UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECTS OF IRRIGATION METHOD AND SOIL AMENDMENT PRACTICES ON GROWTH AND YIELD OF OKRA (*ABELMOSCHUS ESCULENTUS*) IN NORTHERN REGION OF GHANA

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BY

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A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

2025

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.

Niyonkuru Pascal		28/03/ 2025
(UIN: 22001625)	Signature	Date

Declaration by Supervisor

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

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ABSTRACT

Achieving equitable, sustainable and healthy food systems is essential to meeting global development goals. Improving the agricultural industry is one of the best strategies for eradicating extreme poverty. The main objective of this research was to assess the effects of irrigation methods and soil amendment practices on the yield and growth of okra in Northern Region of Ghana. The experiment was started on 16th May to 01st July 2024 at the West African Centre for Water, Irrigation and Sustainable Agriculture, University for Development Studies (WACWISA - UDS) Experimental Field in Nyankpala. A 2 x 4 factorial experimental set up in a split-plot design with three (3) replications was used. Supplementary irrigation (SI) by drip irrigation system and rainfed agriculture were the main plots, whereas soil amendment practices (Cow dung, NPK, combination of Cow dung + NPK and zero Cow dung + NPK) were sub-plots. The field area was 8 m × 10.2 m. Results showed that the soil pH, EC, phosphorus and nitrogen decreased after all treatments were administered. The interaction of Cc0NPK*S had the best plant growth parameters, including leaf area index (mean was 2.33), plant height (65.1 cm); stem girth (1.97 cm), number of leaves per plant (28.67) and chlorophyll (55.4) content. The best yield was in the interactions, CcNPK*S (41.4 kg/ha) and Cc0NPK*S (39.9 kg/ha). The interaction of CcNPK*R (42.48 kg/m^3) had the highest crop water productivity, thereby making more productive use of water. The supplementary irrigation method had the best-performing leaf area index, plant height, stem girth, number of leaves per plant, chlorophyll content and yield. However, the rainfed method of irrigation used water more productively. The best yield (30.85 t/ha), growth parameters, and crop water productivity (30.89 Kg/m^3) were obtained from the CcNPK*R soil amendment practice. This practice is recommended for farmers to improve their yield while using water more efficiently.

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DEDICATION

I dedicate this dissertation to my God almighty Father in heaven, my beloved family and my colleagues.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
AWC	Available Water Content
CD	Cow Dung
CSIR	Council for Science and Industrial Research
CWP	Crop Water Productivity
CWR	Crop Water Requirement
E_C	Electrical Conductivity
ETc	Evapotranspiration
ETo	Crop Coefficient
FAO	Food and agricultural organization
FC	Field Capacity
FUE	Fertilizer Use Efficiency
IRg	Gross Irrigation Requirement
Irn	Net Irrigation Requirement
K	Potassium
Kc	Crop Factor
MoFA	Ministry of Food and Agriculture
N	Nitrogen
P	Phosphorus
PWP	Perment Wilting Point
RF	Rainfed
SARI	Savanna Agricultural Reasearch Institute
SI	Supplemental Irrigation

WAP	Week After Planting
WP	Water Productivity
WUE	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background

The primary factor in the rise of sedentary human civilization has been agriculture, which produces enough surplus food to support urban living through the farming of domesticated species (Barker, 2006). Ghanaians find the majority of their jobs in the agriculture sector, which is dominated by smallholder farmers (Darfour *et al.,* 2016). The agroecology's diversity presents challenges for the agriculture sector, as do limitations in terms of technical development, food insecurity, management of natural resources, and human resource and managerial abilities (Sjah *et al.,* 2020). Climate change and food insecurity are closely linked since weather factors like high temperatures and precipitation directly affect agricultural productivity. The final outcome is less food available as pests and illnesses proliferate and rainfall patterns become less predictable (Sanlier *et al.,* 2018).

Rainfall has historically been a major factor in Ghanaian agricultural production, and improper use of pesticides and fertilizers has occurred in part because of a lack of agriculture extension services (Fagariba *et al.,* 2018). All things considered, prolonged and intense heat waves, erratic rainy seasons, and delayed rainy season onsets have an impact on farming systems. In the sub-Saharan region, crop productivity suffers greatly by the availability of water (Khan *et al.,* 2015). The region's commercial vegetable production needs to continuously enhance its irrigation techniques due to the growing rivalry for water among industrial, urban, and agricultural users (Odo, 2017). Water is the key limiting element for crop diversification and productivity. Over 80% of available water resources are being used for irrigation in agriculture (Tan *et al.,* 2009).

To deal with the water crisis, it is necessary to adopt water-saving agriculture countermeasures as efficient use of irrigation water is becoming increasingly important.

At the moment of germination to the whole growth stage, irrigation is essential to plant life and has an impact on both the quantity and quality of the crop produced (Kumar, 2020). Efficient irrigation techniques are therefore needed to maximize the efficient use of water and applied nutrients (Sedara *et al.,* 2021). Drip irrigation is the most efficient method of water application for crop growth. It is an advanced method of irrigation that helps to achieve a considerable amount of water saving with high water use efficiency (WUE) compared to surface irrigation, which has relatively low irrigation efficiency because of field-level water distribution losses (Fan *et al.,* 2020). When it comes to surface irrigation, soil is thought of as a storage tank. While the primary goal of irrigation is to restore soil water, drip irrigation allows for the application of a modest amount of water based on plant evapotranspiration (Sezen *et al*., 2006). When the precipitation is insufficient to provide moisture content for healthy plant growth, supplemental irrigation (SI) is the practice of applying small amounts of water to essentially rainfed crops in an effort to boost and stabilize yields. The revenue of farmers is greatly increased by SI, which produces greater and more consistent harvests as well as noticeably higher agricultural water productivity (Dahlin *et al*., 2019).

Beyond seasonal rainfall volumes and its uneven distribution, SI helps meet crop water needs. SI adapts the crop schedule to avoid extreme weather conditions in response to global warming. With cheap/low energy, optimal water application amount and timing, suitable fertilization, and crop variety, SI is meant to be a straightforward but incredibly successful solution for farmers. It will enable them to plant and manage crops at the best time while taking climate variability under consideration (Webber *et al*., 2014).It is used as a precautionary measure when there are frequent dry spells and insufficient precipitation to support healthy crop development. Sprinklers, drip irrigation, or normal surface irrigation can all be used for this.

Okra thrives in drought situations because it is a drought-resistant tropical and subtropical crop. Okra has a large number of potentials for improving livelihoods in urban and rural regions. The applications of fertilizers help to enhance plant growth by providing amendments to the soil via various macro-and micronutrients (Dhaliwal *et al.,* 2019). Organic fertilizer was applied at the rate of 40 t/ha whilst inorganic (NPK) was applied at a rate of 250 kg/ha (Mahmoud *et al.,* 2017). The incorporation of organic fertilizers in okra cultivation can enhance plant growth, yield, and nutrient content, making it a sustainable approach for okra production. Organic fertilizer is incorporated into the soil one week before transplanting the seedlings to enable decomposition of the organic matter whereas the inorganic fertilizer was applied one week after transplanting of the okra seedlings (Moyin-Jesu *et al.,* 2010).The application of organic fertilizers improves water holding capacity, and availability of nutrients, maintains the C: N ratio increases the macro/micronutrient content of soil, and crop yields, size, flavor, aroma, and quality (Asomah *et al.,* 2021). Crops treated with organic fertilizers yield 20% less than those treated with inorganic fertilizers, despite these enormous advantages (Verma *et al.,* 2020). Because of these restrictions, it is necessary to use a combination of inorganic and organic fertilizers. It has been demonstrated that integrated nutrient management of fertilizers organic or inorganic is an effective strategy to maintain yields, enhance the physical and chemical characteristics of the soil, and increase crop nutrient absorption (Selim, 2020).

1.2 Problem Statement and Justification

The majority of jobs in Ghana are in the agriculture industry, which is dominated by smallholder farmers. Climate change and degraded soil health are the primary obstacles to Africa's agricultural development (Sissoko *et al.,* 2011). In the majority of countries, low crop productivity is caused by poor soil health. It manifests in the loss of soil structure, permeability, and nutrients. The most significant factors contributing to soil degradation are nutrient leaching, erosion, and poor cultural practices (Chamberlin, 2008). The impacts of climate change and land degradation are decreasing the volume of water needed in Ghana for food production. The water needed for food production is being affected by the growing demand for water and the drought, which directly affects food production around the world.

Climate change presents a number of obstacles to agriculture, including higher temperatures, droughts, and a shortage of water, but it also offers chances of increasing crop yields in dry and semiarid regions (Misra, 2014). Aside In addition to weather-related challenges agricultural producers are facing increasing pressure to raise food production while maintaining water and minimizing nutrient loss due to population growth. However, the sustainability of water resources is threatened by uncertainties related to climate change and worries about water quantity and quality.

Implementing water-saving agricultural remedies is essential to dealing with the water trouble while efficient irrigation water application is becoming more and more important. Considering irrigated agricultural production makes up almost 40% of the world's total agricultural output, it is critically important to global food security (Mahato, 2014). Among various factors affecting crop growth, water, and fertilizer are the leading components that can be adjusted and controlled. In certain agricultural production, to obtain greater yields, exceeding water use has become standard practice, and these habits not only leach nutrients from surface soil to deep soil, reducing water and nutrient use capability but may also cause soil environmental degradation (Yengoh *et al.,* 2010). Unsecured nutrients and other contaminants from commercial fertilizers and animal manures can have detrimental effects on human health as well as other plant and animal species. Algal blooms that cause surface waters to lose oxygen, pathogens and nitrates in drinking water, and the discharge of gasses and fragrances into the atmosphere are a few of these effects (Payne, 2010). Runoff and soil erosion allow nutrients from fertilizers and manure to find their way into lakes and streams. More plant-available nitrogen (N) and phosphorus (P) often flow with water when soil N and P amounts increases. Fields with high soil N and P content may discharge runoff water that is extremely rich in these dissolved nutrients, raising the likelihood of contaminating wetlands, lakes, and streams (Fagariba *et al.,* 2018).

The quantity and quality of soil and water that are altered by irrigation, as well as the ensuing consequences on the natural and social conditions in river basins and downstream of an irrigation project, are all considered aspects of irrigation's environmental effects (Mylonas *et al.,* 2020). In the majority of countries, low crop productivity is caused by poor soil health. It shows up as a loss of nutrients, permeability, and soil structure. The most significant elements contributing to soil degradation are nutrient leaching, erosion, and poor cultural practices (Lal, 2015). Okra faming in Ghana is not without its challenges. One of the main challenges is unpredictable weather patterns, particularly rainfall, pests and diseases. Droughts or excessive rainfall can adversely affect okra plants and reduce yield. To mitigate this, farmers can invest in irrigation infrastructure and water conservation techniques. Warm-season crops like okra do well in tropical and subtropical climates. For optimum development and growth, a minimum temperature of 20°C is necessary. Okra farming in Ghana grows best in regions with a long growing season and consistent temperatures between 25°C and 35°C. Okra requires loamy or sandy soils that drain well and have a pH between 6.0 and 6.8. Making ensuring the soil has a high organic matter content and sufficient ability of holding moisture is essential (Benchasri, 2012). This can be achieved through the addition of compost or well-rotted manure before planting. Proper soil preparation is crucial to create a favorable environment for okra plants to establish strong root systems and absorb essential nutrients.

1.3 Research Question

1. How do supplementary irrigation and soil amendment practices affect the growth parameters and yield of Okra?

2. How do supplementary irrigation and soil amendment practices affect the water use efficiency of Okra?

3. How do supplementary irrigation and soil amendment practices affect soil moisture?

1.4 Study Objectives

1.4.1 Main Objectives

The main objective of this research was to determine the effects of irrigation method and soil amendment practices on the growth and yield of okra (Abelmoschus Esculentus) in Northern Region of Ghana.

1.4.2 Specific Objectives

The specific objectives of the study were to:

1. Evaluate the irrigation method and amendment soil practices effect on soil chemical properties.
2. Evaluate the irrigation method and amendment soil practices effect on the growth and yield parameters of okra.
3. Evaluate the irrigation method and amendment soil practices effect on crop water productivity of okra.

1.5 Structure of the Thesis

The structure of thesis is structured in five (5) main chapter. Chapter One contained introduction, background, problem statement and justification, research question and main objective of research. Second chapter is description of okra, benefits of okra farming, okra cultivation, and climate and soil requirements for okra farming, preparation of the land for okra cultivation. Sowing okra seeds, irrigation and fertilizing okra plants, controlling pests and diseases in okra farming, harvesting okra pods, effects of irrigation and soil amendment practices on growth and yield of okra and crop water productivity of okra. Chapter three describes the methods and materials including study are, experiment design, agricultural practices, irrigation methods, soil properties and growth and yield parameter. Chapter four the result and discussion for growth and yield parameter while the last chapter provides conclusions and recommendation for the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Description of Okra Plant

Lady's fingers or gumbo are common names for okra (Abelmoschus esculentus) in the country that speak English. It belongs to the mallow family of flowering plants, which also includes hibiscus and cotton (Singh *et al*., 2014). Okro is a West African origin. The vegetable okra is referred to as "Okro" or "Okworo" in the Igbo language of South Eastern Nigeria, where the word "Okro" originated. When British colonists arrived in Southern Nigeria and learned of its many health benefits, the term adulteration was coined (Sylver-Francis, 2022). The Igbo term "Okworo" was difficult for them to say, so they called it "Okro/Okra" instead. This helped the vegetable become more widely known in Europe and other warm climates throughout the world. It is appreciated for its nutritious, health-promoting green seed pods (Kumari *et al.,* 2021). It is cultivated for its immature pods, which are harvested and used in soups, salads, and other preparations. In many Asian and West African nations, including India and Pakistan, as well as in Nigeria and Ghana, it is the national vegetable. It is often eaten fried, grilled, or as a soup base.

By 1658, when its presence in Brazil was first mentioned the plant had been brought to the Americas by ships that operated in the Atlantic slave trade (Carney, 2010). In Suriname, it was further recorded in 1686. It's possible that in the early 1700s, okra was brought from Africa to southeast North America. It was grown as far north as Philadelphia by 1748. Thomas Jefferson observed that by 1781, it was well-established in Virginia (Lewis, 1948). It was commonplace throughout the Southern United States by 1800, and the first mention of different cultivars was in 1806.

Okra, or Abelmoschus esculentus (L) Moench, is a flowering plant native to tropical and sub-tropical Africa. It is a member of the Malvacea family of plants (Benchasri, 2012). It is one of the important crops cultivated in Ghana. It is a leading vegetable in the Ghana market on the basis of land area, production, and value. Okra is mainly cultivated for its 'pods' which are cooked and eaten in Ghana (Agbenorhevi *et al.,* 2020). In the way of vitamins, minerals, calories, and amino acids, okra is a rich source of the seeds, which also contain comparable amounts to those in soy beans and chicken eggs. Young fruits can be used as thickeners in soups or eaten raw.

2.2 Benefits of Okra Farming

Okra farming in Ghana offers numerous benefits for both farmers and consumers. Firstly, okra is a highly nutritious vegetable that is rich in fiber, vitamins, and minerals (Uwiringiyimana *et al.,* 2014). It is known to improve digestion, boost immunity, and promote healthy skin. By cultivating okra, farmers have the opportunity to contribute to the local food supply and provide nutritious produce for their communities. Additionally, okra farming can be a profitable venture for farmers. Due to its high demand both domestically and internationally, okra has the potential to generate a steady income for farmers (Sudha *et al.,* 2006). The export market for okra is particularly lucrative, with Ghana being a major supplier to countries in Europe and North America. This presents an excellent opportunity for farmers to tap into global markets and increase their earnings.

Moreover, okra farming is environmentally friendly. Okra plants have a natural ability to improve soil quality by fixing nitrogen and reducing the need for synthetic fertilizers (Choudhary *et al.,* 2015). This helps to preserve the ecosystem and minimize the negative impact of chemical inputs on the environment (Tan *et al.,* 2009). Furthermore, okra plants are relatively drought-tolerant, making them suitable for farming in regions with insufficient water resources.

The benefits of okra farming in Ghana are manifold (Adaku, 2020), ranging from improved nutrition and economic opportunities for farmers to sustainable agricultural practices that protect the environment.

2.3 Okra Cultivation

2.3.1 Climate and Soil Requirements for Okra Farming

Climate change and soil poverty are the main problems of agriculture development in Africa (Thornton *et al.,* 2008). In many countries, low crop productivity is caused by poor soil health. It creates a movement that is specifically for soil permeability, soil structure, and nutrient loss (West *et al.,* 2004). The most significant contributing elements to soil degradation, according to the causes, are nutrient leaching, erosion, and improper cultural practices (Lal, 2015). In tropical and subtropical regions, okra is a crop that tolerates varying climates. Okra growing requires a temperature of 20 0C to mature. Okra cultivation is most successful in Ghana in the 25–35°C temperature range. When it comes to soil needs, okra favors sandy loamy soil that has a pH range of 6.0 to 6.8 and high drainage. Making ensuring the soil has a significant amount of organic matter and a sufficient ability to retain moisture is crucial (Benchasri, 2012). This can be achieved through the addition of compost or well-rotted manure before planting. Proper soil preparation is crucial to create a favorable environment for okra plants to establish strong root systems and absorb essential nutrients.

2.3.2 Preparing the Land for Okra Cultivation

Before planting okra seeds, it is important to prepare the land properly (Nkongho *et al.,* 2022). The first step is to clear the field of any weeds, rocks, or debris that may hinder the growth of okra plants. This can be done manually or with the help of machinery, depending on the size of the land. Once the field is cleared, farmers should plow or till the soil to a depth of 20-25 centimeters (8-10 inches). This helps to loosen the soil and improve its structure, allowing for better root penetration and water infiltration (Mohammadi *et al.,* 2011). After tilling, the soil should be leveled and any large clods of soil should be broken down to create a smooth surface.

After leveling, farmers should incorporate with organic manure such as cow dung goat droppings, compost sewage sludge and food processing wastes for as soil nutrient. This helps can increase the soil health and moisture retention. The compost matter can be spread evenly across the land and incorporated into the soil using a tractor or manual labor.

2.3.3 Sowing Okra Seeds

Farmers can choose to sow the seeds through in the soil or start them by nursery and transplant them later. Both methods have their advantages and depend on the specific circumstances of the farmer. When sowing directly in the field, farmers should create furrows or ridges and sow 2 to 3 seeds for each sowing spot about 2 to 3 cm deep keeping intervals of 30cm and 1m between intra-row spacing (Landis *et al.,* 2008). Cover the seeds with the soil around them. Regardless of the method chosen, it is important to water the seeds immediately after sowing to ensure proper germination. The soil should be kept moist but not waterlogged throughout the germination period.

2.3.4 Irrigation and Fertilizing Okra Plants

Okra plants require regular watering to ensure healthy growth and development. Adequate moisture is particularly crucial during flowering and fruiting stages. In Ghana, where rainfall patterns can be unpredictable, farmers often rely on irrigation to supplement water requirements (Fagariba *et al.,* 2018).

Drip irrigation is an efficient method for providing water to okra plants (Adejumo *et al.,* 2019). The advantage of using drip line it helps the crop for receiving water through the root zone, to avoid the runoff and to reduce the loss of water caused by evaporation. Reduces water loss from evaporation and runoff by delivering water directly to the root zone. By irrigating at the base of the plants, farmers can also reduce the risk of foliar diseases caused by wet foliage (Embioweil *et al.,* 2017)

In addition to water, okra plants also require balanced nutrition to thrive. Fertilizers can be applied during different stages of growth to meet the nutrient requirements of the plants (Aboyeji *et al.,* 2021). Before planting, farmers can incorporate a basal dose of organic or inorganic fertilizers into the soil. This provides a good foundation of nutrients for the plants. During the growing season, farmers can apply side dressings of nitrogen-rich fertilizers to promote vigorous growth and fruiting (Wang *et al.,* 2019). This can be done in two or three split applications, starting when the plants are about 30 centimeters (12 inches) tall. Farmers should follow the recommended rates and timing specified for the specific fertilizer they are using.

The adequate water for okra irrigation varies from mm 380 mm to 500 mm but it depending on the climate and the growing season length. The response to water supply increases with the development of the crop (Chen *et al.,* 2010). During the slow development in the vegetative period, the crop yield is little affected by water deficit. Once rapid growth during the yield formation period is reached, the yield depressing effect of limited water supply becomes increasingly pronounced until the end of the growing period (Xin, 2022).

2.3.5 Controlling Pests and Diseases in Okra Farming

Like any crop, okra is susceptible to various pests and diseases that can reduce yield and quality (Mohankumar *et al.,* 2016). Aphids, spider mites, whiteflies and fruit borers are the common pest diseases which was affect okra plants. Powdery mildew us diseases, bacterial leaf spot, and fusarium wilt can also pose significant challenges to okra farmers. To control pests, farmers can employ both cultural and chemical methods. Culturally, farmers can practice crop rotation, intercropping, and the use of resistant varieties to minimize pest populations (Altieri, 2019). Additionally, regular monitoring of the crop is essential to detect pests early and take appropriate action. Chemical control measures, such as the use of insecticides and fungicides, may be necessary for severe infestations or disease outbreaks. It is important to follow the recommended dosage and application guidelines to ensure effective control while minimizing negative impacts on the environment.

2.3.6 Harvesting Okra Pods

Okra fruit are ready for harvest approximately 50-60 days after sowing, depending on the variety and growing conditions (Begum *et al.,* 2022). Harvesting should be done when the pods are young and tender before they become tough and fibrous. This ensures the best flavor and quality of the okra.

To harvest okra pods, farmers should use a sharp knife or pruners to cut the pods from the plant. It is important to handle the pods carefully to avoid damage. Harvesting should be done regularly, every 2-3 days, as the pods mature quickly. Leaving mature pods on the plant for too long can affect the fruit and pods property of subsequent harvests.

2.4 Practices of Amended Soil and Watering Effects on Growth and Yield of Okra

Irrigation is the supply of water to crops by artificial means. It is designed to permit the desired plant growth in arid regions (Fernández-Cirelli *et al.,* 2009). The growing of the crop mostly it depending on irrigation and fertilizes for to maintain the plant production and vegetable for helping the addition of different nutrient in the soil. Soils in agriculture are of great importance, they can be explained differently according to their uses, and they consist of inorganic particles and organic matter (Mohammadi *et al.,* 2011). 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 productive (Gianquinto *et al.,* 2013). Soil fertility and nutrient management are one of the important factors that have a direct impact on crop yield and quality. Plants having 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 (Brust *et al.,* 2019). The process of collecting soil samples and conducting soil testing at the start of each planting season can assist in providing an ongoing report on the organic matter material, pH, electrical conductivity, cation exchange capacity, and levels of micro and macronutrients in the soil. The three essential nutrients that plants needed are nitrogen, phosphorus, and potassium. These nutrients are typically required in high concentrations (Malvi *et al.,* 2011). 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 their properties must be understood to use them to their best advantage (Timsina *et al.,* 2018). While selecting the best fertilizer for the plant, other considerations to take into account include the crop's needs and the consequences on the environment.

For maximum growth and yield, okra plants require N, P, and K. The requirements for fertilizer may vary depending on the type, soil, and other variables (Adekiya *et al.,* 2020). The proper amount and timing of these nutrients must be provided. Okra plants with organic manures applied either alone or combined with inorganic fertilizers showed a significant increase in plant height, branch measure, leaf measure, fruit measure, and average fruit output (SHARMA *et al.,* 2016). The combination of organic and inorganic fertilizers was shown to be the most effective in promoting okra production. Additionally, the use of slow-release fertilizer-manure blocks containing fertilizes and organic manures improved the quality and quantity of okra production, with interaction showing significantly improved the pods yield per plant, fruit length, stem girth, and pods width on the plant (Shahbaz et al., 2014).

2.5 Crop Water Productivity of Okra

Okra's resilient nature, nutritional fiber content, and unique seed protein balance of lysine and tryptophan amino acids have earned it the moniker "a perfect villager's vegetable" (Idowu *et al.,* 2022). Okra fruits can be used as a blood volume expander or blood plasma replacement after being prepared in a mucilaginous preparation. They are also a high source of iron. Crop Water Production (CWP) is defined as a measure of the economic or biophysical gain from the use of a unit of water consumed in crop production (Blatchford *et al.,* 2018). Net primary productivity, another name for crop productivity (or yield), is the total amount of plant produced in a given year. Depending on the plant's intended use, crop productivity can be divided into different tissue types, such as grains, leaves, stems, etc (Niklas *et al.,* 2002). The selection of water-efficient, adapted crops, the mitigation of wasteful water loss, and the maintenance of optimal agronomic conditions for agricultural production are the primary avenues for increasing crop water productivity. Agronomic practices for healthy, rapidly growing crops typically prioritize transpiration and productive water losses over unproductive ones (Eid *et al.,* 2019). The production of rainfed or irrigated crops must be increased in order to improve agricultural water productivity. Removing or reducing water stress alone won't boost crop water productivity; other stresses, such as nutrient shortages, weeds, and diseases, must also be reduced or eliminated (Oluwasemire *et al.,* 2018), water management should go hand in hand with nutrient management, soil management and pest management.

A key idea in crop water productivity is that removing one source of stress such as water deficiency or weed growth will only lead to a greater yield of crops when other stresses, such as nutrient deficiencies, diseases, and weeds, are also reduced or eliminated (Sharma *et al.,* 2015). An irrigation system is considered efficient if its efficiency rating is more than 60%. The following equation was used to calculate the water use efficiency based on the data on the corresponding yield and volume of water applied (Badr *et al.,* 2012). According to agronomist's the volume of water used divided by the efficiency of that use per unit of crop yield (kg) produced after using season water lost by evapotranspiration (m^3). The yield that may be produced from a given amount of irrigation water is known as water use efficiency (WUE) (Blum, 2009). It is calculated as follows:

$IWP = \frac{Y}{ETc}$ ………………………………….... Equation 2.1

Where

IWP = Irrigation Water Productivity (kg ha mm^{-1})

Y = Yield in (kg ha^{-1}),

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

ETc = Water Used (mm).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

This research was carried out at the experimental field of the West African Centre for Water, Irrigation and Sustainable Agriculture, University for Development Studies (WACWISA-UDS) at Nyankpala Campus. Nyankpala is situated in the Northern Region of Ghana, 16 km west of Tamale. It is 200 meters above sea level and sits at latitude N 09º 25' and longitude W 0º 58'. A single, unimodal rainy season and roughly 1000–1200 mm of annual precipitation are characteristics of northern Ghana. A typical year's rainy season spans 140 to 190 days, with the highest precipitation occurring in August and September. The domestic and agricultural sectors find it challenging to secure water during the extremely dry months of November and May.

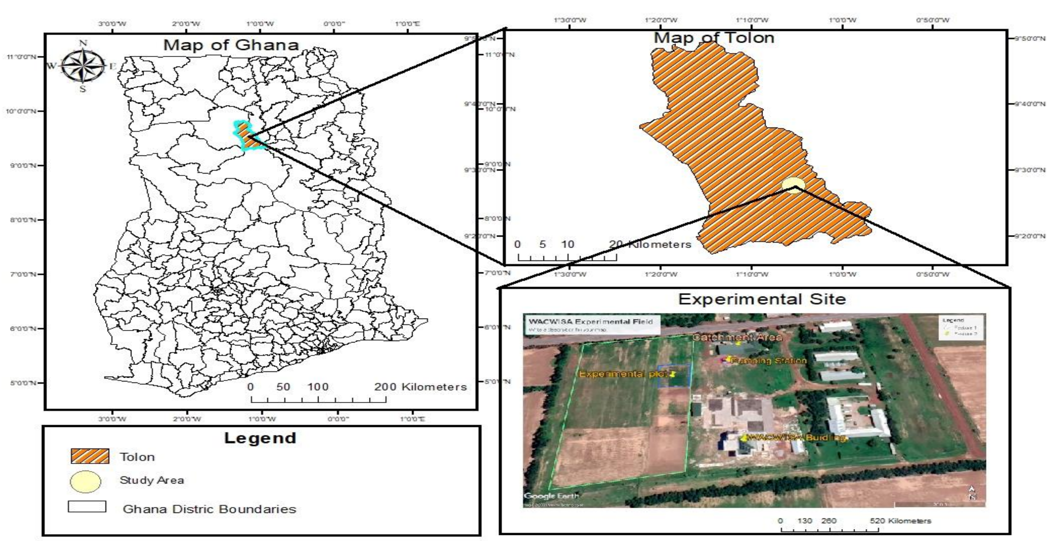


Figure 3.1: Map of Study Area

3.2 Experimental Design

The study implemented a split-plot design with three replications, using a 2 x 4 factorial design. water application thus 100% of Crop water requirement in the form of supplementary irrigation (SI) and rainfed method were the main plots, soil amendment (Cow dung, NPK (15:15:15), combination of Cow dung + NPK and zero application) were the subplots. In a field area of 8 m × 10.2 m, the eight treatments were replicated three times (Table 3.1 and Figure 3.2). The drip irrigation system was used under supplementary irrigation.

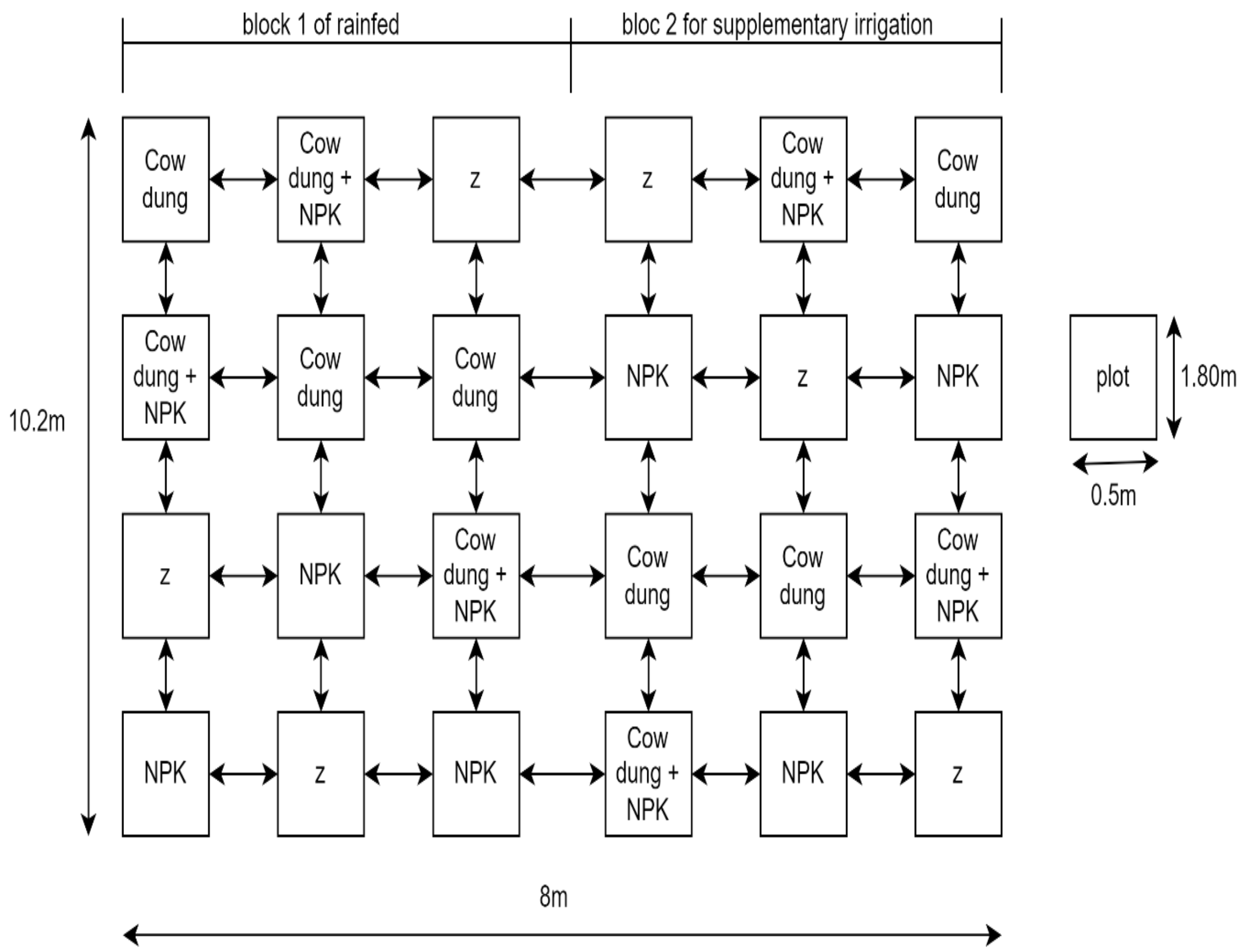


Figure 3.2: Layout of Experimental Design

Table 3.1: Experimental Treatments

Treatment No.	Variety	Water applications	Soil Amendment
T1	Okra Indiana	Rainfed	Zero amendment
T2	Okra Indiana	Rainfed	NPK
T3	Okra Indiana	Rainfed	C D
T4	Okra Indiana	Rainfed	C D + NPK
T5	Okra Indiana	Full Supplementary irrigation	Zero amendment
T6	Okra Indiana	Full Supplementary irrigation	NPK
T7	Okra Indiana	Full Supplementary irrigation	C D
T8	Okra Indiana	Full Supplementary irrigation	C D +NPK

To establish the plants, all plots were initially provided with the same quantity of water for the initial two (2) weeks after planting, ensuring that the soil reached its maximum water retention capacity.

3.2 Culture Practices

3.2.1 Preparing the field for Okra Cultivation

The experiment was carried out on a plot size of 10.2 m × 8m = 81.6 m^2. The land was ploughed and weeds and other plant debris removed using a manual hoe. Twenty-four (24) planting beds of size 1.8 m × 0.5 m were raised and leveled with a rake.

(a) (b)

Figure 3.3: (a) Land Preparation for Okra Sowing and (b) Sowing Okra Seeds

3.2.2 Application of Fertilizer

Applying organic fertilizer at a rate of 15 t/ha two weeks before to okra seed sowing and inorganic NPK (15:15:15) at a rate of 20 g per hill two weeks after okra seed sowing produced the expected outcomes.

3.2.3 Sowing Okra Seeds

Sowing of okra seeds was done directly at two seeds per hole on 16th May 2024, at a plant spacing of 30cm and 1m between plots with 10 seed/m^2 (Saichand *et al.,* 2024).

3.2.4 Irrigation Methods

The research used supplemental irrigation with a focused-on drip irrigation system. The daily water supply amounts were calculated with the CROPWAT 8.0 software, according to the water requirements (Kitila *et al*., 2014). Drip irrigation systems were used to measure and apply water volumes in practice.

3.3 Estimation of Crop Water Requirement

Table 3.2: Weather Parameter Average of Monthly

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	19.5	35.4	26	193	7.6	18.7	6.25
February	22.1	37.7	27	203	7.6	19.9	6.92
March	26.3	37.7	36	228	7.5	20.8	7.4
April	26.2	36.1	49	257	7.3	20.8	7.04
May	25	34.6	58	240	7.2	20.2	6.15
June	24.2	32.5	63	242	10.3	24.3	6.22
July	23.5	30.4	70	210	5.1	16.8	4.46
August	22.8	29.8	70	195	4.5	16.2	4.21
September	23.2	31.8	72	147	5.5	17.7	4.28
October	23.3	32.6	64	150	7.8	20.4	4.92
November	22.8	35.4	47	138	8.2	19.7	5.26
December	20.1	35.7	33	161	7.2	17.7	5.54
Average	**23.3**	**34.1**	**51**	**197**	**7.2**	**19.4**	**5.72**

Source: CSIR – SARI 2001 to 2023

The monthly average relative minimum and highest temperatures, humidity, wind speed, hours of sunshine, were uploaded in climate data section of CropWAT to generate the monthly average ETo (Table 3.2). Soil, plant and rain data as defined were entered into model to help calculate the amount of water needed for plant FAO (1984) the optimal required water was calculated by using the equation 3.1

$ETc = Kc \; x \; ETo$ …………………………………………... Equation 3.1

Where Kc is the crop coefficient and ETo is the reference evapotranspiration calculated in the Penman-Monteith model (FAO, 1974) using climate data (Table 3.2). In line with the reproductive stage, mid-season Kc values were determined to be the greatest.

Table 3.3: Estimated Amount of Water used by Okra using CROPWAT 8.0

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	2	Init	0.46	2.78	13.9	0.6	13.3
May	3	Init	0.46	2.81	30.9	1.4	29.5
Jun	1	Deve	0.51	3.21	32.1	1.5	30.5
Jun	2	Deve	0.79	5.07	50.7	1.7	49
Jun	3	Deve	1.11	6.37	63.7	1.9	61.9
Jul	1	Mid	1.25	6.21	62.1	2	60.1
Jul	2	Late	0.97	4.22	37.9	1.9	35.8
					291.4	**11**	**280.1**

3.4 Analysis of Physical and chemical soil property

The soil samples collected from the experimental field were analyzed at WACWISA laboratory for the following characteristics: pH, electrical conductivity (EC), nitrogen, phosphorus, and potassium; soil physical characteristics included field capacity, permanent wilting point, water content, bulk density, and texture.

3.4.1 Soil Property

Based on the particle size distribution as shown in (Table 3.4), the soil texture was categorized using the hydrometer method to examine the particle size distribution. The USDA textural triangle was then utilized to indicate the textural class.

Table 3.4: Soil Classification

Soil	Diameter (mm)
Gravel	> 2.0
Very coarse sand	< 2.0 to > 1.0
Medium sand	0.5 to > 0.25
Very fine sand	0.10 to > 0.05
Coarse silt	0.05 to > 0.02
Fine silt	0.02 to > 0.002
Coarse clay	0.002 to > 0.0002
Fine clay	≤0.0002

Source: USDA, 2016.

3.4.2 Density of Soil

Using the oven-dry method at 105 ºC, the dry bulk density (BD) of the soil was ascertained. The soil in the field was collected using a core sampler, which was pushed vertically into the experimental soil until it was filled with enough soil. The soil was then carefully extracted from the core without disturbing any soil particles, and it was placed straight into an oven to dry over a 24-hour period. Equation 3.2 was used to calculate the bulk density measured through weight the core sample both before and after drying. Root penetration issues were caused by more compacted soil, which is indicated by a higher bulk density value.

(a) (b)

Figure 3.4: (a) Results of Bulk density in Laboratory and (b) Pressure Plate Apparatus

Dry bulk density (g/cm^3) = $\frac{M2-M1}{V}$ ……………………….... Equation 3.2

Where:

M1 - Mass of empty core sampler (g),

M2 - Mass of core sampler + oven dried sediment (g),

V - Volume of core sampler ($\pi r^2 h$), cm^3

π - 3.14, r – radius of core sampler (cm), and h – height of core sampler (cm).

3.4.3 FC and PWP

A soil sample was taken on the experimental field with a soil core sampler, the sample was saturated in water 24 hours before putting in the pressure plate apparatus. For field capacity the saturated soil was extracted at 1/3 bars whereas 15 bars were considered for the permanent wilting point (PWP). After the sample was put it in dry oven for 24 hours at the 105 ^{0}C.

$FC = W2 - W1$ ………………………………………. Equation 3.3

$PWP = W2 - W1$ ……………………………………...Equation 3.4

Where:

FC- Field Capacity, PWP: Permanent wilting point

W_2- Initial weight after leaving the pressure plate

W_1- Final weight after drying

3.4.4 Electrical Conductivity and pH in Soil

The Ec and pH in soil were tested using the pH and EC meter 12.5 grams of the soil in 175 milliliters of purified water suspended. The blend was thoroughly shaken and the pH and EC meter was dipped into it to determine the pH and EC respectively.

(a) (b)

Figure 3.5: (a) pH and EC Determination in Laboratory and (b) SPAD-502 plus Konica Minolta Chlorophyll

3.4.5 Nitrogen

The total amount of nitrogen that is available in includes digesting a soil sample in hot sulfuric acid with a catalyst to convert organic N to NH4 +, and then measuring the NH4 + concentration (Juo et al., 1978). The Bray-P solution method was utilized to determine phosphorus (P), whereas the Kjeldahl method was used to investigate the soil. The potassium (K) was measured using the flame photometer method.

3.4.6 Soil Moisture Data Collection

The soil moisture content under each treatment was measured using Campbell H2S hydro Sense II (CS658) moisture meter. Measurement was taken at depth of twenty centimeters by inserting the moisture sensor into the soil. Every day, both before and after irrigation, the soil's moisture content was measured.

3.5 Agronomic Parameters

3.5.1 Parameters of Growth

Three plants were chosen at random, tagged, and watched throughout the plant growth season in each plot. On these plants, all data were collected. Two-weekly intervals were used to measure the following growth parameters: plant height, number of leaves, number of branches, area of leaves, number of pods per plant, length and weight of pods, day till first blooming, and stem girth.

The following parameters are measured:

1. Days until first flower bud sight: The duration between seeding and the first flower bud sight was counted to record this.
2. Days to First Flower Opening: This was determined by calculating the interval between the date of sowing and the first flower opening.
3. Days to 50% flowering: This was calculated by keeping track of the number of days that passed between planting and the time at which half of the plant population flowered.
4. The number of leaves was ascertained through leaf counting.
5. A meter rule was used to measure the plant's height (in centimeters) from the base to the tip of the last leaf.
6. Counting the fruits harvested from each plot allowed us to calculate the number of fresh fruits per plot.
7. Using a Mettler weighing balance, the weight of each harvest of fresh fruit was calculated for each plot, and the total weight was recorded.
8. Each leaf's leaf area (LA) was computed using the equation that follows.

   $LA\ (m^2) = L \times W \times k\ (1)$ ……………………………... Equation 3.5

   Where, L =leaf length (m) W = leaf width (m). k= 0.62 for okra (Musa *et al.,* 2016)

   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 (Tunca *et al.,* 2018)

   $\text{Leaf Area Index} = \text{LA} \times \left(\frac{\text{leaves numbers}}{\textit{Area occupied by each plant}}\right)$ ………………. Equation 3.6

9. **Chlorophyll Content:** Using the Konica Minolta chlorophyll meter in conjunction with the SPAD-502, the weekly chlorophyll content of every crop was ascertained. All plant's

leaves were subjected to the device, and after every treatment, the device recorded the mean of the set it calculated.

3.5.2 Parameter of Production (Yield)

1. The pods number per plant was determined by counting the pods on the plant by hand. The average of pods was equal the total of fruit number on the 3-plant selected divided by three for getting the overall number of harvested.

2. Weight of pod and length per Plant (g per plant).

3. Yield (t/ha): The product weight (in kilograms per m^2) was convert into tone per hectare.

3.6 Data Analysis

After data correct on growth and yield parameters the arrangement was made by using Microsoft Excel and statistically analyzed to find out where was significant difference by using GenStat Discovery Edition 12th (ANOVA) Analysis of Valiance to separate the means at a 5% probability level.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 The physical and chemical soil properties of the Experimental Field

The soil particle size distribution before and after the experiment were are indicated in Table 4.1 and table 4.2 were determined as 65.15 %, 6.83 % and 28.02 % as percentage sand, clay and silt respectively. The soil was classified as sandy loam according to the triangular texture. The bulk density of soil was also calculated as 1.42 g/cm^3 which is conducive for agricultural purposes. The critical value of bulk density for restricting root growth varies with soil type but in general bulk densities greater than 1.6 g/cm^3 tend to restrict root growth (Amhakhian *et al.,* 2021). When the bulk density exceeded 2.0g / cm^3 it means that soil is compacted at depth and subsoils or the horizons is strongly.

Table 4.1: Physical Properties of the Soil in the Experimental Field

Soil Properties	Value
Sand (%)	65.15
Silt (%)	28.02
Clay (%)	6.83
Soil	Sandy loam
Bulk density (g/cm^3)	1.42
Field capacity (%)	21.9
Permanent Wilting point (%)	8.9
Available water (%)	13

Source: Laboratory Results, 2024

Soil chemical analysis was carried out before and after the experiment, to know the pH, EC, nitrogen and phosphorous levels in the soil as impacted by the conversation of watering methods with soil amendment practices. Initially, pH level was within the neutral level and optimal for plant growth. However, upon the application of treatments, the pH increased in the interaction of

CcNPK*S (7.05) but reduced for all other treatments. While okra may grow in a variety of soil types, it thrives on soil that is between 6.0 and 6.8 in pH. Soils with pH at or below 5.8 can result in okra with poorly developed pods (Brandenberger *et al.,* 2018). The electrical conductivity of soil was low at the initial stage but was further reduced to as low as 0.2 µS/cm (CcNPK*S). Most crops like okra, preferably to grow well in EC range of 2.0 to 3.5 µs/cm (Azad et al., 2018). Similarly, the initial phosphorus and nitrogen content of soil were 7.44 mg/l and 1100 mg/l respectively. After the application of treatments, the was a general reduction in soil phosphorus and nitrogen levels ranging from 1.43 – 0.1 mg/l and 1.89 – 0.3 mg/l respectively (Table 4.2).

Table 4.2: Variation in Soil Chemical Properties Before and After Experiment

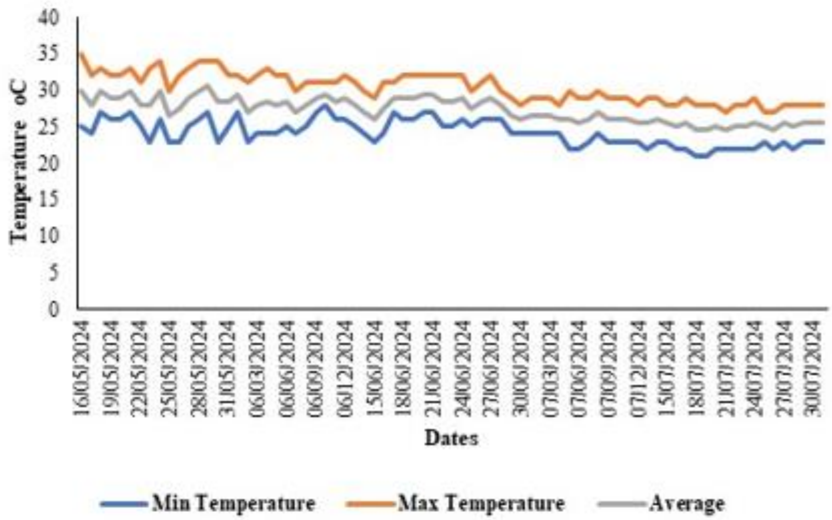
Treatments	**pH**	**EC**(µS/cm)	**Phosphate** (mg/l)	**Nitrogen** (mg/l)
Initial	6.8	5.42	7.44	1100
CoNPK*R	5.57	0.6	1.43	0.3
CcNPK*R	6.1	0.7	0.1	1.89
Cc0NPK*R	5.56	0.4	0.1	0.3
Co0NPK*R	5.82	0.4	0.12	0.44
CoNPK*S	6	0.4	0.1	0.3
CcNPK*S	7.05	0.2	0.1	0.43
Cc0NPK*S	5.65	0.3	0.1	0.3
Co0NPK*S	5.77	0.6	0.1	0.3

Source: WACWISA Laboratory Result, 2024

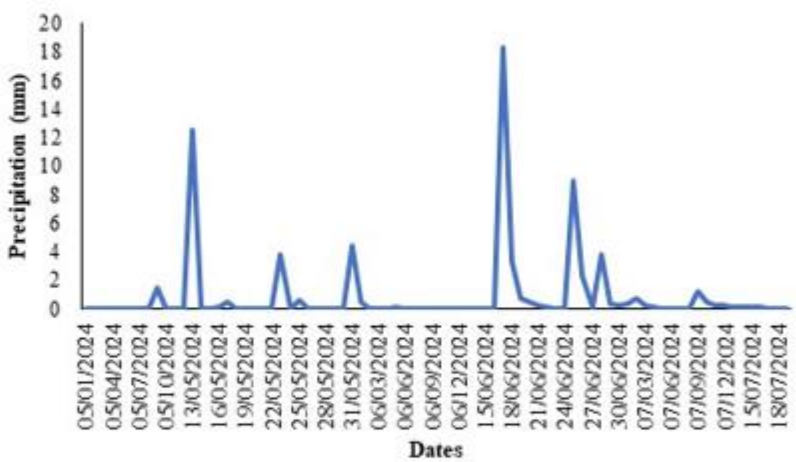
4.2 Weather Parameter on Okra Growing Season

The average temperature reading ranged from 23ºC to 35ºC.in particular (Figure 4.1a). The weather is the most factor affecting the plant production.

The maximum rainfall recorded was 100 mm which was recorded at the flowering stage of the plant. There was mostly little to no rainfall throughout the growth period thereby affection the moisture content of the soil. The presence of excess rainfall can affect the plant production, can commit the famers to planting on time, and have also delay to harvesting which can cause the decay for the fruit on the field. Excessive rain can be causing the soil erosion, soil degradation and removing necessary nutrients that can help crop to grow. Too much water also leads to fungus and mold in the soil which can kill crops and excessive rain can cause flooding and make it difficult for farmers to take care of their crops.



(a)

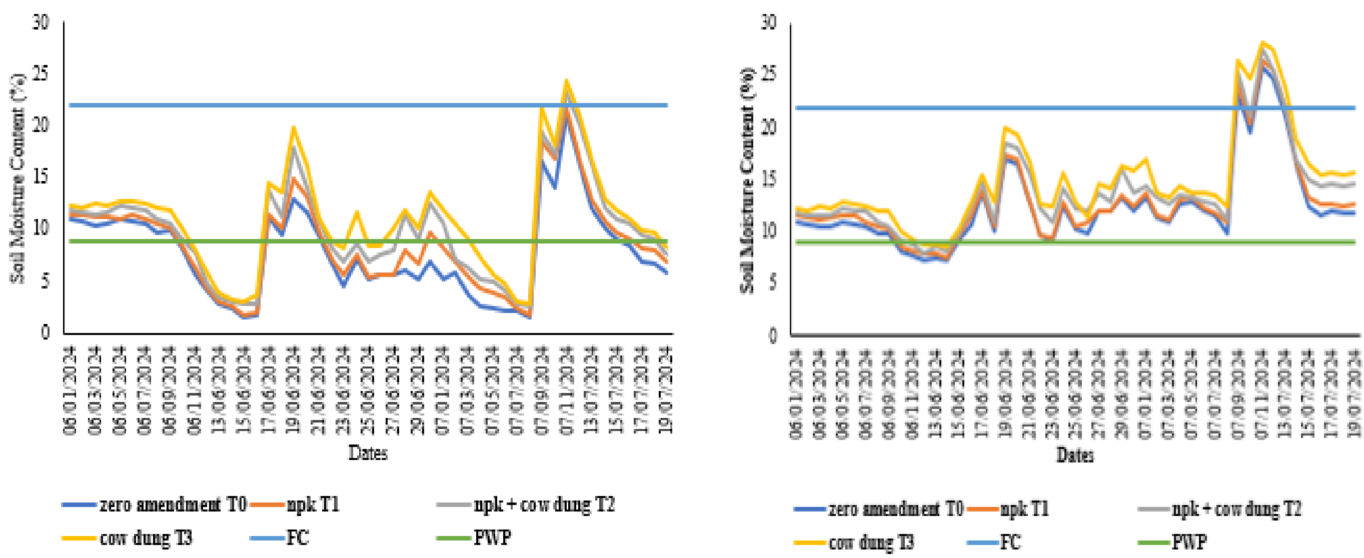


(b)

Figure 4.1: (a) Daily Temperature During Experiment and (b) Daily Rainfall During Experiment

4.3 Soil Moisture Content Variation under Rainfed and Supplementary Irrigation as Affected by Soil Amendment Practices

Water needed for okra was computed. Crop: 291.4 mm of irrigation water were applied total for supplemental irrigation based on the crop's daily evaporation on crop evapotranspiration (ETo) and crop coefficient (KC), as shown in Table 3.3 and Figure 4.2a presents the variation in different dates for water holder by soil during the growth period of Okra under rainfed conditions. The highest soil moisture content under rainfed was 24.40 % which was recorded in the cow dung amended soil (T3) and the least moisture content was 1.50 %, recorded for zero amended soils (T0). Under supplementary irrigation the highest soil moisture content was 28.20 % which was as well recorded for the Cc0NPK amended soil (T3) while the lowest moisture content was 7.20 % also recorded for the zero amended soils (T0) as presented in Figure 4.2b. The variations in soil moisture may be facilitated by rainfall patterns, supplementary irrigation water, soil amendment practices and evapotranspiration in the field (Konheya and Alatise, 2013).



(a) (b)

Figure 4.2: (a) Moisture Soil Content under Rainfall as Soil Amendment Practices impact (b) Soil Moisture Content Under Supplementary Irrigation as Affected by Soil Amendment Practices

4.4 The Impact of watering method and Soil Amendment Practices on the Growth Parameters of Okra

Effect on growth parameter data for plant height, number of leaves, number of branches, Chlorophyll Content (SPAD), Leaf area index (LAI) and Stem Girth were arranged in excel and the analysis of variance (ANOVA) model in GenStat Discovery Edition 12th was used to identify the means at a 5% probability with Tukey level.

4.4.1 Plant Height

The results from the analysis of valiances were determined. There was significant difference at 2 WAP, 4 WAP, 6 WAP in plant height as affected by soil amendment and irrigation method where p -value for interaction was ($p < 0.05$) as indicated in Table 4.3. The tallest height plant was recorded on Cc0NPK*S (74.13cm), and the least plant height was recorded in Cc0NPK*R as 60.33 cm at six weeks after planting. Irrigation method and soil amendment practices significantly affected plant height at $p < 0.05$ and $p < 0.001$ respectively.

Table 4.3: Impact of the Interaction of Watering Method with Soil Amendment Practices on Plant Height.

Treatments	Mean Plant Height (cm)		
	Two WAP	**Four WAP**	**Six WAP**
Co0NPK*R	5.333 c	20.3 d	54.77 h
Co0NPK*S	5.3 c	19.267 e	64.67 d
CoNPK*R	6.167 b	19.367 e	60.77 f
CoNPK*S	7.233 a	25.733 b	71.3 b
Cc0NPK*R	6.4 b	24.4 c	60.33 g
Cc0NPK*S	6.333 b	27.233 a	74.13 a
CcNPK*R	7.1 a	24.733 c	63.63 e
CcNPK*S	6.867 ab	24.333 c	71.2 bc
Grand Mean	6.342	23.171	65.1
LSD	0.5604	0.4615	5.646
C.V	5.4	1.2	1.7
Fpr			
Irrigation Method	0.203	0.001	0.023
Soil Amendment	<.001	<.001	<.001
Irrigation Method*Soil Amendment	0.024	<.001	0.003

Key: Co = Zero Cow Dung, O N P K = Zero Amendment, N P K, Cc = Cow Dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

4.4.2 Number of leaves per plant

There was significant difference in number of leaves at 2WAP, 4 WAP and 6 WAP as affected by the interaction of irrigation method and soil amendment ($p < 0.001$) as indicated in table 4.4. The interaction, Cc0NPK*S recorded the highest number of leaves at 38.8 whereas the interaction CoNPK*R recorded the least leaf numbers of 21.3. The individual effect of irrigation method and soil amendment were highly significant at $p < 0.001$.

Table 4.4: Interaction Impact of Irrigation Method with Soil Amendment Practices on Leaves Number

Treatments	Mean Leaf Number		
	Two WAP	Four WAP	Six WAP
Co0NPK*R	4.67 de	9.3 bc	25.17 ef
Co0NPK*S	4 ef	8.7 de	30.733 c
CoNPK*R	5 cd	9.3 bc	21.3 h
CoNPK*S	5 cd	10.9 a	35.033 b
Cc0NPK*R	5.5 bc	10.2 a	23.7 g
Cc0NPK*S	7a	8.8 cd	38.8 a
CcNPK*R	6 b	10.033 a	29 d
CcNPK*S	6 b	9.367 ab	25.667 e
Grand Mean	5.4	9.575	28.675
LSD	0.895	0.1431	0.7294
C.V	9.8	0.9	1.4
Fpr			
Irrigation Method	0.37	0.007	<.001
Soil Amendment	<.001	<.001	<.001
Irrigation Method*Soil Amendment	0.025	<.001	<.001

Key: Co = Zero Cow Dung, O N P K = Zero Amendment, N P K, Cc = Cow Dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

4.4.3 Number of Branches

The result showed was significant difference in 6 WAP where the branches number from the analysis of valiance result the p value was ($p < 0.05$), resulted in the highest number in RF was (4.6 in T2), while SI performed is (7 in T3) as indicated by figure (4.3) and appendix in table of analysis of variance.

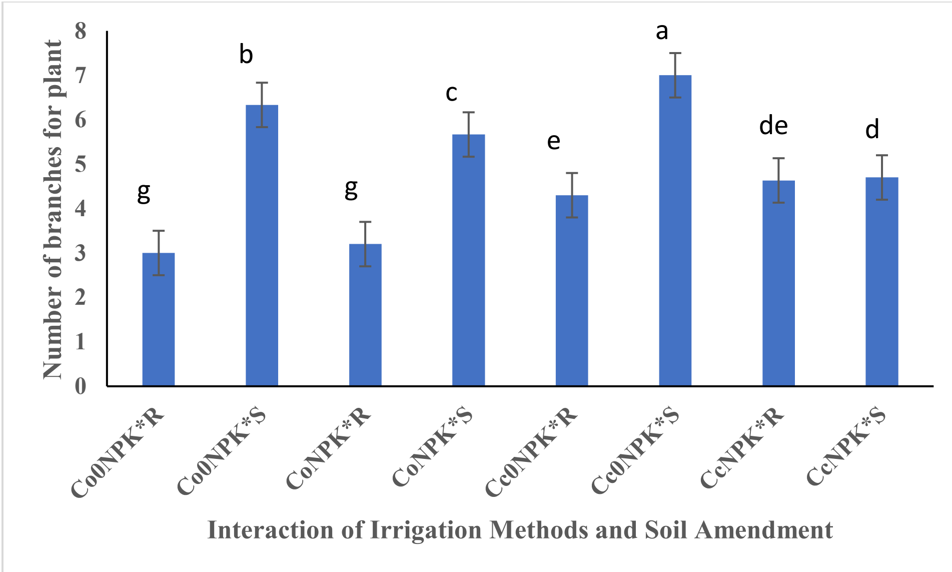


Figure 4.3: Impact of Irrigation Method Interaction and Methods of Amending Soil of Number of branches on Okra plant

Where Co = Zero cow dung, O N P K = zero Amendment, N P K, Cc = Cow dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

4.4.4 Chlorophyll Content (SPAD)

At table 4.5 the result showed was significant variation ($p < 0.05$) in chlorophyl II content at 4 WAP upon the interaction of soil amendment practices and irrigation methods. At six WAP, the interaction, CcNPK*S (51.433) as the highest chlorophyl content and Co0NPK*R recorded the least at 40.467. There was high significant variation ($p < 0.001$) in chlorophyl content due to the effects of soil amendment practices and irrigation methods.

Table 4.5: Influence of Soil Amendment Techniques and Irrigation Method on Chlorophyll Content

Treatments	Chlorophyll Content		
	Two WAP	**Four WAP**	**Six WAP**
Co0NPK*R	54.73 a	49.23 ed	40.467 gh
Co0NPK*S	54.73 a	51.08 b	48.767 d
CoNPK*R	55.9 a	48.9 df	41.567 ef
CoNPK*S	55.87 a	52.77 a	50.1 b
Cc0NPK*R	54.37 a	50.04 c	41.1 fg
Cc0NPK*S	55.07 a	53.13 a	50.033 bc
CcNPK*R	56.1 a	49.97 cd	42.2 e
CcNPK*S	56.47 a	53.57 a	51.433 a
Grand Mean	55.4	51.09	45.708
LSD	2.157	0.933	1.0689
C.V	2.5	1.1	0.8
Fpr			
Irrigation Method	0.314	0.002	0.001
Soil Amendment	0.166	0.001	<.001
Irrigation Method*Soil Amendment	0.962	0.045	0.148

Key: Co = Zero cow dung, O N P K = zero Amendment, N P K, Cc = Cow dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

4.4.5 Leaf Are Index (LAI)

Table 4.6, showed the combination of irrigation methods and soil amendment practices significantly ($p < 0.001$) caused by LAI at four and 6 weeks after planting (WAP) (Table 4.10). The LAI that was highest was reported in the interaction of Cc0NPK*S (2.81) and the least leaf area index was recorded in the interaction of Co0NPK*R (1.6267). At six weeks after planting, there was a high significant variation in leaf area index due to irrigation methods and soil amendment respectively.

Table 4.6: Influence of Soil Amendment Techniques and Irrigation Method on Leaf Area Index

Treatments	Leaf Area Index		
	Two WAP	**Four WAP**	**Six WAP**
Co0NPK*R	1.4867 cd	2.0667 b	2.4 e
Co0NPK*S	1.34 h	1.94 f	2.5967 b
CoNPK*R	1.55 b	2.253 bc	1.6267 g
CoNPK*S	1.4133 ef	2.25 cd	2.8 a
Cc0NPK*R	1.6 a	1.8 g	2.29 d
Cc0NPK*S	1.42 e	2.283 a	2.81 a
CcNPK*R	1.5133 bc	2.177 de	2.55 bc
CcNPK*S	1.3867 fg	1.947 f	1.96 f
Grand Mean	1.4638	2.131	2.3375
LSD	0.03808	0.1009	0.04801
C.V	1.6	2.7	1.3
Fpr			
Irrigation Method	0.002	0.152	<.001
Soil Amendment	<.001	<.001	<.001
Irrigation Method*Soil Amendment	0.269	<.001	<.001

Key: Co = Zero Cow Dung, O N P K = Zero Amendment, N P K, Cc = Cow Dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

4.4.6 Stem Girth

Table 4.7 shows the interaction impact of watering methods and amendment soil practices. There was a highly significant variation ($p < 0.001$) in stem girth due to the connection between watering methods and soil amendment practices. Similarly, the individual watering impact methods and amendment soil practices on stem girth were high. The combination of Cc0NPK*S recorded the highest stem girth of 2.55 cm whereas 1.567 cm was recorded by Co0NPK*R as the least stem girth. Plants respond to water stress as in the rainfed method by closing their stomata, which then inhibits photosynthesis, thereby affecting its development (Boland *et al.,* 2000).

These results may be due to a conducive nutritional environment aiding in the absorption of moisture and nutrients for plant physiological growth.

Table 4.7: Effect of Interaction of Irrigation Method and Soil Amendment Practices on Stem Girth

Treatments	Stem Girth (cm)		
	Two WAP	Four WAP	Six WAP
Co0NPK*R	0.2 b	0.8267 d	1.567 fg
Co0NPK*S	0.25 a	0.7667 e	1.943 cd
CoNPK*R	0.3 a	0.9 c	1.733 e
CoNPK*S	0.2667 a	0.9 c	2.267 b
Cc0NPK*R	0.2 b	1 b	1.667 ef
Cc0NPK*S	0.2 b	1.0367 a	2.55 a
CcNPK*R	0.2333 b	0.7333 f	2.033 c
CcNPK*S	0.2833 a	1.04 a	2 c
Grand Mean	0.2417	0.9004	1.97
LSD	0.05794	0.01646	0.149
C.V	14.4	0.9	3.5
Fpr			
Irrigation Method	0.27	0.004	0.009
Soil Amendment	0.007	<.001	<.001
Irrigation Method*Soil Amendment	0.16	<.001	<.001

Key: Co = Zero Cow Dung, O N P K = Zero Amendment, N P K, Cc = Cow Dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

4.5 Effect of Irrigation Method and Soil Amendment on Yield Production of Okra

4.5.1 Fruit Weight and Diameter

A highly significant difference ($p < 0.001$) was observed. in fruit weight due to the interaction effect of irrigation method and soil amendment practices as indicated in Figure (4.4a). The interactions Cc0NPK*S and CcNPK*S recorded the highest fruit weight of 59.2 g, whereas, Co0NPK*R recorded the least fruit weight of 27.86 g. The impact of watering method and Fruit weight was significantly affected by soil amendment measures ($p < 0.001$).

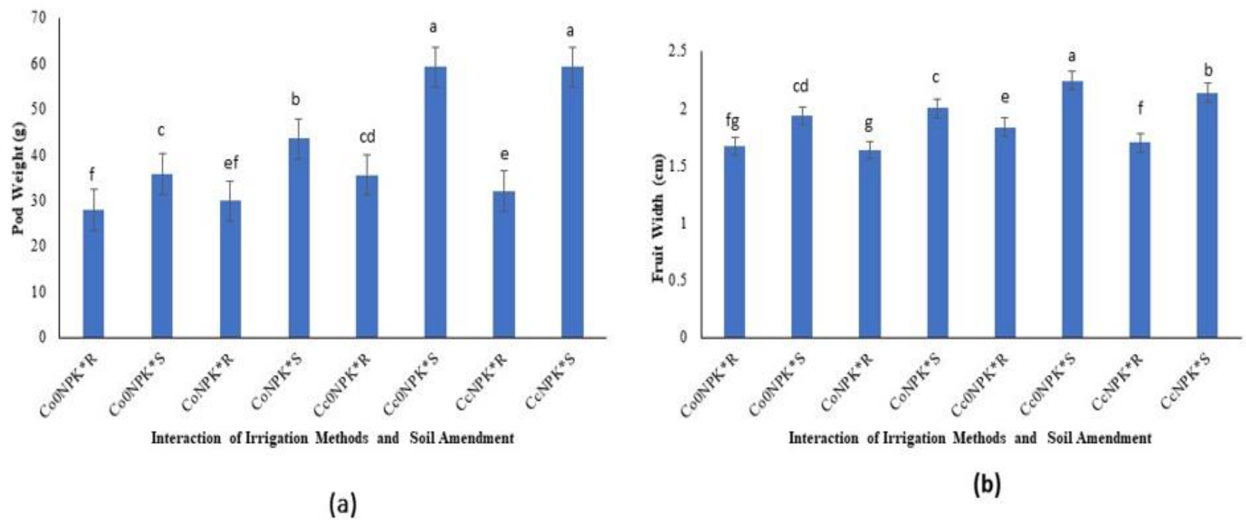


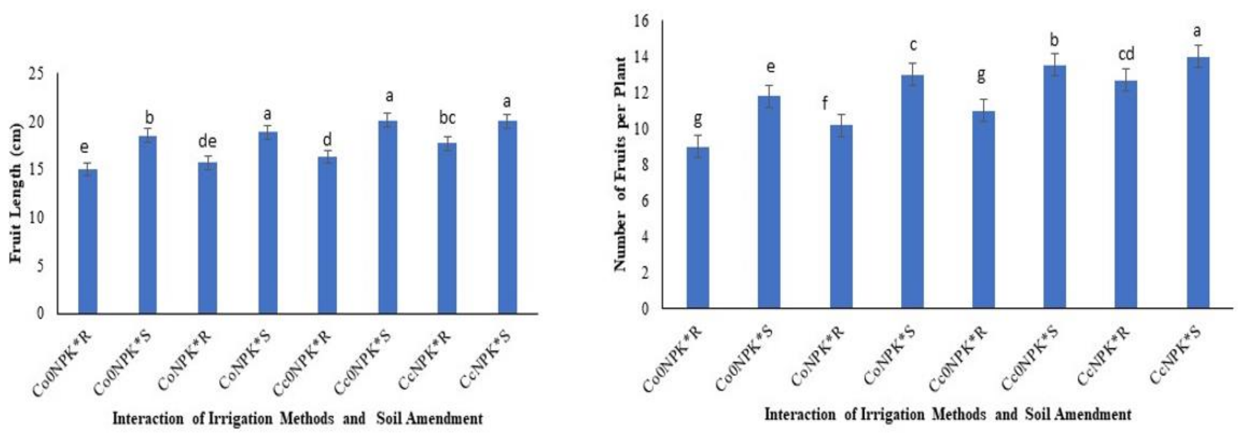
Figure 4.4: (a) Impact of Irrigation Method Interaction and Methods of Amending Soil on Okra Fruit Weight and (b) Impact of Irrigation Method Interaction and Methods of Amending Soil on Okra Fruit Width

Key: Co = Zero Cow Dung, O N P K = Zero Amendment, N P K, Cc = Cow Dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

The result shows were significant difference on the fruit diameter as caused by the connection between watering methods with amendment soil practices ($p < 0.05$). This is indicated in Figure (4.4b). The interaction Cc0NPK*S (2.24 cm), recorded the highest fruit diameter and the interaction CoNPK*R (1.633 cm) recorded the least stem diameter. Supplementary irrigation method varied significantly ($p < 0.05$) from rainfed. Among the soil amendment practices, Cc0NPK was highly significant ($p < 0.001$) from the other treatments.

4.5.2 Fruit Length and Number of Fruits per Plant

The effect of irrigation method and soil amendment practices showed no significant different variation on the fruit length of okra (Figure 4.5a). The most lengthy and short fruit were 20.1 and 15 recorded by Cc0NPK*S and Co0NPK*R respectively. Irrigation method and soil amendment practices significantly affected fruit length at $p < 0.05$ and $p < 0.001$ respectively. Supplementary irrigation was the best performing irrigation method as CcNPK*S was the best soil amendment practice.



(a) (b)

Figure 4.6: (a) Impact of Irrigation Method Interaction and Methods of Amending Soil on Okra Fruit Length and (b) Impact of Irrigation Method Interaction and Methods of Amending Soil on Okra Fruit Per Plant

Key: Co = Zero Cow Dung, O N P K = Zero Amendment, N P K, Cc = Cow Dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

The fruits number per plant differed significantly ($p < 0.001$). As affected by the interaction of irrigation methods with soil amendment practices (Figure 4.5b). The highest and least fruit number per plant were 14 and 9 recorded by CcNPK*S and Co0NPK*R respectively. The watering method has a substantial impact ($p < 0.05$) and soil amendment practices ($p < 0.001$) on fruit number per plant.

4.5.3 Fruit Yield (t/ha) and Crop Water Productivity (kg/m3)

In Figure 4.6a, the yield (41.4 t/Ha) recorded through the interaction of CcNPK*S was the highest and the least was recorded through the interaction of Co0NPK*R (12.5 t/Ha). There was highly significant variation in yield due to the interaction of irrigation methods and strategies for amending soil However, the yield recorded as a result of the interaction of CcNPK*S and the interaction of Cc0NPK*S were similar. The watering method impact and soil amendment practices were highly significant. This aligns with results by Embiowei and Emiri (2017) which indicated that okra farming under NPK plus organic manure amended soils performed significantly better in yield. Similarly, West *et al*. (2004), Owusu-Sekyere and Annan (2010), Babu et al. (2015) and Sam-Amoah et al. (2016) affirmed that fruit weight, length, circumference and yield reduced with deficit irrigation, as it retards nutrient availability to plant.

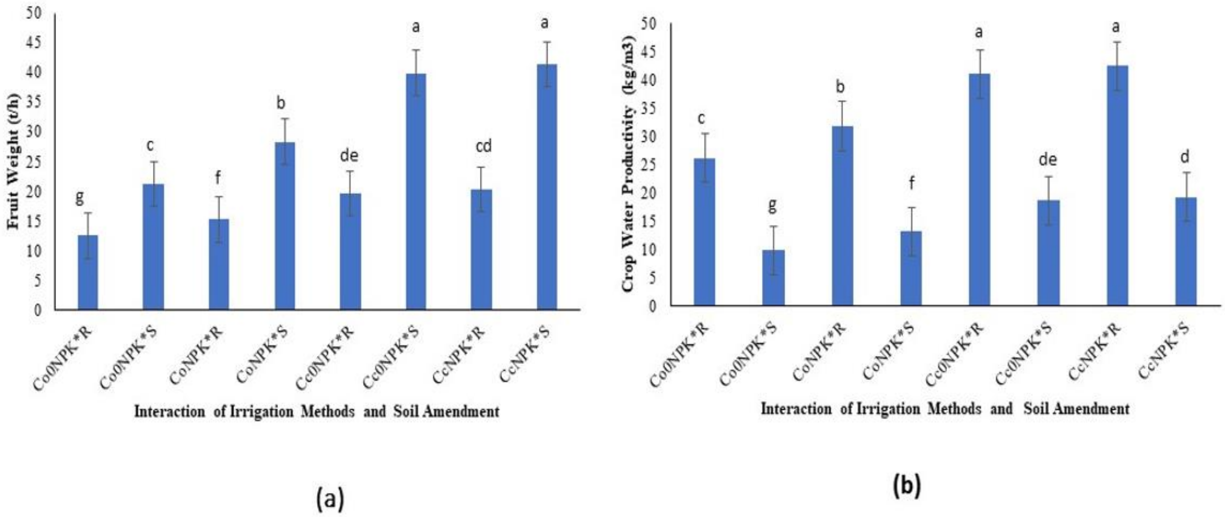


Figure 4.6: Impact of Irrigation Method Interaction and Methods of Amending Soil on Okra Yield (t/ha) and (b) Impact of Irrigation Method Interaction and Methods of Amending Soil on Crop Water Productivity (Kg/m^3) Key: Co = Zero Cow Dung, O N P K = Zero Amendment, N P K, Cc = Cow Dung, R = Rainfed, S = Supplementary Irrigation (As per Tukey confidence intervals, shows that the letters are not the same are considered to differ significantly at 95% the probability level)

A significant variation ($p < 0.05$) was observed in the results in crop water productivity, influenced by the interplay between soil amendment techniques and irrigation techniques. The combination of CcNPK*R had the highest crop water productivity of 42.48 Kg/m^3 and 13.19 Kg/m^3 was the least recorded due to the combination of CoNPK*S as represented in Figure 4.6b. Impact of Irrigation Method Interaction and Methods of Amending Soil on crop water productivity (CWP) was highly significant. Likewise, the CWP under rainfed was significantly different from supplementary irrigated fields.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Assessing the effect of soil amendment and strategies for irrigation on okra development and product during the rainy season was the aim of this study. Eight treatments and the experiment were set up using a split-plot design. The interaction of Cc0NPK*S had the ideal conditions for plant growth, such as LAI, height of plant, stem girth, number of leaves per plant, and chlorophyll content. The best yield was in the interactions, CcNPK*S (41.4 kg/ha) and Cc0NPK*S (39.9 Kg/ha). The interaction of CcNPK*R (42.48 Kg/m^3) had the highest crop water productivity, thereby making more productive use of water. The supplementary irrigation method had the best-performing leaf area index, plant height, stem girth, leaves number, chlorophyll content and yield. However, the rainfed method of irrigation used water more productively. The best yield (30.85 t/ha), growth parameters, and crop water productivity (30.89 kg/m^3) were obtained from the CcNPK soil amendment practice. It is important to remember that, aside from rain-fed farming, farmers can adopt supplementary irrigation to significantly increase crop yield.

5.2 Recommendations

The following recommendations are suggested based on the findings of study:

1. Cc0NPK*S combination is recommended to farmers for the best growth parameters and yield.
2. The results of this research have shown that SI has produced the best results. We recommended to supplementary irrigation method in times of during the wet season, to make available water to plants in times of limited rainfall.
3. In the event of water scarcity, the rainfed irrigation method is recommended for good crop water productivity.
4. The soil amendment practice, CcNPK*S, is recommended best yields and CcNPK*R on crop water productivity.
5. Comparable studies need to be conducted at various times of year and in difference places.

REFERENCE

1. Aboyeji, C. M., Olaniyan, D. O., Dunsin, O., Adekiya, A. O., Okunlola, F. O., Ejue, S. W., & Adeniyi, H. A. (2021). Physiological growth, yield and quality responses of okra to sole and combined soil application of green biomass, poultry manure and inorganic fertilizers. *Plant Physiology Reports*, *26*, 709-721.
2. Adaku, A. A. (2020). *Farmers' motivation for participating in inter-organizational relationships in Ghana*. Kansas State University.
3. Adejumo, S. A., Ezeh, O. S., & Mur, L. A. (2019). Okra growth and drought tolerance when exposed to water regimes at different growth stages. *International Journal of Vegetable Science*, *25*(3), 226-258.
4. Adekiya, A. O., Ejue, W. S., Olayanju, A., Dunsin, O., Aboyeji, C. M., Aremu, C., & Akinpelu, O. (2020). Different organic manure sources and N P K fertilizer on soil chemical properties, growth, yield and quality of okra. *Scientific Reports*, *10*(1), 1-9.
5. Agbenorhevi, J. K., Kpodo, F. M., Banful, B. K., Oduro, I. N., Abe-Inge, V., Datsomor, D. N., & Obeng, B. (2020). Survey and evaluation of okra pectin extracted at different maturity stages. *Cogent Food & Agriculture*, *6*(1), 1760476.
6. Altieri, M. A. (2019). Designing and improving pest management systems for subsistence farmers. In *Crop Protection Strategies for Subsistence Farmers* (pp. 1-20). CRC Press.
7. Amhakhian, S. O., Otene, I. J. J., Adava, I. O., Muhammed, B., Are, E. C., & Ozovehe, N. O. (2021). Bulk density of soils from oil palm agroforestry systems in Kogi East, Nigeria. *International Journal of Environment and Climate Change*, *11*(12), 396-402.

8. Asomah, S., Anankware, J. P., & Adjei, R. R. (2021). Impact of organic and inorganic fertilizers on the growth and yield of cabbage in Ghana. *International Journal of Horticultural Science*, *27*, 46-49.

9. Azad, K. N., Salam, M. A., & Hossain, M. Z. (2018). Performance evaluation of different bedding media in aquaponic system for growth and production of okra and tilapia. *Int. J. Eng. Res. Sci*, *4*.

10. Babu, R. G., I. B. Rao, and K. N. R. Kumar. (2015) Response of okra to different levels of drip irrigation on growth, yield and water use efficiency. *International Journal of Agricultural Engineering*, 8(1): 47-53.

11. Badr, M. A., El-Tohamy, W. A., & Zaghloul, A. M. (2012). Yield and water use efficiency of potato grown under different irrigation and nitrogen levels in an arid region. *Agricultural Water Management*, *110*, 9-15.

12. Barker, G. (2006). *The agricultural revolution in prehistory: why did foragers become farmers?* Oxford University Press.

13. Begum, F., & Ayub, G. (2022). Effect of Harvesting Stages on Seed Yield and Quality of Okra (Abelmoschus esculentus L. Moench). *Sarhad Journal of Agriculture*, *38*(3).

14. Benchasri, S. (2012). Okra (Abelmoschus esculentus (L.) Moench) as a valuable vegetable of the world. *Ratarstvo i povrtarstvo*, *49*(1), 105-112.

15. Blatchford, M. L., Karimi, P., Bastiaanssen, W. G. M., & Nouri, H. (2018). From global goals to local gains—A framework for crop water productivity. *ISPRS international journal of geo-information*, *7*(11), 414.

16. Blum, A. (2009). Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field crops research*, *112*(2-3), 119-123.

17. Boland, J., & Sinclair, R. (2014). Developing age-size relationships for long lived tree species. *Journal of Biological Systems*, *22*(02), 309-326.

18. Brandenberger, L., Shrefler, J., Damicone, J., & Rebek, E. (2018). *Okra production*. Oklahoma Cooperative Extension Service.

19. Brust, G. E. (2019). Management strategies for organic vegetable fertility. In *Safety and practice for organic food* (pp. 193-212). Academic Press.

20. Carney, J. (2010). *In the shadow of slavery: Africa's botanical legacy in the Atlantic world*. Univ of California Press.

21. Chamberlin, J. (2008). *It's Small World After All: Defining Smallholder Agriculture in Ghana* (Vol. 823). Intl Food Policy Res Inst.

22. Chen, C., Wang, E., & Yu, Q. (2010). Modelling the effects of climate variability and water management on crop water productivity and water balance in the North China Plain. *Agricultural Water Management*, *97*(8), 1175-1184.

23. Choudhary, K., More, S. J., & Bhanderi, D. R. (2015). Impact of biofertilizers and chemical fertilizers on growth and yield of okra (Abelmoschus esculentus L. Moench). *The ecoscan*, *9*(1&2), 67-70.

24. Dahlin, A. S., & Rusinamhodzi, L. (2019). Yield and labor relations of sustainable intensification options for smallholder farmers in sub-Saharan Africa. A meta-analysis. *Agronomy for Sustainable Development*, *39*(3), 32.

25. Darfour, B., & Rosentrater, K. A. (2016). Agriculture and food security in Ghana. In *2016 ASABE annual international meeting* (p. 1). American Society of Agricultural and Biological Engineers.

26. Dhaliwal, S. S., Naresh, R. K., Mandal, A., Walia, M. K., Gupta, R. K., Singh, R., & Dhaliwal, M. K. (2019). Effect of manures and fertilizers on soil physical properties, build-up of macro and micronutrients and uptake in soil under different cropping systems: a review. *Journal of Plant Nutrition*, *42*(20), 2873-2900.

27. Eid, A. R., & Negm, A. (2019). Improving agricultural crop yield and water productivity via sustainable and engineering techniques. *Conventional Water Resources and Agriculture in Egypt*, 561-591.

28. Embiowei1 S. E. and Emiri U. N., (2017) Agronomic Evaluation of Okra under Different Irrigation and Soil Management Practices at Isampou, Bayelsa State, Nigeria. International Journal of Science and Research (IJSR). Volume 6 Issue 5, May 2017 DOI: 10.21275/ART2017275

29. Fagariba, C. J., Song, S., & Soule Baoro, S. K. G. (2018). Climate change adaptation strategies and constraints in Northern Ghana: Evidence of farmers in Sissala West District. *Sustainability*, *10*(5), 1484.

30. Fan, J., Lu, X., Gu, S., & Guo, X. (2020). Improving nutrient and water use efficiencies using water-drip irrigation and fertilization technology in Northeast China. *Agricultural Water Management*, *241*, 106352.

31. FAO (1984). Crop water requirements. By: J. Doorenbos and W.O. Pruitt. *FAO Irrigation and Drainage Paper* 24. Rome, Italy.

32. FAO. 1974. Measurement of effective rainfall. *Irrigation and Drainage Paper No*, 24.

33. Fernández-Cirelli, A., Arumí, J. L., Rivera, D., & Boochs, P. W. (2009). Environmental effects of irrigation in arid and semi-arid regions. *Chilean Journal of Agricultural Research 69 (2009), Nr. SUPPL. 1*, *69*(SUPPL. 1), 27-40.

34. Gianquinto, G., Muñoz, P., Pardossi, A., Ramazzotti, S., & Savvas, D. (2013) Soil fertility and plant nutrition. *Good Agricultural Practices for greenhouse vegetable crops*, 205.

35. Idowu, G. A., Oyewale, R. O., Bolajoko, M. H., Ibrahim, R. O., & Isah, C. (2022). Management of Insect Pests of Okra (Abelmoschus esculentus L.).

36. Juo, A. S. R. (1978). Selected methods for soil and plant analysis: IITA manual series, No. 1.

37. Khan, M. A., & Akhtar, M. S. (2015). Agricultural adaptation and climate change policy for crop production in Africa. *Crop production and global environmental issues*, 437-541.

38. Khan, M. A., & Rab, A. (2019). Plant spacing affects the growth and seed production of okra varieties. *Sarhad Journal of Agriculture*, *35*(3), 751-756.

39. Kitila, G., Gebrekidan, H., & Alamrew, T. (2014). Assessment of irrigation water quality and suitability for irrigation in the Fincha'a Valley Sugar Estate, Nile Basin of Western Ethiopia. *Science, Technology and Arts Research Journal*, *3*(1), 64-73.

40. Kumar, S. (2020). Abiotic stresses and their effects on plant growth, yield and nutritional quality of agricultural produce. *Int. J. Food Sci. Agric*, *4*, 367-378.

41. Kumari, T., & Deka, S. C. (2021). Potential health benefits of garden pea seeds and pods: A review. *Legume science*, *3*(2), e82.

42. Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, *7*(5), 5875-5895.

43. Landis, T. D., Bonner, F. T., & Karrfalt, R. P. (2008). Nursery practices. *The woody plant seed manual*, *727*, 125-146.

44. Lewis, A. M. (1948). Jefferson and Virginia's Pioneers, 1774-1781. *The Mississippi Valley Historical Review*, *34*(4), 551-588.

45. Mahato, A. (2014). Climate change and its impact on agriculture. *International Journal of Scientific and Research Publications*, *4*(4), 1-6.

46. Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M., & Ullah, S. (2017). Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *Journal of soil science and plant nutrition*, *17*(1), 22-32.

47. Malvi, U. R. (2011). Interaction of micronutrients with major nutrients with special reference to potassium. *Karnataka Journal of Agricultural Sciences*, *24*(1).

48. Meena, R. P., Sharma, R. K., Chhokar, R. S., Chander, S., Tripathi, S. C., Kumar, R., & Sharma, I. (2015). Improving water use efficiency of rice-wheat cropping system by adopting micro-irrigation systems. *International Journal of Bio-resource and Stress Management*, *6*(3), 341-345.

49. Misra, A. K. (2014). Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment*, *3*(1), 153-165.

50. Mohammadi, K., Heidari, G., Khalesro, S., & Sohrabi, Y. (2011). Soil management, microorganisms and organic matter interactions: A review. *African Journal of Biotechnology*, *10*(86), 19840.

51. Mohankumar, S., Karthikeyan, G., Durairaj, C., Ramakrishnan, S., Preetha, B., & Sambathkumar, S. (2016). Integrated pest management of okra in India. *Integrated Pest Management of Tropical Vegetable Crops*, 167-177.

52. Moyin-Jesu, E. I., & Adekayode, F. O. (2010). Comparative evaluation of different organic fertilizers on soil fertility improvement, leaf mineral composition and growth performance of African cherry nut (Chrysophyllum albidium L.) seedlings. *Journal of American science*, *6*(8), 217-225.

53. Musa, U. T., and T. H. Usman. (2016) Leaf area determination for maize (zea mays l), okra (abelmoschus esculentus) and cowpea (Vigna unguiculata L). Journal of Biology, Agriculture and Healthcare, 6(4): 103-111.

54. Mylonas, I., Stavrakoudis, D., Katsantonis, D., & Korpetis, E. (2020). Better farming practices to combat climate change. In *Climate change and food security with emphasis on wheat* (pp. 1-29). Academic Press.

55. Niklas, K. J., & Enquist, B. J. (2002). On the vegetative biomass partitioning of seed plant leaves, stems, and roots. *The American Naturalist*, *159*(5), 482-497.

56. Nkongho, R. N., Efouba-Mbong, J. T., Ndam, L. M., Ketchem, G. A., Etchu-Takang, E. G., & Agbor, D. T. (2022). Seed production system and adaptability of okra (Abelmoschus esculentus L.) cultivars in Buea, Cameroon. *Plos one*, *17*(12), e0278771.

57. Odo, A. O. (2017). Agricultural water management in sub-Sahara Africa: options for sustainable crop production. *Green. J. Agric. Sci*, *6*(4), 151-158.

58. Oluwasemire, K. O., & Oladuji, Y. F. (2018). Development and Yield of Two Okra (Abelmoschus esculentus (L.) Moench) Cultivars under Limiting Soil Water Conditions on a Sandy Loam. *Nigerian Journal of Ecology*, *17*(1), 14-28.

59. Owusu-Sekyere, J.D. and Annan E. (2010) Effect of deficit irrigation on growth and yield of okra (*Abelmoscus esculentus*). J. Sci. Technol., 30: 128-134.

60. Payne, W. A. (2010). Farming systems and food security in sub-Saharan Africa. *Food security and soil quality*, 23-56.

61. Saichand, N., & Kumar, A. (2024). Field Efficacy and Economics of Selected Biopesticides and Chemicals against Shoot and Fruit Borer, Earias vittella (Fabricius) on Okra. *International Journal of Plant & Soil Science*, *36*(7), 618-624.

62. Sam-Amoah L.K., Willie W.K.T. and Owusu-Sekyere J.D. (2016) Effects of Deficit Irrigation and Chicken Manure Interactions on the Growth and Yield of Okra in a Pot Experiment. Asian Journal of Agricultural Research 10 (1): 47-55, 2016 ISSN 1819-1894 / DOI: 10.3923/ajar.2016.47.55

63. Sanlier, N., & Guler, S. M. (2018). The benefits of Brassica vegetables on human health. *J. Hum. Health Res*, *1*(1), 1-13.

64. Sedara, O. S., Sedara, A. M., Alatise, M. O., & Faloye, O. T. (2021). Effect of varying water applications on growth, yield and water use efficiency of okra (Abelmoschus esculentus) under drip irrigation in Akure. *Agricultural Engineering International: CIGR Journal*, *23*(1), 100-108.

65. Selim, M. M. (2020). Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. *International Journal of Agronomy*, *2020*.

66. Sezen, S. M., Yazar, A., & Eker, S. (2006). Effect of drip irrigation regimes on yield and quality of field grown bell pepper. *Agricultural Water Management*, *81*(1-2), 115-131.

67. Shahbaz, M., Akhtar, M. J., Ahmed, W., & Wakeel, A. (2014). Integrated effect of different N-fertilizer rates and bioslurry application on growth and N-use efficiency of okra (Hibiscus esculentus L.). *Turkish Journal of Agriculture and Forestry*, *38*(3), 311-319.

68. Sharma, P., & Kaushal, A. (2015). Growing okra with drip fertigation-a review. *Inter. J. Engg. Sci. Inven*, *4*(9), 2319-6734.

69. Sharma, V., Khan, A., & Shukla, R. K. (2016). Growth and yield attribute of Okra (Abelmoschus esculentus L.) under the application of bio and chemical fertilizers either alone or in combination. *International Journal of Agricultural Science and Research (IJASR), 1 (6), 189*, *198*.

70. Singh, H. K., Singh, K. M., & Meraj, M. (2018). Growth and yield performance of okra [Abelmoschus esculentus (L.) Moench] varieties on farmer's field. *International Journal of Current Microbiology and Applied Sciences. Special Issue*, *7*, 1411-1417.

71. Singh, P., Chauhan, V., Tiwari, B. K., Chauhan, S. S., Simon, S., Bilal, S., & Abidi, A. B. (2014). An overview on okra (Abelmoschus esculentus) and its importance as a nutritive vegetable in the world. *International journal of Pharmacy and Biological sciences*, *4*(2), 227-233.

72. Sissoko, K., van Keulen, H., Verhagen, J., Tekken, V., & Battaglini, A. (2011). Agriculture, livelihoods and climate change in the West African Sahel. *Regional Environmental Change*, *11*, 119-125.

73. Sjah, T., & Zainuri, Z. (2020). Agricultural supply chain and food security. In *Zero Hunger* (pp. 79-88). Cham: Springer International Publishing.

74. Sudha, M., Gajanana, T. M., & Murthy, D. S. (2006). Economic impact of commercial hybrid seed production in vegetables on farm income, employment and farm welfare–A case of tomato and okra in Karnataka. *Agricultural Economics Research Review*, *19*(2), 251-268.

75. Sylver-Francis, R. A. (2022). *Medicinal plants use in Nigeria for the management of hypertension and diabetes* (Doctoral dissertation, University of London, University College London (United Kingdom).

76. Tan, Y. C., Lai, J. S., Adhikari, K. R., Shakya, S. M., Shukla, A. K., & Sharma, K. R. (2009). Efficacy of mulching, irrigation and nitrogen applications on bottle gourd and okra for yield improvement and crop diversification. *Irrigation and Drainage Systems*, *23*, 25-41.

77. Thornton, P. K., Jones, P. G., Owiyo, T., Kruska, R. L., Herrero, M., Orindi, V., & Omolo, A. (2008). Climate change and poverty in Africa: Mapping hotspots of vulnerability. *African Journal of Agricultural and Resource Economics*, *2*(1), 24-44.

78. Timsina, J. (2018). Can organic sources of nutrients increase crop yields to meet global food demand? *Agronomy*, *8*(10), 214.

79. Tunca, E., E. S. Koksal, S. Cetin, N. M. Ekiz, and H. Balde. (2018) Yield and leaf area index estimation for sunflower plants using unmanned aerial vehicle images. Environmental Monitoring Assessment, 190(682): 1-12.

80. USDA. (2016). *SSM - Ch. 3. Examination and Description of Soil Profiles | NRCS Soils*.

81. Uwiringiyimana, T., Habimana, S., Umuhozariho, M. G., Bigirimana, V. P., Uwamahoro, F., Ndereyimana, A., & Naramabuye, F. X. (2014). Review on Okra (Abelmoschus

esculentus (L.) Moench) Production, Nutrition and Health Benefits. *Rwanda Journal of Agricultural Sciences*, *3*(1), 71-87.

82. Verma, B. C., Pramanik, P., & Bhaduri, D. (2020). Organic fertilizers for sustainable soil and environmental management. *Nutrient dynamics for sustainable crop production*, 289-313.

83. Wang, X., Fan, J., Xing, Y., Xu, G., Wang, H., Deng, J., & Li, Z. (2019). The effects of mulch and nitrogen fertilizer on the soil environment of crop plants. *Advances in agronomy*, *153*, 121-173.

84. Webber, H., Gaiser, T., & Ewert, F. (2014). What role can crop models play in supporting climate change adaptation decisions to enhance food security in Sub-Saharan Africa?. *Agricultural Systems*, *127*, 161-177.

85. West G., D. Inze and Beemster G.T.S. (2004) Cell cycle modulation in the response of the Primary root of *Arabidopsis* to salt stress. Plant Physiol., 135: 1050-1058.

86. Xin, L. (2022). Chemical fertilizer rate, use efficiency and reduction of cereal crops in China, 1998–2018. *Journal of Geographical Sciences*, *32*(1), 65-78.

87. Yengoh, G. T., Tchuinte, A., Armah, F. A., & Odoi, J. O. (2010). Impact of prolonged rainy seasons on food crop production in Cameroon. *Mitigation and Adaptation Strategies for Global Change*, *15*, 825-841.

APPENDICES

Appendix 1: collection of field data

Appendix 2: Infection and Vermin Management at the Field

Appendix 3: Okra pods maturity for harvested

Okra pods at difference measurement Appendix 4

Appendix 5. ANOVA

Variate 1: Height plant (cm) in 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.490	0.245	0.02	
Irrigation	1	655.215	655.215	42.53	0.023
Residual	2	30.810	15.405	12.84	
Soil amendment	3	238.617	79.539	66.28	<.001
Irrigation. Soil amendment	3	29.768	9.923	8.27	0.003
Residual	12	14.400	1.200		
Total	23	969.300			

Variate 2: Stem Diameter (cm) in 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.059575	0.029788	2.7	
Irrigation	1	1.1616	1.1616	105.24	0.009
Residual	2	0.022075	0.011038	2.33	
Soil amendment	3	0.410633	0.136878	28.84	<.001
Irrigation. Soil amendment	3	0.649967	0.216656	45.65	<.001
Residual	12	0.05695	0.004746		
Total	23	2.3608			

Variate 3: Leaf Area (LA) in 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.583E-06	7.917E-07	2.11	
Irrigation	1	3.750E-07	3.750E-07	1.00	0.423
Residual	2	7.500E-07	3.750E-07	0.31	
Soil amendment	3	1.248E-04	4.160E-05	34.83	<.001
Irrigation. Soil amendment	3	2.231E-04	7.438E-05	62.27	<.001
Residual	12	1.433E-05	1.194E-06		
Total	23	3.650E-04			

Variate 4: Leaf Area Index (LAI) in 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0025	0.00125	5.77	
Irrigation	1	1.000417	1.000417	4617.31	<.001
Residual	2	0.000433	0.000217	0.23	
Soil amendment	3	0.404483	0.134828	146.2	<.001
Irrigation. Soil amendment	3	2.41375	0.804583	872.44	<.001
Residual	12	0.011067	0.000922		
Total	23	3.83265			

Variate 5: Number of Branches in 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0208	0.0104	1	
Irrigation	1	27.5204	27.5204	2641.96	<.001
Residual	2	0.0208	0.0104	0.09	
Soil amendment	3	5.2846	1.7615	15.34	<.001
Irrigation. Soil amendment	3	9.2146	3.0715	26.74	<.001
Residual	12	1.3783	0.1149		
Total	23	43.4396			

Variate 6: Chlorophyll Content (CC) in 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5.5103	2.7551	19.52	
Irrigation	1	57.691	57.691	408.71	0.002
Residual	2	0.2823	0.1412	0.43	
Soil amendment	3	9.8589	3.2863	9.92	0.001
Irrigation. Soil amendment	3	3.6131	1.2044	3.64	0.045
Residual	12	3.9744	0.3312		
Total	23	80.93			

Variate 7: Number of leaves per plant in 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.3875	0.1938	1.16	
Irrigation	1	361.849	361.849	2160.24	<.001
Residual	2	0.335	0.1675	0.98	
Soil amendment	3	55.2738	18.4246	107.28	<.001
Irrigation. Soil amendment	3	326.1653	108.7218	633.06	<.001
Residual	12	2.0609	0.1717		
Total	23	746.0716			

Variate 8: Yield Production

1. **Analysis of variance: Fruit length (cm)**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.8125	0.4062	0.43	
Irrigation	1	61.1204	61.1204	64.48	0.015
Residual	2	1.8958	0.9479	3.85	
Soil amendment	3	15.8446	5.2815	21.42	<.001
Irrigation. Soil amendment	3	1.7446	0.5815	2.36	0.123
Residual	12	2.9583	0.2465		
Total	23	84.3763			

2. Analysis of variance: Fruit weight (tones /hectare)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.4375	0.2187	0.15	
Irrigation	1	1497.8400	1497.8400	1053.89	<.001
Residual	2	2.8425	1.4212	1.94	
Soil amendment	3	804.2433	268.0811	365.01	<.001
Irrigation. Soil amendment	3	160.2233	53.4078	72.72	<.001
Residual	12	8.8133	0.7344		
Total	23	2474.4000			

3. Analysis of variance: Fruit width (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.024825	0.012412	4.03	
Irrigation	1	0.814017	0.814017	264.36	0.004
Residual	2	0.006158	0.003079	1.61	
Soil amendment	3	0.214050	0.071350	37.31	<.001
Irrigation. Soil amendment	3	0.024050	0.008017	4.19	0.030
Residual	12	0.022950	0.001912		
Total	23	1.106050			

4. Anova on pods number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.04083	0.02042	0.30	
Irrigation	1	33.60667	33.60667	494.82	0.002
Residual	2	0.13583	0.06792	1.24	
Soil amendment	3	27.16167	9.05389	165.45	<.001
Irrigation. Soil amendment	3	2.35667	0.78556	14.36	<.001
Residual	12	0.65667	0.05472		
Total	23	63.95833			

5. Analysis of variance: Pod weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.896	1.448	0.83	
Irrigation	1	1970.006	1970.006	1134.87	<.001
Residual	2	3.472	1.736	1.09	
Soil amendment	3	979.474	326.491	205.63	<.001
Irrigation. Soil amendment	3	355.604	118.535	74.65	<.001
Residual	12	19.053	1.588		
Total	23	3330.506			

6. Variance Analysis: WUE (kg /m3)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.745	2.373	0.67	
Irrigation	1	2430.496	2430.496	684.17	0.001
Residual	2	7.105	3.552	1.26	
Soil amendment	3	676.427	225.476	80.03	<.001
Irrigation. Soil amendment	3	47.343	15.781	5.60	0.012
Residual	12	33.809	2.817		
Total	23	3199.926			