 g was recorded in the plants treated with compost and cow dung.

4.5.3 Above-ground Biomass Fresh Weight

Above-ground biomass fresh weight results ranged from 114.5 to 159.0 g, with the least recorded in the control plants and the highest in pots treated with sheep droppings. ANOVA results indicated significant difference at p = 0.005 on the effect of organic soil amendments on above-ground biomass fresh weight at the end of rainy season (Figure 4.12a). In the dry season, ANOVA results showed that there was no significant difference on the effect of organic soil amendments on the above-ground biomass fresh lettuce that ranged from 44.6 to 54.9 g with the least recorded in the control pots and highest recorded in the pots treated with sheep droppings. The effect of irrigation regime recorded significant difference at p = 0.034 in the dry season with the highest aboveground biomass fresh weight of 60.1 g recorded at 100 % CWR irrigation regime followed by 44.5 g recorded in the 50 % CWR irrigation regime and the least above-ground biomass fresh weight of 42.1 g recorded at 75 % CWR irrigation regime (Figure 4.12b). The interactive effect of organic soil amendments and irrigation regimes on aboveground biomass fresh weight was not significant statistically. At 100 % CWR irrigation regime the highest aboveground biomass fresh weight, 80.8 g was recorded in the pots treated with sheep droppings, at 75 % CWR irrigation regime the highest aboveground biomass fresh weight of 49.4 g was recorded in the pots treated with cow dung, and at 50 % CWR irrigation regime, the highest canopy weight of 47.0 g was recorded in the plants treated with the sheep droppings.



(a) Effect of Organic Fertilizer on Individual Weight and aboveground biomass of Lettuce during Rainy Season



(b) Effect of Irrigation Regimes on Lettuce Individual weight and aboveground biomass Fresh weight

Figure 4.12: Effect of Organic Fertilizer and Irrigation Regimes on Yield Parameters

4.5.4 Above-ground Biomass Dry Weight

ANOVA results recorded significant difference ($p = 0.012$) on above-ground biomass dry weight of lettuce at the end of rainy season. Above-ground biomass dry weight ranged from 8.84 to 14.91 g, with the least recorded in control pots and highest in the pots treated with sheep dropping (Figure 4.12a). ANOVA results at the conclusion of the dry season experiment revealed that the effect of organic soil amendment was not significantly different ($p > 0.05$) on the above-ground biomass dry weight of lettuce, the results in this season for above-ground biomass dry weight ranged from 4.95 g recorded in the pots treated with cow dung to 6.30 g recorded in the pots treated with compost. Similarly, the effect of irrigation regimes was not significantly different ($p > 0.05$) on the aboveground biomass dry weight of lettuce in the dry season, however the highest weight of 6.18 g was recorded in the plants with 50 % CWR irrigation regime, followed by 5.44 g which was recorded in the plants with 100 % CWR irrigation regime, while the least above-ground biomass dry weight of 4.97 g was recorded in the plants with 75 % CWR irrigation regime. The interactive effect of organic soil amendment and irrigation regimes on above-ground biomass dry weight was also not significant ($p > 0.05$). At the 100 % CWR irrigation regime the highest aboveground biomass dry weight 6.08 g, was recorded in the pots treated with sheep droppings, at 75 % CWR irrigation regime the highest above-ground biomass dry weight of 5.51 g was recorded in the plants treated with cow dung, at 50 % irrigation regime, the highest aboveground biomass weight 8.34 g, was recorded in the pots treated with compost.

Generally, the effect of organic soil amendment on lettuce yield parameters was positive, as the pots treated with cow dung recorded the highest fresh root weight, followed by the plant treated with sheep dropping while the least was recorded in the control pots. Organic fertilizers increases the aeration of the soil, nutrient holding capacity and encourage the production of thicker root

(Zhao *et al.*, 2019). The results agreed with Zhao *et al.* (2019) and was in agreement with Arslanoglu (2022) who recorded higher values in fresh weight of soybeans root treated with sheep manure. In the dry season, organic soil amendment and irrigation regime recorded a positive effect with significant difference in the interaction of organic soil amendment and irrigation regime on the fresh root weight of lettuce, it was observed that the pots treated with sheep dropping experienced a gradual increase as irrigation regime increases thus presenting a linear relationship. There was significant difference on the effect of organic soil amendment on dry root weight of lettuce as the highest dry root weight was recorded in the pot treated with sheep dropping. Arslanoglu (2022) reported that optimal P and K percentages were important for dry matter accumulation in plant. Table 4.3 presents that sheep dropping and cow dung have the highest total P and K. For canopy dry weight, the pots treated with sheep dropping and cow dung recorded the highest weight. Organic soil amendment also resulted in significant difference on the weight of lettuce in the rainy season, and the highest weight was recorded in pots treated with sheep dropping and this can be attributed to the high organic carbon in sheep droppings which helps to improve soil aeration, root development and thus results in weight and yield increase. Similar results were recorded in the dry season experiment. Irrigation regimes was significant on lettuce weight, and the highest weight was recorded in the pots with 100 % CWR irrigation regime as more water was supplied for the basic plant needs compared to other regimes. Similar results were reported by Mostafa *et al.* (2019) as recorded in this experiment for the highest weight of lettuce at 100 % CWR irrigation regime in two seasons. Canopy diameter and aboveground biomass fresh weight had similar experience, recording the highest weight and diameter in the pots treated with sheep dropping and cow dung respectively in both seasons. Mostafa *et al.* (2019) and El-Mogy *et al.* (2020) reported that organic fertilizer sources depend on its mineralization by which nutrients are available to the plant and will influence fresh weight, dry weight, leaf number and canopy diameter.

4.6 Yield of Lettuce per Hectare

Lettuce yield at the end of rainy season ranged from 10.80 to 18.24 t/ha with the least yield recorded in the control pots while the highest was recorded in the plants treated with sheep dropping fertilizer. Results from ANOVA showed that there was no significant difference ($p > 0.05$) in the effect of organic soil amendment application on the yield of lettuce. Similarly, during the dry season the effect of organic soil amendment was not statistically significant ($p > 0.05$) on lettuce yield, however the yield ranged from 3.35 to 4.01 t/ha with the least recorded in the pots treated with compost and the highest recorded in the pot treated with sheep dropping. The ANOVA results showed that there was significant difference ($p = 0.031$) in effect of irrigation regimes on lettuce yield. The highest yield of 4.85 t/ha was recorded at the 100 % CWR irrigation regime followed by 3.04 t/ha recorded at 75 % CWR irrigation regime while the least yield of 2.97 t/ha was recorded in the most stressed regime 50 % CWR irrigation regime (Figure 4.13). There was no significant difference ($p > 0.05$) in the interaction of irrigation regime and organic soil amendment application on the yield, the highest yield of 6.52 t/ha was recorded in plants treated with sheep dropping at 100 % CWR irrigation regime.

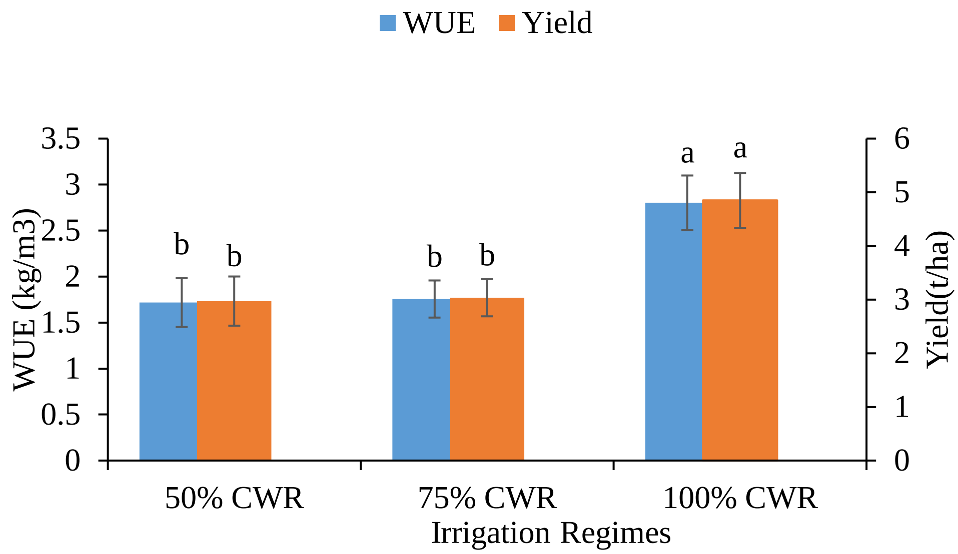


Figure 4.13: Effect of Irrigation Regime on Lettuce Yield and Crop Water Use Efficiency

(Means that do not share a letter are significantly different)

High yield was recorded across the organic soil amendment treatment compared to the control pots, though the yield from the rainy season was relatively high (12-19 t/ha) compared to the dry season (3 - 6.5 t/ha), this can be attributed to the season which each experiment was carried out. The rainy season was characterized by more water whilst the weather condition in the dry season was harsh and challenging climate, 9 hours sunlight duration with up to 900 W/m^2 radiation and 35º C air temperature. The results indicated a general increase in the yield of experimental crops with organic soil amendment compared to the control pots. Masarirambi *et al.* (2012) reported that organic fertilizer application significantly affected growth, yield and nutritional quality of lettuce. As presented in Figure 4.13, irrigation regimes significantly affected yield, in the dry season, 100 % CWR irrigation regime recorded the highest yield compared to other regimes, and this could be attributed to more water supply to negating the effect of the harsh weather and for effective plant growth.

4.7 Crop Water Use Efficiency of Lettuce

The average amount of water used for irrigation in 50 %, 75 % and 100 % CWR irrigation regimes were 882 L, 1302 L and 1,729.5 L respectively. The crop water use efficiency of lettuce ranged from 1.94 to 2.31 kg/m^3, with the least recorded in the control plant while the highest was recorded in the pots treated with sheep dropping. The ANOVA results showed that there was no significant difference ($p > 0.05$) on the effect of organic soil amendment application on crop water use efficiency of lettuce. However, the results showed significant difference ($p = 0.013$) on the effect of irrigation regime on crop water use efficiency of lettuce. The highest crop water use efficiency of 2.80 kg/m^3 was recorded at 100 % CWR irrigation regime followed by 1.75 kg/m^3 recorded at 75% CWR irrigation regime, while the least crop water use efficiency 1.71 kg/m^3 was recorded at 50 % CWR irrigation regime (Figure 4.13). There was no significant difference ($p > 0.05$) recorded in the interaction of irrigation regimes and organic fertilizer on WUE of lettuce. At 100 % CWR irrigation regime, higher WUE was recorded in the plants treated with sheep dropping with 3.77 kg/ha/L. The plants treated with compost recorded the highest value of 1.99 kg/m^3 at 75 % CWR irrigation regime, while at 50 % CWR irrigation regime, the plants treated with cow dung has the highest WUE of 2.17 kg/m^3. Water supply is a major constraint to crop production in modern agriculture, especially in areas with water scarcity and therefore, efficient use of water by irrigation is becoming increasingly important (Abd El-Kader *et al.*, 2010). The plants treated with sheep dropping had the highest WUE in terms of organic fertilizer. The interaction of 100 % CWR and cow dung fertilizer recorded the best WUE. This study reports similar findings as Ye *et al.* (2020) who reported significant increase in WUE of pear jujube treated with sheep droppings.

4.8 Effect of Organic Fertilizers and Irrigation Regime on Growth and Development of Beetroot

4.8.1 Plant Height

At harvest (7 WATP), the plant height of beetroot ranged from 27.58 to 30.44 cm, with the least height recorded in the plant treated with cow dung and the tallest recorded in the pot treated with compost, the ANOVA results showed that there were no significant differences ($p > 0.05$) in the effect of organic fertilizers on plant height of beetroot throughout the rainy season. During the second experiment, ANOVA results showed significant difference at 4 and 5 WATP ($p = 0.006$) and ($p = 0.039$) respectively. At 4 WATP the plant height ranged from 14.11 to 20.67 cm with the least height recorded in the pots treated with cow dung and the tallest plant recorded in the pots treated with the sheep droppings. At 5 WATP the plant height ranged from 17.94 to 24.28 cm, with the least height recorded in the pots treated with cow dung while the tallest plant was recorded in the pots treated with the sheep droppings (Table 4.12). Similarly, the ANOVA results showed that there was significant difference ($p = 0.002$) on the effect of irrigation regimes on plant height of beetroot at harvest. The tallest plant of 31.17 cm was recorded in the 100 % CWR irrigation regimes, followed by 31 cm recorded at 75 % CWR irrigation regime while the least, 26.67 cm was recorded in the 50 % CWR irrigation regime (Figure 4.14). The interaction between irrigation regimes and organic fertilizer was not statistically significant throughout the second experiment. At harvest, 100 % irrigation regime recorded the tallest plants of 33 cm in the pots treated with compost at 75 % irrigation regime and with the tallest plant of 34 cm recorded in the control, while at 50 % irrigation regime the tallest plant of 27.33 cm was recorded in the pots treated with compost.

Table 4.12: Effect of Organic Fertilizer on Plant Height of Beetroot at 4 and 5 WAP

Organic fertilizers (Treatments)	Weeks 4 WAP (cm)	5 WAP (cm)
CTR	16.22ab	20.94ab
CMT	19.43bc	22.11ab
CWD	13.75c	17.94b
SHD	20.67a	24.28a
P-value	0.006	0.039

(Means that do not share a letter are significantly different)

4.8.2 Number of Leaves

The application of organic fertilizers on beetroot recorded no significant difference ($p > 0.05$) on number of leaves throughout the rainy season. However, at harvest mean number of leaves ranged from 7.24 to 7.78 with least recorded in the pots treated with cow dung and the highest recorded in the pots treated with compost. During the dry season experiment, results from ANOVA showed that there was no significant difference ($p > 0.05$) on the effect of organic soil amendment on beetroot's number of leaves. At harvest the mean number of leaves ranged from 9.67 to 10.78 with the least recorded in the pot treated with cow dung and the highest recorded in the pot treated with compost. However, the results from ANOVA showed that there was significant difference ($p < 0.001$) at harvest resulting from the effect of irrigation regimes number of leaves of beetroot. The highest number of leaves 12.17 was recorded at 100 % CWR irrigation regime followed by 9.67 recorded at 75 % CWR irrigation regime while 50 % CWR irrigation regime recorded the least of 9.33 (Figure 4.14). ANOVA showed significant difference at 5 WATP ($p = 0.039$) and at harvest ($p = 0.01$) resulting from the interaction between irrigation regimes and organic soil amendment, at 5 WATP. The highest number of leaves of 9.67 at the 100 % irrigation regime was recorded in the pots with no organic soil amendment treatment whilst at 75 % CWR irrigation regime the highest number of leaves of 8 was recorded in the pots treated with sheep dropping, and at 50 % CWR irrigation regime, the highest number of leaves was 8.67 for pots treated with sheep droppings. At harvest, 14 leaves were recorded in the pots treated with compost at 100 % CWR irrigation regime, 11 leaves at 75 % CWR irrigation regime for pots treated with cow dung and 11.79 leaves in pots treated with sheep droppings with 50 % CWR irrigation regime (Table 4.13).

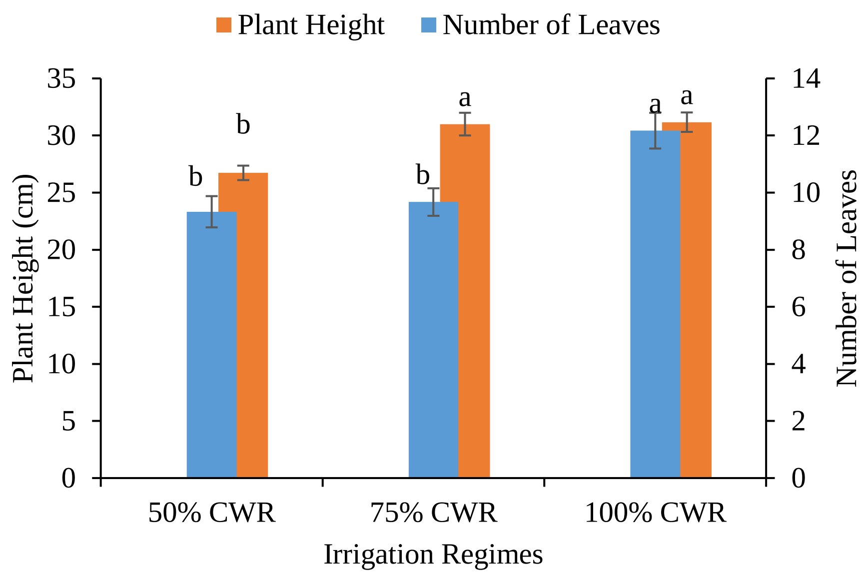


Figure 4.14: Effect of Irrigation Regimes on Plant Height and Number of Leaves (Beetroot)
(Means that do not share a letter are significantly different)

Table 4.13: Interactive Effect of Irrigation Regimes and Organic Soil Amendment on Number of Leaves of Beetroot at 5 WATP

Irrigation (% CWR) levels	**5 WATP**				**AT harvest**			
	Organic Fertilizers							
	CTR	CMT	CWD	SHD	CTR	CMT	CWD	SHD
50%	6.33bc	6.33bc	8.00abc	8.67a	7.33f	8.67def	9.33cdef	11.79abc
75%	8.00abc	6.67bc	6.00c	8.00ab	11.00bcde	9.67cdef	8.33ef	9.67cdef
100%	9.67a	8.67a	6.67bc	8.00ab	12.67ab	14.00a	11.33abcd	10.67bcde
	P- value	0.024				0.014		

(Means that do not share a letter are significantly different)

4.8.3 Chlorophyll Content

There was no significant difference ($p > 0.05$) resulting from the effect of organic soil amendment on chlorophyll content of beetroot during the rainy season. Mean value of chlorophyll content at harvest was observed to range from 38.00 to 49.38 spad with the least levels recorded in the pots treated with cow dung and the highest in pots treated with sheep dropping. In the dry season, the ANOVA results of chlorophyll content recorded significant difference relating to the effect of organic soil amendment at 4 WATP ($p = 0.015$), 6 WATP ($p < 0.001$) and at harvest ($p = 0.033$). At 4 WATP, chlorophyll content ranged from 35.31 to 44.04 spad, with the least recorded in the pots treated with cow dung and the highest recorded in the pots treated with sheep dropping. At 6 WATP chlorophyll content ranged from 41.55 to 54.38 spad, with the least recorded in cow dung amended pots and sheep dropping yielding the highest chlorophyl content. Chlorophyll content at harvest was from 50.21 to 62.84 spad, with the least recorded in pots treated with sheep droppings and the highest in compost treated pots (Table 4.14). ANOVA showed no significant difference ($p > 0.05$) at harvest relating to the effect of irrigation regimes on beetroot's chlorophyll content. The highest chlorophyll content of 57.53 spad was recorded at 100 % CWR irrigation regime followed by 57.32 spad for 75 % CWR irrigation regime and 54.58 spad for 50 % CWR irrigation regime. ANOVA results had no significant difference ($p > 0.05$) on the interaction between the irrigation regimes and organic soil amendment during the dry season. At harvest the pots treated with compost recorded the highest chlorophyll content of 64.07, 64.53 and 59.93 spad in the three irrigation regimes of 100 %, 75 % and 50 % CWR respectively.

Table 4.14: Effect of Organic Fertilizer on Chlorophyll Content at 4 WATP, 6 WATP and at Harvest of Beetroot

Organic fertilizers (Treatments)	4 WATP (spad)	Weeks 6 WATP (spad)	At Harvest
CTR	41.62a	51.72a	54.02b
CMT	39.74a	50.86a	62.84a
CWD	35.311b	41.53b	58.83ab
SHD	44.06a	54.38a	50.20b
P-value	0.015	< 0.001)	0.033

(Means that do not share a letter are significantly different)
CNTRL – Control, CMPT – Compost, CWD – Cow dung, and SHD – Sheep droppings

4.8.4 Leaf Area

ANOVA showed that there was no significant difference ($p > 0.05$) on the effect of organic fertilizer on leaf area at the end of the rainy season. At harvest the leaf area ranged from 40.3 to 76 cm^2 with the least area recorded in the pot with no organic soil amendment and the broadest leaf area recorded in the pots treated with compost. In the dry season, there was no significant difference ($p > 0.05$) on the effect of organic fertilizer on leaf area and at harvest the leaf area was observed to range from 68.7 to 78.96 cm^2 with the least area recorded in the pots treated with sheep dropping whilst the broadest area was recorded in the pots treated with compost. Statistically significant difference resulting from ANOVA at $p = 0.033$ on the effect of irrigation regimes on leaf area of beetroot at harvest was recorded and the broadest leaf area 89.1 cm^2 was observed at 100 % CWR irrigation regimes, then 72.2 cm^2 recorded for 75 % CWR regime and the least of leaf area of 60.5 cm^2 was recorded for 50 % CWR (Figure 4.13). The interaction between irrigation regimes and organic soil amendment recorded no significant difference ($p > 0.05$) at the end of the dry season, with 100 % CWR irrigation regime having the leaf area of 98.2 cm^2 resulting from pots treated with sheep droppings, the control pots with no treatment at 75 % CWR irrigation regime recorded leaf area of 85.7 cm^2 and at 50 % CWR irrigation regime the leaf area recorded was 84.0 cm^2 for plants in pots treated with compost.

4.8.5 Leaf Area Index

The results of the study from the ANOVA showed that there was no significant difference ($p > 0.05$) on the effect of organic soil amendment on leaf area index for the rainy season but at harvest the leaf area index ranged from 0.34 to 0.81, with the least recorded in the pots with no organic soil amendment and with the highest recorded in the pots treated with compost. For the dry season, there was no significant difference ($p > 0.05$) on the effect of the application of organic soil amendment on leaf area index of beetroot. However, at harvest the leaf area index was observed to range from 0.951 to 1.15 and with the least recorded in the plant pot with organic soil amendment with the application of compost. ANOVA indicated statistically significant difference ($p = 0.001$) on the effect of irrigation regimes for leaf area index of beetroot at harvest in dry season. The highest leaf area index of 1.41 was recorded at 100 % CWR irrigation regimes whilst for 75 % CWR, a 0.945 LAI was reported, and a 0.73 LAI was recorded at 50 % CWR irrigation regime (Figure 4.15). The interaction between irrigation regimes and organic soil amendment recorded no significant difference ($p > 0.05$) at the end of the dry season. 100 % CWR irrigation regime recorded the highest LAI of 1.66 in plants of pots treated with compost. At 75 % CWR irrigation regime, LAI of 1.25 was recorded in the control pots whilst 0.97 LAI was recorded in plant pots treated with compost at 50 % CWR.

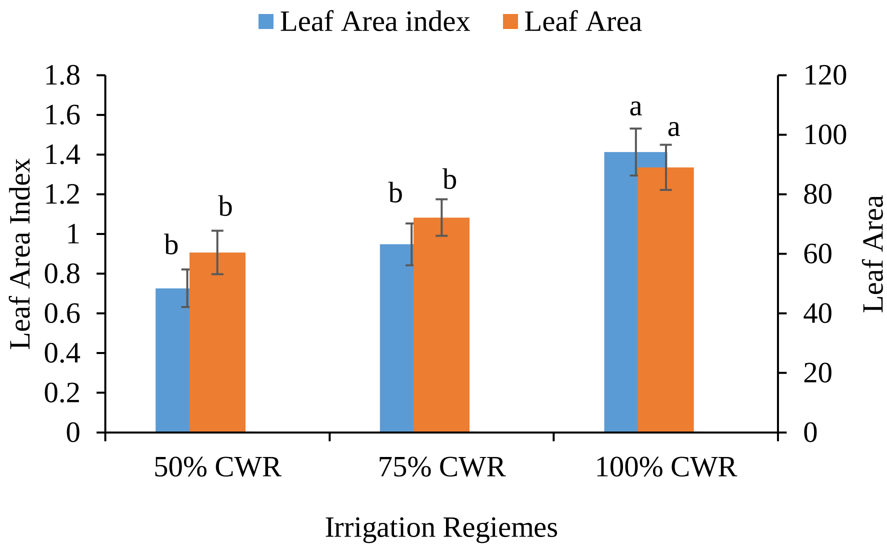


Figure 4.15: Effect of Irrigation Regimes on Leaf Area and Leaf Area Index of Beetroot ***(Means that do not share a letter are significantly different)***

There was a positive impact resulting from the effect of organic soil amendment on beetroot growth parameters as the highest plant height was recorded in the plants treated with compost and sheep droppings and cow dung with the least performance in the rainy season. In the dry season, there experimental setup did not record a significant difference at 4 and 5 WATP for the interactive effect of organic soil amendment and plant height, although plant pots treated with the sheep droppings recorded the highest plant height followed by compost soil amendment and cow dung in that order. Similar results were reported by Dlamini *et al.* (2020) for cow dung fertilizer applied at 60 t/ha. Irrigation regime affected plant height of beetroot during the dry season at 100 % CWR irrigation regime with the highest plant height while the least was recorded at 50 % CWR irrigation regime. Similar results have been reported by Topak *et al.* (2011) which indicated that 100 % CWR regime gives an adequate soil water supply during the growing period of the crop. The highest number leaves in the rainy season were recorded in plants pots treated with compost while the least was in the plant pots treated with cow dung. In the dry season, more leaves were recorded in pot plants treated with compost, sheep droppings and cow dung soil amendments in that order.

At 5 WATP, the 100 % CWR irrigation regime recorded the highest number of leaves for the control treatment unit and with the deficit irrigation, the sheep droppings had a better advantage with more leaf number. Chlorophyll content was highest in the plant pots treated with organic soil amendment of sheep droppings during the rainy season while plant pots treated with compost were highest during the dry season. Irrigation regimes and fertilizer application at 100 % CWR irrigation regime recorded the highest chlorophyll content in the plant pots treated with compost. The results corresponds with Jabeen *et al.*(2018) who reported an increase in chlorophyll content of chili leaves with increasing manure application rate. The results were however in contrast with Dlamini *et al.* (2020) who recorded the highest chlorophyll content in control plants where no soil amendment was applied. Chlorophyll is associated with nitrogen levels, therefore the increase of nitrogen application can increase the chlorophyll content of sugar beets, and can give rise to the photosynthetic rate of plants (Tsialtas and Maslaris, 2012). The higher chlorophyll content in some plants can be attributed to the increase in soil nutrient especially nitrogen. The leaf area and leaf area index recorded their highest levels in plants treated with compost and sheep droppings for soil amendment in the raining season experiment. In the dry season, the highest levels of leaf area were recorded in the compost and the sheep droppings. The 100 % CWR irrigation regime was observed to have recorded the highest leaf area and leaf area index as the interaction of irrigation regimes and organic fertilizers application on leaf area and leaf area index resulted in plants treated with sheep droppings at 100 % CWR irrigation regime having high leaf area.

4.9 Effect of Organic Fertilizers and Irrigation Regime on Beetroot Yield Parameters

4.9.1 Root development

The rainy season experimental period recorded beetroot's root length ranging from 9.67 to 11.7 cm, with the least recorded in the control pots with no soil amendment, and highest in pots amended with sheep droppings. ANOVA showed no significant difference ($p > 0.05$) resulting from the addition of organic soil amendment on beet's root length. Also, ANOVA results showed no significant difference ($p > 0.05$) from the effect of organic soil amendment on beet's root length in the dry season. Beet root lengths ranged from 10 to 11.06 cm with the least recorded in the pots treated with compost and highest in soils amended with sheep droppings. Irrigation regime was noted to be statistically significant ($p = 0.047$) on beetroot length with 100 % CWR irrigation regime recording the longest root length of 11.69 cm, followed by 10.48 cm at the 75% CWR and 50 % CWR recording the least length of 9.67 cm. The interactive effect of organic soil amendment and crop water requirements on the beetroot length was not statistically significant ($p > 0.05$). At 100 % CWR irrigation regime the longest root length of 12.27 cm was recorded in pots treated with sheep droppings, at 75% CWR irrigation regime the longest beetroot length of 10.67 cm was recorded in pots treated with sheep droppings while at 50 % CWR irrigation regime the longest root length of 11.67 cm was recorded in pots treated with cow dung (Table 4.15).

Table 4.15: Effect of Organic Soil Amendment and Irrigation Regime on Beetroot's Root Length

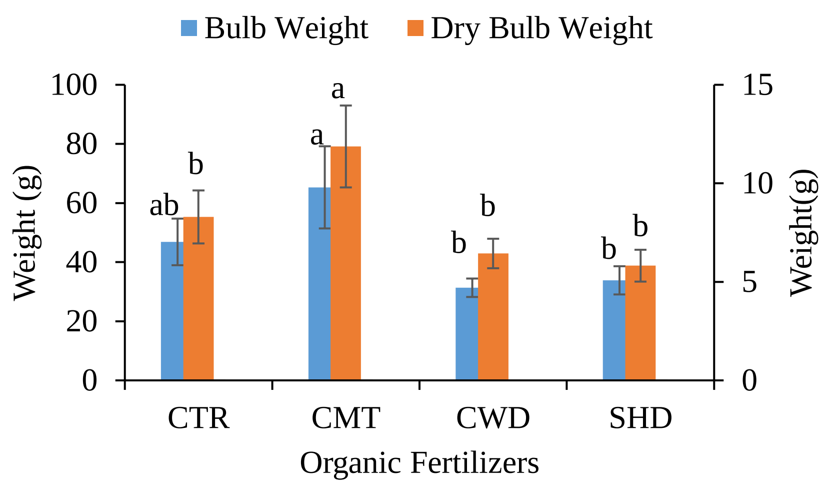
Treatments	**Root length (cm)**
Organic fertilizers	**At harvest**
CTR	10.78a
CPT	10.00a
CWD	10.61a
SHD	11.06a
p-value	**0.697**
Irrigation Regimes	
100 % CWR	11.69a
75 % CWR	9.67b
50 % CWR	10.48ab
p-value	0.047

Irrigation (% CWR) Levels			**At harvest (cm)**	
	Organic Fertilizers			
	CTR	CPT	CWD	SHD
50% CWR	10.50ab	9.50a	11.68ab	10.25ab
75% CWR	10.00ab	9.33ab	8.67b	10.67ab
100% CWR	11.83ab	11.17ab	11.50ab	12.27a
	p- value		0.827	

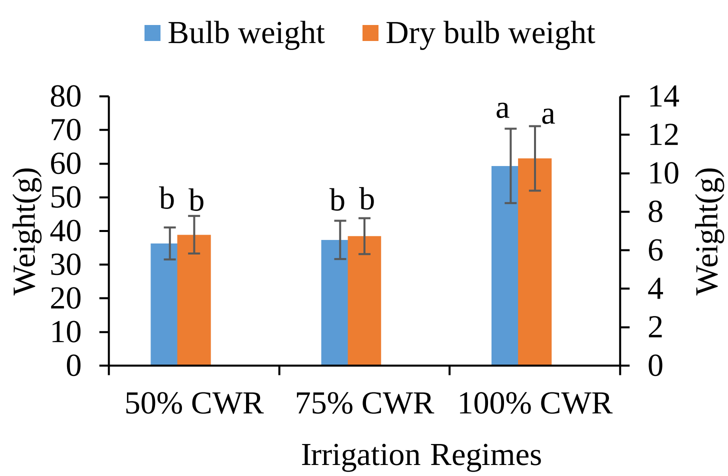
(Means that do not share a letter are significantly different)

4.9.2 Bulb Weight

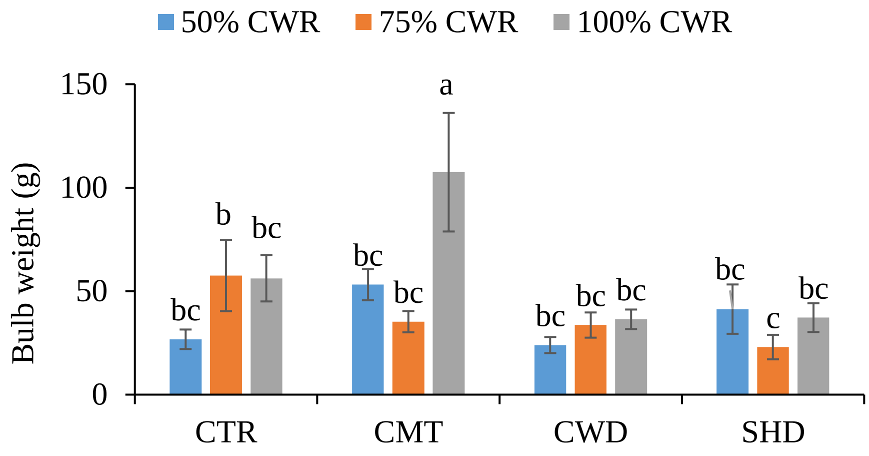
Beetroot's bulb weight in the rainy season ranged from 19.95 to 40.72 g with the least recorded in pots treated with cow dung and highest recorded in pots treated with compost. ANOVA showed no significant difference ($p > 0.05$) on the effect of organic soil amendment on beetroot's bulb weight. In the dry season, ANOVA recorded significant difference ($p = 0.007$) on the effect of organic soil amendment on beetroot's bulb weight and ranging from 31.33 to 65.30 g. The least bulb weight was recorded in the pots treated with cow dung and highest recorded in the pots treated with compost (Figure 4.16a). Similarly, irrigation regime was significantly different ($p = 0.017$) on bulb weight of beetroot, 100 % CWR recording the highest bulb weight of 59.32 g followed by 37.35 g recorded at 75 % CWR while the least weight of 36.30 g was recorded at 50 % CWR as presented in Figure 4.16b. The interactive effect of organic soil amendment and irrigation regime on bulb weight of beetroot was significantly different ($p = 0.035$). At 100 % CWR irrigation regime the highest bulb weight of 107.48 g was recorded in the pots treated with compost and at 75% CWR irrigation regime, the highest bulb weight of 57.53 g was recorded in the control pots. At 50 % CWR irrigation regime the highest bulb weight of 53.16 g was recorded in the plants treated with compost (Figure 4.16c).



(a) Effect of Organic Fertilizer on Fresh and Dry Bulb Weight (2nd Season)



(b) Effect of Irrigation Regimes on Fresh and Dry bulb Weight



(c) Interactive effect of Irrigation Regimes and Organic Fertilizer

Figure 4.16: Effect of Organic Soil Amendment and Irrigation Regimes on Beetroot

4.9.3 Dry Bulb Weight

Dry weight of beetroot in the rainy season ranged from 4.06 to 6.69 g with the least recorded in the cow dung experimental pots and the highest in the compost amended soils. There was no significant difference ($p > 0.05$) in organic amended soils in the rainy season but significant difference ($p = 0.004$) was recorded in the dry season for beetroot's dry bulb weight. Dry bulb for the treatments applied in the form of soil amendment are presented in Figure 4.16a. Effect of irrigation regime was significantly different ($p = 0.009$) on dry bulb weight of beetroot as presented Figure 4.16b in for various regimes of the experimental setup. The combined effect of organic soil amendment and irrigation regime on dry bulb weight of beetroot was not significantly different ($p > 0.05$). At 100 % CWR, the highest dry bulb weight of 17.8 g was recorded for compost amended soils, 9.51 g for control pots at the 75 % CWR and 10.85 g for treatments of 50 % CWR and compost amendments.

4.9.4 Bulb Diameter

Beetroot in the rainy season recorded bulb diameter ranging from 34.9 to 42.7 mm with the least and highest recorded in the pots with no organic soil amendment (control) and compost respectively. ANOVA for results of the dry season showed no significant difference at $p > 0.05$ whilst at $p = 0.001$ in the dry season, soil amendment recorded a significant difference for its effect on beetroot bulb diameter. Bulb diameter in the dry season ranged from 29.0 to 36.3 mm, with the least in pots with no organic soil amendment but the highest was in pots treated with cow dung (Figure 4.17). Similarly, the interactive effect of organic soil amendment and irrigation regime was not significantly different ($p > 0.05$) on beetroot bulb diameter.

Similar results were recorded by Zhao *et al.* (2019) who reported that application of organic fertilizer increases soil aeration, give allowance to root growth development and also recorded more root development in the organically treated plant in contrast to the control. Also, Dlamini *et al.* (2020) reported high fresh weight of beetroot on cattle manure application compared to the control.

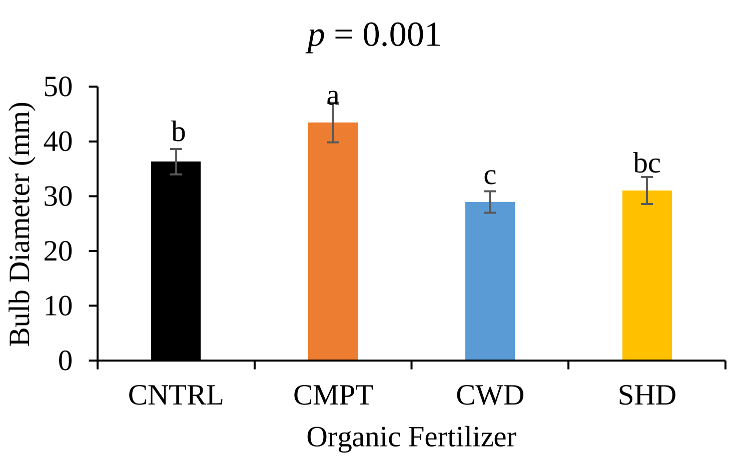


Figure 4.17: Effect of Organic Fertilizer and Irrigation on Yield parameters of Beetroot

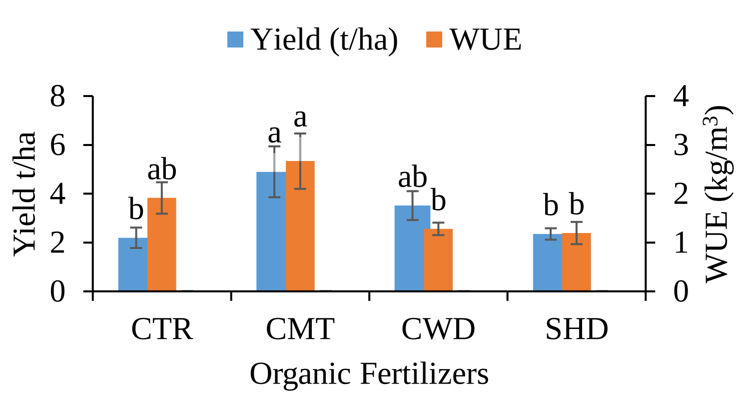
4.10 Yield of Beetroot

Beetroot's yield ranged from 2.02 to 3.19 t/ha in the rainy season and 2.19 to 4.90 t/ha in the dry season. ANOVA showed no significant difference ($p > 0.05$) in the effect of organic soil amendments on beetroot yield in the rainy season whilst in the dry season there was significant difference ($p = 0.004$) resulting from the effect of organic soil amendment (Figure 4.18a). Piskin, (2019) reported an increase in the yield of sugar beets treated with sheep manure application. Irrigation regime was significantly different ($p = 0.011$) on yield of beetroot, and 100 % CWR recorded the highest yield of 4.45 t/ha, 75 % recorded 2.80 t/ha and 50 % recorded 2.46 t/ha (Figure 4.18b). The interactive effect of organic soil amendment and irrigation regime on beetroot yield was not significantly different ($p > 0.05$). At 100 % CWR the highest yield of 8.06 t/ha was recorded in compost amended soils, whilst at 75% CWR, 4.32 t/ha was recorded in the control pots and at 50 % CWR the highest yield 3.99 t/ha was recorded in compost amended soils.

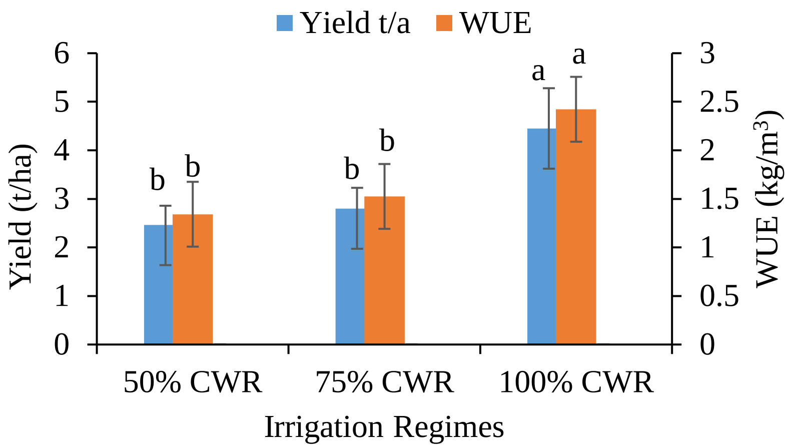
Generally, the experimental results recorded lower yield of beetroots compared to the standard and literatures and may be resulting from the weather condition of the study area as beetroots are recommended to grow well in 6 hours sunlight of 24ºC maximum, but the study area recorded 9 hours of sunlight and maximum temperature 41.2 ºC which can be considered undesirable for the crop development.

4.11 Crop Water Use Efficiency

The average quantity of water used for beetroot irrigation in 50 %, 75 % and 100 % CWR irrigation regimes were 811.5 L, 1217.25 L and 1,836.75 L respectively. The mean crop water use efficiency of beetroot ranged from 1.19 to 2.671 kg/m^3, with the least recorded in the pots treated with sheep dropping while the highest was recorded in the pot treated with compost. ANOVA results showed significant difference ($p = 0.004$) resulting from the effect of organic soil amendments on crop water use efficiency on beetroot (Figure 4.18a). Similarly, the results showed significant difference (p = 0.011) on the effect of irrigation regime on crop water use efficiency of beetroot. The highest crop water use efficiency of 2.42 kg/m^3 was recorded at 100 % CWR, 1.53 kg/m^3 at 75% CWR, and 1.34 kg/m^3 at 50 % CWR (Figure 4.18b). There was no significant difference ($p > 0.05$) recorded in the interaction of irrigation regimes and organic soil amendment on WUE of beetroot. At the 100 % CWR, higher WUE was recorded in the plants treated with compost with 4.39 kg/m^3. At 75 % CWR, compost amended soils recorded the highest value of 2.35 kg/m^3 whilst at 50 % CWR, the pots treated with compost recorded the highest WUE of 2.17 kg/m^3. Water supply is a major constraint to crop production in modern agriculture, especially in areas with water scarcity and therefore, efficient use of water by irrigation is becoming increasingly important (Abd El-Kader *et al.*, 2010). The pots treated with sheep dropping recorded the highest WUE in terms of organic soil amendment. Ye *et al.* (2020) reported similarly on significant increase in WUE of pear jujube treated with sheep droppings. The results might also be due to ability of organic soil amender's ability to increase aeration and conserve moisture. The tendency of a plant to retain moisture would result in increased water use and increased yield per unit applied (Beheshti and Behboodi, 2010). Subhan *et al.* (2017) reported higher water use efficiency in plants treated with organic fertilizer over control plant in wheat cultivation.



(a) Effect of Organic Fertilizer on Beetroot's Yield and WUE (2nd Season



(b) Effect of Irrigation Regimes on Yield and WUE

(Means that do not share a letter are significantly different)

Figure 4.18: Effect of Irrigation and Organic Fertilizer on Yield and Water Use Efficiency

4.12 Effect of Organic Fertilizers and Irrigation on Growth and Development of Okra

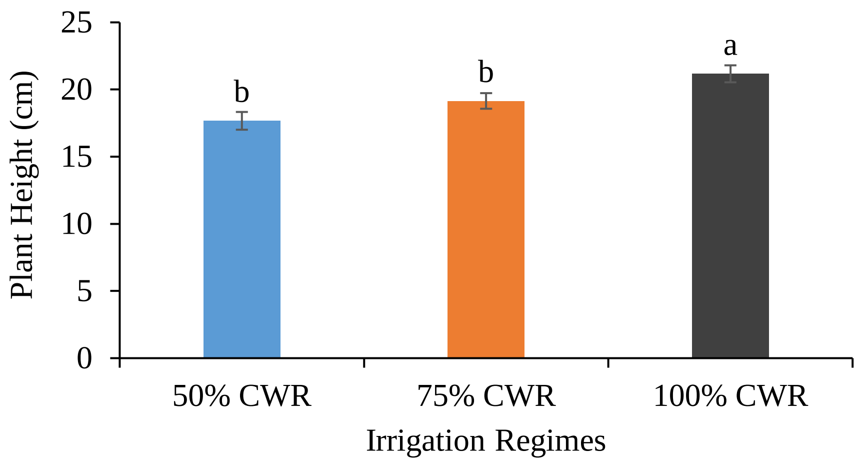
4.12.1 Plant Height

The rainy season experiment results indicated ANOVA with no significant difference ($p > 0.05$) whilst in the dry season, ANOVA showed that the effect of organic soil amendment had significant difference on plant height of okra at 3 WAP ($p < 0.016$), and 7 WAP ($p < 0.034$) (Table 4.16). As presented in Table 4.17, at 3 WAP average plant height ranged from 10.94 to 13.94 cm with the least recorded in the pots treated with sheep droppings and highest recorded in the pots treated with cow dung, at 7 WAP, mean plant height ranged from 23.89 to 27.89 cm, with the least recorded in the control pot and the highest recorded in the pot treated with cow dung.

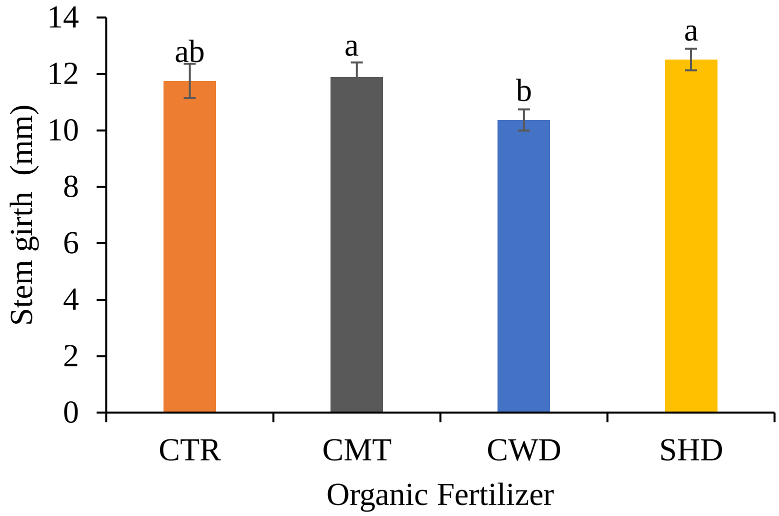
ANOVA results revealed that there was significant difference ($p = 0.002$) on the effect of irrigation regimes on plant height of okra at 5 WAP. The tallest plants of 21.17 cm were recorded at 100 % CWR, 19.15 cm at 75 % CWR while the least 17.67 cm was recorded in the 50 % CWR (Figure 4.19a). The interaction between irrigation regimes and organic soil amendment was not statistically significant throughout the dry season experiment ($p > 0.05$). At 8 WAP, 100% CWR recorded the tallest plants at 28.33 cm in the pots treated with compost, at 75 % CWR the tallest plants were 29 cm in the pots treated with cow dung, while at 50 % CWR the tallest plants of 27.67 cm were recorded in the pots treated with sheep dropping.

Table 4.16: Effect of Organic Fertilizer on Okra's plant height at 3 and 7 WAP (Dry Season)

Organic fertilizers (Treatments)	3 WAP (cm)	Weeks 7 WAP (cm)
CTR	12.11 b	23.89 b
CMT	11.72 b	26.11 ab
CWD	13.94 a	27.89a
SHD	10.94 b	26.44 ab
p-value	0.016	0.034



(a) Effect of Irrigation Regimes on Plant Height at 5 WAP



(b) Effect of Irrigation Regimes on Stem Girth at 5 WAP (Rainy Season)

(Means that do not share a letter are significantly different)

Figure 4.19: Effect of Organic Fertilizer and Irrigation Regimes on Okra Growth Parameter

4.12.2 Stem Girth

ANOVA results for the rainy season showed significant difference ($p = 0.025$) at 5 WAP for stem girth and with stem girths presented in Figure 4.19b. Also, ANOVA in the dry season indicated that the effect of organic soil amendment had significant difference on stem girth of okra at 6 WAP ($p = 0.016$), and 7 WAP ($p = 0.011$) (Table 4.17). ANOVA results showed that the effect of irrigation regimes had significant difference on stem girth of okra at 2 WAP ($p = 0.001$), 4 WAP ($p = 0.008$), 5 WAP ($p < 0.001$) and 6 WAP ($p = 0.002$) Table 4.17. The results of the interactive effect of irrigation regimes and organic soil amendment had significant difference on stem girth of okra at 2 WAP ($p = 0.002$). 100 % irrigation regime recorded a stem girth of 3.37 mm in the pots with no organic soil amendment and at 75 % CWR irrigation regime, stem girth of 3.86 mm was recorded in the pots treated with cow dung whilst at 50 % CWR irrigation regime the stem girth was 2.81 mm and in the pots with no organic fertilizer treatment (Table 4.17).

Table 4.17: Effect of Organic Fertilizer on Stem Girth at Dry season Experiment

Irrigation Regimes (Treatments) CWR	2 WAP (mm)	4 WAP (mm)	Weeks 5 WAP (mm)	Weeks 6 WAP (mm)
100 %	3.03a	5.63a	6.86a	7.59a
75 %	3.15a	5.48a	6.32a	7.10a
50 %	2.57b	4.65b	5.25b	6.10b
***p*- value**	0.001	0.008	< 0.001)	0.002)

OF * IR		**2 WAP**		
(Irrigation Regimes)		**Organic Fertilizer**		
CWR	**CTR**	**CPT**	**CWD**	**SHD**
50 %	2.81bcd	2.77cd	2.53de	2.16e
75 %	2.84bcd	2.54de	3.86a	3.34abc
100 %	3.38ab	3.03bcd	2.79bcd	2.93bcd
	p-value		0.002	

Organic fertilizers (Treatments)	**6 WAP (mm)**	**7 WAP (mm)**
CTR	6.11b	6.95b
CPT	7.05a	8.08a
CWD	6.97ab	7.88ab
SHD	7.59a	8.59a
p-value	0.016	0.011

OF: Organic Fertilizer, IR: Irrigation Regimes, CTR: Control, CPT: Compost Fertilizer, SHD: Sheep dropping Fertilizer, CWD: Cow Dung Fertilizer. *Means that do not share a letter are significantly different.

4.12.3 Number of Leaves

At the end of rainy season experiment, ANOVA results showed that there was no significant difference ($p > 0.05$) throughout the season. At 8 WAP mean number of leaves ranged from 10.76 to 17.39, with the least recorded in the plant treated with cow dung and highest recorded in the plants with no organic soil amendment. The dry season experimental results using ANOVA showed that the effect of organic soil amendment had significant difference on okra's number of leaves at 6 WAP ($p < 0.005$) with mean number of leaves ranging from 11.33 to 16.00 and with the least recorded in the control pots and highest recorded in the pots treated with sheep droppings. ANOVA results showed significant difference ($p = 0.008$) on the effect of irrigation regimes on okra's number of leaves at 6 WAP. The mean highest number of leaves of 16.42 was recorded in 100 % CWR whilst 75 % and 50 % CWR recorded the same mean number of leaves 13.25 (Table 4.18). The interaction between irrigation regimes and organic soil amendment was not statistically significant throughout the dry season experiment ($p > 0.05$). At 8 WAP, 100 % CWR recorded the highest number of leaves 25.33 in the pots treated with sheep droppings at 75 % CWR the highest number of leaves of 23.67 was recorded in the pots treated with cow dung, while at 50 % CWR recorded the highest number of leaves of 23.00 in the pots treated with compost.

Table 4.18: Effect of Organic Fertilizer and Irrigation Regimes on Number of Leaves of Okra

Organic fertilizers (Treatments)	**6 WAP**
CTR	11.33b
CPT	14.56a
CWD	15.33a
SHD	16.00a
p-value	0.005
Irrigation Regimes	
50 % CWR	13.25b
75 % CWR	13.25b
100 % CWR	16.42a
p-value	0.008

CTR: Control, CPT: Compost Fertilizer, SHD: Sheep dropping Fertilizer, CWD: Cow Dung Fertilizer, WAP: Weeks After Planting *Means that do not share a letter are significantly different

4.12.4 Chlorophyll Content (SPAD)

ANOVA of results at the end of the rainy season showed no significant difference ($p > 0.05$) but at 8 WAP the mean chlorophyll content ranged from 32.4 to 44.4 spad, with the least recorded in the pots treated with cow dung and the highest recorded in the control pot. Also, ANOVA in the dry season showed that the effect of organic fertilizer had no significant difference ($p > 0.05$) on chlorophyll content. At 8 WAP however, mean chlorophyll content ranged from 36.7 to 40.66 spad, with the least recorded in the pots treated with sheep dropping and highest recorded in the pots treated with compost.

For ANOVA on the effect of irrigation regimes, significant difference on chlorophyll content of Okra was recorded at 5 WAP ($p = 0.001$), 6 WAP ($p = 0.008$), 7 WAP ($p < 0.001$) and 8 WAP ($p = 0.002$) (Table 4.19). The interactive effect of irrigation regimes and organic soil amendment had no significant difference ($p > 0.05$) on chlorophyll content of okra throughout the season, at 8 WAP of 100 % CWR recording the highest chlorophyll content of 38.1 spad in the pots treated with sheep dropping, at 75 % CWR irrigation regime the plants treated with compost had the highest chlorophyll content 40.5 spad while at 50 % CWR irrigation regime the highest chlorophyll content of 47.2 spad was recorded in the plants with no organic soil amendment.

Table 4.19: Effect of Irrigation Regimes on Chlorophyll Content of Okra

Irrigation Regimes (Treatments)	5 WAP (spad)	6 WAP (spad)	Weeks 7 WAP (spad)	Weeks 8 WAP (spad)
50 % CWR	60.63a	59.70a	72.41a	43.18a
75 % CWR	58.92a	55.34a	59.22a	38.28ab
100 % CWR	43.85b	41.18b	39.45b	34.88b
p- value	0.003	< 0.001	0.001	0.008

WAP: Weeks After Planting. *Means that do not share a letter are significantly different

4.12.5 Leaf Area Index

At the end of rainy season experimental period, ANOVA results showed that there was no significant difference ($p > 0.05$) in the treatments whilst in the dry season, there was significant difference ($p < 0.015$) on leaf area index at 6 WAP. Mean leaf area index at 6 WAP ranged from 0.81 to 1.5 in the dry whilst in the rainy season it ranged from 1.31 to 3.06 (Figure 4.20).

ANOVA on the effect of irrigation regimes recorded significant difference on leaf area index of okra at 4 WAP (p = 0.029), 5 WAP (p = 0.001), and 6 WAP (p = 0.002) as presented in Table 4.20. The interactive effect of irrigation regimes and organic soil amendment had no significant difference ($p > 0.05$) on leaf area index of okra throughout the seasons. At 8 WAP 100 % CWR irrigation regime, the highest leaf area index of 2.85 was recorded in pots treated with sheep droppings whilst at 75 % CWR irrigation regime the pots treated with cow dung had the highest leaf area index of 2.47 and at 50 % CWR the highest leaf area index of 1.83 was recorded in the pots treated with compost.

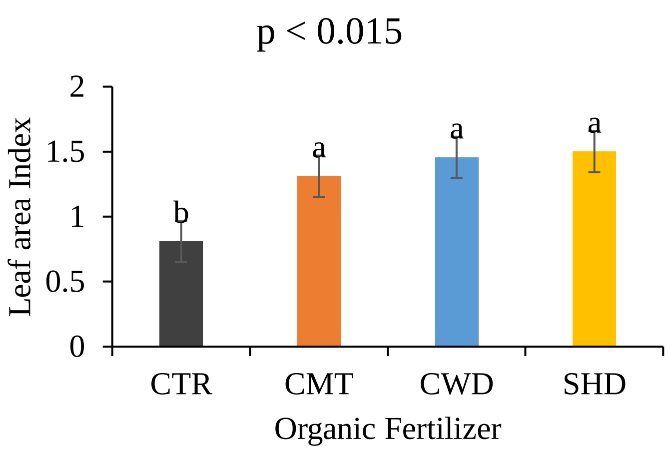


Figure 4.20: Effect of Organic Fertilizer on Leaf area Index of Okra
CTR: Control, CPT: Compost Fertilizer, SHD: Sheep dropping Fertilizer, CWD: Cow Dung Fertilizer. *Means that do not share a letter are significantly different

Table 4.20: Effect of Irrigation Regimes on Leaf Area Index of Okra

Irrigation Regimes (Treatments)	**4 WAP**	**Weeks 5 WAP**	**6 WAP**
50 % CWR	0.365b	0.574b	0.915b
75 % CWR	0.55ab	0.861b	1.218b
100 % CWR	0.633a	1.219a	1.674a
p- value	0.029	0.001	0.002

WAP – Weeks After Planting. *Means that do not share a letter are significantly different

Organic fertilizers increase the level of organic carbon in the soil and increases soil aeration that influence the root development and growth parameters of plants (Zhao *et al.*, 2019). The effect of organic fertilizers was noted to be positive at different stages of plant growth, i.e. plant height, leaf area and leaf area index. Masarirambi *et al.* (2012) studied the effect of kraal manure application rates on growth of wild okra, and reported that the plants applied with 60 t/ha recorded the highest vigour in terms of plant height, leaf area and leaf area index. The sheep droppings organic fertilizer also gave a positive result in both seasons, it recorded the highest in the number of leaves of okra and the second highest in most of the growth parameters in the dry season, the result agreed with the Tiamiyu *et al.* (2012) also reported the effect of sheep droppings as recording the highest growth parameter after poultry waste

4.12.6 Root Development

The ANOVA results showed that the effect of organic soil amendment on okra's root length had no significant difference ($p > 0.05$) in the rainy season. Also, there was no significant difference ($p > 0.05$) in the effect of irrigation regimes on the root length and at 75 % CWR the longest root length of 26.3 cm followed by 25.8 cm at 100 % CWR irrigation regime was recorded while the 50 % CWR recorded the least root length of 20.4 cm (Table 4.21)

Table 4.21: Effect of Organic Fertilizer, Irrigation Regimes and Interaction on Okra Root Development

Organic Fertilizer (Treatments)	At harvest (cm)
CTR	25.33a
CPT	23.33a
CWD	24.78a
SHD	23.33a
p- value	0.973
Irrigation Regimes (IR)	
50 % CWR	20.42a
75 % CWR	26.33a
100 % CWR	25.83a
p- value	0.370

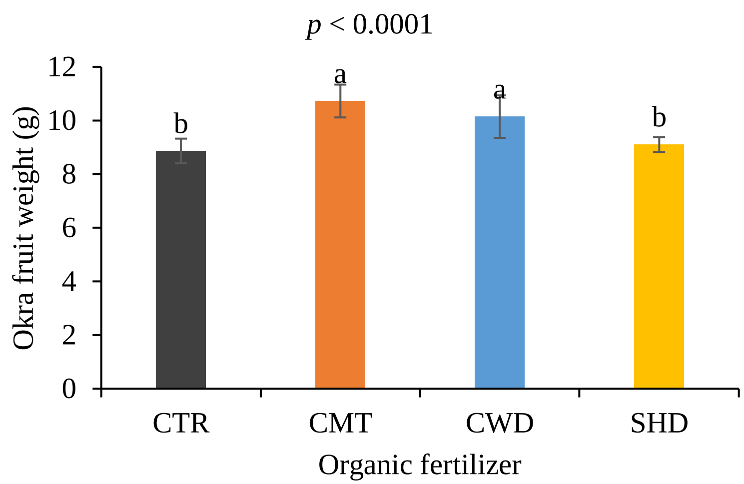
(Irrigation Regimes)		**Organic Fertilizer**		
IR*OF	**CTR**	**CPT**	**CWD**	**SHD**
50 % CWR	24.67a	19.33a	18.67a	19.00a
75 % CWR	20.00a	29.00a	32.00a	24.33a
100 % CWR	31.33a	21.67a	23.67a	26.67a
p- value		0.722		

CTR: Control, CPT: Compost Fertilizer, SHD: Sheep dropping Fertilizer, CWD: Cow Dung Fertilizer, WAP: Weeks After Planting *Means that do not share a letter are significantly different

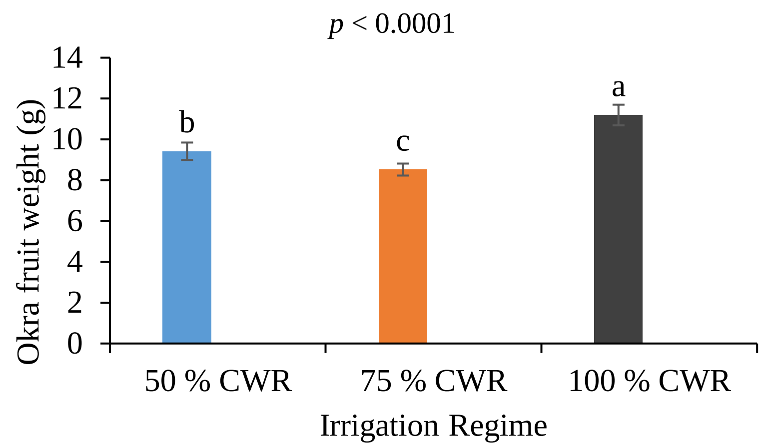
4.13 Effect of Organic Soil Amendment and Irrigation Regime on Yield Parameters of Okra

4.13.1 Fruit Weight

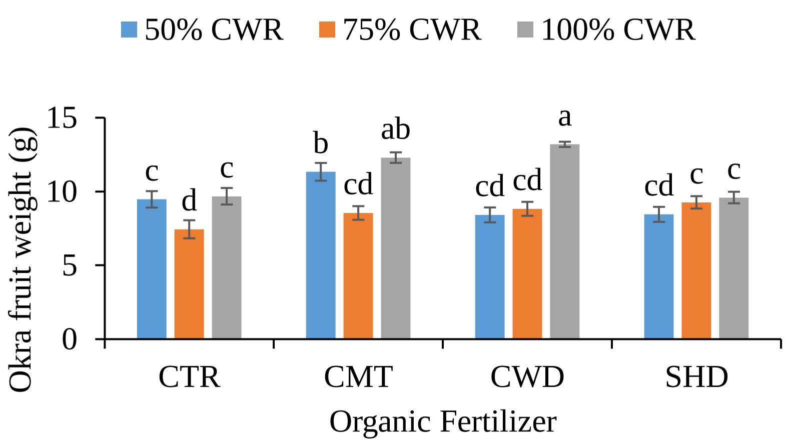
ANOVA recorded no significant difference ($p > 0.05$) on fruit weight of okra at the end of rainy season experiment but there was significant difference ($p < 0.0001$) at the end of the dry season. The fruit weight in the rainy season ranged from 15.28 to 17.53 g whilst in the dry season it was from 8.86 to 10.73 g as shown in Figure 4.21a. Irrigation regimes was significantly different ($p < 0.0001$) on the fruit weight of okra in the dry season. Figure 4.21b presents the fruit weights for the various irrigation regimes whilst Figure 4.21c presents the interactive effects of organic soil amendment and irrigation regimes



(a) Effect of Organic Fertilizer on Fruit Weight (2nd Season)



(b) Effect of Irrigation Regimes on Okra Fruit Weight.



(c) Interactive effect of Irrigation Regimes and Organic Fertilizer on Okra Fruit Weight.

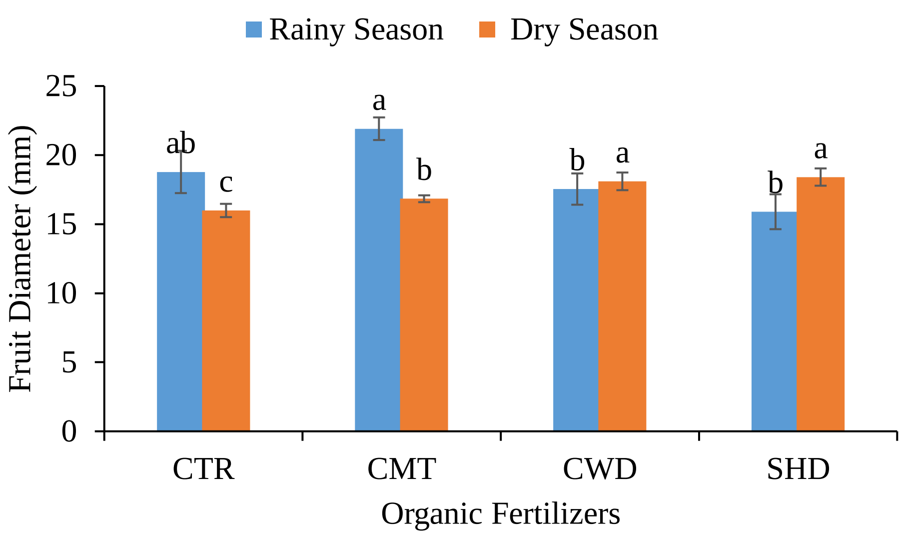
***Means that do not share a letter are significantly different**

Figure 4.21: Effect of Organic Fertilizer, Irrigation and Interaction on Okra Fruit Weight

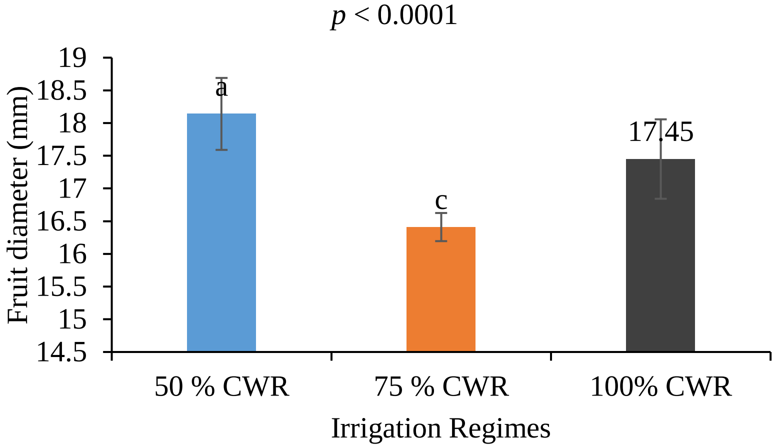
4.13.2 Fruit Diameter

The effect of organic fertilizer on okra fruit diameter was significantly different ($p = 0.011$) in the rainy season and the dry season from the ANOVA. Mean fruit diameter ranged from 15.90 to 21.91 mm, in the rainy season and 15.99 to 18.41 mm in the dry season (Figure 4.22a).

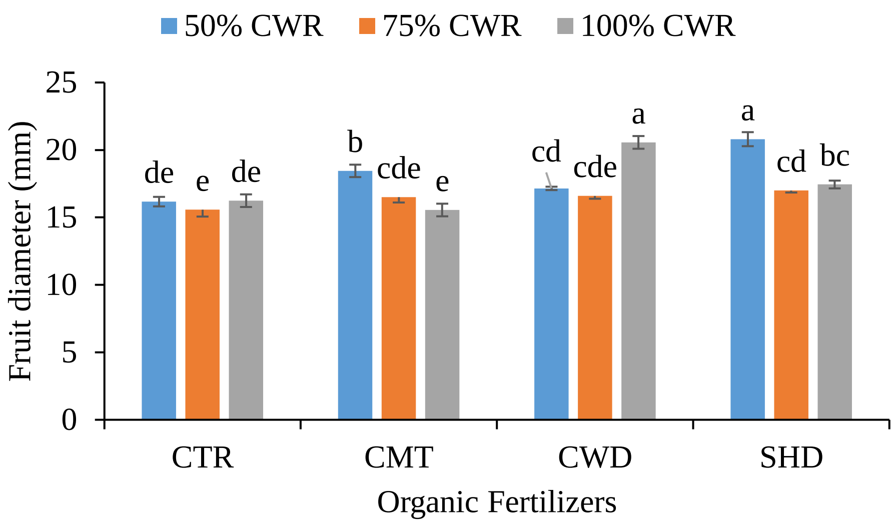
The effect of irrigation regimes showed significant differences ($p < 0.0001$) on the fruit diameter of okra in the dry season and the interactive effect of organic soil amendment and irrigation regimes on fruit diameter also showed significant different ($p < 0.0001$). Figure 4.22c presents the fruit diameter and the irrigation regimes of the experiment.



(a) Effect of Organic Fertilizer on Okra Fruit Diameter



(b) Effect of Irrigation Regimes on Okra Fruit Diameter



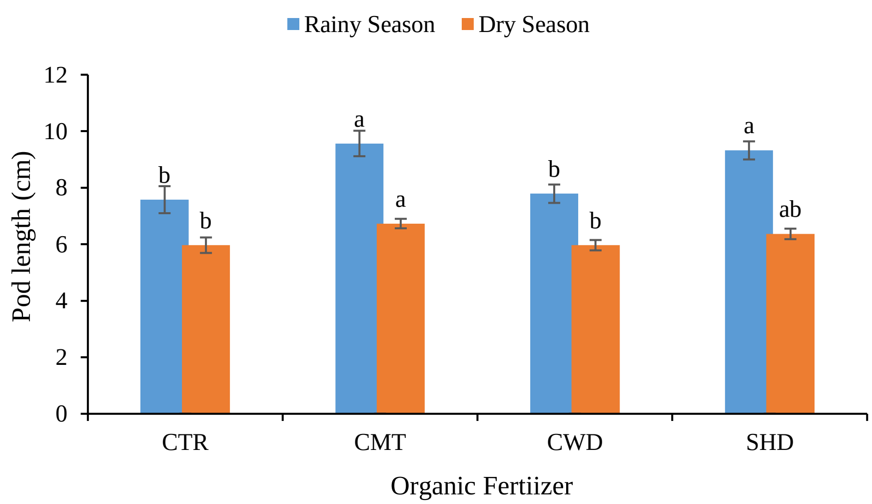
(c) Interactive effect of Irrigation Regimes and Organic Fertilizer on Okra Fruit Diameter.

Figure 4.22: Effect of Organic Fertilizer, Irrigation and Interaction on Okra Fruit Diameter

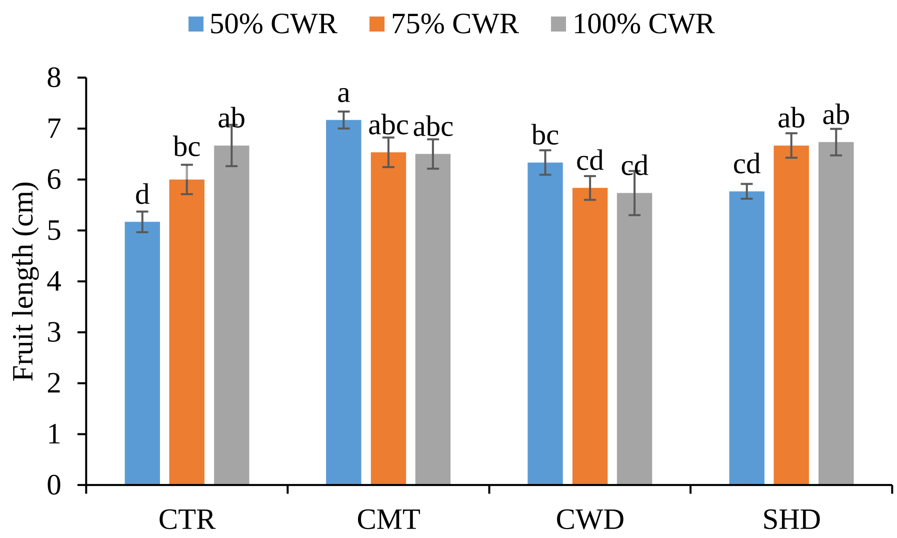
CTR – Control, CMT – Compost, CWD – Cow dung, and SHD – Sheep droppings *Means that do not share a letter are significantly different

4.13.3 Fruit Length

There was significant difference ($p = 0.001$) for pod length at the end of the rainy season with mean pod length ranging from 7.58 to 9.57 cm and the least length recorded in the control pot and the longest length recorded in the compost amended pot treated. At the end of dry season, ANOVA results showed that organic soil amendment on okra pod length was statistically significantly different ($p = 0.006$) with a pod length ranging from 5.96 to 6.73 cm (Figure 4.23a). Irrigation did not significantly affect pod length at ($p > 0.05$) in the dry season. 100 % CWR irrigation regime recorded the longest pod length of 6.4 cm followed by 6.26 cm at 75 % CWR and 50 % CWR as 6.11 cm. The interactive effect of organic fertilizer and irrigation regimes on pod length also showed significant difference ($p < 0.004$). Figure 4.23b presents the relationship between irrigation regime and pod length for the experiments.



(a) Effect of Organic Fertilizer on Fruit Length



(b) Interaction of Organic Fertilizer and Irrigation Regime on Okra's Fruit Length

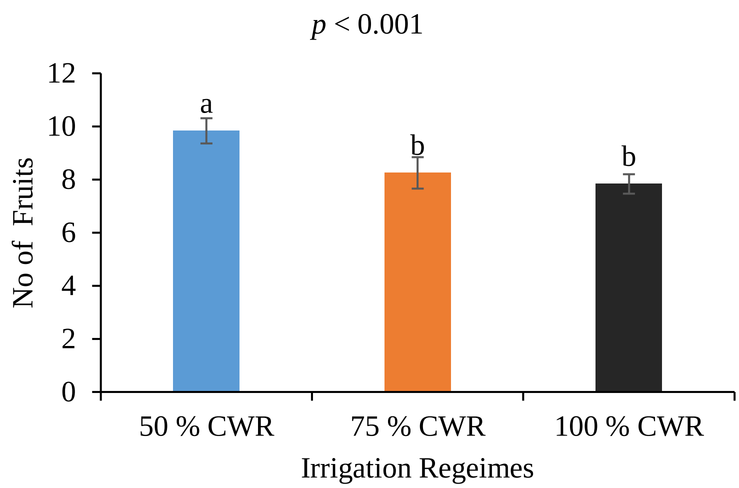
Figure 4.23: Effect of Organic Fertilizer, Irrigation and Interaction on Okra Pod Length

4.13.4 Number of Fruits per Plant

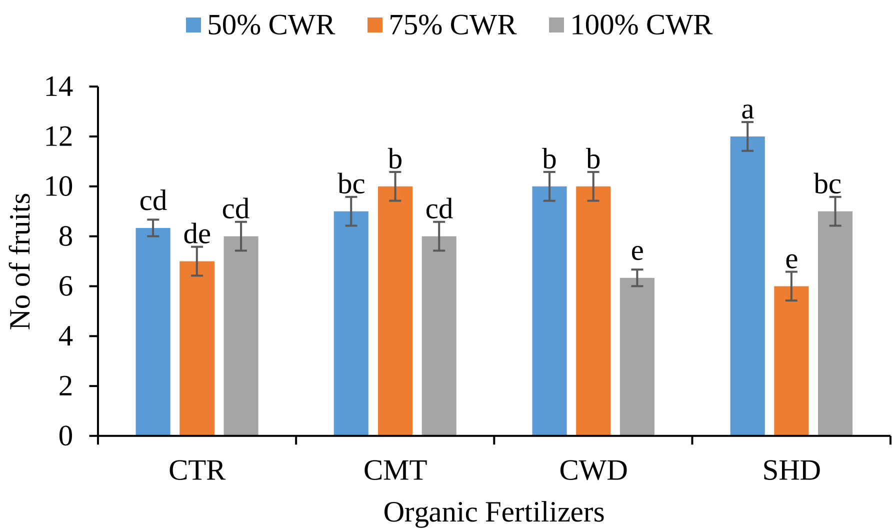
The effect of organic soil amendment on number of fruits per plant at the end of the rainy and dry seasons indicated an ANOVA result with no significant difference ($p > 0.05$). Mean fruit number ranged from 5.11 to 5.89 in the rainy season and 8.11 to 9.00 in the dry season (Table 4.23). Significant difference ($p < 0.001$) was recorded on the effect of irrigation regimes on number of okra pods (Figure 4.24a). The interactive effect of organic soil amendment and irrigation regimes on pod number also showed significant difference ($p < 0.001$) and with the detailed interactive effect of each treatment presented in Figure 4.24b.

Table 4.22: Effect of Organic Fertilizer on Okra Fruit's Number during the First and Second Season

Organic Fertilizer (Treatments)	Rainy Season	Dry Season
CTR	5.88a	8.11a
CPT	5.44a	9.00a
CWD	5.11a	8.78a
SHD	5.44a	8.67a
p- value	0.285	0.253



(a) Effect of Irrigation Regimes on Okra's Fruit Number



(b **Interaction of Organic Fertilizer and Irrigation Regime on Number of Fruit per Okra Plant.**

(Means that do not share a letter are significantly different)

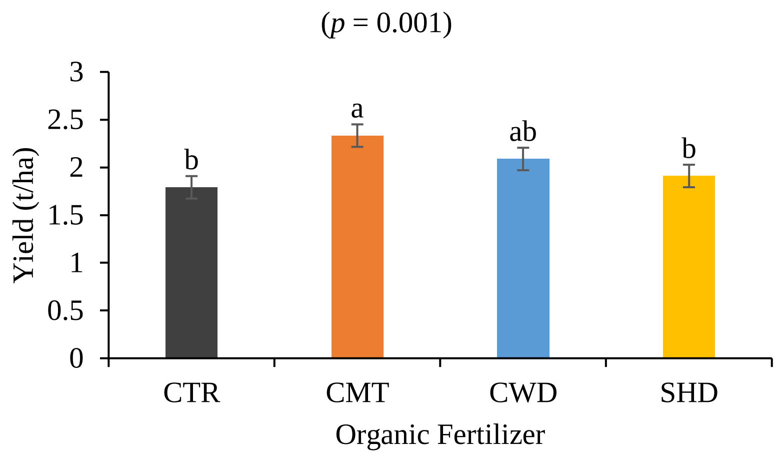
Figure 4.24: Effect of Irrigation Regimes and Interaction on Okra Fruit Number

Okra fruit diameter, length, weight, and number of fruits per okra plant are important parameters in measuring okra fruit attribute and yield. In both seasons of the experiment the results indicated that, organic soil amendment affected the yield and growth parameters of okra with significant difference recorded through ANOVA. The contribution to increase in organic carbon resulting from the incorporation of organic material was noted to affect the growth parameters. Similar results were obtained by Tiamiyu *et al.* (2012) using cow dung and sheep droppings as the second highest effective organic fertilizer after poultry waste on pod parameters. Akanbi *et al.* (2010) also reported that compost application to okra plant has a significant influence on its fruit number and fruit yield.

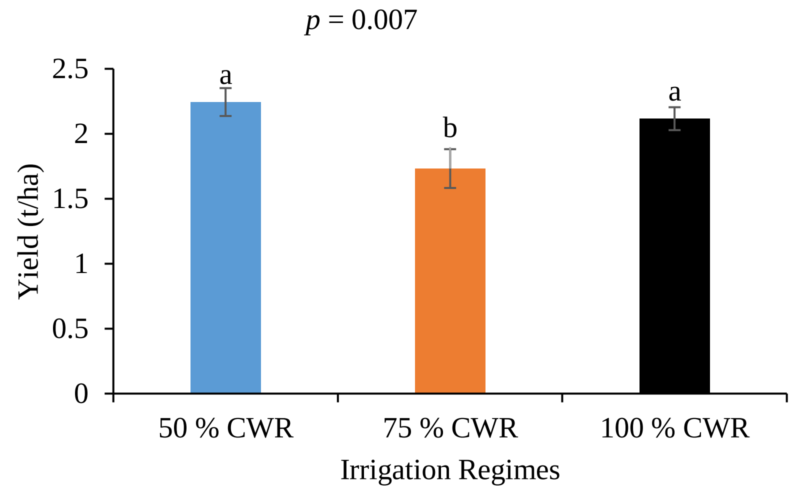
4.14 Okra Yield per Hectare

No significant difference was recorded at $p < 0.05$ on yield of okra in the rainy season whilst the dry season recorded significant difference (p =0.001) in the treatments. Mean yield ranged from 1.99 to 2.48 t/ha in the rainy season and 1.79 to 2.33 t/ha in the dry season (Figure 4.25a). Irrigation regimes recorded significant difference ($p = 0.007$) on okra yield and the various yields as affected by irrigation regimes are presented in Figure 4.25b. There was significant difference in the interactive effect of organic soil amendment and irrigation regimes from ANOVA at $p = 0.029$. Figure 4.25c presents the irrigation regimes and the yield per treatment of the experiments.

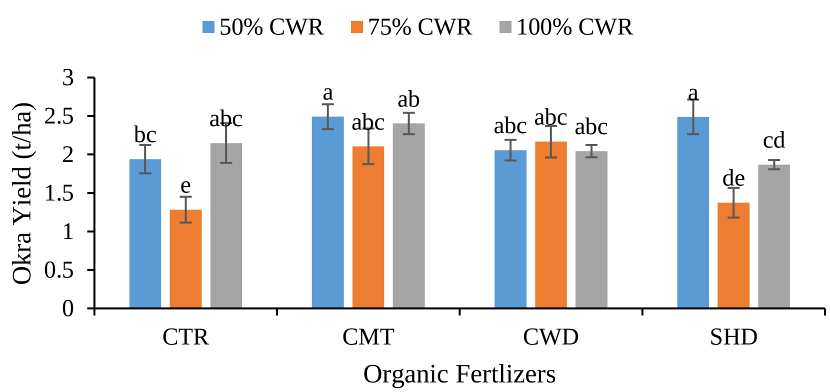
The experiment was affected by white fly infestation thus affecting and resulting in low crop yield as it even resulted in crop death. White flies are substantial pest of okra crop and can cause severe damage to okra plants and can reduce the yield (Akbar *et al.*, 2011; Athar *et al.*, 2011). Akanbi *et al.* (2010), reported yield increased in okra from the application of compost whilst Masarirambi *et al.* (2012) recorded 60 ton/ha from the application of kraal manure



(a) Effect of Organic fertilizer on Okra's Yield



(b) Effect of Irrigation Regimes on Okra's Yield



(b) Interaction of Irrigation Regimes and Organic Fertilizer Application on Okra Yield

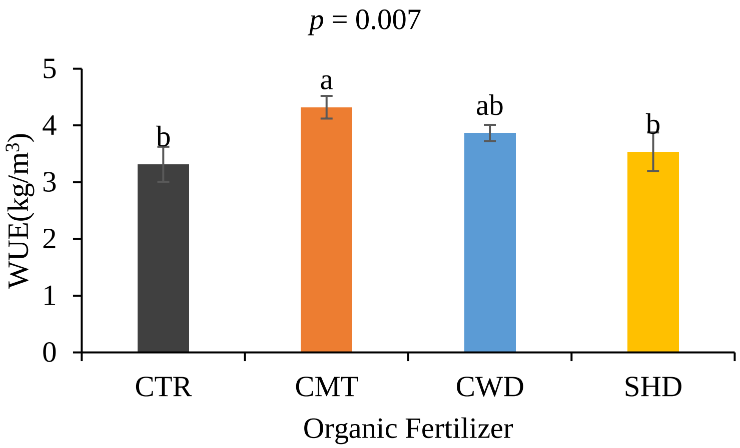
Figure 4.25: Effect of Irrigation Regimes, Organic Fertilizers and Interactions on Yield of Okra

Means that do not share the same letter are significantly different* CTR – Control, CPT – Compost, CWD – Cow dung, and SHD – Sheep dropping

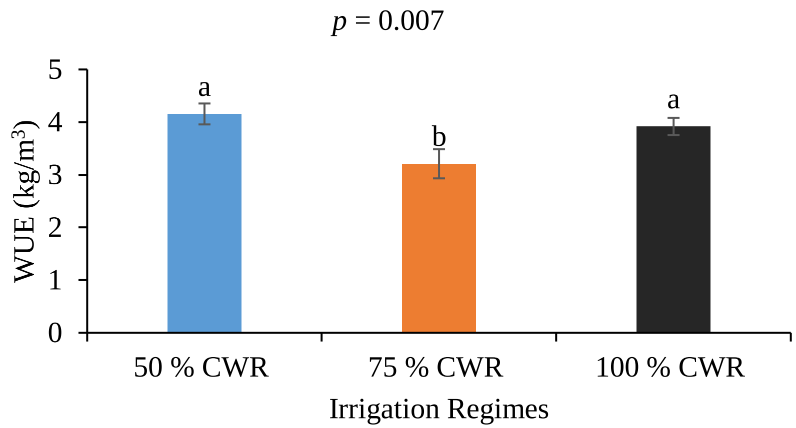
4.15 Crop Water Use Efficiency for Okra

The average water used for 50 %, 75 %, and 100 % CWR irrigation regimes for okra during the dry season experiment were 277.5 L, 400.4 L, and 540 L respectively. The mean crop water use efficiency of okra ranged from 3.31 to 4.32 kg/m^3, with the least recorded in the control plants while the highest was recorded in the plant treated with compost fertilizer. ANOVA results showed significant difference (p = 0.007) from the effect of organic soil amendment application on crop water use efficiency of okra (Figure 4.26a). Similar result was recorded with significant difference at (p = 0.001) in the effect of irrigation regime on crop water use efficiency of okra. The highest crop water use efficiency of 4.15 kg/m^3 was recorded in 50 % CWR, 3.92 kg/m^3 at 100% CWR, and 3.21 kg/m^3 at 75 % CWR (Figure 4.26b). There was significant difference (p = 0.029) recorded in the interaction of irrigation regimes and organic soil amendment on WUE of okra. At 100 % CWR, higher WUE was recorded in the pot treated with compost with 4.45 kg/m^3. Pot treated with cow dung recorded the highest value of 4.01 kg/m^3 at 75 % CWR, while at 50 % CWR, the plants treated with compost recorded the highest WUE of 4.61 kg/m^3 (Figure 4.26c).

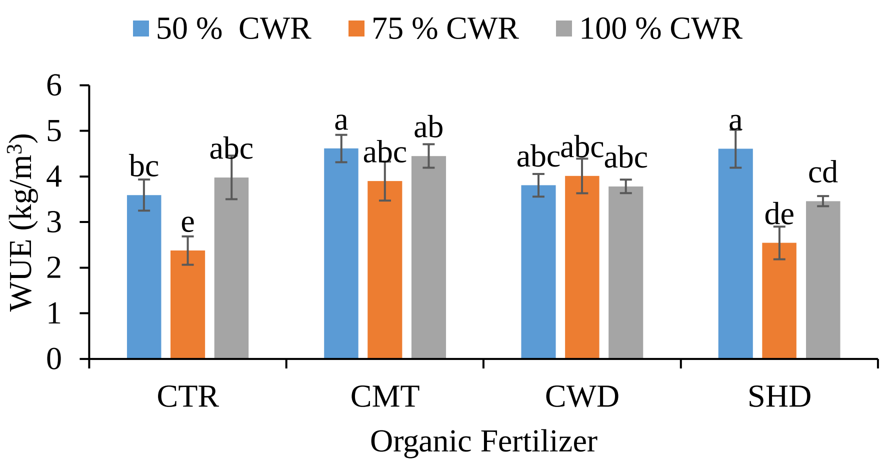
Limited precipitation and water scarcity is a major factor that restrict WUE as there is no water resources to replenish deeper soil water (Wang *et al.*, 2020). Application of organic fertilizers can effectively improve the instantaneous water use efficiency of crops and can have more significant effect if application continues over the years (Ye *et al.*, 2020). The results agreed with the findings of Wang *et al.* (2020) that reported increase in WUE of maize as a result of additional organic manure input



(a) **Effect of Organic Fertilizer on Water Use Efficiency of Okra**



(b) Effect of Organic Fertilizer on WUE of Okra



(c) Interaction of Irrigation Regimes and Organic Fertilizer Application on WUE of Okra

Figure 4.26: Effect of Organic Fertilizer, Irrigation Regimes and Interaction on Okra's WUE

Means that do not share the same letter are significantly different

CTR- Control, CPT - Compost CWD - Cow dung and SHD - Sheep droppings

4.16 Effect of Organic Fertilizers on the Physical and Chemical Properties of the Soil used for the Experiments

4.16.1 Soil pH

The pH of the soil in the treatment pots was measured after harvesting the crops. From the ANOVA results, there was significant difference ($p < 0.0001$) in the effect of organic soil amendment at the end of the experimental period in the rainy season. The mean pH of the soil at the end of the rainy season experiment ranged from 5.96 recorded in the soil with no organic amendment to 7.43 recorded in the soil amended with cow dung (Figure 4.27). Similarly, during the dry season experiment there was significant difference ($p < 0.0001$) recorded and the mean pH during this season ranged from 6.30 recorded in the soil with no organic amendment to 7.71 recorded in the soil amended with sheep droppings (Figure 4.27). There was no significant difference ($p > 0.05$) in the effect of irrigation regimes and the interaction on soil pH value. Soil pH also referred to as soil reaction, it is a characteristic that is important in terms of nutrient availability and plant growth. Amending acidic soils by the addition of agricultural lime, increases pH and ensure plant growth at their maximum provided that other requirement and nutrient are available as indicated by Agegnehu *et al.* (2016). At the end of both seasons, there was an increase in the pH value for all the treatments, as the rainy season soil had an initial soil pH of 6.18 and recorded increase to the highest pH value of 7.43 which was recorded in the cow dung amended soil, the second highest pH 6.99 was recorded in the sheep droppings amended soil whilst a reduction of 5.97 was recorded in the control soil. At the end of the dry season the soil pH recorded increased from the initial value of 6.18 to the highest pH value of 7.71 recorded in the soil amended with sheep droppings, and the second highest of 7.23 was recorded in the soil amended with cow dung. The results agreed with a study by Reis *et al.* (2014) which recorded an increase in soil pH value with organic compost application. The results obtained also conformed with the study of Agegnehu *et al.* (2016) that recorded significant increase in soil pH in two locations as a result of organic amendment in soil.

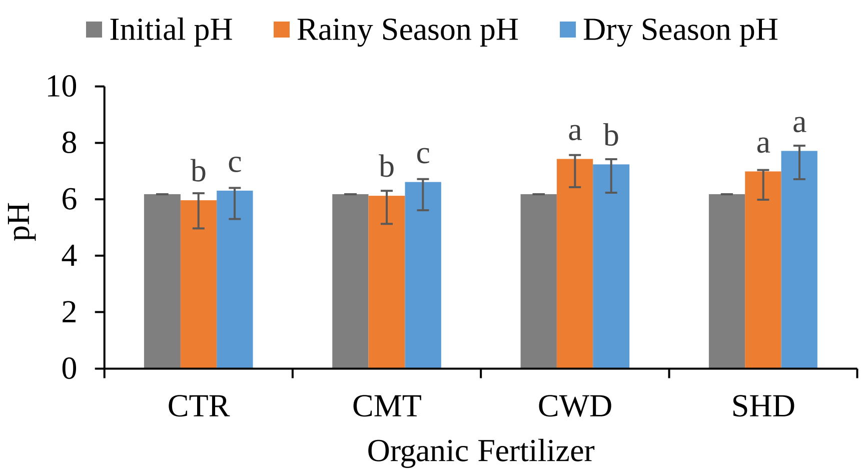


Figure 4.27: Effect of Organic Fertilizer Application on Soil pH after Harvesting

Bar = SEM (Standard Error of Means), *Means that do not share a letter are significantly different* CTR – Control, CPT – Compost, CWD – Cow dung, and SHD – Sheep droppings

4.16.2 Dry Bulk Density of Soil

The dry bulk density of the soil was calculated after harvesting the crops and from the ANOVA results, there was significant difference ($p = 0.0002$) in the effect of organic soil amendment. The mean bulk density of the soil ranged from 1.03 g/cm^3 recorded in the soil amended with compost to 1.23 g/cm^3 recorded in the control soil. Similarly, during the rainy season, dry bulk density ranged from 0.93 g/cm^3 recorded in the soil amended with cow dung to 1.16 g/cm^3 recorded in the soil with no organic amendment (Figure 4.28). There was no significant difference ($p > 0.05$) in the effect of irrigation regimes and on the interaction of both on soil bulk density. At the end of both seasons, there was decrease across all the treatments. Bulk density is a main driving force of soil physical properties, it reflects soil structural support and aeration (Celik *et al.*, 2010). The decreased bulk density of the soil after the application of organic soil amendment material can be attributed to the increased organic matter as a result of the organic fertilizer application. The outcome from the study corresponds to Vengadaramna and Jashothan (2011) conclusion, who reported a reduction in bulk density as a result of cow dung and compost incorporated in the soil. Zhao *et al.* (2019) similarly recorded a decreased dry bulk density in soil after treating the soil with different organic materials namely wheat husk and wheat straw.

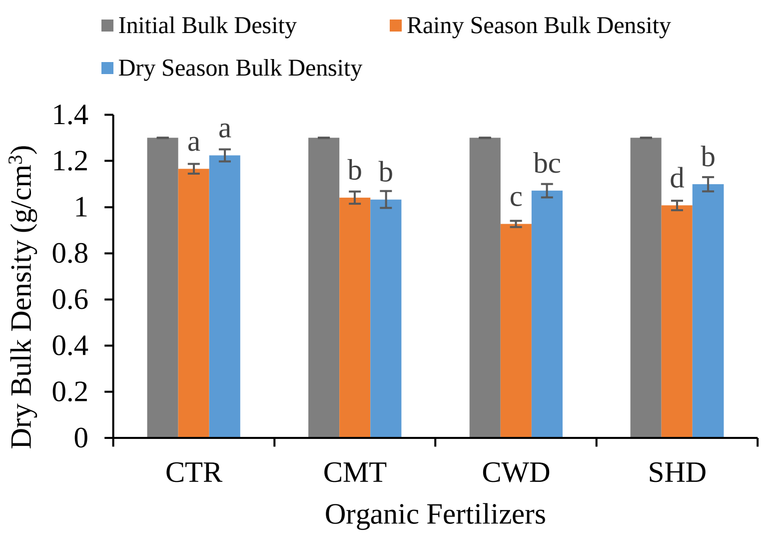


Figure 4.28: Effect of Organic Fertilizer Application on Soil Dry Bulk Density

Means that do not share a letter are significantly different* Bar = SEM (Standard Error of Means), CTR – Control, CPT – Compost, CWD – Cow dung, and SHD – Sheep droppings

4.16.3 Soil Electrical Conductivity

Soil electrical conductivity from the ANOVA results recorded significant difference ($p < 0.001$) in the effect of organic soil amendment material. Soil electrical conductivity was found to range from 50.4 µS/cm recorded in the soil amended with the compost to 173.0 µS/cm recorded in the soil amended with cow dung. Similarly, during the rainy season, the soil electrical conductivity ranged between 89.2 µS/cm recorded in the control soil to 247 µS/cm recorded in the soil amended with sheep droppings (Figure 4.29). The increased soil EC values due to application of organic fertilizer, might be attributed to the amount of dissolved salt in the manures as reported by Ozlu and Kumar (2018). The source of salts in the manure are feed additives and the results from this study are in line with Reis *et al.* (2014), who reported increase in soil EC due to compost application in soils . Similarly, Ozlu and Kumar (2018) also reported an increased soil EC with application of organic fertilizer.

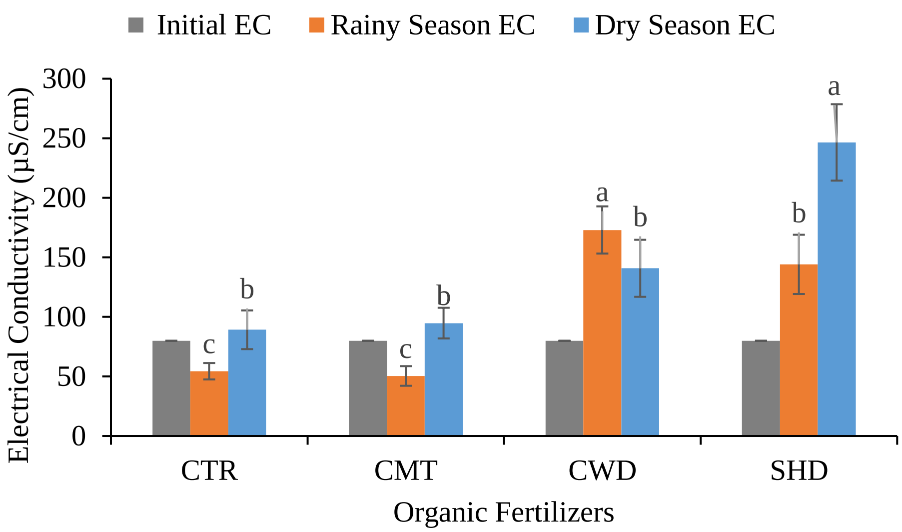


Figure 4.29: Effect of Organic Fertilizer on the Electrical Conductivity of Soil

Means that do not share a letter are significantly different* Bar = SEM (Standard Error of Means), CTR – Control, CPT – Compost, CWD – Cow dung, and SHD – Sheep droppings

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This study has ventured into the world of sustainable agriculture by exploring the dynamic interplay between irrigation regimes and organic fertilizers in the context of vegetable production. the goal intended is to unleash the potential for boosting crop yields, conserving valuable water resources, and encouraging environmentally friendly farming practices. In the following sections we are outline important facts, insights, and implications garnered from the study.

5.1 Conclusions

The study revealed that:

- Organic soil amendments are effective and can be used for vegetable production depending on availability, the variation depends basically on the level of the organic carbon present and the plant nutritional requirement.
- Soil amended with sheep droppings was effective in producing more lettuce leaves and high yield of lettuce of about 19 t/ha.
- Soils amended with sheep droppings produced more and gave a higher yield of beetroots compared to the other organic materials.
- Beetroots when treated with organic compost tends to have more weight than the other compared organic materials.
- Okra treated with compost fertilizer and cow dung produced higher yield and qualities in terms of length, diameter and weight of fruit than the other compared organic materials.
- Application of Organic fertilizers can be used to increases the soil organic carbon, soil pH, EC and thereby reduces bulk density, increases soil aeration that improve root developments of crops.

- Organic materials improve the ability of the soil to conserve moisture, and increase water use efficiency.
- Vegetables watered at 100 % CWR irrigation regime perform better in yield than other compared irrigation regimes.

5.2 Recommendations

The following recommendation is given considering the study's findings:

- Decomposed organic materials, especially animal manures can be applied to vegetables at 60 tons/ha to prevent crop burning.
- Organic materials should be applied seasonally for sustainability and for more improvements in the soil properties.
- Dry season lettuce should be planted in a controlled environment for higher yield.

It is recommended that for future study the experiment can be focused on sone other vegetable crop, each vegetable crop may have different irrigation and organic fertilizer requirements. In-depth research on various crops can provide significant information for customized management practices. Future studies can also study to bridge the gap between controlled experiments and practical agriculture, validate the controlled environment findings in real-world field circumstances.

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