UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF SUPPLEMENTARY IRRIGATION AND FERTILIZER LEVELS ON GROWTH AND YIELD OF CHILI PEPPER (*Capsicum annuum* L.) AND OKRO (*Abelmoschus esculentus* L.) IN NORTHERN REGION OF GHANA

ALAAZI TERAH AKANGAAMKUM

2023

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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

2023

DECLARATION

DECLARATION BY CANDIDATE

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for a 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.

Alaazi Terah Akangaamkum (UDS/MID/0003/21)	Signature	19th July, 2023 Date

DECLARATION BY SUPERVISORS

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

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ABSTRACT

Soil moisture and fertility are the most predominant factors influencing crops productivity. The rainfall pattern in northern Ghana is often not reliable and hence leads to drought during the wet season. This has been reported to have a major effect on vegetable production. Therefore, rainfall needs to be supplemented by irrigation to fully utilize the potential of the agricultural soils and improve yield. The main objective of the study was to assess the effect of supplemental irrigation and fertilizer (nitrogen, phosphorus and potassium (NPK 15-15-15)) levels on Chili pepper and Okro growth and yield. The experiment was conducted at Nyankpala in the Guinea Savannah Agro-ecological zone of Ghana during the 2022 wet season. The study was a 4 x 2 x 2 factorial experiment laid out in Randomized Complete Block Design (RCBD) with 3 replications. The treatments included two (2) crops (Chili pepper and Okro), four (4) levels of inorganic fertilizer (0 kgha^{-1}, 100 kgha^{-1}, 150 kgha^{-1} and 200 kgha^{-1} in Chili pepper and 0 kgha^{-1}, 150 kgha^{-1}, 200 kgha^{-1} and 250 kgha^{-1} in Okro), rainfed (RF) and Supplemental Irrigation (SI) using spray tubes system. The results showed that, crop water requirement of Chili pepper and Okro were estimated at 459.90 mm and 263.0 mm respectively. The main effect of SI and 200 kgha^{-1} fertilizer level recorded the highest plant height in both Chili pepper and Okro respectively. SI and 200 kgha^{-1} and SI and 250 kgha^{-1} fertilizer level produced the highest number of leaves in Chili pepper and Okro respectively. SI recorded the highest number of flowers per plant in Chili pepper (12.00), leaf area (16.50 cm^2), Leaf Area Index (LAI) (0.00461) of Chili pepper, LAI (0.00824) of Okro, fruit diameter of Okro (34.90 mm) and number of fruits of both crops. Fertilizer application at 200 kgha^{-1} recorded the maximum leaf area (86.80 cm^2) in Okro. Fertilizer application at 200 kgha^{-1} recorded chlorophyll content of 71.60 spads in Okro whilst SI recorded the highest chlorophyll content of 69.50 spad in Chili pepper. SI + 250 kgha^{-1} fertilizer dosage (51.73 spad) recorded the highest chlorophyll content of 51.73 spad in Okro. SI + 200 kgha^{-1} fertilizer level produced the highest biomass in Chili pepper and Okro. The SI treatment produced the maximum yield of 3.51 tons/ha in Chili pepper and the maximum yield of 1.80 tons/ha in Okro. A Gross Margin (GM) of Gh¢ 7,539.30/ha and Gh¢ 3,707.90/ha in SI Chili pepper and Okro respectively. Under rainfed, GM of Gh¢ 2,000 and Gh¢ 1,112.40 for Chili pepper and Okro respectively. Overall, the application of fertilizer level at 200 kg/ha at the initial stage of the crop and SI spray tube irrigation system is recommended for maximum Chili pepper and Okro growth, yield and gross margin. There was no significant difference in the crop water productivity of SI and rainfed crops.

ACKNOWLEDGEMENTS

To start with, I am very grateful to the living God for giving me an outstanding guidance and wisdom to complete this MPhil. thesis. This thesis was made possible through the support provided by the West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, Ghana with funding support from the Government of Ghana and World Bank through the African Center of Excellence for Development Impact (ACE Impact) initiative.

Had it not been the consistent and systematic guidance, suggestion, inputs and advice of my project supervisors; Dr. Thomas Apusiga Adongo and Dr. Sylvester N. Ayambila this thesis would not have been successful. I am extremely grateful for their immense support and guidance throughout the academic journey. I am equally indebted to all the staff of WACWISA especially the Director, Ing. Prof. Felix K. Abagale, administrator, Mr. Bernard Alando and the staff of School of Engineering for contributing in one way or the other to the success of the programme.

I also acknowledge my mother, Mama Ayogsimboka and brothers, Prof. Dominic Alaazi and Mr. Simeon Alaazi who have been my backbone and source of motivation since the beginning of the academic journey.

Finally, I will also like to thank everyone who provided assistance to me during the field experiment. May the good lord bless you in every area of endeavors.

DEDICATION

I dedicate this thesis to my beloved brother, Prof. Dominic Alaazi whose unwavering support, boundless love and constant encouragement have shaped my life. May God bless you abundantly.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CSIR	Council for Scientific and Industrial Research Institute
CWR	Crop Water Requirement
DU	Distribution Uniformity
FAO	Food And Agriculture Organization
FC	Field Capacity
LSD	Least Significant Difference
NGOs	Non-Government Organizations
NPK	Nitrogen, Phosphorus and Potassium
PVC	Polyvinyl Chloride
PWP	Permanent Wilting Point
RAW	Readily Available Water
SARI	Savanna Agricultural Research Institute
SEM	Standard Error of Means
SI	Supplementary Irrigation
SPIS	Solar Powered Irrigation System
SWC	Soil Water Content
TAW	Total Available Water
TDR	Time Domain Reflectometry
UC	Uniformity Coefficient
UDS	University for Development Studies
USA	United States of America

USDA	United States Department of Agriculture
VWC	Volumetric Water Content
WAS	Weeks after Sowing
WAT	Weeks after Transplanting
WP	Water Productivity
WUE	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background

Chili pepper (*Capsicum annuum* L.) is an important crop worldwide, with an estimated rate of 25 % of people consuming it every day. It is a Solanaceous family, native to Mexico, Central America and South America (Basu and De, 2003). Given their economic importance, it is an important crop in many parts of the world, ranking second in global production. It is one of the most popular and high value vegetable crops grown for its fruits throughout the world (Saqib and Anjum, 2021). Chili pepper is one of the most popular crops grown by smallholder farmers due to its high dema nd and capacity to withstand different climatic conditions with 31 million tons produced on approximately 1.9 million hectares of land (Garruna-Hernandez *et al*., 2014).

Recent studies show that Chili pepper is a good source of vitamins A and C, which are essential for the body optimal function. It has many vital benefits such as adding taste, flavors, pungency and colour to meals (Kumar *et al.*, 2006; Bridgemohan *et al*., 2017). It is often believed that including pepper in one's diet can help treat people with fever, cold, indigestion, constipation and pain (Dagnoko *et al*., 2013).

Okro is a vegetable crop that belong to the Malvaceae family. Globally, it is estimated that six (6) million metric tons of Okro are produced as fresh fruits vegetables annually (Das *et al*., 2022). The leading producers of Okro are Nigeria, Sudan, Ivory Coast, Ghana, Benin and Egypt (Adigun *et al*., 2018). Okro is an important vegetable crop grown for its immature pods, which are eaten raw or cooked and used to prepare salads, soups and stews (Kashif *et al*., 2008). It is rich in essential and non-essential amino acids as well as contributes significantly to human nutrition by providing nutrients such as protein, carbohydrates, vitamins, fat and minerals that are typically lacking in most staple foods. The pods are among vegetables with extremely low calories and no cholesterol or saturated fats.

The crop is commonly grown by farmers in Ghana under conditions of rain-fed agriculture, despite the crop's high economic value and the potential for high output in Ghana. For higher yield, Okro requires enough water with fertilizer application and soil that is generally moist throughout the growth season. Due to water shortages caused by conflicting water demands from other economic sectors, such as rapid industrialization and rapid population increase, food production has recently been significantly hindered (Konyeha and Alatise, 2013). Given that the agricultural industry uses more water than other sectors and since our rainfall patterns are unpredictable, it is essential to manage water resources properly (Norman *et al*., 2013). Irregular rainfalls patterns necessitate the introduction of diverse methods that will help supply water to crops during drought spells. Therefore, supplementary irrigation (SI) is considered an alternative. In order to improve and stabilize required growth and yields of crops, SI which is the application of limited amounts of water to primarily rain-fed crops when the precipitation is unable to provide enough moisture for proper plant growth is required (Nangia *et al*., 2018).

During dry spells, supplemental irrigation is an effective way to mitigate the negative effects of soil moisture stress on rain-fed crops growth and yield. In dry rain-fed locations, a lack of soil moisture occurs frequently during the most critical phase of the crop growth usually at the flowering and grain and filling phase (Oweis *et al*., 2012). As a result, rain-fed crop growth is poor and yield turns out to be low, therefore, supplemental irrigation increases yield and water productivity significantly, especially when given during critical crop growth stages (WP).

1.2 Problem Statement and Justification

After tomato, Chili pepper and Okro are ranked the second world most important vegetables (Dessie *et al*., 2017). They are essential to the traditional diets, food security and livelihoods of farmers in most households. Ghana has a competitive advantage to be a major exporter of Chili pepper and Okro, which can generate foreign income to help the country's socioeconomic development (Addo and Marshall, 2000). According to Robert *et al*. (2021), vegetables production by smallholder farmers in Ghana is highly profitable. Furthermore, demand for Chili pepper and Okro is increasing rapidly on both domestic and international markets, providing farmers with an excellent opportunity to increase yield in the country, optimize revenues and ultimately improve their standard of living.

Despite the crops numerous advantages and its potentials, Inusah *et al*. (2015) established that, their production is mostly under rain-fed conditions which is often unreliable, resulting in a massive drop in yield during the growth season. Soil moisture deficit and poor soil fertility are common in rainy season in tropical regions which mostly occur during the sensitive growth stages of the crops (flowering and seed filling). Also, soil moisture and fertility are the most predominant factors influencing the crops productivity.

Dry spell stress due to erratic and low rainfall during the critical crop development periods considerably reduces crop yield which cannot be regained by subsequent application of water. The low yield of vegetables in northern Ghana is likely to be enhanced by increasing soil fertility with the right fertilizer rate and keeping the right amount of soil moisture. It therefore, becomes necessary to employ technology that can increase soil moisture and fertility for increase in crop growth and yield (Nimatu *et al*., 2022). Previous research revealed that NPK 15-15-15 is one of the quickest and simplest techniques to enhance improve soil fertility and enhance yield.

It has been established that Okro and Chili plants establishment, vegetative and reproductive growth (fruit setting stages) are vulnerable to water stress and there is the need to ensure continuous water availability. There is also the need to improve drought mitigation strategies to minimize the effect of the drought spell on the productivity and therefore, supplementary irrigation is the best alternative to reduce water stress condition and ensure continuous availability of water (moisture) throughout the growing season. Previous studies considered the effect of SI on pepper but little is known on its effect on Okro and combining SI with different fertilizer rates. Applying a limited amount of water at the critical periods of crop growth increases yield and water productivity significantly. SI is therefore an effective method of minimizing the detrimental effects of soil moisture stress on the yields of rainfed crops during dry periods. Aside improving yield, SI also stabilizes rainfed crops and reduces crop failure (Oweis and Hachum, 2003).

The significance of the study was to assess the effects of supplemental irrigation and fertilizer levels (NPK 15- 15-15) on Chili pepper and Okro productivity in Northern Region of Ghana. The study's significance also lies in its potential to improve agricultural productivity, enhance food security, promote sustainable resource management, and contribute to climate resilience in the Northern Region of Ghana. It addresses important agricultural and environmental challenges while offering practical insights for local farmers and policymakers. It provides farmers with adequate knowledge on the productivity of these vegetables under supplementary irrigation condition. The results of the work will help improve famers' economic status by increasing crop yield and economic returns.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of the study was to assess the effect of supplementary irrigation and fertilizer levels on growth and yield of Chili pepper (*Capsicum annuum*) and Okro (*Abelmoschus esculentus*) in the Northern Region of Ghana

1.3.2 Specific Objectives

The specific objectives of the study were;

1. To determine the physicochemical properties and infiltration characteristics of the soil in the experimental field.
2. To estimate the crop water requirement (CWR) of Chili pepper and Okro in the Guinea Savannah Agro-ecological zone of Ghana.
3. To assess the growth and yield response of Chili pepper and Okro cultivated under supplementary irrigation, rainfed and fertilizer levels.
4. To estimate the cost involved and gross margin of producing the two (2) crops under supplementary irrigation and rainfed.

1.4 Organization of Thesis

Five (5) major chapters make up the thesis. The background of the study, problem statement and justification, objectives and organization of thesis are presented in Chapter One (1). In Chapter Two (2), the pertinent empirical literature is reviewed concerning the taxonomy, origin and distribution of Chili pepper and Okro, Chili pepper and Okro water requirement, sensitivity of Chili pepper and Okro to water stress, supplementary irrigation agriculture, supplementary irrigation scheduling etc. The study's materials and methods are described in Chapter Three (3), including the study regions, how the various data parameters were calculated, data collection techniques, data analysis and spray tubes performance indicators. The results and discussions, as well as the study's conclusions and recommendations, are presented in the fourth (4^{th}) and fifth (5^{th}) chapters respectively.

CHAPTER TWO

LITERATURE REVIEW

2.1 Taxonomy, Origin and Distribution of Chili Pepper

Chili pepper (Capsicum spp.) is a vegetable crop and a member of the Solanaceae family, which also includes the tomato (*Solanum lycopersicum*), potato (*Solanum tuberosum*), tobacco (*Nicotiana tabacum*), and eggplant (*Solanum melongena*) (Barchenger *et al*., 2020). There are approximately twenty-five species of the Chili pepper (Capsicum spp.), five of which are domesticated taxa (Mufeeth and Mubarak, 2021). These taxa include; C. annuum L., C. baccatum L. var. pendulum (Wild) Eshbaugh, C. chinense Jacq., C. frutescens L., and C. pubescens Ruiz and Pavon. Botanists generally agree that the eastern slopes of highland Bolivia are where the Capsicum genus's nuclear origins may be found; from there, the wild Capsicum species spread throughout the Americans, dispersed by birds before humans arrived. After intense interaction and domestication, humans later spread them further (Pickersgill, 2016). It is indigenous to South and Central America and grown all over the world. Its nutritional and medical values are due to the abundance of vitamins C and E in it as well as its antioxidant capabilities, which work to prevent diseases like cancer, cataracts and cardiovascular diseases. The fruit size, shape, color, its ability to adapt to biotic and abiotic stresses and productivity of Chili pepper are some of the traits that vary from variety to variety (Paran and Van Der Knaap, 2007). The world's use of Chili peppers, likely one of the earliest spices or food additives, is steadily increasing. Production from Ghana, Nigeria, and Egypt is all sold on the global market (Glodjinon *et al*., 2021).

2.2 Taxonomy, Origin and Distribution of Okro

Okro, sometimes known as lady's finger, is from the genus, Abelmoschus and family, Malvaceae. There are conflicting assertions regarding its geographic origin, with claims that it came from West Africa, Ethiopia, and South Asia. The plant is grown all over the world in warm, temperate, and tropical climates (Council, 2002). The ancient Egyptians were growing Okro in the 12th century B.C., which originated in or around Ethiopia. Its cultivation extended widely over the Middle East and North Africa (Matthew *et al*., 2018). van Borssum Waalkes (1966) studies on the taxonomy of the genus Abelmoschus are the ones that are the most in-depth. Despite the fact that more than 50 species have been described, eight are the most often accepted (Suneetha *et al*., 2018). Many countries around the world particularly those with tropical and subtropical climates cultivate Okro (Saifullah and Rabbani, 2009; Benchasri, 2012). This crop can be cultivated as a garden crop or on a large commercial farm. Many countries such as Malaysia, Japan, Turkey, India, Iran, West Africa, Afghanistan, Bangladesh, Yugoslavia , Pakistan, Burma, Thailand, India, Cyprus, Brazil, Ethiopia and the Southern United States cultivate Okro plants for commercial purposes (P. Singh et al., 2014).

Okro can be grown on a variety of soil types, although it yields best on fertile, well-drained soils with enough organic matter (Akinyele and Temikotan, 2007). The crop is regularly grown all year round in the tropics and is a nutritious vegetable that is essential for supplying market demand (Ahmed and Lorica, 2002). The world's total area under cultivation in 2009–2010 was 0.43 million hectares, and production total of 4.54 million tons, with India producing 5,784 thousand tons of Okro with a yield of 11.1 tons/ha (Olutola *et al*., 2020).

2.3 Chill Pepper Water Requirement

Chili pepper water requirement depends on the variety, type and the developmental phase of the crop (Allen *et al*., 1998), the timing and duration of planting, the soil's physical properties, the water distribution system, the distance between the water supply and the planting area, and the overall area of the land where the plant will be cultivated (Kurnia, 2004). The crop coefficient (K_c) of Chili pepper depends on the crop growth phase. The K_c at the initial phase of Chili pepper growth was 0.391. During the developmental stage of the crop, the crop coefficient moved from 0.391 to 0.68. At the flowering phase, the crop had a K_c value of 1.07. By the late season (time of harvest), the K_c value drops to 0.87. The Kc values vary during the phase of a crop development, increasing from a minimum value at the time of planting to a maximum Kc under full canopy cover (Allen *et al*. (1998). The Kc is frequently used to estimate crop water needs and schedule irrigation intervals (Dirirsa *et al*., 2015; Vieira *et al*., 2016). The water requirements of the Chili pepper are 1.22 mm/day during the initial growth phase (first week after planting). The flowering and fruiting phases required the most water because of the significant volume of water transpired by the flowers and early fruits, in addition to the leaves. As harvest time approaches, the Chili pepper's daily water requirements drop to about 3.73 mm/day; this helps in the fruit's maturity and dissolved solids in the fruit (Mosisa, 2016).

2.4 Okro Water Requirements

Crop water requirement is define as the amount of water needed to replace the water lost by evapotranspiration, which causes crops to lose water to the atmosphere (Yakubu, 2016). On a drip-irrigated field, Danso *et al*. (2015) estimated the seasonal water requirements of Okro in a sandy soil in south-east Ghana and came out with the following results; 236 mm, 269 mm, 233 mm and 233 mm with an average of 243 mm for four seasons. In India, 250 mm, 232 mm, and 279 mm of water were used to irrigate Okro under partial root zone furrow irrigation (Panigrahi and Sahu, 2013). According to a report by Hashim *et al*. (2012) on crop water requirement using a center-pivoted irrigation method, Okro has a water need of 502 mm in Saudi Arabia. According to Jayapiratha *et al*. (2010), the water requirements for Okro under drip irrigation set for 30 minutes and 15 minutes, respectively, were 359 mm and 212 mm. The significance of estimating crop water requirements is to assist the farmer and irrigation engineer in providing the crop with the right amount of water. Additionally, this will maximize water use efficiency (WUE) and address the issue of low crop production caused by water scarcity, especially in arid and semi-arid regions of the world (Yakubu, 2016).

2.5 Sensitivity of Chili Pepper and Okro to Water Stress

The physiology of plant drought tolerance has been researched over the past few years. Plants have a variety of mechanisms for adapting to drought, including characteristics that maintain high tissue content and those that can withstand tolerance to low water concentrations (Farooq *et al*., 2009). The response of the plants to drought is divided into three categories: tolerance; where plants can tolerate water insecurity or be able to survive with low water potential; escape; where plants finish their life cycle before the occurrence of drought in order to maintain some of their reproductive processes; and avoidance; where plants can maintain tissue hydration during drought (Manavalan and Nguyen, 2017). Chili peppers are known for being sensitive plants, both to low and high-water availability (Kramer and Boyer, 1995). This plant is vulnerable to stress conditions throughout the flowering and fruit-development stages, which are regarded as the most critical phases of Chili pepper plant growth (Okunlola *et al*., 2017). The low productivity of Chili pepper can be attributed to a variety of factors, including environmental factors such as drought and a lack of suitable agricultural land. The availability of arable land, the accessibility of water and light, and the use of fertilizers are examples of environmental factors. It is required to conduct research on the availability of water to physiological parameters, including crop growth outcomes and capsaicin levels of the Capsicum frutescens cayenne pepper fruit, in order to meet the demand figures for Chili peppers and stabilize their price (Lathifah and Siswanti, 2022).

One of the most prevalent challenges in Okro production is drought. It significantly lowers plant biomass, which reduces crop productivity (Chakraborty *et al*., 2018; Dubois and Inzé, 2020). When there is a drought, both water and nutrients may be less readily available than when there is enough water (Rouphael *et al*., 2012). Inadequate moisture frequently reduces the availability of nutrients, especially P, as low soil moisture can disrupt nutrient diffusion and mass flow (He and Dijkstra, 2014). The first organ to detect variations in soil moisture is the plant root. As a result, key adaptations to drought stress include root morphological and physiological responses (Wang *et al*., 2016). Moreover, in times of low soil moisture, plants frequently redistribute nutrients to support root growth rather than shoot growth, increasing root growth into deeper soil layers (Kunert *et al*., 2016). The most destructive abiotic stress to crop growth and productivity worldwide is heat and water stress combined, which increases evapotranspiration and lowers photosynthetic rate (Lamaoui *et al*., 2018). Both heat and drought stresses are significant threats that affect and limits plant photosynthetic rate and stomatal function of crops (Silva *et al*., 2010).

2.6 Irrigated Agriculture

According to Blasi *et al*. (2021), irrigation is the artificial means of supplying water to crops. Venot *et al*. (2014) also described irrigation as the process of providing water to crops using methods that cater for their demands and correspond with the climatic, agricultural, and other conditions that work best for the selected irrigation systems. It is designed to reduce drought in semiarid or subhumid areas while facilitating the establishment of suitable crops. Even in areas with average seasonal precipitation that may seem enough, traditional rainfed agriculture is a high-risk enterprise because rainfalls is frequently erratically distributed, or soils have inadequate water retention capacity. Irrigation aids in stable food production. In some regions, irrigation can help stretch the growing season.

Previous studies showed that the security offered by irrigation agriculture made it feasible to use other farm inputs like higher-yielding varieties, fertilizer, better pest management, and improved tillage. It therefore lessens the possibility that these costly inputs may be wasted due to drought (Blasi *et al*., 2021). A lack of rainfall or rainfall that is erratic has an adverse impact on agriculture. Low rainfall results in droughts and famines. Even in areas with little rainfall, irrigation helps to enhance productivity.

Irrigation as an abiotic factor aimed at supplying water to the soil for crop uptake has several key merits:

1. Irrigation contributes to improved productivity in areas experiencing insufficient rains or rainfall that is erratic has an adverse impact on agriculture.
2. Compared to unirrigated land, irrigated land has a higher productivity.
3. Most of the fallow land has now been put under agriculture due to irrigation.
4. Output and yield levels have been stabilized through irrigation.
5. The availability of water is increased by irrigation, thereby increasing the farmers' income.

2.7 Spray Tube Irrigation Method

Spray tube also called a rain hose or sprinkler hose is a set of polythene made pipes used for irrigating crops. Spray tube irrigation systems work like sprinklers; technically, they are also sprinklers since they spray water to crops. The spray tubes irrigation system uses hoses or tapes that resembles sprinklers to apply water to crops. Farmers may grow crops all year long and receive the best output even in dry seasons with the help of this system. The water is evenly distributed by a system of spray tubes, which accelerates seed germination and increases seedling survival after planting.

Pumps are typically used to distribute water across the system pipes. Water is sprayed into the air using the spray tubes irrigation technique, where it breaks down into tiny water drops and falls to the ground as rain. The spray is created when water is forced under pressure through tiny orifices or pores (Ransford *et al*., 2019). Modern spray tube irrigation technologies typically use pipes to transport water which reduces water waste. Systems for spray tube irrigation appear to have a lot of potential for increasing the water use efficiency of crops. Although spray tube irrigation boosts crop production and yields in terms of water savings, one issue is the uniform distribution or the irrigation that is delivered consistently throughout the entire area where the water is required (Ransford *et al*., 2019). A typical spray tube irrigation system consists of a pump, power source, a water source, pipes, spray tubes, valves and end pegs.

Plate 2.1: Spray Tube Irrigation System
(Source: WACWISA field)

Spray tube is an accessory of the irrigation system which serves as water-saving equipment that requires low water pressure, saving electricity and water usage. This system though adequately not put to use but has the following advantages:

1. The spray tube system sprays water evenly, helping to improve the germination rate of seeds and the survival rate of seedlings.
2. The system is anti-clogging, lower costs, lower hydraulic pressure, fewer investments, and simple assembly and disassembly.
3. Since the system sprays water uniformly and gently, the soil does not become compacted and rigid.
4. There will be no room for any water to remain in the pipe because the water supply is adequate.
5. It mists irrigation water like light rain, which is safe for crops. Moreover, a variety of fruits, vegetables and flowers can be grown under this system.

6. Using the equipment in late afternoon reduces the survival rate of moths (harmful insects) and thus, reduces the amount of pesticides usage.

2.8 Supplementary Irrigation Agriculture

When rainfall is insufficient to supply enough moisture for regular plant growth, supplementary irrigation (SI) is used to augment rain-fed crops with a little amount of water to increase and stabilize yields (Nangia *et al*., 2018). SI relies on precipitation as its primary source of water.

The best option for increasing crop yields is SI using rainwater, harvested in an excavated or embanked reservoirs, or dryland farming combined with limited irrigation. When rainfall is insufficient to maintain the required soil moisture to guarantee a harvest, this system is quite efficient in supplying water. Irrigation scheduling in such systems is not meant to entirely satisfy the crop water requirements, rather, the importance of this system is its ability to bridge dry spells, which reduces risks in rainfed agriculture (Singh and Sidhu, 2014). Water harvesting can be used to collect runoff from rainfall in small storage facilities (100-1000 m^3) in rainfed areas so that it can be used as supplemental irrigation for agricultural purposes. Using runoff water effectively requires both efficient water application techniques and timing irrigation to the crop in relation to sensitive stages of the crop development. To get the highest WUE, supplementary irrigation should be used at crucial growth phases. There is broad agreement by researchers that the reproductive growth stage is the most sensitive crop stage to water shortage, especially in rainfed agriculture that is prone to drought (Merah, 2001; Blum, 2009).

Additionally, in the majority of rainfed ecosystems, rainfall throughout the crop season decreases towards the time of flowering and harvest. According to Sharma *et al*. (2010), an average increase of 50 % in overall production can be estimated if a portion of India's potential rainfed cultivated area of 114 billion m^3 of excess rainfall is harvested for a single supplemental irrigation of rainfed crops. With improvements in agronomic practices, rainfed crop productivity can be tripled compared with traditional crop yields (Sharma *et al*., 2005). For different crop, the productivity increase as a result of supplemental irrigation typically ranges between 14 % and 74 % (Singh and Sidhu, 2014). Zongo *et al*. (2015) indicated farmers' willingness to employ supplementary irrigation systems. However, farmers and extension officers continue to face difficulties due to financial limitations and a lack of information regarding the scheduling of supplemental irrigation (Raju, 2016).

2.9 Crop Response to Supplementary Irrigation

The best option for increasing agricultural yields in this area is supplemental irrigation using harvested rainwater in a reservoirs, or dryland farming combined with minimal irrigation (Deng *et al*., 2006). When rainfall is not enough to provide the required soil moisture to ensure a harvest, this technique is very effective in supplying water. It was discovered that in Northern Syria, using only 50 % of the entire supplemental irrigation would increase yield by 10 to 15 % while using the saved water to irrigate lands that would have otherwise relied only on rainfed increased overall farm production by 38 % (Oweis and Hachum, 2006). The key to increased production is reducing soil moisture stress during the critical periods of crop growth. The scientists came to the conclusion that avoiding drought through supplemental irrigation during early flowering and maturity was the main factor of enhanced crop yield (Ghanbari-Malidarreh *et al*., 2011). More irrigation is required in this region to increase vegetables yield, yield components and ensure food security.

2.10 Supplementary Irrigation Water Requirement

Calculating the amount of water required to make up for the water lost through evapotranspiration (ETc) requires reference evapotranspiration (ETo) and different crop coefficients (Kc) provided by Allen *et al*. (1998) for the mid-season stage and for the late-season stage.

Throughout the growing season, crop water requirements (ET_c) were calculated using the CROPWAT software by employing ETo and crop coefficient (Kc).

$ETc = ETo \ x \ Kc$……………………………………………Equation 2.1

Where:

ETc–Actual evapotranspiration (mm/day),

Kc – crop coefficient and

ET_o – Reference crop evapotranspiration (mm/day).

The net irrigation requirement was determined using the CROPWAT software.

$IRn = ETc - Pe$ ……………………………………… Equation 2.2

Where:

IRn – Net irrigation requirement (mm), and

ET_c– Evapotranspiration (mm)

Pe –Effective rainfall (mm)

Estimation of the effective rainfall (pe) was done using the method proposed by Allen *et al.* (1998).

$Pe = 0.6 \ xP - \frac{10}{3} for \ P \ month > 70 \ mm$……………………… Equation 2.3

$Pe = 0.8 \ x \ p - \frac{24}{3} \ for \ P \ month < 70 \ mm$……………………… Equation 2.4

Where:

Pe - Effective rainfall (mm) and P - Total rainfall (mm).

2.11 Supplementary Irrigation Scheduling

Irrigation scheduling refers to making decisions about when and how much water to apply to a crop. Managers of irrigation systems use irrigation scheduling as a tool to choose the appropriate frequency and duration of watering. In order to increase productivity and minimize adverse environmental effects, good scheduling will apply water at the appropriate time and in the right amount (Ibrahim and de Niamey, 2020). In order to encourage root growth, efficient nutrient use, and the avoidance of water stress, irrigation scheduling seeks to supply just enough water to completely wet the plant's root zone and to allow the soil to dry out between watering (Ibrahim and de Niamey, 2020). Small farms agronomic and economic viability is influenced by appropriate irrigation scheduling because it ensures water savings and increased yield (Nangia *et al*., 2018). Scheduling irrigation depends on the crop water requirements and the soil moisture status.

Irrigation is frequently planned based on the moisture content of the soil when a portion of the soil moisture has been depleted by the crop. Gypsum block, gravimetric, tensiometer and neutron scattering methods were used in the past to measure and estimate Soil Water Content (SWC) for irrigation scheduling, but these techniques had many limitations (Blonquist Jr *et al*., 2006), as a result, models and sensors are currently been used to measure the in-situ water content of soil due to recent technological advancements. In most experiments, moisture content of the soil is measured using Time Domain Reflectometry (TDR) with sensors.

2.12 Rainfed Agriculture

"Rainfed farming" refers to the kind of agriculture that is dependent on the whims of the weather such as rainfall. Rainfed agriculture still provides the most of the food for hungry communities in developing countries, although its significance varies by area. Compared to over 90 % of the agricultural land in Latin America, 60 % in South Asia, 65 % in East Asia, and 75 % in the Near East and North Africa, more than 95 % of the agricultural area in sub-Saharan Africa is rainfed (Organization, 2005). Most nations rely heavily on rainfed agriculture to produce the most of their food. Despite significant progress achieved in many developing countries in enhancing productivity and environmental condition, many poor families still live in poverty, hunger, food insecurity and malnutrition in places where rainfed agriculture is the primary agricultural activity, particularly in Africa and Asia (Wani *et al*., 2009). Several developing countries nations with dry or semi-arid climates have a difficult time getting enough water for the growth of rain-fed crops. However, rainfall in semi-arid regions may be sufficient each year to support crop growth, but because it is dispersed so unevenly over time or distance, rainfed agriculture is not viable (Rosegrant *et al*., 2002). Problems with water scarcity in dry areas are simply the result of insufficient rainfall.

2.13 Water Use Efficiency (WUE) in Irrigated Agriculture

With a growing population, higher need for food and fiber, and the predicted negative effects of climate change, there is an increasing need for fresh water resources, and this trend is projected to continue. There is universal agreement that irrigated agriculture will face challenges from a future with less water**.** Compared to other industries, agriculture is frequently characterized by inefficiency and reduced profitability. Comparably, Wallace and Gregory (2002) estimated lower values for irrigated agriculture. The greatest water concern in the world today is thought to be future water scarcity (Jury and Vaux Jr, 2007). Water supply may soon be a constraint on world food production as it will be more challenging to locate new water sources for agriculture due to competition from other industries. It is obvious that increasing the water use efficiency for food production is the best way to address this competition for water resources.

Literally, efficiency is a measure of the output produced from a given input (Danso, 2014). The type of inputs and outputs under consideration might define the water use efficiency in irrigated agriculture. WUE is a measurement of how productive water is used by crops. WUE in terms of economic criteria, is the financial return from crop produced per volume of water utilized (Kadigi, 2004). From an agronomic perspective, WUE is the crop yield per volume of water (rainfall and irrigation) used to produce that yield (Fan *et al*., 2005). The ratio of biomass accumulation to water consumption, which is typically expressed as transpiration, evapotranspiration (ET), or total water input to the system, is known as water use efficiency.

To improve WUE in rain-fed and irrigated agriculture, many measures are required. Breeding crop types with efficient water use is one approach. Others include improved water resource management and better agriculture management. By using water-saving irrigation techniques like drip and spray tube irrigation, water use efficiency can also be increased (Costa *et al*., 2007). WUE is calculated as

$$WUE = \frac{\textbf{Yield}\ (\textbf{YD})(\frac{kg}{ha})}{\textbf{Quantity of water used}\ (\textbf{WU})(\textbf{m3})} \quad \text{...Equation 2.1}$$

2.14 Fertilizer Application and Recommendations

It has been reported that the use of poor soil fertility, low-yielding cultivars, insufficient soil moisture, especially during the dry season and a reduction in agricultural land are the main causes of the low yield from farmers' fields, especially in Northern Ghana (Nyarko *et al*., 2011). The Northern region's low yield and poor Chili pepper and Okro quality are likely to be enhanced by increasing soil fertility with the right fertilizer rate and ensuring there is suitable soil moisture. NPK is one of the most popular fertilizers for use during sowing because it meets the demands of crops after sowing or transplanting. The 15-15-15 complex fertilizer with Sulphur is a highly adaptable fertilizer with a perfect balance of nitrogen, phosphorus, and potassium. Olaniyi and Ojetayo (2010) proposed that NPK is one of the quickest and simplest way of increasing the development and yield of vegetables. Farmers in Ghana typically produce less pepper than they should, primarily due to poor soil fertility. The recommended rate of fertilizer as well as management practices for obtaining the most of the fertilizer investment while preserving the environment are included in fertilizer recommendations. Hochmuth and Hanlon (2010a) provided a summary of these principles for fertilization of vegetables. Only a portion of the current fertilizer recommendation is based on rate. Good fertilizer recommendations also take fertilizer components, application, and duration into account, among other things (Hochmuth and Hanlon, 2010b). The commercial output and quality, the economics of crop production, and environmental protection are all addressed in the fertilization recommendations.

2.15 Soil Field Capacity

Field capacity (FC) refers to the soil water content after sufficient drainage has reduced (Mulazzani *et al*., 2022). This term is symbolically expressed as θ_{FC}. Even though it is the discontinuity of the water films in soil pores, there are several interpretations based on a particular matric potential, time after thorough soaking, or minimal flow rate at the bottom of the profile. Field capacity is normally measured in the lab after desorbing an undisturbed soil sample to a certain matric potential (usually 300 or 100 Pa). A soil sample is taken, and its volumetric water content is measured in the field one or two days after the soil has been thoroughly wet. Some field methods employ sensors to assess soil water content and a tensiometer to analyze matric potential.

Field methods are more realistic than output based on modeled flux (Chandler *et al*., 2017). In many soils, the soil begins to drain to deeper levels right away following rain or irrigation. After one or two days, the soil's water content will, over time, for many soils, attain a value that is practically constant for the specific depth in question (Horne and Scotter, 2016).

The origin of "field capacity" is unknown. Briggs and Shantz, who developed the concept of the wilting point, did not include field capacity. According to Briggs, the "moisture equivalent" is the volume of water that can be kept against soil centrifugation at 3000 g, where g stands for acceleration gravity (Landa and Nimmo, 2003). While the term is being outmoded, it served as a precursor to the concept of field capacity. Early researchers noticed that after a rain or irrigation, there was a point at which water moved slowly (Taylor and Ashcroft, 1972). The idea of field capacity emerged because of their desire to give this point value. They identified it as the amount of water that a well-drained soil can store against gravity when downward drainage is significantly reduced. They believed it to be a true equilibrium and the maximum amount of water that could be used by plants (Green *et al*., 2006).

2.16 Permanent Wilting Point (PWP)

The wilting point (WP) or permanent wilting point (PWP) is the lowest amount of water in the soil that a plant needs to avoid wilting. A plant wilts and is no longer able to regain its turgidity after being exposed to a saturated environment for 12 hours if the soil water content falls below this or lower than this level. Conventional knowledge states that the wilting point definition is the water content at 1,500 kPa (15 bar) of suction pressure or negative hydraulic head. This term is symbolically expressed as θ_{pwp} or θ_{wp}

(Vopravil *et al*., 2020). It was first proposed in the early 1910s. The wilting coefficient, first proposed by Lyman Briggs and Homer LeRoy Shantz in 1912, is defined as the percentage water content of the soil. In an atmosphere that is roughly saturated, plants growing there are initially brought to a stage of wilting from which they cannot recover (József, 2015).

The permanent wilting point is significant because it can be used to establish irrigation plans and predict crop yields since it can precisely predict when plants will begin experiencing water stress. This is important in agriculture, as water availability frequently restricts crop growth and productivity (Delgado *et al*., 2023). Permanent wilting point can be determined by process of measuring the water content of soil samples under various pressures and determining when the soil can no longer provide plants with water. This point is often represented as a percentage of the water content of the soil, and for most soils, it ranges between 10 to 15 %. Reduced crop yields and plant water stress are the results of a low wilting coefficient. Moreover, this may result in decreased overall plant health and higher susceptibility to pests and diseases. Climate change, soil degradation and over irrigation are only a few of the causes of low permanent wilting points (Delgado *et al*., 2023). The methods commonly used in the determination of permanent wilting point in soil samples are the filter paper method and the pressure plate method. Monitoring soil moisture levels, implementing conservation measures practices and making necessary adjustments to irrigation schedules are all required to control permanent wilting point effectively.

2.17 Gross Margin Analysis

Many management techniques have been developed to evaluate the technical and financial efficiency of conventional farm business. These include full cost accounting and gross and net margin analysis (Firth, 2002). Also, before doing a comprehensive economic study, the potential for intervention has previously been evaluated using gross margin analysis (Armenia *et al*., 2013).

A Gross margin therefore refers to the difference between the total income derived from a farm enterprise and the variable costs incurred in the enterprise. Sales from both the marketable and non-marketable crop yields make the total revenue. The variable cost consists of direct inputs such as the price of pesticides, fertilizer, fungicides, seeds, materials cost, labor cost, overhead expenses like machine rental (Castillo *et al*., 2021). In comparing gross margin with other enterprises, only figures from farms with similar characteristics and production methods can be used to make the comparison. It creates room to assess the performance of farm businesses with comparable capital and labor requirements. The comparisons can provide a useful indication of an enterprise's production and economic efficiency. Generally, gross margins are useful in organic systems for farms planning and comparing enterprises, whether they are on the same farm, between organic holdings or conventional and organic businesses (Stockdale *et al*., 2001). It does not often include fixed costs (administration, insurance, rates, taxes etc.) and capital costs (buildings, land, irrigation kits, machinery etc.), hence, it cannot be used to measure farm profit. However, it offers a helpful tool for budgeting, farm management, and estimating the potential profits or losses of a specific crop under production (Mersha *et al*., 2017).

2.18 Estimating Costs and Returns for a Production System

Supplemental irrigation is using water stored in a small reservoir built close to the field to deliver water to crops during the prolonged drought periods that occur during the rainy season (Lodoun *et al*., 2013). Supplemental irrigation, which is based on four principles, allows for the irrigation of a portion of farmland used for intensive production.

(i) The farmer and his family build the pond, perhaps with assistance from the neighbors

(ii) Collecting runoff water from the beginning of the wet season

(iii) The crop selection and

(iv) Using irrigation techniques during drought periods throughout the rainy season.

In order to properly adjust to climate change in the agricultural sector, modern irrigation methods can significantly improve efficiency (Berbel and Mateos, 2014). Cost estimates of production includes labor for agricultural operations, irrigation inputs, land preparation, seeds, cultivation, weeding, fertilizer application, spraying, insecticides and pesticides.

Estimation the gross margin (GM) is done using the difference between the gross product (GP) and the input cost (IC) (Andres and Lebailly, 2011). By multiplying the amount of produce harvested in kilograms (kg) by their market price per kg of the produce gives the gross revenue. Fertilizers (nitrogen, phosphorus and potassium), improved seeds and other production inputs were among the purchased inputs during the season. Each unit cost including hired labor was calculated by multiplying its quantity by its purchasing price. The revenue/GM generated from using supplemental irrigation and rainfed can be determined by the difference in GM between the experimental plot and the total cost of production (Zongo *et al*., 2022).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was conducted at the WACWISA Research Field from July to November, 2022. The study area is within the University for Development Studies, Nyankpala Campus, which lies in the Guinea Savannah Agro-Ecological Zone in the Tolon District of Northern Region of Ghana. It is located 167 m above seas level and 16 km (10 miles) away from the regional capital, Tamale. The area falls within latitude 9°24' N and longitude 0° 59'W. It has a mean annual temperature of 28.5 °C, temperatures typically fluctuate between 15 °C (lowest) to 42 °C (maximum). At noon, the mean annual relative humidity is 54 %. The mean annual rainfall of the area is 1043 mm which is distributed evenly from April to November (Tenakwa *et al*., 2022). The soil of the study area is brown in colour with a mixture of a little gravel and a moderately drained sandy loam texture (Tenakwa *et al.*, 2022). The common crops cultivated in the study area include; bell and Chili pepper, Okro, garden eggs, tomatoes, maize, groundnut, cowpea, soybeans etc.

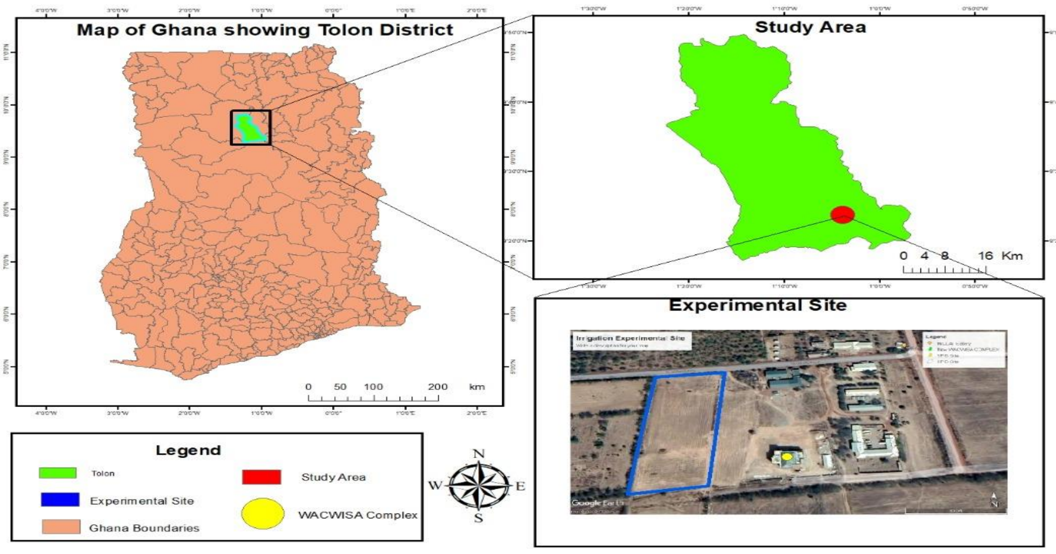

Figure 3.1: Map of Ghana Showing the District of Tolon and the Experimental Area

3.2 Land Preparation and Varietal Selection

The supplementary irrigation and rainfed fields were set differently to avoid any interruption between supplemental irrigated plots and non-supplemental irrigated (rainfed) plots. For both crops (Chili pepper and Okro), a field size of 21.6 m x 16.6 m (0.036 ha) was used and divided into twelve (12) beds each for both Chili pepper and Okro on supplementary irrigation field and the same demarcation was done for the rainfed fields making a total of twenty-four (24) well demarcated beds for each of the crop under investigation. Each bed for the two crops measured 5 m x 2.2 m with an alley of 1 m between beds and 40 cm between plots. The planting distance for the two crops were 45 cm x 45 cm and 60 cm x 50 cm for Chili pepper and Okro respectively.

The experiment used one local variety of Chili pepper (Shamsi 1) and one local variety of Okro (Essoumtem). These varieties were selected due to their availability and adaptability to the weather conditions within the study area. The Chili pepper and Okro certified seeds were both obtained from Agriseed limited. The Chili pepper seeds were nursed on a nursery bed size of 2 m x 2 m for a period of four (4) weeks. The nursery bed was shaded with thatch as mulching to protect seedlings from direct sun light and to reduce harmful effect of water droplets during watering or rainfall. Healthy and viable seedlings were transplanted to the experimental plots at the rate of one seedling per stand with each bed containing forty-four (44) seedlings. Both rainfed and supplementary irrigation beds were initially irrigated to saturation to enable seedlings to recover from the transplanting shock. The Okro certified seeds were planted directly on the beds. Three (3) to four (4) seeds were initially sown per stand and prior to the application of treatments, they were thinned to two (2) seedlings.

3.3 Treatment and Experimental Design

The experiment was a 4 x 2 x 2 factorial, replicated three (3) times and laid out in Randomized Complete Block Design (RCBD). The treatments included four (4) levels of inorganic fertilizer (NPK 15-15-15), supplemental irrigation and rainfed and two (2) crops (Chili pepper and Okro). The supplementary irrigation was done using spray tube irrigation system. The fertilizer (NPK 15-15-15) was applied at a rate of 0 kgha^{-1},100 kgha^{-1},150 kgha^{-1} and 200 kgha^{-1} for the Chili pepper (Table 3.1) and 0 kgha^{-1}, 150 kgha^{-1}, 200 kgha^{-1} and 250 kgha^{-1} for the Okro (Table 3.2). The rates were reached based on the results of the soil analysis for NPK. The treatments combinations were sixteen (16) with crop type the blocking factor.

Table 3.1: Treatment Combination of Chili Pepper

T1	C + SI + NPK 0 kgha^{-1}	**T5**	C + RF + NPK 0 kgha^{-1}
T2	C + SI + NPK 100 kgha^{-1}	**T6**	C + RF + NPK 100 kgha^{-1}
T3	C + SI + NPK 150 kgha^{-1}	**T7**	C +RF + NPK 150 kgha^{-1}
T4	C + SI + NPK 200 kgha^{-1}	**T8**	C +RF + NPK 200 kgha^{-1}

Table 3.2: Treatment Combination of Okro

T9	O + SI + NPK 0 kgha^{-1}	**T13**	O + RF + NPK 0 kgha^{-1}
T10	O + SI + NPK 150 kgha^{-1}	**T14**	O + RF + NPK 150 kgha^{-1}
T11	O + SI + NPK 200 kgha^{-1}	**T15**	O +RF + NPK 200 kgha^{-1}
T12	O + SI + NPK 250 kgha^{-1}	**T16**	O + RF + NPK 250 kgha^{-1}

Where: C =Chili pepper, O = Okro, SI =Supplementary irrigation, RF =Rainfed
NPK = Nitrogen, Phosphorus and Potassium

3.3.1 Supplementary Irrigation Experimental Layout

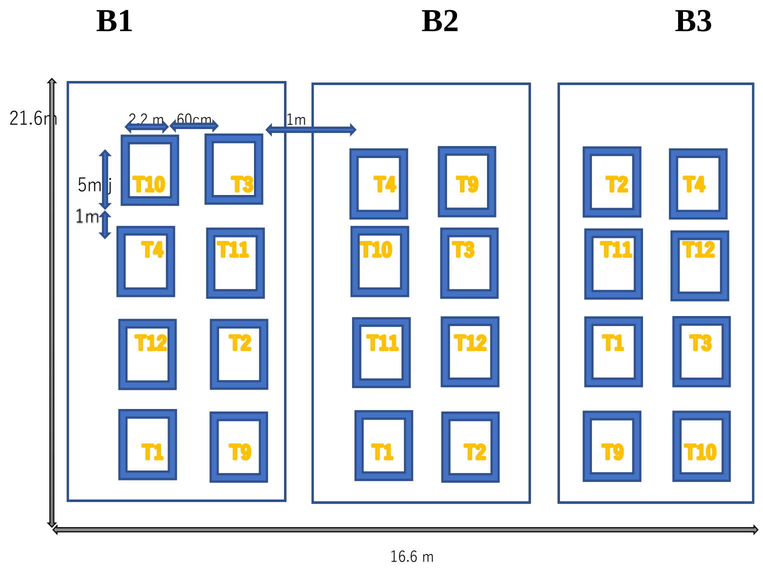

Figure 3.2: The Experimental Layout of Supplementary Irrigation

3.3.2 Rainfed Experimental Layout

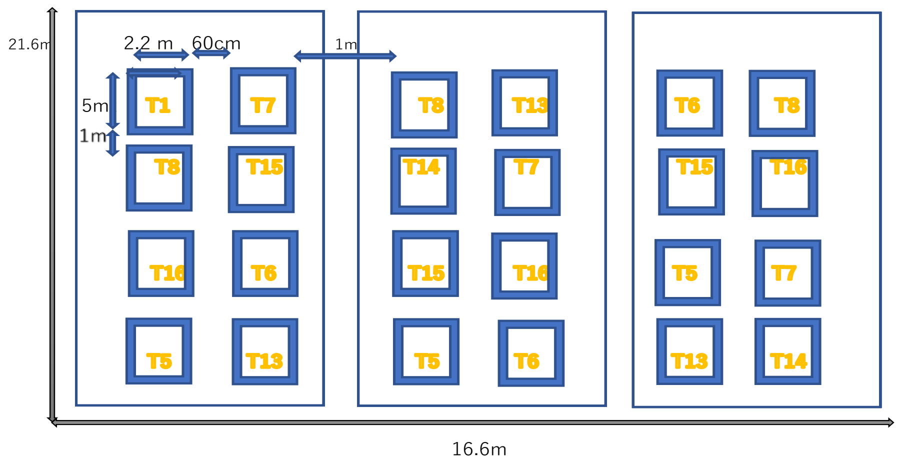

Figure 3.3: The Experimental Layout of Rainfed

3.4 Soil Properties

Zigzag-shaped composite soil samples from the experimental field were collected using soil auger to determine the baseline physicochemical properties prior to transplanting and sowing. Two depths of soil were sampled: 0–20 cm and 20–40 cm to be able to assess the physicochemical properties at both depths. Using a shallow tray and a well-ventilated space, the samples were air dry. The soil lumps were gently crushed to release the pebbles, roots and organic wastes. Gravel was not used in the smashing. The soil was sieved through a 2 mm sieve and the gravels, roots and other debris were then carefully rubbed through the screen. The AgSSiP at the University for Development Studies (UDS) soil laboratory examined the soil's physical properties (particle size distribution, bulk density, FC, PWP) while the CSIR-SARI soil laboratory determined its chemical properties (NPK, EC, PH, OC and OM).

3.5 Determination of Soil Dry Bulk Density

The dry bulk density of the soil was determined using the metal core sampler methods, as reported by Blake and Hartge (1986). The procedure includes;

1. Collect soil samples from a depth of 0-20 cm and 20-40 cm using the sharp-edged cylindrical auger of 5 cm internal diameter. The auger was driven carefully into the soil so that negligible compaction occurs.
2. Measure the mass (g) of the empty core sampler as M_1
3. Take the mass (g) of the soil and the core sampler in the field
4. Once the sample is weighed it will be oven dried at 105°C unless constant weight is achieved. It results in dry mass of the soil as M_2
5. The volume of the core sampler is calculated using the equation below
6. The bulk density is estimated by dividing the dry mass of the soil material ($M_2 - M_1$) by the inner volume of auger (V).

The dry bulk density was determined using equation 3.1.

$$Dry\ bulk\ density\ (g/cm3) = \frac{M_2 - M_1}{V} \qquad \text{......Equation 3.1}$$

Where:

M_1–Mass of empty core sampler (g),

M_2 – Mass of core sampler + oven dried sediment (g),

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

π – 3.142

r – Radius of core sampler (cm) and

h – Height of core sampler (cm).

The following procedure can be used to estimate the bulk density of soil:

3.6 Soil Particle Size Distribution

The soil particle size distribution was examined in a laboratory by using the sieve analysis based on the U.S. Department of Agriculture.

Hydrometer method were employed in the determination of soil particle size distribution where sample were carefully collected using auger and analyzed for gravel, silt, clay and sand. Soil was sieved in 2 mm sieve. 51 g of soil was transferred into plastic beaker and mixed with 100 ml of distilled water and mixed to wet the soil thoroughly after the mixture, 20 ml of 30 % H_2O_2-H_2O_2 were added to destroy soil organic matter, 50 ml of 5 % Sodium Hexamethaphosphate $(NaPO_3)_6$ were also added for soil particle separation and shake well by using mechanical shaker and solution was transferred again in beaker and 1000 ml of distilled water were added. Thermometer was used to measure temperature whiles the hydrometer readings were taken from the hydrometer instrument in 40 second. The same reading procedure were repeated after 3 hours period. Finally, clay, silt and sand percentage were obtained by using equation 3.2, 3.3 and 3.4.

% Sand = $100 - [H1 + 0.2\ (T1 - 20) - 2] \times 2$………. Eqn 3.2

% Clay= $[H2 + 0.2\ (T2 - 20) - 2] \times 2$………………. Eqn 3.3

% Sand= $100 - (\ \%\ clay + \%\ sand$…………………. Eqn 3.4

The value obtained were used to classify soil texture using the soil textural triangle method.

Table 3.3: Soil Classification

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

Source: USDA, 2016

3.7 Soil Chemical Properties

The soil samples were collected from the field and were analyzed for N, P, K, pH, EC, and organic carbon at CSIR-SARI soil laboratory**.** EC is a function of its chemical decomposition and salinity and is quantified in term of the total concentration of the solute salts and measured in Ds/m (Corwin, 2003). Total nitrogen available in the soil was examined by Kjeldahl method while the Bray-P solution method was used to determine phosphorus (P). Flame photometer method was used to determine potassium (K) (Abukari *et al.*, 2018).

3.8 Irrigation Scheduling and Water Use

To be able to determine when and how much water to apply, soil water deficit (D) was determined by measuring the soil moisture content (SWC) after the crop had used up a percentage (p) of the total quantity of total water available (TAW). When the deficit (D) was more than the amount of water that was readily available, irrigation was initiated for the irrigated treatment plots.

3.9 Field Capacity

To determine the moisture content at field capacity, soil samples were collected using the pressure plate apparatus method and then immersed in water for a day (24 hours). A pressure of 0.33 bars was used for moisture extraction (Protocol for Analysis, 2021). The soil moisture in the sample is assessed gravimetrically and equated to field capacity and permanent wilting point when water is no longer leaving the sample. Plate 3.1 illustrates how the field capacity test was conducted using pressure plates in the laboratory.

Plate 3.1: Laboratory Measurement of Field Capacity

3.10 Permanent Wilting Point (PWP)

When the amount of water in soil is held by forces larger than 15 bars, it is known as the PWP and is the lowest point at which a plant may access water (Ewaid *et al*., 2019). This PWP was determined using the membrane device. The semi-disturbed sample was soaked in this arrangement and put inside a man-made ring. A 15-bar compressor high-pressure was attained in the pressure membrane extractor after samples were saturated for 24 hours. The samples were removed after equilibrium was attained, weighed (W1), then dried in an oven at 105 °C before being weighed (W2) again.

$PWP = W1 - W2$ ………………………………………………………… Equation 3.5

Where:

PWP – Permanent wilting point (PWP) (%),

W1 –Soil samples initial weighed before oven drying (g), and

W2 – Final weight of soil samples after oven drying at 105° C.

3.11 Scheduling of Supplementary Irrigation

Permanent wilting point (WP) and field capacity (FC) were determined prior to the transplanting of the Chili pepper seedlings and sowing of the Okro to help in the scheduling of the supplementary irrigation. Prior to each irrigation, soil moisture content was always measured. The length of TDR probe was taken as rooting depth (Zr) (20 cm). Readily available water (RAW), Total available water content (TAW and soil water deficit (D) was estimated using Equations 3.6, 3.7 and 3.8.

3.12 Estimation of Total Available Water (TAW) in the Soil

This was calculated using equation 3.6:

$TAW = (\theta FC - \theta WP)\, Zr$ ……………………………………………….Equation 3.6

TAW –Total available water,

Zr – Depth of the root zone (The length of TDR probe),

θ_{FC}–Soil water content at field capacity (%), and

θ_{WP} – Water content at the permanent wilting point (%).

3.13 Estimation of Readily Available Water (RAW) in the Soil

RAW is the soil moisture held between field capacity and the refill point for unrestricted crop growth. It was estimated using equation 3.7:

$RAW = p \times TAW$ ………………………………………………………… Equation 3.7

Where:

RAW – Readily available soil water,

P – Fraction of TAW depleted by crop at the root zone before water stress occur, and

TAW –Total available water.

3.14 Estimation of Irrigation Deficit

This is the actual amount of water needed to replenish the crop's root zone and bring the soil's current moisture back to field capacity. It was estimated using 3.8 as;

$D = FC - SWC$ ………………………………………………………… Equation 3.8

Where:

D –Soil water deficit,

FC – Field capacity, and

SWC – Soil water content at the time of TDR measurement.

Therefore, the amount of water needed to irrigate the soil back to FC was estimated by comparing the amount of soil water depleted by the crop (D) to the amount of soil water that is readily available water (RAW).

The soil was irrigated back to field capacity whenever the amount depleted was more than the readily available soil water.

3.15 Supplementary Irrigation Water Requirement

The reference evapotranspiration (ETo) and Chili pepper crop coefficient (Kc) given by FAO for the initial stage, mid-season stage and late-season stage were needed to calculate the quantity of water required (CWR) to compensate for the amount of water lost through evapotranspiration

(ETc) (Pandorfi *et al*., 2016). During the growing season, crop water requirements (ETc) were calculated using the CROPWAT software utilizing ETo and crop coefficient (Kc).

$ETc = ETo \times Kc$ ……………………………………………………………Equation 3.9

Where:

ETc –Actual Evapotranspiration (mm/day),

Kc – Crop Coefficient, and

ETo – Reference crop evapotranspiration (mm/day).

The net irrigation requirement was calculated using equation 3.7.

$IRn = ETc - Pe$ …………………………………………………………… Equation 3.10

Where:

IRn – Net irrigation requirement (mm),

ETc -Evapotranspiration of crop (mm), and

Pe – Effective rainfall (mm). The effective rainfall (pe) was estimated using equations 3.11 and 3.12.

$Pe = 0.6 \times P - 10/3 \ for \ P \ month \leq 70mm$…………………………………Equation 3.11

$Pe = 0.8 \times P - 24/3 \ for \ P \ month > 70mm$ …………………………………Equation 3.12

Where:

Pe (mm) –Effective rainfall and

P (mm) –Total rainfall.

3.16 Water Use Efficiency (WUE)

The water use efficiency (WUE) of a crop was determined by dividing its yield per unit area by the seasonal water use (rainfall plus supplemental irrigation). It was calculated using equation 3.13 as;

$$WUE = \frac{Yield(\frac{kg}{ha})}{Quantity\ of\ water\ used(m3)}$$ ....Equation 3.13

The quantity of water used was estimated as the sum of effective rainfall and supplementary irrigation for the supplementary irrigation experimental units while the rainfed volume of water used was basically the effective rainfall. A rain gauge was mounted on the field and after every rainfall, the amount of effective rainfall was measured and recorded in mm in the field note book.

3.17 Coefficient of Uniformity

Uniformity coefficient (UC) of the spray tubes irrigation system was determined using Christiansen's coefficient of uniformity. Under the spray tube system, the UC technique entails arranging a grid of measuring beakers with identical dimensions in a regular grid pattern and measuring the quantities of water collected throughout the course of an experiment with a known duration. It can be assumed that all measurements of application represent the same spatial area across the plot if collection containers are spaced in a regular gridded way. Th UC was finally calculated using Equations 3.14, 3.15 and 3.16.

$$\boldsymbol{UC} = \left(\mathbf{1} - \frac{\boldsymbol{D}}{\boldsymbol{M}}\right) X\ \mathbf{100}$$ ....Equation 3.14

$$\boldsymbol{D} = \frac{\mathbf{1}}{\boldsymbol{n}} \sum_{i=1}^{n} |\boldsymbol{X_i} - \boldsymbol{M}|$$ ....Equation 3.15

$$\boldsymbol{M} = \frac{\mathbf{1}}{\boldsymbol{n}} \sum_{i=1}^{n} \boldsymbol{X_i}$$ ....Equation 3.16

Where:

UC – Coefficient of uniformity (%),

D –Average of the absolute values of the deviation from the mean discharge,

M –Average of water in the catch can values (mm),

Xi – Water in the catch can (mm), and

n – Number of waters in the catch can values.

3.18 Distribution Uniformity

Merriam and Keller (1978) established a methodology for assessing water application uniformity for irrigation systems in the field and derived the following formulas. The distribution uniformity was determined using Equation 3.17 as given by Marriam and Keller.

$$D_u = \frac{q_{1/4}}{q_a} x 100$$ ……………………………………………… Equation 3.17

Where:

DU – Distribution uniformity (%), and

$q_{1/4}$ – Average of water in the catch can for low quarter.

q_a – Overall Average Depth of Application

3.19 Reference Evapotranspiration (ET_o)

To calculate and estimate the daily crop water demand, a climatic parameter called daily ET_o is needed. The FAO Penmann-Monteith (P-M) equation was used in computing ET_o. The basic climatic variables required for estimating ET_o using FAO Penmann-Monteith equation are, Relative humidity (RH), Temperature (T), Net radiation (Rn) for computing vapor pressure deficit (es - ea) and Wind speed (u^2). Other supporting climatic parameters required for computing the ET_o using the FAO P-M model are outlined in details by Allen *et al*. (1998).

The daily ET_o was calculated using a Microsoft Excel spreadsheet and climatic data from the meteorological station. The mean daily climate data were used to calculate the mean monthly ET_o values. Total monthly precipitation during the experimental period was recorded. Equation of the FAO Penman Monteith for calculating ET_o is stated in equation 3.18:

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma\frac{900}{T+273}\ u2(\ es - ea)}{\Delta + \gamma(1 + 0.34u2\ )}$$ ……………………………………………Equation 3.18

Where:

ETo − Reference evapotranspiration [mm day-1]

Rn − Net radiation at the crop surface [MJ m-2 day-1]

G −Soil heat flux density [MJ m-2 day-1]

T − Mean daily air temperature at 2 m height [°C]

u2 − Wind speed at 2 m height [m s-1]

es − Saturation vapor pressure [kPa]

e_a −Actual vapor pressure [kPa]

$(e_s - e_a)$ = Saturated vapor pressure deficit [kPa]

Δ – Slope of vapor pressure curve [kPa °C-1]

γ – Psychrometric constant [kPa °C-1].

3.20 Crop Water Requirement Estimation

The CROPWAT software (FAO, version 8.0) was used in the computation of irrigation water requirements for the two crops varieties. This was done by extracting the climate data from CLIMWAT 2.0 climatic database of fifty-one (51) years (1970-2021) and the data inputted into CROPWAT software for the crop water requirement estimation. The location's coordinates, altitude, and seven long-term monthly climatic characteristics are all included in CLIMWAT. The climate data included the monthly mean and minimum temperatures (in degrees Celsius), the wind speed (in kilometers per hour), the mean relative humidity (in percent), the number of hours of daylight (in hours), the amount of rainfall (in millimeters), and the effective rainfall (mm).

$ETc = ET0 \times Kc$…………………………………….…………………Equation 3.19

Where:

ET_c – Crop evapotranspiration (mm/day),

ET_0 – Reference evapotranspiration (mm), and

K_c –Crop coefficient.

3.21 Estimation of the Net Irrigation Requirement (IRn)

A good understanding of crop irrigation water requirements and irrigation schedules leads to better field irrigation management. The adjusted ET_c under the assumptions of no leaching. The IRn did not account for losses caused during the application of the water. The IRn was calculated using the formula in equation 3.20:

$$IRn = ETc - Pe \quad \text{...Equation 3.20}$$

Where:

$P_e = 0$, therefore, $IR_n = ET_{crop\text{-}localized}$

3.22 Estimation of the Gross Irrigation Requirement (IR_g)

Water losses that happened during transportation and application at the field were considered during gross irrigation requirement estimation. The gross irrigation demand was calculated using a field application efficiency (Ea) of 70 % due to the usage of the spray tubes application method. Previous studies showed that the spray tube irrigation application efficiency normally ranges between 30 % and 70 %. The gross irrigation demand was calculated using equation 3.21.

$$Rg = \frac{IRn}{Ea} \quad \text{...Equation 3.21}$$

Where:

IR_g – Gross irrigation requirement (mm),

IR_n – Net irrigation requirement (mm), and

E_a − Field application efficiency (%).

3.23 Soil Moisture Measurement

Soil moisture was measured every day to monitor the rise and fall of the moisture content of the soil. The Hydrosense II handheld soil moisture sensor meter was used to measure soil moisture. The Hydrosense II soil-water sensor is made up of a strong handle and pole which makes it easier to insert the probes in soil. It takes soil moisture in volumetric water content (VWC %). The supplementary irrigation and amount of water required was done based on the results of the soil moisture meter.

3.24 Fertilizer Application

Inorganic fertilizer (NPK 15−15−15) was used for the Chili pepper at one week after transplanting and prior to flowering and fruit formation as top dressing. 0 kg/ha, 100 kg/ha, 150 kg/ha and 200 kg/ha were used for Chili pepper whereas 0 kg/ha, 150 kg/ha, 200 kg/ha and 250 was applied to Okro. These rates were chosen based on the NPK analysis results. For the Okro, NPK 15−15−15 was also applied two (2) weeks after sowing and was top dressed prior to flowering.

3.25 Pest and Disease Control

For insects and disease control, K-optimal, an insecticide was applied to crops at every five (5) days to prevent insects from feeding on the leaves, flowers and fruits of the crops. When few flowers initially appeared on the Chili pepper and Okro, Technokel, was also applied to enhance flower formation and as well prevent flower and fruit abortion.

3.26 Measurement of Growth and Yield Parameters

The parameters measured were total yield (kg), fruit number (number/plant), yield per plant (g/plant), fruit weight (g), fruit length (cm), plant height (cm), Number of leaves, Leaf area (LA), leaf chlorophyll content, green canopy cover, above ground biomass whereas the leaf area index (LAI) was calculated using the leaf area data. Five (5) plants in each experimental units were properly identified and tagged with sticks for data collection. The data parameters are;

3.27 Above -Ground Biomass (BM)

Five plants were uprooted from each experimental unit at week six (6) after transplanting of the Chili pepper and week seven (7) after sowing of the Okro. The samples from each plot were put into brown envelops and the fresh weight of each sample were measured in grams (g) with an electronic scale. The samples were finally oven dried at 75 ^{o}C for 24 hours in the case of Chili pepper and 48 hours for the Okro. The dried samples were weighed and the difference between the fresh weight and dry weight were recorded as above- ground biomass for the crops.

3.28 Plant Height

Meter rule was used to measure the plant height at every two weeks intervals on five (5) tagged plants but started at the two (2) weeks after transplanting for Chili pepper and four (4) weeks after sowing for Okro. The measurement was taken from the base of the plants on the soil surface to the highest leaf from the ground using a meter rule.

3.29 Leaf Area

The leaf area was measured using a meter rule on five (5) tagged plants. The measurement was done on the newly matured leaves by measuring the length and breadth of the selected leaves. After which the leaf area was calculated as a product of the length and breadth.

3.30 Leaf Area Index (LAI)

The Leaf Area Index (LAI) which is a dimensionless quantity describes a plant canopy. It was calculated using the leaf area per plant using equation 3.22:

$$\text{LAI} = \frac{leaf\ area\ (\text{m2})}{surface\ area(m2)}\ x\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.22}$$

3.31 Number of Fruits per Plant

The fruits from five plants each of Chili pepper and Okro were randomly selected from the net harvest area and counted to obtain the number of fruits per plant and the average was taken.

3.32 Fruit Diameter

This parameter was measured in only Okro. A digital vernier caliper was used in the direct measurement of the fruit diameter in millimeters (mm) for the tagged plants and the average was struck out and recorded as the fruit diameter of that treatment.

3.33 Number of Leaves (NL)

This was done every two (2) weeks up to six (6) weeks after transplanting and sowing. The tagged plants' leaves were manually counted and recorded in the data sheet and the average was determined and recorded as the number of leaves per plant.

3.34 Chlorophyll Content (CC)

The chlorophyll content of the two (2) crops was taken at 6 weeks from four (4) leaves per plant from the tagged plants. This was done with the help of a SPAD chlorophyll meter.

3.35 Number of Flowers per Plant

Each experimental unit's tagged plants' flowers were manually counted to determine the average number of flowers, which was then calculated and recorded.

3.36 Fruit Set Rate Per Plant

Fruit set rate was expressed as a percentage of total flowers as presented in Equation 3.23:

$$\textbf{Fruit Set rate} = \frac{\textbf{Total number of fruits}}{\textbf{Total number of flowers}} \times \mathbf{100}$$ ………………………………….Equation 3.23

3.37 Yield Data

An area of 2 m × 1.5 m of each experimental unit of Chili pepper was harvested and 3 m ×1.5 m area of Okro plots were harvested, counted and weighed in kilograms (kg). After each (series) harvest from each plot and in each replication, the weight of the fresh fruit production was measured using a sensitive electronic scale balance.

3.38 Gross Margin Analysis

Using data from this study, gross margin evaluation and analysis was estimated using the cost of production and revenues accrued. The cost of production inputs such as seeds, insecticides, fungicides, fertilizers, water cost, irrigation system cost and labor were all considered when calculating the production costs for both Chili pepper and Okro growth and development in the research area. The cost of water for SI was considered as the charges for the irrigation system. The parameters used in estimating SI are presented include water cost, cost of irrigation equipment etc. Using the conventional formula, the gross margin for each treatment was calculated by deducting all production expenses from gross incomes: produced income – inputs cost as indicated in equation 3.24.

$$GM = TR - TVC$$ ………………………………………. Equation 3.24

Where:

GM–Gross Margin,

TR–Total Revenue

TVC–Total Variable Cost

TR and TC are indicated as;

$TR = The\ Quantity\ of\ output\ (Qi)\ x\ Unit\ price\ (Pi\ )$……………...…Equation 3.25

$TVC = The\ Quantity\ of\ inputs\ (Xi\ )\ x\ Price(Pj)$……………………………...Equation 3.26

$$GM = \sum_{i=1}^{n} \text{Pi Qi} - \sum_{j=1}^{n} \text{Pj Xj} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.27}$$

Where:

P_i – Average price of output i (Gh¢ per kg),

Q_i – Average quantity of output i (kg per ha),

P_i – Average price of input j (Gh¢ per kg), and

X_i – Average quantity of input j (kg per ha).

Based on equation 3.27, this study employed the following formulae to estimate gross margins for Chili pepper and Okro at the farm level in the study area:

$$\text{GMp} = \sum_{i=1}^{n} \text{Ppi Qpi} - \sum_{j=1}^{n} \text{Ppj Xpj} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation } 3.28$$

$$\text{GMo} = \sum_{i=1}^{n} \text{Poi Qoi} - \sum_{j=1}^{n} \text{Poj Xoj} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation } 3.29$$

Where:

GM_p and GM_o are gross margins for Chili pepper and Okro.

P_{pi} and Q_{pi} are the average price and average quantity of Chili pepper.

P_{pj} and X_{pj} are the average cost for pepper production

P_{oj} and X_{oj} are the average cost for Okro production. Like yields, all gross margin estimates were made using the mean experimental plot area before being adjusted to a unit area of 1 ha.

3.39 Statistical Analysis

Data collected for all the variables were subjected to analysis of variance (ANOVA) to evaluate the variability and the significant differences among the treatments using GenStat statistical package (12^{th} Edition). Least Significant Difference (LSD) at 5% was used to compare treatment means. Mathematical calculations and CROPWAT 8.0 model were also used to achieved some of the objectives in the study.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physicochemical Properties and Infiltration Characteristics of Soil in the Experimental Field

4.1.1 Physicochemical Properties of Soil in the Experimental Field

Before planting, soil samples from the experimental field were collected using an auger and examined in a lab to determine the main physicochemical characteristics and the results are shown in Table 4.1. The particle size distribution at 0–20 cm depth was found to be 7 %, 55 % and 38 % for clay, sand and silt respectively whereas at 20 – 40 cm depth, the particle size distribution was found to be 10 %, 53 % and 37 % for clay, sand and silt respectively. Using the soil textural triangle, the soil texture was found to be sandy loam. The results obtained agreed with the findings of Tetteh *et al*. (2016) who reported that, most soils in Northern Ghana are sandy loam in texture and are good for the vegetables production.

The dry bulk density was found to be 1.37 and 1.68 g/cm^3 at 20– 40 cm and 0– 20 cm depth respectively. This falls within the range of 1.55 – 1.75 g/cm^3 recorded for sandy loam by Yu *et al*. (2014). The soil moisture at field capacity was 19.6 % and 24.26 % at 0 – 20 cm and 20 – 40 cm respectively whereas the permanent wilting point was 6.4 and 9 % at 0-20 cm and 20-40 cm layers respectively. The findings of the study agreed with the findings of Enoviti (2012) who reported that, soils with field capacity and permanent wilting point within these ranges are described as sandy loam.

Table 4.1: Physicochemical Properties of Soil at the Experimental Field

Soil Properties	Soil Depth (cm)	
Physical Properties	**0-20**	**20-40**
% Clay	7	10
% Sandy	55	53
% Silt	38	37
Soil Texture	Sandy loam	Sandy loam
Field Capacity (%)	19.6	24.26
Permanent Wilting Point (%)	6.4	9
Bulk Density (g/cm^3)	1.37	1.68
Chemical Properties		
% N	0.064	0.005
P (mg/kg)	4.71	3.32
K (mg/kg)	61	39
% OC	0.741	0.467
% OM	1.28	0.81
PH	6.23	5.30
EC (µS/cm)	0.89	0.84

N = nitrogen, P = Phosphorus, K = Potassium, OC = Organic carbon, OM = Organic matter, EC = Electrical conductivity

As presented in Table 4.1, the soil in the experimental site had a mean pH of 5.7 and is described as slightly acidic soil. This agreed with Tsujimoto *et al*. (2013) who reported that, soils with pH of 5.7 is described as slightly acidic soils. Previous works by Motsara (2015) showed that, most soil nutrient elements are made available to crop at a pH range of 5.5 – 6.5. The EC was between 0.84 and 0.89 µS/cm which was described as a non-saline soil. This finding agreed with Rhoades *et al*. (1999) who revealed that, soils with EC between 0–2 dS/m are non-saline soils. The potassium (K) was determined to be within the range of 39 to 61 mg/kg. This is not sufficient for maximum growth and yield of crops and additional fertilizer application is required to boost the amount of K. This finding conformed with Akbas *et al*. (2017) who reported that, soils with K below 50 mg/kg are extremely low whiles those between 51 and 140 mg/kg are low. The phosphorus (P) was also found to be 3.32 and 4.71 mg/kg. According to Ma *et al*. (2015), the recommended amount of P required for crop production ranged from 3.40 to 4.08 mg/kg. Total soil nitrogen (TN) levels were between 0.005 and 0.064, which were regarded as very low and low respectively. This confirmed the findings of Tadese (1991) who reported that, soil total nitrogen availability of less than 0.05 % is very low, 0.05 – 0.12 % is described as low, 0.12– 0.25 % is moderate and more than 0.25 % is regarded as high total nitrogen. The low amount of available N could be attributed to the fact that N is one of the most restricting soil nutrients required for optimum crop growth in the zone and it has the ability to leached with ease.

The soil total organic carbon (TOC) was 0.467– 0.741 % which are considered low and this agrees with Tadese (1991) whose findings reported that, soils with TOC within the range of 0.5 to 1.5 % are considered low. Hence, it requires continuous fertilizer application for TOC revitalization. The organic matter (OM) ranges from 0.81– 1.28 % and is also at a very low level. This results concords with Biernbaum (2012) who reported that, the OM in mineral soils (sand, loam and clay) between 0-2 % is considered low.

4.1.2 Infiltration Characteristics of the Experimental Field

The infiltration rate describes the velocity at which water enters the soil which was determined by the depth of the water that can enter the soil in one hour. The results of the test are presented in Figure 4.1.

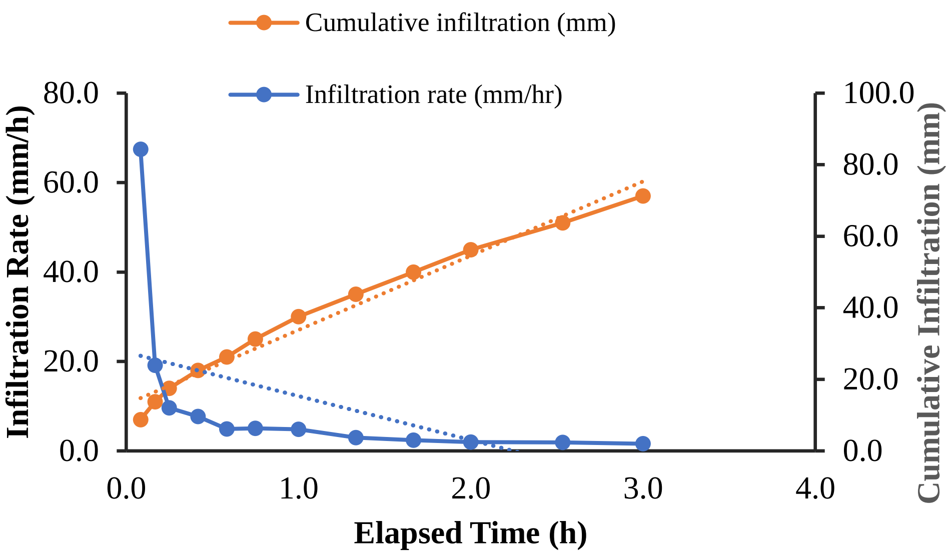

Figure 4.1: Infiltration Rate Curve of the Experimental Area

It was determine be 13.5 mm/h, which was in the range of 13 to 76 mm/h for sandy loam soil reported by Waller *et al*. (2016). Patle *et al*. (2019) reported that, soil with basic infiltration rate between 3 and 68 mm/h (0.3 to 6.8 cm/h) is described as sandy loam.

4.2 Crop Water Requirement of Chili Pepper and Okro and Performance of Spray Tube Irrigation System

4.2.1 Crop Water Requirement of Chili Pepper

To estimate the amount of water needed by Chili pepper, the FAO CROPWAT model version 8.0 was used. The irrigation water requirement for Chili pepper was estimated at 197.30 mm with an effective rainfall of 421.70 mm for the growing season. The crop water required by Chili pepper from July to November was estimated at 459.90 mm for the entire growing season.

The estimated crop water requirement of Chili pepper agreed with the findings of Dimple *et al*. (2019) who observed that, the seasonal water requirement of Chili pepper is between 411.11 mm and 525.11 mm under different irrigation regimes. The seasonal Chili pepper water requirement is contrary to that of Huguez and Philippe (1998) who asserted that, the overall water requirement of Chili pepper is between 750 mm and 900 mm, and up to 1250 mm for extended growing periods and several pickings. The findings also agreed with Dimple *et al*. (2019) who reported that, crop water needs might vary from 300 to 700 mm depending on the location, crop season and climatic conditions. This also agreed with Grimes and Williams (1990) who indicated that, Chili pepper require between 400 and 500 mm of water every growth season, depending on the season of the year it is planted and the local climatic condition.

Table 4.2: Crop Water Requirement of Chili Pepper

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jul	3	Init	0.6	2.51	7.5	12.9	7.5
Aug	1	Init	0.6	2.42	24.2	49.5	0
Aug	2	Init	0.6	2.33	23.3	51.7	0
Aug	3	Deve	0.61	2.39	26.3	53.1	0
Sep	1	Deve	0.72	2.82	28.2	57.6	0
Sep	2	Deve	0.84	3.33	33.3	60.6	0
Sep	3	Deve	0.97	4	40	49.1	0
Oct	1	Mid	1.04	4.47	44.7	35.5	9.2
Oct	2	Mid	1.04	4.66	46.6	25.4	21.2
Oct	3	Mid	1.04	4.7	51.7	17.9	33.9
Nov	1	Mid	1.04	4.75	47.5	8	39.5
Nov	2	Late	1	4.6	46	0	46
Nov	3	Late	0.92	4.04	40.4	0.4	40
Total					**459.9**	**421.7**	**197.3**

(CROPWAT Output,2022)

4.2.2 Crop Water Requirement of Okro

The irrigation water requirement for Okro was estimated at 21.0 mm/dec. The effective rainfall of Okro for the growing season was estimated at 370.80 mm whereas the crop water requirement of the crop from July to October was estimated at 263.0 mm for the entire growing**.**

The seasonal water requirement fell within the range of Yakubu (2016) who estimated the accumulated seasonal water requirement of Okro to be between 246.44 mm and 273.17 mm. The seasonal water requirements values reported in this study were consistent with those recorded by Panigrahi and Sahu (2013) under three distinct treatments of partial root zone furrow irrigation, which were 250 mm, 232 mm, and 279 mm but differed slightly from Yakubu *et al*. (2020) who estimated the seasonal Okro water requirement at 236 mm for drip irrigation.

Table 4.3: Crop Water Requirement of Okro

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jul	3	Init	0.46	1.92	3.8	8.6	3.8
Aug	1	Init	0.46	1.86	18.6	49.5	0
Aug	2	Deve	0.47	1.82	18.2	51.7	0
Aug	3	Deve	0.71	2.78	30.6	53.1	0
Sep	1	Deve	1.04	4.09	40.9	57.6	0
Sep	2	Mid	1.24	4.9	49	60.6	0
Sep	3	Mid	1.24	5.14	51.4	49.1	2.3
Oct	1	Late	1.03	4.44	44.4	35.5	8.8
Oct	2	Late	0.68	3.04	6.1	5.1	6.1
					263.0	**370.80**	**21.0**

(CROPWAT Output, 2022)

4.3 Quantity of Water Pumped for Supplemental Irrigation

The results on the amount of water applied revealed that, the lowest amount of water applied was observed in the month of July whereas the highest amount of water applied was observed in the month of October. The quantity of water required for supplemental irrigation can varied widely depending on several factors, including the type of crop, time of the year, growth stage of the crop, local climate conditions, soil type, available moisture and the irrigation method used (Evans and Sadler, 2008).

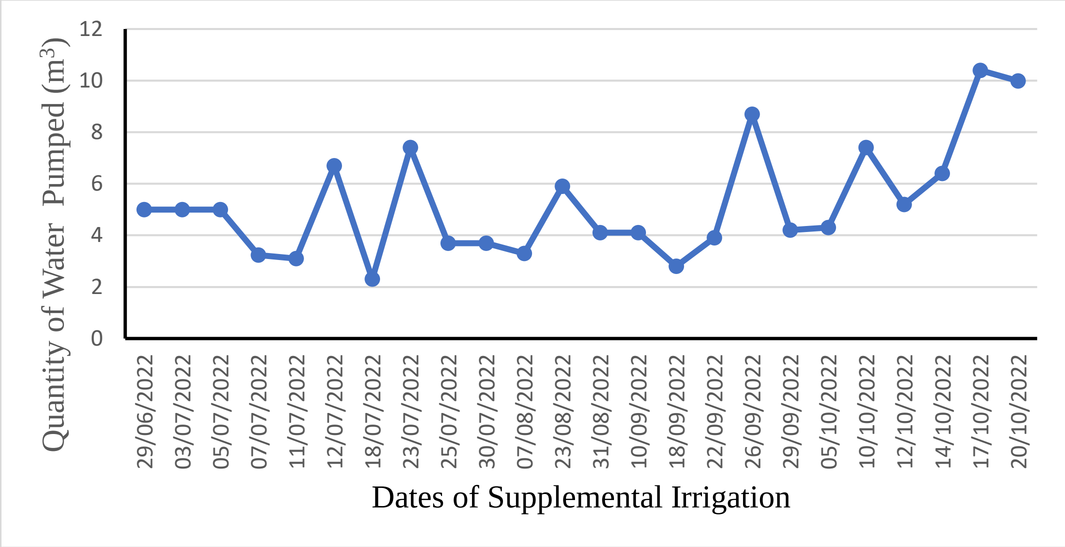

Figure 4.2: Amount of Water Pumped for Supplemental Irrigation

4.3 Performance of Spray Tube Irrigation System

The mean application rate (MAR), uniformity coefficient (CU) and the distribution uniformity (DU) of the spray tube irrigation system were determined at a pressure of 2 psi, 7 psi, 10 psi, 15 psi and 17 psi. The results are presented in Table 4.4 and Figure 4.2.

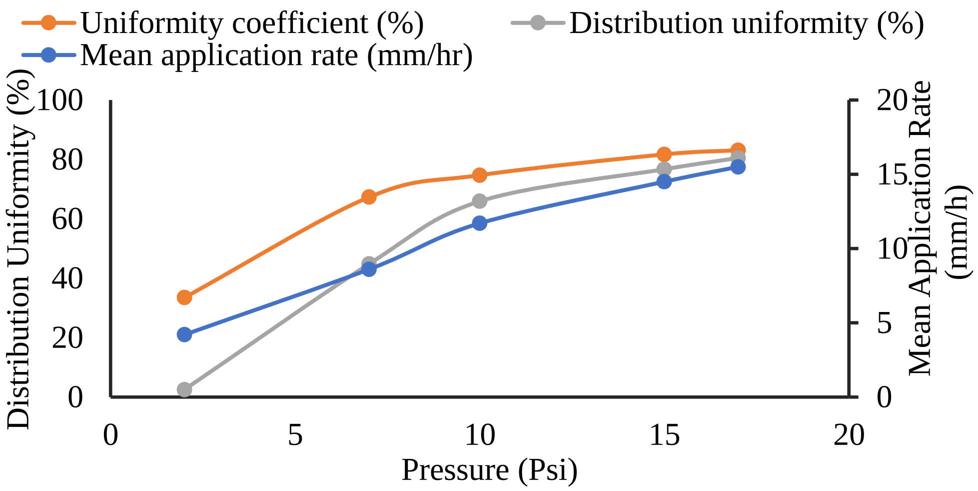

Figure 4.3: Effect of Change in Pressure on % UC, % DU and MAR (mm/h) due to Change in Solar Radiation

The results revealed that the measured performance indicators of the spray tube irrigation system namely; CU, MAR and DU increase as the pressure of the system increases. The findings of this study agreed with Dwivedi *et al*. (2015) who established that as the change in system pressure increases, DU, UC, MAR and spray radius (R) and area of coverage (A) also increase. These results also agreed with Osman *et al*. (2014) who observed the same trend in DU and UC in a sprinkler system. However, the pressures used in this study are low pressures and therefore, pressures above 250 psi leads to a corresponding decreasing performance indicator.

4.4 Growth and Yield Response of Chili Pepper and Okro under Supplementary Irrigation, Rainfed and Different Fertilizer Application Levels

4.4.1 Plant Height of Chili Pepper and Okro

4.4.1.1 Effects of Supplementary Irrigation and Rainfed on Plant Height of Chili Pepper

The SI application was based on water depleted by the crop (D) to the amount of soil water that is Readily Available Water (RAW). The soil was irrigated back to field capacity whenever the amount depleted was more than the readily available soil water.

As presented in Figure 4.4, the plants height of Chili pepper was significantly increased ($p<0.005$) by the main effect of rainfed (RF) and supplementary irrigation (SI) at 2WAT. It was found that, SI recorded the highest plant height (16.84 cm) and rainfed system recorded the least (12.71 cm). The interaction effects between rainfed (RF), supplementary irrigation (SI) and fertilizer at different levels did not significantly increase plant height at 2WAT ($p<0.419$). At 4 and 6WAT, a highly significant difference was also observed for the main effect of rainfed and SI ($p<0.001$ and $p<0.001$ respectively).

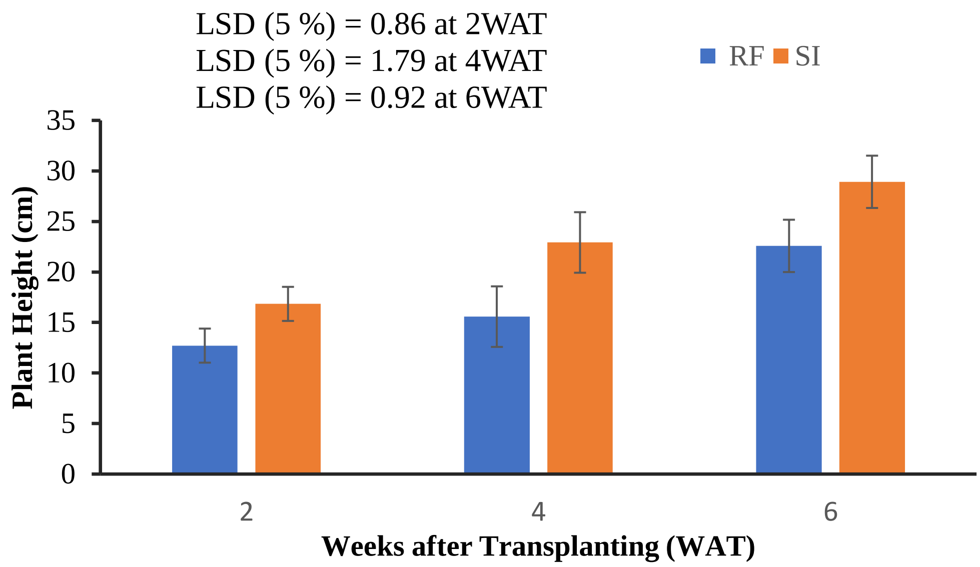

Figure 4.4: Effects of Supplementary Irrigation (SI) and Rainfed (RF) on Plant Height of Chili Pepper at 2WAT, 4WAT and 6WAT. Bars =Standard error of means (SEM)

In all the weeks, it was observed that SI treatment performed best in plant height of Chili pepper than the rainfed treatment. This variation could be attributed to the continuous availability of soil moisture during the vegetative stage of the crop because of SI. This finding agreed with Origa (2011) who observed a similar trend in onions and reported that, SI plots had better access to soil moisture and soil moisture contributes to the vegetative growth of vegetables which might have contributed to the variations in plant height between SI and rainfed treatments at 2, 4 and 6 WAT. The results are similar to the findings of Álvarez *et al*. (2009) who observed that when water stress occurs during the vegetative phases, the plant height and leaf area development of tomato were reduced and since there is available moisture in SI plots compared to the rainfed resulted in the variation in the plant height. The finding in this study also agreed with the findings of Recep (2004).

4.4.1.2 Effect of Fertilizer Levels on Plant Height of Chili Pepper

There was significant difference in plant height among the main effect of fertilizer levels treatments at 6WAT ($p<0.002$) and 8WAT ($p<0.026$). The fertilizer level at 200 kgha^{-1} recorded the highest mean plant height of 29.83 cm, 100 kgha^{-1} recorded the second highest plant height of 27.0 cm whilst 0 kgha^{-1} recorded the least plant height of 20.83 cm at 6WAT. At 8WAT, fertilizer dosage at a rate of 200 kgha^{-1} recorded the highest plant height of 35.20 cm, followed by 150 kgha^{-1} (32.00 cm) and 0 kgha^{-1} recorded the least plant height of 28.20 cm as presented in Table 4.5. The interaction effect of rainfed, SI and fertilizer levels showed no significant difference between 6 and 8 weeks after transplanting of Chili pepper.

Table 4.4: Effects of Fertilizer Levels on Plant Height of Chili Pepper at 6WAT and 8WAT

Fertilizer Levels (kgha^{-1})	**Plant Height**	
	6WAT	**8WAT**
0	20.83a	28.2a
100	27.00b	29.83b
150	25.33bc	35.0b
200	28.3b	35.2c
LSD (5 %)	**3.96**	**6.31**
P-value	**<.002**	**<.026**

WAT=Weeks after transplanting, LSD =Least significant difference, Different letters in a row denote significant difference between treatment

This variation could be linked to the increased in availability and uptake of NPK, which progressively increased plant height than crops that received lesser or no amount of fertilizer. These findings conformed with Fawole *et al*. (2022) whose results revealed that, higher levels of NPK influence higher plant height in sweet pepper due to the higher levels of the essential nutrients (nitrogen, phosphorus, and potassium) than those with lower levels of essential nutrients. This agreed with the findings of Kanneh *et al*. (2017) who reported that NPK 15-15-15 applied to sweet pepper at higher rate registered taller plant height than those with less or no NPK level. The study of Nimatu *et al*. (2022) found that the application of 200 kgha^{-1} NPK increased plant height in Chili pepper in both field and pot experiments than the other fertilizer treatments of lesser rate. The results however disagreed with the findings of Bridgemohan *et al*. (2017) who reported that, 0 kgha^{-1} contributed to the tallest plant height, whereas other treatments of higher rate recorded less in sweet pepper.

4.4.1.3 Effects of Supplementary Irrigation and Rainfed on Plant Height of Okro

The results revealed that, the effect of SI and rainfed have significantly increased the plant height of Okro at 4WAS ($p<0.001$). It was observed that SI recorded the highest plant height (7.84 cm) while the lowest plant height was observed in rainfed (4.56 cm). Plant height at 6WAS followed the same trend as that of 4WAS with a highly significant difference between rainfed and SI ($p<0.007$) (Figure 4.5). The interaction effect between fertilizer levels, SI and rainfed did not significantly influence the height of Okro at 4 and 6 weeks after sowing.

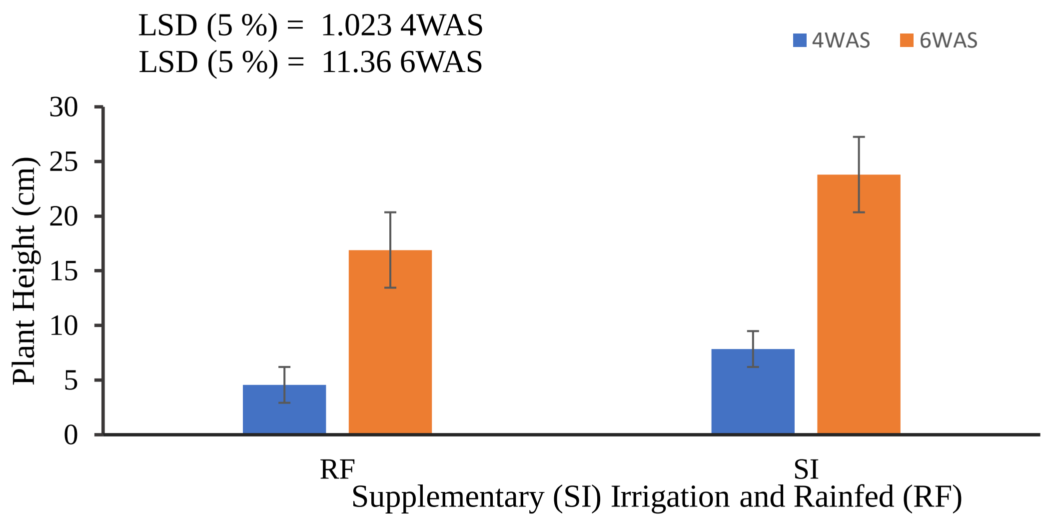

Figure 4.5: Effects of Supplementary Irrigation and Rainfed on Plant Height of Okro at 4WAS and 6WAS. Bars = SEM

The incremental effect in plant height with SI of Okro plant than rainfed could be traced to the supply of available soil moisture in supplemental irrigated plots compared to the rainfed. This agrees with Zeleke (2020) who reported that, plots which received 100 % SI produced the tallest plants in maize than plots under rain-fed (non- supplementary irrigated). Previous research by Ghodsi *et al*. (2004) showed that one of the main effects of water stress on vegetables is the reduction in plant height, which also results in a drop in dry matter accumulation and ultimately plant productivity and therefore, the less Okro plant height observed in rainfed than in SI may be attributed to this fact. Mogaji and Oloruntade (2017) established that, the height of the Okro plants in the field plots varied significantly with higher plant height observed in supplemented sprinkler irrigated plots than the control which relies only on rainfed.

4.4.1.4 Effects of Fertilizer Levels on Plant Height of Okro

Fertilizers at different application levels on plant height showed that, there was significant difference in plant height at 6WAS ($p<0.049$) and 8WAS ($p<0.005$). The 0 kgha^{-1} recorded the least (14.3 cm). Fertilizer level at 150 kgha^{-1} recorded the highest means (22.7 cm) whereas 200 kgha^{-1} resulted in the second highest plant height at 6WAS. Eight (8) weeks after sowing, the highest plant height mean was also observed at 200 kgha^{-1} (78.4 cm), followed by 250 kgha^{-1} and lowest means plant height observed at 0 kgha^{-1} (38.9 cm) (Table 4.6). The interaction effects between SI, rainfed and fertilizer levels did not show any significant difference between 6 and 8 weeks after sowing.

Table 4.5: Effects of Fertilizer Levels on Plant Height of Okro at 6WAS and 8WAS

Fertilizer Levels (kgha^{-1})	**PH 6WAS**	**PH 8WAS**
0	14.3a	38.9a
150	22.7b	54.0ab
200	22.3b	70.40b
250	22.0b	63.6b
LSD (5 %)	**6.63**	**16.06**
p-value	**<.007**	**<.005**

PH= Plant height, WAS= Weeks after sowing, Different letters in a row denote significant difference between treatment

The results at 6WAS agree with the findings of Jallow *et al*. (2021) who found that, taller plants, higher number of branches, number of leaves and stand count was recorded by the Okro that received fertilizer at a rate of 200 kgha^{-1} which was attributed to the high nitrogen content that was applied which induced fast growth in plants. The results at 8WAS could be due to the application of high nitrogen levels, which accelerated plant growth. This is in conformity with the findings of Babatola (2013). This is also in agreement with Amina *et al*. (2023) who asserted that the fertilizer (NPK 15-15-15) applied at 200 kgha^{-1} was adequately for the plant growth of than those treated with 0 kgha^{-1}.

4.4.2 Number of Leaves of Chili Pepper and Okro

4.4.2.1 Effects of Supplementary Irrigation and Rainfed on Number of Leaves of Chili Pepper

The number of leaves of Chili pepper was significantly affected by SI and rainfed system at 2WAT (p<0.001). The highest mean was observed at the SI treatment (14.58) and least mean observed at the rainfed (6.67). At 4WAT (P<0.002), the main effect of SI and rainfed significantly influenced number of leaves of Chili pepper (Figure 4.6). At both weeks 2 and 4, the interaction effect between SI, rainfed and fertilizer levels did not significantly influence the number of leaves of Chili pepper.

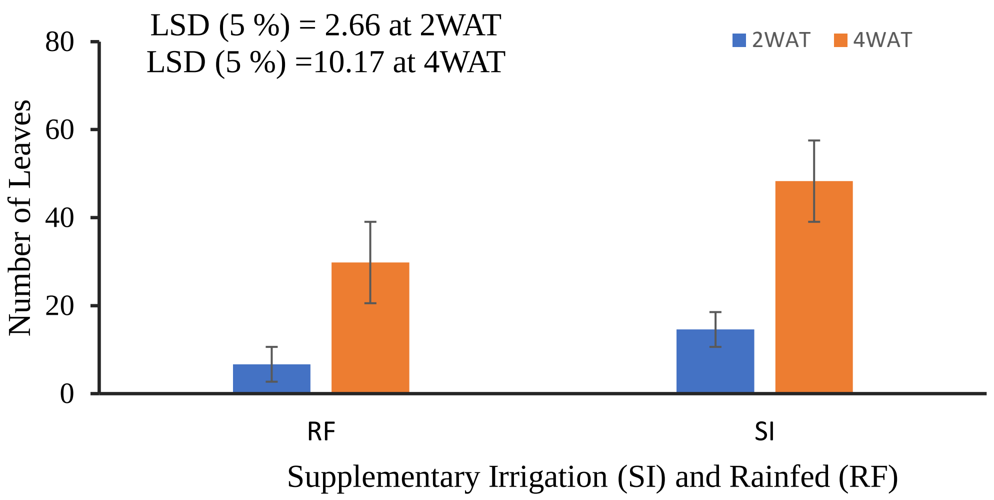

Figure 4.6: Effects of Supplementary Irrigation and Rainfed on Number of Leaves of Chili Pepper at 2WAT and 4WAT. Bars = SEM

The observed variation could be attributed to the fact that since additional irrigation was used to maintain crop growth and development in SI crops whiles rainfed crops experienced water stress during periods of low or no rainfall. These results agree with Pérez-Pérez *et al*. (2009) who asserted that, during times of water stress, plants naturally tend to shrink and/or shed their leaves off resulting in low leaves count. This resulted in fewer leaves count in rainfed than in SI treatment. Origa (2011) also observed that, water stress occurring during vegetative stages in tomato plants reduces leaf area development and this resulted in the significant difference in number of leaves between SI and rainfed plots. The variation in number of leaves could also be trace to the fact that, supplemental irrigation had the stimulatory effects in branching compared to control at all the stages of plant growth which led to the formation of more leaves (Origa, 2011).

4.4.2.2 Effects of Fertilizer Levels on Number of Leaves of Chili Pepper

The effect of fertilizer levels on number of leaves of Chili pepper established that, the main effect of the levels of fertilizer significantly influenced the number of leaves at 4WAT ($p<0.035$). It was observed that, the fertilizer applied at 200 kgha^{-1} performed much better in number of leaves (47.50) whereas fertilizer applied at 150 kgha^{-1} recorded the second highest number of leaves in Chili pepper (42.8). The least number of leaves of this result was observed at 0 kgha^{-1} (26.0) (Figure 4.7). However, the interaction effect between the fertilizer levels, SI and rainfed treatments did not significantly influence the number of leaves at 4 weeks after transplanting.

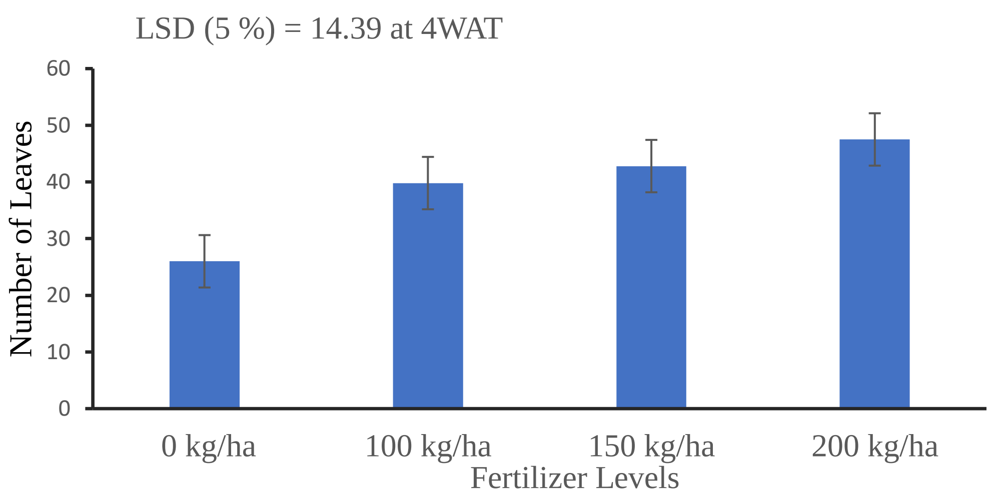

Figure 4.7: Effects of Fertilizer Levels on Number of Leaves of Chili Pepper at 4WAT.Bars = SEM

This variation occurred due to the high availability of N in 200 kgha^{-1} than in 0 kgha^{-1} which is responsible for the vegetative growth of crops. According to Hewitt and Smith (1974) who conducted a similar experiment reported that, the increase in vegetative growth is as a result of the availability of higher N since more cells and increased carbohydrate that is used to make protoplasm result from increased N supply. N-deficient plants have reduced cell division and growth and hence leading to fewer leaves number than those that received more N.

4.4.2.3 Interaction Effects of Supplementary Irrigation, Rainfed and Fertilizer Levels on Number of Leaves of Okro

At 6WAS, there was an interaction effect between the rainfed, SI and fertilizer levels ($p<0.009$).The results showed that, the plots treated with SI combined with fertilizer level at 200 kgha^{-1} (SI+200 kgha^{-1}) recorded the highest number of leaves (16.00), those under the SI combined with 250 kgha^{-1} (SI +250 kgha^{-1}) produced the second highest number of leaves (14.33) and the plants treated with rainfed combined with 0 kgha^{-1} registered the least number of leaves per plant (7.67) at 6WAS (Table 4.7).

Table 4.6: Interaction Effect of Supplementary Irrigation, Rainfed and Fertilizer Levels on Number of Leaves of Okro

	6WAS	
Fertilizer Levels (kgha^{-1})	**SI**	**RF**
0	8.33a	7.67a
150	12.33b	7.67a
200	16.00c	8.65a
250	14.33bc	9.70a
LSD (5 %)	**2.48**	
P-value	**<.009**	

WAS=Weeks after sowing, SI=Supplementary irrigation, RF=Rainfed, Different letters in a row denote significant difference between treatment.

The interaction between the fertilizer levels, SI and rainfed revealed that, the treatment that received fertilizer at a rate of 200 kgha^{-1} in addition to SI produced plants that had higher number of leaves and the application of additional level of NPK might have provided nutrients that maybe poisonous and not useful to the plant. This agrees with the findings of Jallow *et al*. (2021) who reported that, the application of high NPK levels initiate plants vegetative growth. A similar finding was reported by Babatola (2013). Mogaji and Oloruntade (2017) also reported higher number of leaves in supplemented sprinkler irrigated plots than control plots (rainfed).

4.4.3 Number of Flowers per Plant of Chili Pepper

4.4.3.1 Effects of Supplementary Irrigation and Rainfed on Number of Flowers of Chili Pepper

The results of the study revealed that, the main effect of rainfed and SI significantly influenced the number of flowers per plant of Chili pepper at 6WAT ($p<0.001$) and 8WAT ($p<0.001$). The SI treatment had the best performance in number of flowers in all weeks whereas rainfed treatment produced the least (Figure 4.8). At week 6 and 8, the fertilizer levels did not significantly affect the number of flowers per plant. Also, there was no interaction effect between SI, rainfed and fertilizer levels.

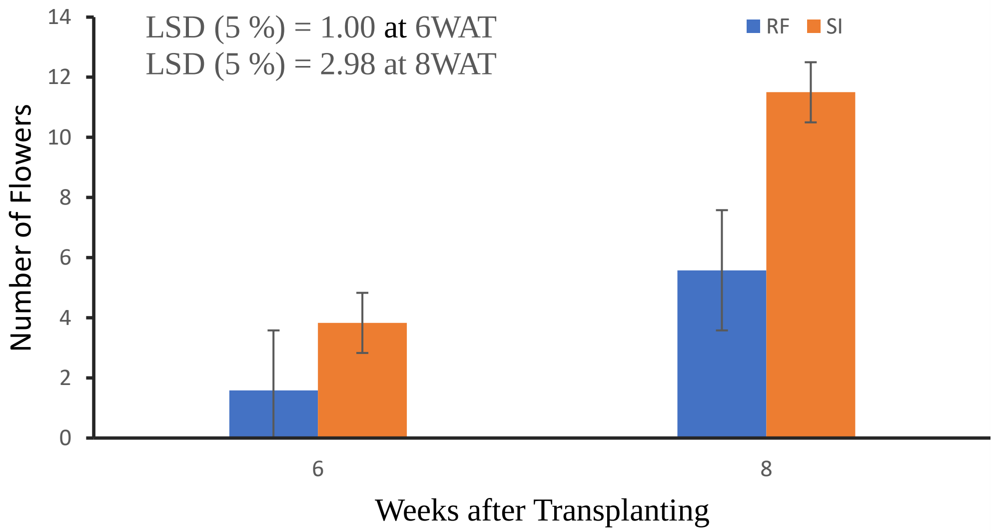

Figure 4.8: Effects of Supplementary Irrigation (SI) and Rainfed (RF) on Number of Flowers per Plant of Chili Pepper at 6WAT and 8WAT. Bars = SEM

The highest number of flowers in SI than rainfed is traceable to the availability of enough moisture during the critical phases of the crop. This result is similar to El-Kader *et al*. (2010) who found that reducing the morphological characteristics of Okro plants is as a resulted of high drought conditions and decreased humidity in Chili pepper under rainfed which is required for growth, flowering and yield. According to Reddy *et al*. (2004), stomata begin to close as a defense mechanism to lessen transpiration when moisture stress rises. As a result, less carbon dioxide enters the system. This has an impact on leaf area expansion and number of flowers formation which depends on leaf turgor, temperature, and assimilation of growth-supporting nutrients. This resulted in fewer number of flowers recorded in rainfed fields than the SI plots.

4.4.4 Leaf Area and Leaf Area Index (LAI) of Chili Pepper and Okro

4.4.4.1 Effects of Supplementary Irrigation and Rainfed on Leaf Area and Leaf Area Index of Chili Pepper

The results of the study revealed that, leaf area at 2WAT ($P < 0.001$) and 4WAT ($p<0.016$), there was significant difference by the application of rainfed and SI. SI showed the highest means at both 2 and 4WAT (9.22 cm^2 and 16.5 cm^2 respectively) whereas rainfed recorded the lowest leaf area (3.51 cm^2 and 10.9 cm^2 at 2WAT and 4WAT respectively) (Figure 4.9). The interaction effect between SI and rainfed treatment and fertilizer levels at 2 and 4 weeks after transplanting did not significantly affect leaf area.

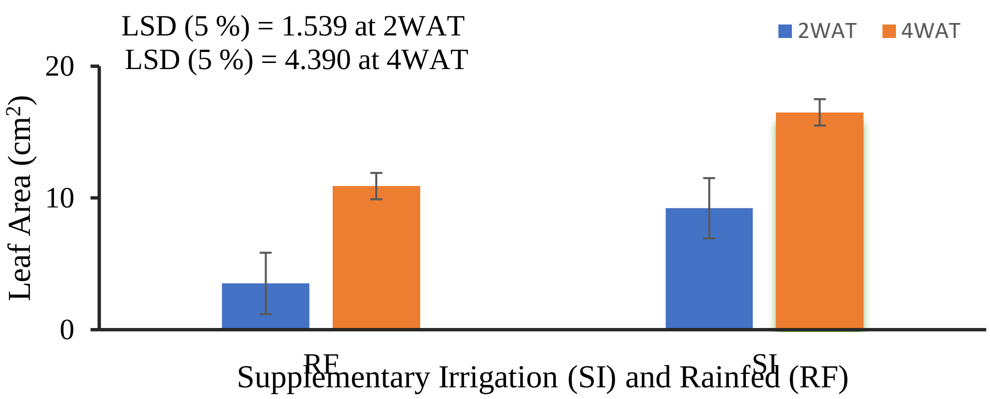

Figure 4.9: Effects of Supplementary Irrigation and Rainfed on Leaf Area of Chili Pepper at 2WAT and 4WAT. Bars = SEM

The leaf area index (LAI) was significantly increased by rainfed and SI at 2WAT ($p<0.001$), 4WAT ($p<0.001$) and 6WAT ($p<0.031$). At 2WAT, the plots treated with SI showed the highest means (0.00461) of LAI compared to those under rainfed (0.00175). 4WAT and 6WAT follow the same trend where SI performed better in LAI than rainfed (Figure 4.10). The results of the study did not show any interaction effect between the treatments.

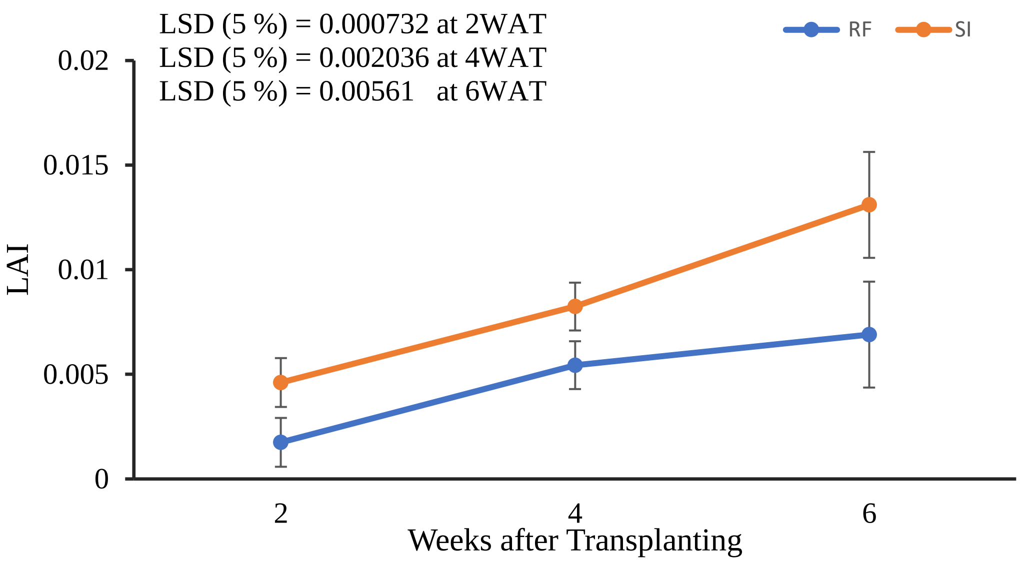

Figure 4.10: Effects of Supplementary Irrigation (SI) and Rainfed (RF) on Leaf Area Index (LAI) of Chili Pepper at 2WAT 4WAT and 6WAT. Bars = SEM

In all the weeks, SI plots recorded higher leaf area and LAI while the rainfed recorded less in leaf area and LAI. The inadequate water availability during plant growth lowers leaf area and LAI and considerably slows crop growth rate. The results conforms with the findings of Beese *et al*. (1982).

4.4.4.2 Effects of Supplementary Irrigation and Rainfed on Leaf Area and Leaf Area Index of Okro

The results revealed that, there was significant difference in leaf area ($P < 0.001$) at 4WAS by the application of rainfed and supplementary irrigation. It was discovered that; SI presented the highest mean leaf area (89.2 cm^2) whereas rainfed recorded the least leaf area (31.6 cm^2) (Figure 4.11). The fertilizer at different levels did not significantly influence the leaf area of Okro at 4WAS. Also, the interaction effect between the SI and rainfed treatment and fertilizer levels at 4WAS did not significantly influence the leaf of Okro at 4WAS (p<0.887).

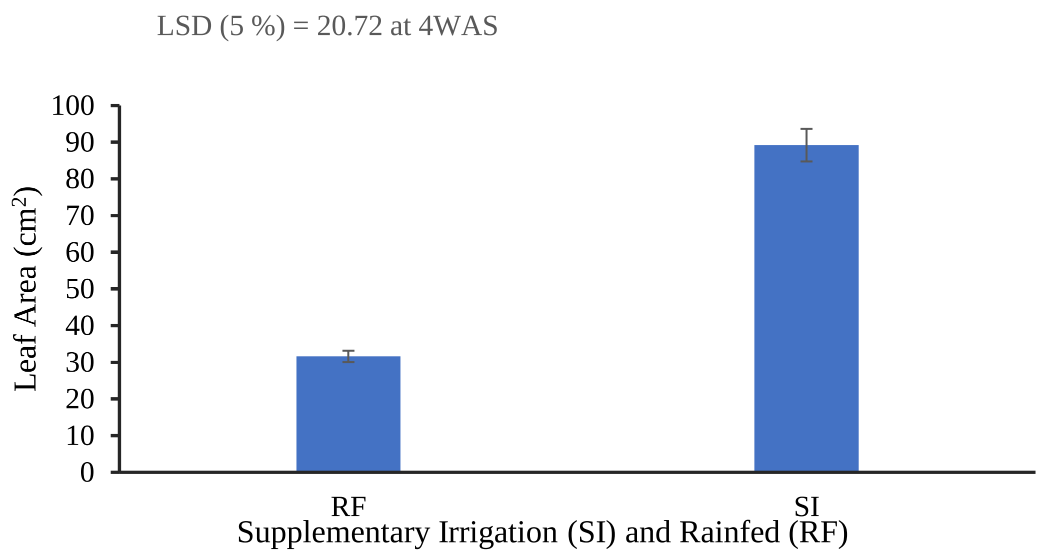

Figure 4.11: Effects of Supplementary Irrigation and Rainfed on Leaf Area of Okro at 4WAT. Bars = SEM

The LAI was significantly different at 2 and 4WAS (p<0.001, p< 0.016 respectively) which range from 0.00175 to 0.00824. The results revealed that, SI formed the highest LAI whereas rainfed recorded the least (Figure 4.12). The fertilizer at different levels was not significantly different from each other at 2 and 4WAS. The interaction effect between fertilizer levels, rainfed and SI was not significantly different from each other at week 2 and 4.

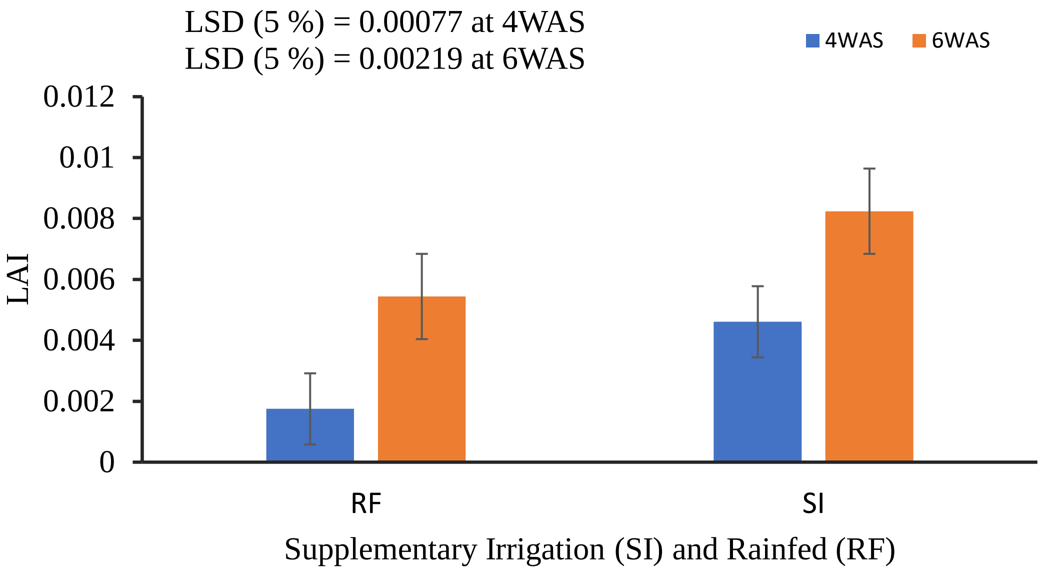

Figure 4.12: Effects of Supplementary Irrigation and Rainfed on Leaf Area Index (LAI) of Okro at 4WAS and 6WAS. Bars = SEM

The results showed that, the SI registered the highest leaf area and LAI in all the weeks studied. This variation could be attributed to the fact that, as water is provided to the crop, more moisture is retained in the soil, which in turn may affect plant metabolism and resulted in an increased in plant growth, leaf area, LAI characteristics and higher dry matter production. This is consistent with the findings of Saied (2000) on sugar beet. The findings also agree with those of Romaisa *et al*. (2015) on Okro.

4.4.4.3 Effects of Fertilizer Levels on Leaf Area of Okro

The results of this study disclosed that fertilizer treatments significantly influence the leaf area ($p<0.043$) of Okro at 4WAT. The highest leaf area of Okro was detected at a fertilizer level of 200 $kgha^{-1}$ with a mean leaf area of 86.8 cm^2, followed by 250 $kgha^{-1}$ (56.3 cm^2). The lowest leaf area was detected at the control treatment, 0 $kgha^{-1}$ with an average value of 45.7 cm^2 (Figure 4.13). At 4WAS, the interaction effect between the levels of fertilizer, SI and rainfed did not show any significant difference.

LSD (5 %)= 29.31 at 4WAS

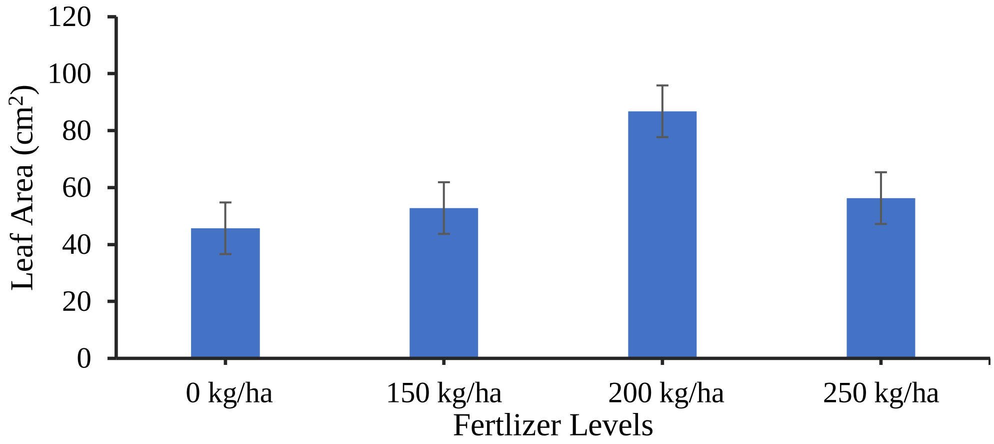

Figure 4.13: Effects of Fertilizer Levels on Leaf Area of Okro at 4WAS. Bars = SEM

The results obtained from this study was because of the increasing NPK to a level of 200 $kgha^{-1}$ increased leaf area of Okro, increasing beyond this level may appear poisonous and non-beneficial to the crop. This is consistent with Amina *et al*. (2023) who reported that increasing fertilizer (NPK) at a reasonable level increase leaf area, LAI and number of leaves significantly. The findings also agree with Danmaigoro *et al*. (2022) who established that, the impact of NPK fertilizer on the Okro growth parameters proved that, application at higher rate leads to a noticeably higher growth parameter being measured. In a comparable observation, Aniekwe (2017) also noted that reasonable increase in NPK fertilizer rate increased the growth parameters of Okro.

4.4.5 Fruit Diameter of Okro

The outcomes demonstrated that there was difference in fruit diameter between the SI and rainfed treatments (p<0.021). The results discovered that; rainfed recorded lowest fruit diameter (28.7 mm). The highest fruit diameter was observed at the SI (34.9 mm) 10 weeks after sowing (Figure 4.14). The fertilizer at different levels had no significant impact on the fruit diameter. The interaction effect between the treatments was not significantly different at 10 WAS.

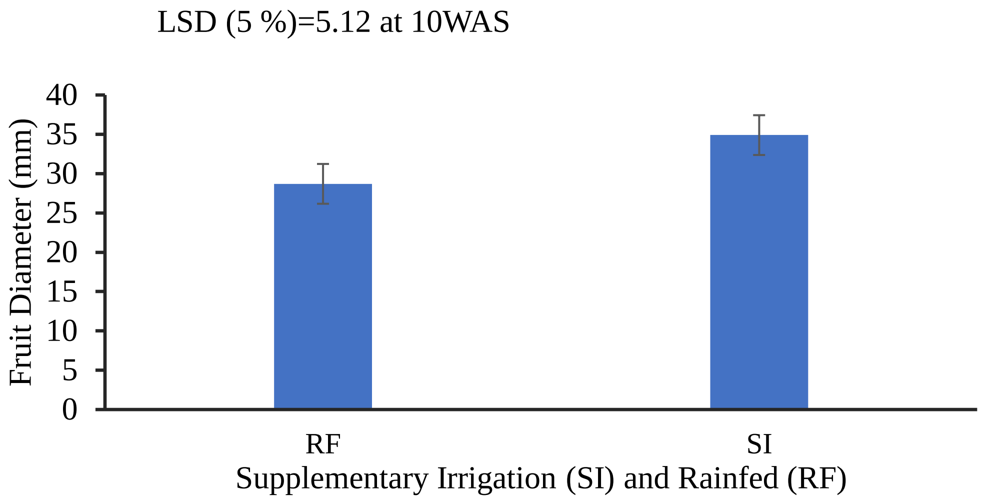

Figure 4.14: Effects of Supplementary Irrigation and Rainfed on Fruit Diameter Okro at 10WAT. Bars = SEM

These variations in fruit diameter could be attributed to the fact that crops cultivated under SI have enough moisture accumulated in the root zone to support evapotranspiration and other biochemical requirements during the vegetative phase and fruiting stage of the crop which is a contributing factor to the difference in fruit diameter observed in this study. These findings agree with Mogaji and Oloruntade (2017).

4.4.6 Chlorophyll Content per Plant of Chili Pepper and Okro

4.4.6.1 Effects of Supplementary Irrigation and Rainfed on Chlorophyll Content of Chili Pepper

The leaf chlorophyll content of Chili pepper at 6WAT was significantly ($p < 0.009$) affected by the application of the main effect of both SI and rainfed. The highest chlorophyll content (SPAD) was recorded in SI treatment (69.50 Spad) whereas the lowest Spad was observed in rainfed plots (60.9 Spad) (Figure 4.15).

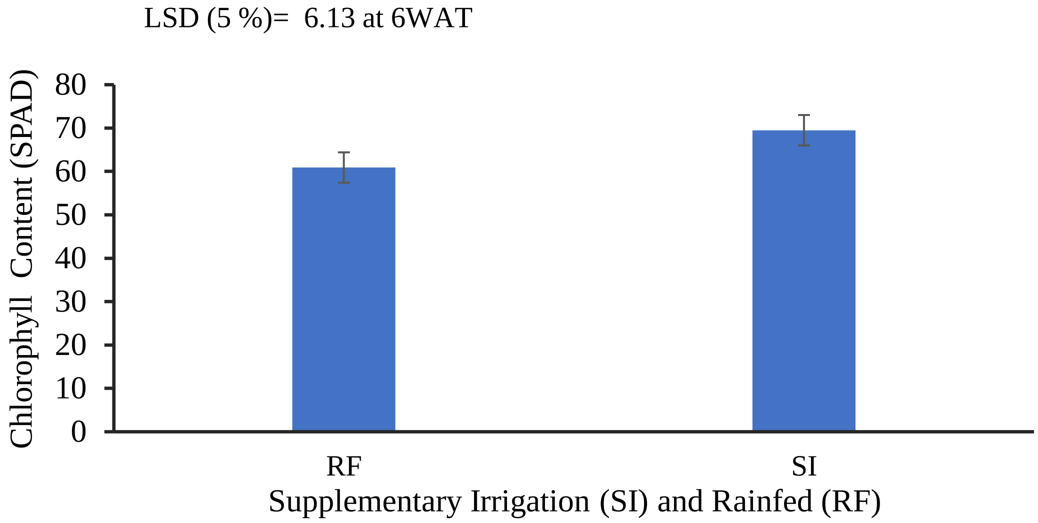

Figure 4.15: Effects of Supplementary Irrigation and Rainfed on Chlorophyll Content (SPAD) of Chili pepper at 6WAT. Bars = SEM

The chlorophyll content recorded in this study range from 55.2 – 71.6 Spad. The low chlorophyll content in rainfed treatment and higher in SI is in line with Amin *et al*. (2009) who observed that, under drought conditions, there was a decline in the amount of leaf chlorophyll content in Okro and watermelon whiles SI plots resulted in higher amount of chlorophyll content.

4.4.6.2 Effects of Fertilizer Levels on Chlorophyll Content of Chili Pepper

The chlorophyll content of Chili pepper at 6WAT significantly influenced ($p<0.007$) by fertilizer at different levels. 200 kgha^{-1} recorded the highest chlorophyll content (71.60 spad), followed by 150 kgha^{-1} (67.8 Spad) and the control (0 kgha^{-1}) gave the lowest Spad value (Figure 4.16). Fertilizer levels did not interact with SI and rainfed at 6WAT.

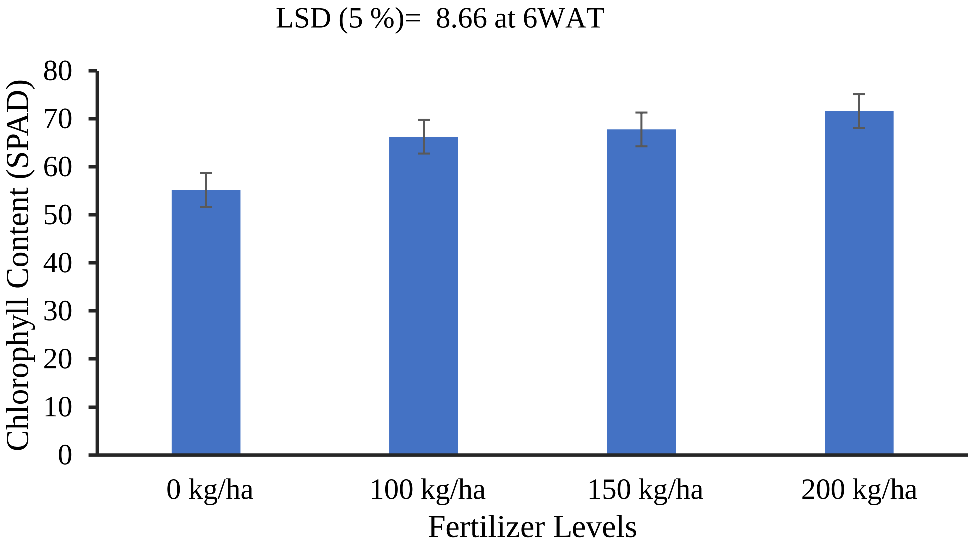

Figure 4.16: Effects of Fertilizer Levels on Chlorophyll Content of Chili Pepper at 6WAT. Bars = SEM

The difference in chlorophyll content is similar to previous research which revealed that, nutrients such as nitrous oxide (NPK) can improve the leaf chlorophyll content. This conforms with the findings of Ojetayo *et al*. (2011) which showed that cultivar and NPK at optimum quantity can influenced the chlorophyll content. Similar with Al-Juthery *et al*. (2022) who reported that, increasing SPAD meter value of chlorophyll from low level to high is as a result of higher level of N concentration. These results agree with Ciećko *et al*. (2012) who established that, the greater amount of NPK fertilizer is accompanied by the higher total leaf chlorophyll content in plants.

4.4.6.3 Interaction Effect of SI, Rainfed and Fertilizer Levels on Chlorophyll Content of Okro

The study investigated the impact of fertilizer, SI and rainfed on above ground biomass. The interaction effect between the fertilizer levels, rainfed and SI treatment was significantly different ($p<0.05$) at 6WAS. From treatment 0 to 250 $kgha^{-1}$, the Spad value ranged from 30.60 to 51.73 spad at 6WAS.The SI in addition to NPK at a rate of 250 $kgha^{-1}$ (SI + 250 $kgha^{-1}$) recorded the highest chlorophyll content (Spad), followed by SI combine with NPK at a rate of 200 kgha^{-1} (SI + 200 kgha^{-1}). It was also detected that, rainfed in addition with 0 kgha^{-1} treatments (RF + 0 kgha^{-1}) performed the lowest (Table 4.8). The Spad value range from 30.60 to 51.73 spad at 6WAS.

Table 4.7: Interaction Effects of Rainfed, SI and Fertilizer Levels on Chlorophyll Content of Okro at 6WAS

	6WAS	
Fertilizer Levels (kgha^{-1})	**SI**	**RF**
0	41.50bc	29.93a
150	48.97cd	31.77a
200	49.53cd	30.60a
250	51.73d	37.10ab
LSD (5 %)	**8.43**	
P-value	**<.033**	

WAS =Weeks after transplanting, SI=Supplementary irrigation, RF=Rainfed, Different letters in a row denote significant difference between treatment

The outcome of the study is similar to the findings of Trueba *et al*. (2019) who reported that, less relative moisture in crops leaves and decreased in water potential can be the cause of the decline in photosynthetic pigments as in the case of the rainfed treatments. This is in conformity with Jaleel *et al*. (2009) who observed a decrease in chlorophyll concentration recorded in Catharanthus roseus and cotton due to drought-stressed during wet season. The results agree with Al-Juthery *et al*. (2022) who asserted that, increasing SPAD meter value of chlorophyll from low spad to high is due N higher concentration which then suggest that the higher the amount of NPK concentration, the higher the chlorophyll content.

4.4.7 Above Ground Biomass of Chili Pepper and Okro

4.4.7.1 Interaction Effects of Supplementary Irrigation, Rainfed and Fertilizer Levels on Above Ground Biomass of Chili Pepper

The interaction effect in above ground biomass of Chili pepper was significantly ($P < 0.001$) increased by the addition of rainfed, spray tube SI and fertilizer levels at 6WAT. The SI in addition with NPK at a rate of 200 kgha^{-1} (SI + 200 kgha^{-1}) induced the highest above ground biomass (55.56 g), this was followed by SI combined with 150 kgha^{-1} (SI + 150 kgha^{-1}) (47.44 g) and the least above ground biomass was observed in rainfed + control (RF + 0 kgha^{-1}) (2.29 g) (Table 4.9).

Table 4.8: Interaction Effects of Supplementary Irrigation, Rainfed and Fertilizer Levels on Above Ground Biomass of Chili Pepper at 6WAT

	6WAT	
Fertilizer Levels (kgha^{-1})	**SI**	**RF**
0	7.27b	2.92a
100	34.51e	29.60d
150	47.44g	43.52f
200	55.56c	24.67h
LSD (5 %)	**1.60**	
P-value	**<.001**	

WAT =Weeks after transplanting, SI=Supplementary irrigation, RF- Rainfed, Different letters in a row denote significant difference between treatment

This result agrees with Kahraman *et al*. (2016) whose findings revealed that lentil BM values from supplemental irrigated plots were greater than those relying on only rainfed. Silim and Saxena (1993) observed that the increase in BM production with SI was because of the improvement in plant water potential during critical stage. The higher BM could also be attributed to the presence of NPK which promotes the vegetative growth of Chili pepper. This concurs with the findings of Okonwu and Mensah (2012) who discovered that the application of NPK at higher levels consistently increase stem diameter, fresh and dry weight of pumpkin.

4.4.7.2 Interaction Effects of Supplementary Irrigation, Rainfed and Fertilizer Levels on Above Ground Biomass of Okro

According to the output of ANOVA, the interaction effect between rainfed, SI treatment and fertilizer levels significantly affected the above ground biomass of Okro ($p<0.001$). The SI in addition with fertilizer level at 250 $kgha^{-1}$ (SI + 250 $kgha^{-1}$) induced the highest above ground biomass (750.41 g) whereas the second highest BM was obtained at SI combined with 200 $kgha^{-1}$ (SI + 200 $kgha^{-1}$) (591.47 g) and the lowest BM was observed at rainfed and fertilizer level at 0 $kgha^{-1}$ (RF + 0 $kgha^{-1}$) (109.62 g) (Table 4.10).

Table 4.9: Interaction Effects of Supplementary Irrigation, Rainfed and Fertilizer Levels on Above Ground Biomass of Okro at 7WAS

	7WAT	
Fertilizer Levels ($kgha^{-1}$)	**SI**	**RF**
0	131.91b	109.62a
150	357.86e	278.91d
200	591.47g	365.36f
250	750.41h	227.26c
LSD (5 %)	**6.51**	
P-value	**<.001**	

WAS =Weeks after sowing, SI=Supplementary Irrigation, RF- Rainfed, Different letters in a row denote significant difference between treatment

The variation in BM between SI +250 $kgha^{-1}$ and RF + 0 $kgha^{-1}$ is attributed to the drought occurrence during the growing phase which slows down leaf growth by causing sclerotic cell walls which result in decreased plant biomass. This is in line with the findings of Ayub *et al*. (2021). This is resulted in less BM in rainfed combined with NPK 0 $kgha^{-1}$. The findings also agree with that of Aniekwe (2017) who observed a reasonable increasing fertilizer rate resulted in a corresponding increase in the BM of Okro.

4.4.8 Yield of Chili Pepper and Okro

4.4.8.1 Effects of Supplementary Irrigation and Rainfed on Yield of Chili Pepper

SI and rainfed treatments significantly affected ($p<0.006$) the yield of Chili pepper. The plots under the SI recorded the highest yield of 3,506.70 kg/ha with total marketable yield of 2067.41 kg/ha and those plots treated with rainfed had the lowest yield of 1,502.20 kg/ha with 1,441.65 kg/ha^{-1} as the total marketable produce (Figure 4.17). The fertilizer level at 0 $kgha^{-1}$, 100 $kgha^{-1}$, 150 $kgha^{-1}$ and 200 $kgha^{-1}$ did not influence the yield of Chili pepper. The interaction effect of the SI, rainfed and fertilizer levels was not significantly different at 5 % ($p<0.962$).

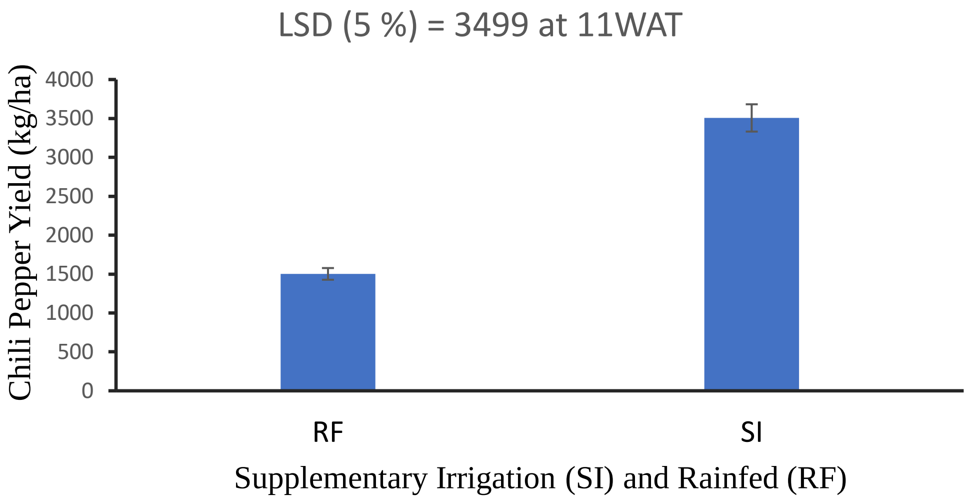

Figure 4.17: Effects of Supplementary Irrigation and Rainfed on Yield of Chili Pepper at 11WAT. Bars = SEM

The application of SI resulted in significant increases in rainfed Chili pepper yields in agrees with the findings of International Center for Agricultural Research in the Dry Areas (ICARDA) and farmer harvest who cultivated Chili pepper under SI and rainfed and reported that, SI performed better in the yield of Chili pepper than rainfed. This results also conforms with Adary *et al*. (2002) who noted that applying supplementary irrigation in conjunction with appropriate agricultural inputs and system management can significantly increase yield and water productivity.

The lower yield in rainfed treatment is attributed to the deficit moisture in the soil during the critical stage of the crop. This is in line with Techawongstien *et al*. (1992) who stated that, Chili pepper plants that are under water stress have less fruits per plant, fruit length and fruit weight than under optimum level of water. Mousavi and Shakarami (2009) reported that by using supplemental irrigation, chickpea grain yield was also reported to increase more than those under rainfed condition.

4.4.8.2 Effects of Supplementary Irrigation and Rainfed on Yield of Okro

There was significant difference ($p<0.001$) between supplementary irrigation and rainfed treatments. The supplementary irrigated plots resulted in higher yield of 1,860.30 kg/ha with 1,415.70 kg/ha as the marketable yield while the rainfed plots produced less fruit total yield of Okro 1,180.60 kg/ha in Okro with 1,135.14 kg/ha as the total marketable yield (Figure 4.18). There was no interaction effect on yield between SI, rainfed and fertilizer levels ($p< 0.456$) at 11WAS. The fertilizer at different levels did not significantly affect the total yield of Okro at 11 weeks after sowing.

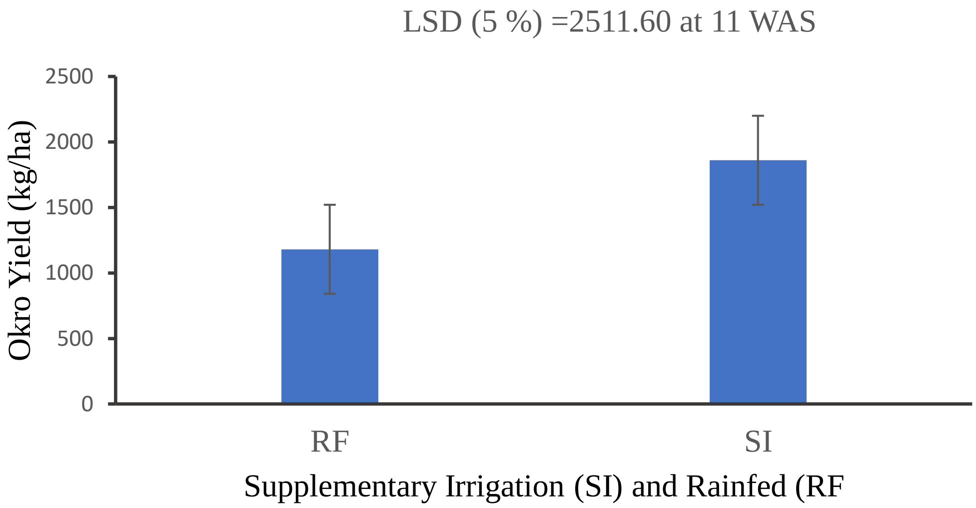

Figure 4.18: Effects of Irrigation on Yield of Okro at 11WAT. Bars = SEM

Under SI and rainfed treatments, it was observed that higher yield of Okro was recorded in SI than Okro under rainfed conditions. This variation could be attributed to water and moisture shortage during vegetative growth and critical stages resulting in yield reduction. Low moisture during such periods reduces yield of crops. This conforms with the results of Calvache and Reichardt (1999). Mogaji and Oloruntade (2017) inferred that SI water application may induce Okro to have more branches, which influenced the development of more flowers and crop yield. The work of Brandenberger *et al*. (2018) confirmed that if supplemental irrigation under rainfed is employed, it keeps soil moisture at ideal levels and Okro yields better. Okro can withstand both heat and drought, but under excessive drought conditions, it will not maximize its potential for yield and profitability. This resulted in less yield in rainfed treatment whiles more yield was achieved in supplemental irrigated treatment. Zeleke (2020) asserted that SI lengthens the vegetative growth cycle of plants, which enhances yield of crops in the growing season.

4.4.9 Number of Fruits of Chili Pepper and Okro

4.4.9.1 Effects of Supplementary Irrigation and Rainfed on Number of Fruits of Chili Pepper

The number of fruits of Chili pepper at 10WAT was significantly ($P<0.001$) affected by the application of the main effect of SI and rainfed. The highest number of fruits were observed at SI treatment (883) and the lowest means (498) observed was at the rainfed plots (Figure 4.19).

The number of fruits of Chili pepper at 10WAT was not significantly different ($p<0.725$) by the application of fertilizer at different levels. The interaction effect between fertilizer rates, rainfed and SI did not significantly affect the number of fruits at 10WAT of Chili pepper.

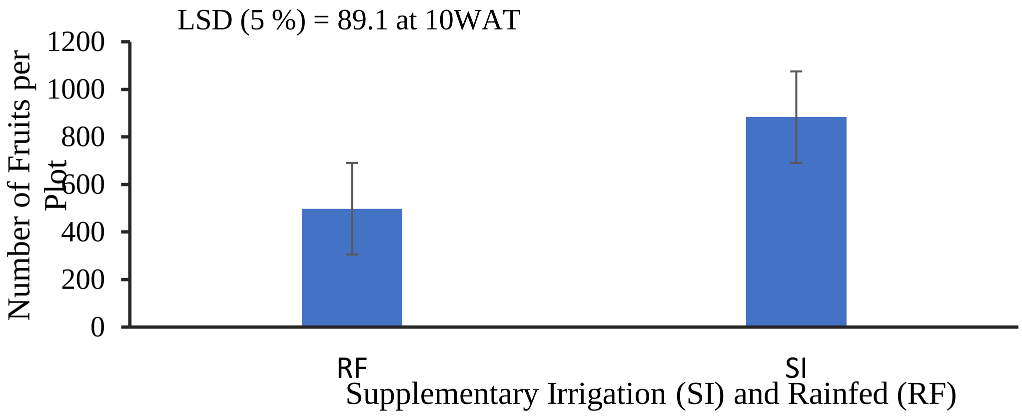

Figure 4.19: Effects of Supplementary Irrigation and Rainfed on Number of Fruits at 10WAT. Bars = SEM

A similar finding by Ouji *et al*. (2016) who reported that, SI before flowering and pod formation significantly increase number of pods than control (rainfed) in chickpea varieties. This agrees with Bicer *et al*. (2004) who reported the maximum number of pods per plant in supplementary irrigated plots than rainfed in chickpea.

4.4.9.2 Effects of Supplementary Irrigation and Rainfed on Number of Fruits of Okro

The number of fruits of Okro at 10WAS was significantly different (p<0.003) by the application of SI and rainfed. The main effect of SI was observed to have recorded the highest mean fruit number (438.0) and the main effect of rainfed plots gave the lowest number of fruits (321.0) (Figure 4.20). The main effect of fertilizer at different levels did not significantly affect the number of fruits per plant.

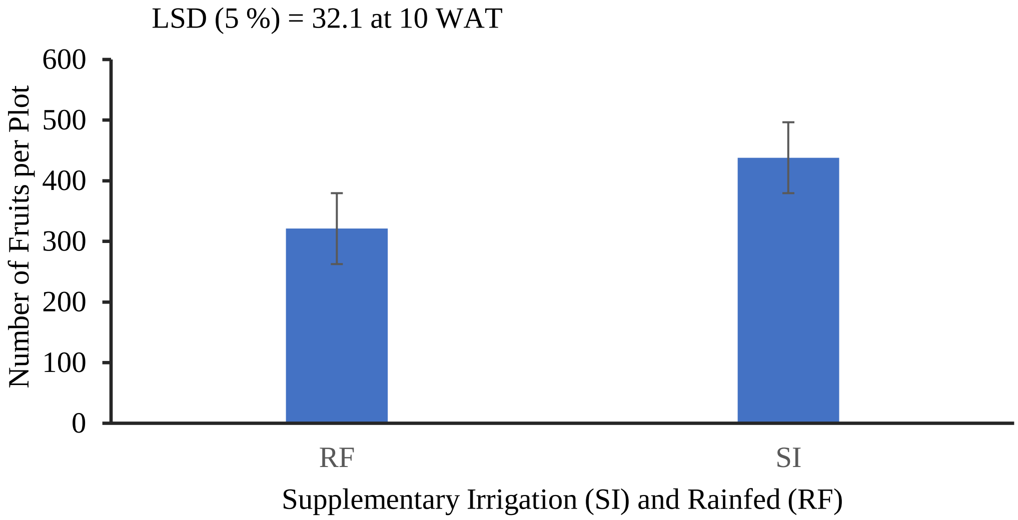

Figure 4.20: Effects of Irrigation on Number of Fruits of Okro at 10WAS. Bars = SEM

These findings conform with the work of Mogaji and Oloruntade (2017) who observed that supplementary application water discharged by sprinkler irrigation methods can enhance Okro vegetative growth and enhance the formation of higher number of fruits in a growing season. It is also in agreement with Girma and Haile (2014) whose findings claimed that supplemental irrigation considerably increased biomass yield, pod length, leaf dry weight, seeds per plant, pod weight, and seed yield per hectare compared to rainfed crops. According to (Molla *et al.*, 2021), durum wheat yield and yield components were significantly decreased as a result of moisture stress levels established during various phases of the crop's growth.

4.5 Gross Margin Analysis of Chili Pepper and Okro Production

Due to simplicity and accuracy of gross margin method, it has been recommended as a good method for analyzing farm income (Kasonga, 2018). This was estimated as gross revenue generated from the farming enterprise minus the total cost of production. The cost of water for the systems was estimated as the cost of irrigation water as in the case of irrigation schemes in similar area. Also, the construction of the water tank is not a typical case of irrigation in northern Ghana, so the cost of water is factored into the cost which includes maintenance and rehabilitation of the irrigation schemes.

4.5.1 Gross Margin of Chili Pepper Production

The total cost of production of Chili pepper observed was estimated at Gh¢ 19,341.60/ha in SI system and Gh¢ 16,741.60/ha in rainfed system (Table 4.11). The revenue of Gh¢ 26,876.40 generated from SI was estimated as the marketable yield (2,067.41 kg/ha) multiply by the unit price (Gh¢ 13.00 per kg). Also, the revenue of Gh¢ 18,741.60 generated from rainfed was also estimated by multiplying the marketable yield (1,441.65 kg/ha) and the unit price (Gh¢ 13.00 per kg). The GM of Chili pepper was initially estimated per unit area cultivated and adjusted to per hectare. The GM of Gh¢ 7,539.30 and Gh¢ 2,000 in SI and rainfed respectively was estimated as the revenue generated minus the cost of production. The GM of SI (Gh¢ 7,539.30/ha) and rainfed (Gh¢ 2,000/ha) was at 5 % level of significant difference (p<0.006) (Table 4.12).

The GM of Chili pepper was estimated per unit area cultivated and adjusted to per hectare.

Table 4.10: Types and Costs (Gh¢) of Farm Inputs used for Chili Pepper Production

Inputs	Quantity	Unit Cost (Gh¢)	Total/ Gh¢	SI Estimated Cost (Gh¢) per Mean Area (0.0089 ha)	Rainfed Estimated Cost (Gh¢) per Mean Area (0.0089 ha)	SI Estimated Cost (Gh¢) per ha	Rainfed Estimated Cost (Gh¢) per ha
Seeds	50 (2 packs)	19.00	38.00	19.00	19.00	2,134.80	2,134.80
Fertilizer	Bowls (3)	15.00	45.00	22.50	22.50	2,528.10	2,528.10
Tecknokel	1L	65.00	65.00	32.50	32.50	3,651.70	3,651.70
Cost of Water	Cost of Water	-	-	5.30	-	600.00	-
Irrigation Kits	Cost of Irrigation Kits	-	-	17.80	-	2000.00	-

Ploughing	Cost of Ploughing	40.00	40.00	20.00	20.00	2,247.20	2,247.20
Labor	Cost of Labor	70.00	70.00	35.00	35.00	3,932.60	3,932.60
Harvesting	Cost of Harvesting	40.00	40.00	20.00	20.00	2,247.20	2,247.20
Total				**172.10**	**149.00**	**19,341.60**	**16,741.60**

Table 4.11: Gross Margin (Gh¢) of Chili Pepper Production

Average	**Estimated Amount per Mean Area 0.0089 ha**		**Estimated Amount per ha**	
	SI	RF	SI	RF
Total Marketed Produce	239.20	166.80	26,876.40	18,741.60
Total Inputs Cost	172.10	149.00	19,337.10	16,741.60
GM	**67.10a**	**17.80b**	**7,539.30a**	**2,000b**
LSD (5 %)	**35.82**		**4,024.72**	
P-value	**<.001**		**<.001**	

GM= Gross margin, SI= Supplementary Irrigation, RF= Rainfed, Different letters denote significant difference between treatments

The difference in GM occurs because of the higher marketable yield in SI than in rainfed field. Despite the fact that Chili pepper in its fresh state is prone to damage, transport losses and storage losses were significantly reduced due to a ready market for the fruit at the local market level. Plots that had been supplemented with irrigation produced higher marketable yields and the revenue also was sufficient enough to compensate for the cost of production. This is also the case for rainfed plots but lower than the SI. This variation in GM is attributed to the difference in quantity of marketable yield (farm produce) harvested in both SI and rainfed plots. The findings of this study conforms with Origa (2011) who observed a difference in GM between SI and rainfed tomatoes was due to the variation in quantity of marketable produce and the difference in yield in the two treatments.

4.5.2 Gross Margin (GM) of Okro Production

The total cost of production was estimated at Gh¢ 22,487.60/ha in SI system and Gh¢ 19,887.60 in rainfed system (Table 4.13). The GM of Okro which was calculated as total revenue generated after sale of the farm produce minus the total cost of production and was estimated per unit area cultivated and adjusted to per hectare. The revenue of Gh¢ 26,191.00 generated from SI was estimated as the marketable yield (1,415.70 kg/ha) multiply by the unit price (Gh¢ 18.50 per kg). Also, the revenue of Gh¢ 21,000.00 generated from rainfed was also estimated by multiplying the marketable yield (1,135.14 kg/ha) by the unit price (Gh¢ 18.50 per kg) (Table 4.14).

The GM of Gh¢ 3,707.90 and Gh¢ 1,112.40 in SI and rainfed respectively was estimated as the revenue minus the production cost. The GM of SI and rainfed was at 5 % level of significant difference ($p<0.001$) (Table 4.14). The GM of Okro was estimated per unit area cultivated and adjusted to per hectare.

Table 4.12: Types and Costs (Gh¢) of Farm Inputs used for Okro Production

Inputs	Quantity	Unit Cost (Gh¢)	Total Cost (Gh¢)	SI Estimated Cost (Gh¢) per Area 0.0089 ha	Rainfed Estimated Cost (Gh¢) per Area 0.0089 ha	SI Estimated Cost (Gh¢) per ha	Rainfed Estimated Cost (Gh¢) per ha
Seeds	1 tin	80.00	80.00	40.00	40.00	4,494.40	4,494.40
Fertilizer	4 bowls	15.00	60.00	30.00	30.00	3,370.80	3,370.80
Insecticides	K-Optimal 250ml (1 bottles)	12.00	12.00	6.00	6.00	674.20	674.20

Fungicides	Mancozeb (250g)	12.00	12.00	6.00	6.00	674.20	674.20
Cost of Water	Cost of Water	-	-	5.30	-	600.00	-
Irrigation Kits	Cost of Irrigation Kits	-	-	17.80	-	2,000.00	-
Ploughing	Cost of Ploughing	40.00	40.00	40.00	40.00	4,494.40	4,494.40
Labor	Cost of Labor	70.00	70.00	35.00	35.00	3, 932.60	3, 932.60
Harvesting	Cost of Harvesting	40.00	40.00	20.00	20.00	2,247.20	2,247.20
Total				**200.10**	**177.00**	**22,487.60**	**19,887.60**

Table 4.13: Gross Margin (Gh¢) of Okro Production

Average	**Estimated Amount per Mean Area 0.00896 ha**		**Estimated Amount per ha**	
	SI	RF	SI	RF
Total Marketed Produce	233.10	186.90	26,191.00	21,000.00
Total Inputs Cost	200.10	177.00	22,483.10	19,887.60
GM	**33.00a**	**9.90b**	**3,707.90a**	**1,112.40b**
LSD (5%)	**21.63**		**2,430.30**	
P-value	**<.001**		**<.001**	

GM= Gross margin, SI= supplementary irrigation, RF= Rainfed, Different letters denote significant difference between treatments

The results of the study have clearly indicated that SI alone can be a major factor in ensuring maximum yield if it is well managed. According to Origa (2011), the extra cost incurred is very necessary since it basically contribute to increasing productivity and hence increase GM compare to the rainfed. The above variation could also be attributed to the difference in yield between the SI and rainfed.

4.5.3 Conclusion and Policy Issues on Gross Margin of Chili Pepper and Okro

The study therefore made it necessary that, the profitability and risk involved in the production of Chili pepper and Okro are compared here. The simple analysis presented here examines the two independent farm enterprises, among which a farmer may choose depending on the perceived risks and advantages involved. This was properly achieved by comparing the production costs, profit margins, marketability, and losses from the two crops. In terms of susceptibility to many pests and diseases, Okro is a more sensitive crop. The results indicate that the cultivation of Okro requires more capital in the controlling of these pests and diseases in commercial bases which is not the case for Chili pepper. This claim is clearly shown in the cost of Okro per hectare which is because of more capital required to purchase different variable inputs such as insecticides and fungicides and high cost of fertilizers, hence, making it risky and susceptible to losses. Therefore, Chili pepper is highly recommended as a common home gardening and commercial crop in the study area especially among small-scale farmers compared to Okro.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter contains conclusions which is a summary of the entire results and recommendations for farmer use and future research.

5.2 Conclusions

The study showed that:

1. The study revealed that, the soil particle size distribution; % clay was higher at a depth of 20-40 cm than 0-20 cm whereas % sand, % silt, FC, PWP, bulk density as well as the soil chemical properties were found to be more at the surface (0-20 cm) than at a depth of 20-40 cm. The soil infiltration characteristics was 13.5 mm/h.
2. The crop water requirement of Chili pepper and Okro from July to November were estimated at 459.90 mm and 263.0 mm respectively.
3. The growth parameters, yield and yield components measured (plant height, number leaves, leaf area, LAI, fruit diameter, above ground biomass, chlorophyll content, number of fruits and yield) were significantly affected by the addition of supplementary irrigation and rainfed in both Okro and Chili pepper. With SI performed best in all the growth parameters and yield whiles the rainfed plots performed less. Yield was not significantly affected by fertilizer whereas plant height, number of leaves, chlorophyll content and above ground biomass of Chili pepper and Okro were significantly influenced by levels of fertilizer.
4. The study underscores the critical role of supplemental irrigation in enhancing the yield and growth of Chili pepper and okra. It provides evidence that water stress in rainfed

conditions can significantly impact crop production. The results of this research have practical implications for farmers and agricultural policymakers, emphasizing the importance of sustainable water management practices to ensure food security and agricultural sustainability, particularly in regions vulnerable to water scarcity and changing climate conditions.

5. With an average investment of Gh¢ Gh¢ 19,341.60 per hectare in SI and Gh¢ 16,741.60 per hectare in Chili pepper, a gross margin of Gh¢ 7,539.30 per hectare was realized in the supplemental irrigated Chili pepper whereas a gross margin of Gh¢ 2,000 per hectare was realized in rainfed Chili pepper. An amount of Gh¢ 22,487.60 and Gh¢ 19,887.60 was invested in SI and rainfed respectively in Okro. Under supplemental irrigated Okro, a GM of Gh¢ 3,707.90 per hectare was estimated whiles Okro under rainfed conditions generated a GM of Gh¢ 1,112.40 per hectare.

5.3 Recommendations

The study therefore recommends that,

1. The application of fertilizer at 200 kg/ha and SI spray tube irrigation system is recommended for maximum Chili pepper and Okro growth, yield and gross margin.
2. SI has performed best in growth parameters, yield and GM of Chili pepper and Okro. Therefore, it would be better to encourage farmers to invest in supplemental irrigation as a way to guard against losses as the existing rainfed production method would almost certainly result in an economic loss (yield and investment) to farmers. It is required that initiatives are put in place to increase farmers' willingness to act with self-interests to adopt it.

3. It would be preferable to launch active rural extension services to promote a cultural shift among small-scale farmers so they may switch to cultivating high-value economic crops such as Chili pepper and Okro instead of traditionally cultivated, low-yielding crops such as maize. This is because a high-value crop is typically required for SI in order to pay for the additional investment.
4. SI appears to be a promising replacement for rainfed agriculture in the study area. Before suggesting these methods for usage, it is crucial to recommend additional research and/or demonstration on other high-value crops which respond to supplemental irrigation, with a focus on low-cost spray tube systems in different locations. This will improve awareness and acceptance of technology in multi-locations.
5. Due to the limited and erratic rainfall, access to water has continued to be a challenge in the study area. Therefore, sustainable measures on soil and water conservation are required. Rain water harvesting and/or storage during rainfall when runoffs become a severe is also required to improve and sustain agriculture in Nyankpala through SI when there is an occurrence of drought spell during critical stages of the crop growth and development.
6. The government and NGOs could offer loans, subsidies and incentives to help farmers and farming groups with limited resources to acquire the necessary infrastructure such as the solar power irrigation system (SPIS) and farming inputs to be able to include SI in their farming practices.

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APPENDICES

Appendix 1. Variate: Plant Height of Chili Pepper 2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	8.673	4.336	0.48	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	102.507	102.507	11.41	0.005
Fertilizer	3	19.182	6.394	0.71	0.561
SI_ and_ Rainfed. Fertilizer	3	27.123	9.041	1.01	0.419
Residual	14	125.721	8.980		
Total	23	283.205			

Appendix 2. Variate: Plant Height of Chili Pepper 4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.000	0.500	0.12	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	322.667	322.667	76.56	<.001
Fertilizer	3	20.500	6.833	1.62	0.229
SI_ and_ Rainfed. Fertilizer	3	19.333	6.444	1.53	0.251
Residual	14	59.000	4.214		
Total	23	422.500			

Appendix 3. Variate: Plant Height of Chili Pepper 6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	15.25	7.62	0.74	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	240.67	240.67	23.49	<.001
Fertilizer	3	255.50	85.17	8.31	0.002
SI_ and_ Rainfed. Fertilizer	3	15.67	5.22	0.51	0.682
Residual	14	143.42	10.24		
Total	23	670.50			

Appendix 4. Variate: Plant Height of Okro 4WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.752	0.376	0.28	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	64.682	64.682	47.39	<.001
Fertilizer	3	1.423	0.474	0.35	0.791
SI_ and_ Rainfed. Fertilizer	3	2.095	0.698	0.51	0.681
Residual	14	19.108	1.365		
Total	23	88.060			

Appendix 5. Variate: Plant Height of Okro 6WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	144.08	72.04	2.51	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	280.17	280.17	9.76	0.007
Fertilizer	3	289.33	96.44	3.36	0.049
SI_ and_ Rainfed. Fertilizer	3	81.83	27.28	0.95	0.443
Residual	14	401.92	28.71		
Total	23	1197.33			

Appendix 6. Variate: Plant Height of Okro 8WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	256.8	128.4	0.76	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	1771.6	1771.6	10.53	0.006
Fertilizer	3	3354.4	1118.1	6.65	0.005
SI_ and_ Rainfed. Fertilizer	3	660.5	220.2	1.31	0.311
Residual	14	2354.8	168.2		
Total	23	8398.2			

Appendix 7. Variate: Number of Leaves of Chili pepper 2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	27.000	13.500	1.46	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	376.042	376.042	40.60	<.001
Fertilizer	3	18.792	6.264	0.68	0.581
SI_ and_ Rainfed. Fertilizer	3	66.125	22.042	2.38	0.113
Residual	14	129.667	9.262		
Total	23	617.625			

Appendix 8. Variate: Number of Leaves of Chili pepper 4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1200.6	600.3	4.45	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	2072.0	2072.0	15.35	0.002
Fertilizer	3	1539.8	513.3	3.80	0.035
SI_ and_ Rainfed. Fertilizer	3	256.5	85.5	0.63	0.606
Residual	14	1890.1	135.0		
Total	23	6959.0			

Appendix 9. Variate: Number of Leaves of Okro 4WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	16.0833	8.0417	14.22	
Rep.*Units* stratum					

SI_ and_ Rainfed	1	28.1667	28.1667	49.81	<.001
Fertilizer	3	1.8333	0.6111	1.08	0.389
SI_ and_ Rainfed. Fertilizer	3	1.8333	0.6111	1.08	0.389
Residual	14	7.9167	0.5655		
Total	23	55.8333			

Appendix 10. Variate: Number of Leaves of Okro 6WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	20.583	10.292	5.13	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	112.667	112.667	56.17	<.001
Fertilizer	3	72.500	24.167	12.05	<.001
SI_ and_ Rainfed. Fertilizer	3	34.000	11.333	5.65	0.009
Residual	14	28.083	2.006		
Total	23	267.833			

Appendix 11. Variate: Number of Leaves of Okro 8WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	540.58	270.29	5.30	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	240.67	240.67	4.72	0.047
Fertilizer	3	370.17	123.39	2.42	0.109
SI_ and_ Rainfed. Fertilizer	3	3.00	1.00	0.02	0.996
Residual	14	713.42	50.96		
Total	23	1867.83			

Appendix 12. Variate: Number of Fruits of Chili Pepper **11WAT**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	28.583	14.292	2.29	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	187.042	187.042	29.96	<.001
Fertilizer	3	22.458	7.486	1.20	0.346
SI_ and_ Rainfed. Fertilizer	3	5.458	1.819	0.29	0.831
Residual	14	87.417	6.244		
Total	23	330.958			

Appendix 13. Variate: Number of Fruits of Okro 11WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	3018.	1509.	0.24	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	82368.	82368.	13.29	0.003
Fertilizer	3	32244.	10748.	1.73	0.206
SI_ and_ Rainfed. Fertilizer	3	21384.	7128.	1.15	0.363
Residual	14	86791.	6199.		

Total	23	225806.

Appendix 14. Variate: Number of Flowers of Chili Pepper **6WAT**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	6.083	3.042	2.29	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	30.375	30.375	22.88	<.001
Fertilizer	3	9.458	3.153	2.38	0.114
SI_ and_ Rainfed. Fertilizer	3	2.458	0.819	0.62	0.615
Residual	14	18.583	1.327		
Total	23	66.958			

Appendix 15. Variate: Leaf Area of Chili Pepper 2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.583	1.292	0.42	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	196.082	196.082	63.46	<.001
Fertilizer	3	6.397	2.132	0.69	0.573
SI_ and_ Rainfed. Fertilizer	3	14.455	4.818	1.56	0.243
Residual	14	43.257	3.090		
Total	23	262.773			

Appendix 16. Variate: Leaf Area of Chili Pepper 4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.47	1.24	0.05	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	188.16	188.16	7.49	0.016
Fertilizer	3	55.42	18.47	0.74	0.548
SI_ and_ Rainfed. Fertilizer	3	25.86	8.62	0.34	0.795
Residual	14	351.69	25.12		
Total	23	623.61			

Appendix 17. Variate: Leaf Area of Okro 4WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	386.3	193.2	0.34	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	19952.7	19952.7	35.62	<.001
Fertilizer	3	5937.5	1979.2	3.53	0.043
SI_ and_ Rainfed. Fertilizer	3	353.7	117.9	0.21	0.887
Residual	14	7841.7	560.1		
Total	23	34471.8			

Appendix 18. Variate: LAI of Chili Pepper 2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SI_ and_ Rainfed	1	4.902E-05	4.902E-05	68.44	<.001
Fertilizer	3	1.599E-06	5.331E-07	0.74	0.541
SI_ and_ Rainfed. Fertilizer	3	3.614E-06	1.205E-06	1.68	0.211
Residual	16	1.146E-05	7.163E-07		
Total	23	6.569E-05			

Appendix 19. Variate: LAI of Okro 2WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	6.458E-07	3.229E-07	0.42	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	4.902E-05	4.902E-05	63.46	<.001
Fertilizer	3	1.599E-06	5.331E-07	0.69	0.573
SI_ and_ Rainfed. Fertilizer	3	3.614E-06	1.205E-06	1.56	0.243
Residual	14	1.081E-05	7.724E-07		
Total	23	6.569E-05			

Appendix 20. Variate: Yield of Chili Pepper 11WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	11.87	5.94	0.28	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	123.40	123.40	5.83	0.030
Fertilizer	3	30.09	10.03	0.47	0.705
SI_ and_ Rainfed. Fertilizer	3	1.05	0.35	0.02	0.997
Residual	14	296.12	21.15		
Total	23	462.53			

Appendix 21. Variate: Yield of Okro 11WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	349.4	174.7	0.63	
Reps.*Units* stratum					
SI and Rainfed	1	2335.0	2335.0	8.44	0.012
Fertilizer	3	2116.1	705.4	2.55	0.098
SI_ and _ Rainfed. Fertilizer	3	404.5	134.8	0.49	0.696
Residual	14	3871.1	276.5		
Total	23	9076.2			

Appendix 22. Variate: Fruit Diameter of Okro 11 WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	41.26	20.63	0.60	
Reps.*Units* stratum					
SI and Rainfed	1	232.50	232.50	6.80	0.021

Fertilizer	3	147.56	49.19	1.44	0.274
SI _and _ Rainfed. Fertilizer	3	14.99	5.00	0.15	0.930
Residual	14	478.69	34.19		
Total	23	915.01			

Appendix 23. Variate: Leaf Chlorophyll Content of Chili Pepper 4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	250.47	125.24	2.56	
Reps.*Units* stratum					
SI and Rainfed	1	448.07	448.07	9.15	0.009
Fertilizer	3	887.99	296.00	6.05	0.007
SI_ and _ Rainfed. Fertilizer	3	178.14	59.38	1.21	0.342
Residual	14	685.43	48.96		
Total	23	2450.11			

Appendix 24. Variate: Leaf Chlorophyll Content of Okro 6WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.63	0.82	0.03	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	1457.04	1457.04	53.96	<.001
Fertilizer	3	7.46	2.49	0.09	0.963
SI_ and_ Rainfed. Fertilizer	3	266.33	88.78	3.29	0.052
Residual	14	378.04	27.00		
Total	23	2110.50			

Appendix 25. Variate: Above Ground Biomass of Chili Pepper 6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	6.0823	3.0411	3.62	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	117.5723	117.5723	140.07	<.001
Fertilizer	3	5786.7937	1928.9312	2297.99	<.001
SI_ and_ Rainfed. Fertilizer	3	1401.7074	467.2358	556.63	<.001
Residual	14	11.7516	0.8394		
Total	23	7323.9072			

Appendix 26. Variate: Above Ground Biomass of Okro 7WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	9.88	4.94	0.36	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	271415.84	271415.84	19657.51	<.001
Fertilizer	3	421487.49	140495.83	10175.52	<.001
SI_ and_ Rainfed. Fertilizer	3	340966.45	113655.48	8231.59	<.001
Residual	14	193.30	13.81		
Total	23	1034072.96			

Appendix 27. Variate: Gross Margin of Chili Pepper

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.093E+07	1.046E+07	0.03	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	4.083E+09	4.083E+09	10.23	0.006
Fertilizer	3	6.259E+08	2.086E+08	0.52	0.674
SI_ and_ Rainfed. Fertilizer	3	1.123E+08	3.743E+07	0.09	0.962
Residual	14	5.589E+09	3.992E+08		
Total	23	1.043E+10			

Appendix 28. Variate: Gross Margin of Okro

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.948E+09	9.741E+08	0.82	
Reps.*Units* stratum					
SI_ and_ Rainfed	1	2.417E+10	2.417E+10	20.40	<.001
Fertilizer	3	6.418E+09	2.139E+09	1.81	0.192
SI_ and_ Rainfed. Fertilizer	3	3.277E+09	1.092E+09	0.92	0.456
Residual	14	1.659E+10	1.185E+09		
Total	23	5.240E+10			

Appendix 29. Left: Data Collection on Okro, Right: Taking Data on Soil Moisture using Hydrosense II Soil Moisture Meter


Appendix 30. Left: Application of Insecticides, Right: Field, 5 weeks after Planting


Appendix 31. Field, 8 weeks after Transplanting and Sowing of Chili Pepper and Okro


Appendix 32. Left: Okro, 5 weeks after Sowing, Right: Taking the Weight of Harvested Okro