UNIVERSITY FOR DEVELOPMENT STUDIES

GROWTH, YIELD, PHYSIOLOGICAL AND FRUIT QUALITY RESPONSE OF TWO TOMATO (*Solanum lycoperscion* L.) HYBRIDS TO DIFFERENT IRRIGATION REGIMES UNDER FIELD CONDITIONS

GBIREH HELEN KAAE

SEPTEMBER, 2023

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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 MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

SEPTEMBER, 2023

DECLARATION

DECLARATION BY CANDIDATE

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

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DECLARATION BY SUPERVISORS

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

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ABSTRACT

The implementation of regulated deficit irrigation has emerged as an effective approach to achieve sustainable crop production in regions facing water scarcity. The main objective of this study was to determine the effects of irrigation regimes and crop variety on the growth, physiological responses and fruit quality of two tomato hybrids in the Northern region of Ghana. The study was conducted under field conditions at Nyankpala in the Guinea Savannah Agro-ecological zone of Ghana from February to June, 2023.The experiment was a 3 x 2 factorial experiment laid out in a split-plot design with three (3) replications. The treatments included three (3) irrigation regimes (60 % CWR, 80 % CWR and 100 % CWR) in the main plots and two (2) tomato varieties (Cobra F1 and Mongal F1) in the sub-plots. Estimated crop water requirement for tomato was 481 mm during the growing season. Irrigation regime at 80 % CWR gave the highest crop water productivity of 2,133kg/ha and the highest yield of 15,020 kg/ha. Irrigation regime at 100 % CWR recorded the highest chlorophyll fluorescence content for Fo, Fm, FvFm and FvFo at 163.7µmols, 578 µmols, 0.816 µmols and 4.383 µmols, respectively. Irrigation regime at 100 % CWR and variety Mongal F1 gave the best quality fruits with fibre (%) and TSS at 7.9 % and 7.6, respectively. Overall, irrigation regime at 80 % CWR using drip system is recommended for higher crop water productivity, plant improved plant health, maximum yield and quality tomato fruits from the hybrids.

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DEDICATION

This work is dedicated to my family, Michael Agyekum Acheampong and Ghana Irrigation Development Authority- Kpong Irrigation Scheme (GIDA-KIS).

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LIST OF ACRONYMS AND ABBREVIATION

AMC	Available Moisture Content
ANOVA	Analysis of Variance
Bd	Bulk Density
Ca	Calcium
CEC	Cation Exchange Capacity
Cmole	Centimole
CSIR	Council for Scientific and Industrial Research
CWR	Crop Water Requirement
DU	Distribution Uniformity
DI	Deficit Irrigation
DAP	Days After Planting
DAS	Days After Sowing
EC	Electrical Conductivity
FAO	Food and Agriculture Organisation
FC	Field Capacity
Fo	Initial Fluorescence Obtained in a dark-Adapted Sample
Fm	Maximum Fluorescence after Illumination of a Dark-Adapted Sample
FvFm	Maximum Quantum Yield of PSII Photochemistry
FvFo	Maximum Primary Yield of PSII Photochemistry
GAP's	Good Agricultural Practices
GDP	Gross Domestic Product
GIPC	Ghana Investment Promotion Centre
IFPRI	International Food Policy Research Institute
IRg	Gross Irrigation Requirement
IRn	Net Irrigation Requirement
K	Potassium
Kc	Crop Co-efficient Factor
Kg	Kilogram
MAD	Manageable Allowable Depletion
Mg	Magnesium
MoFA	Ministry of Food and Agriculture
N	Nitrogen

O.C	Organic Carbon
OECD	Organisation for Economic Cooperating and Development
P	Phosphorus
PGR	Plant Growth Regulators
pH	Power of Hydrogen
PSII	Photosystem II
PWP	Permanent Wilting Point
RAW	Readily Available Water
SARI	Savannah Agriculture Research Institute
SEM	Standard Error of Means
SRID	Statistics Research and Information Directorate
TAW	Total Available Water
TTA	Total Titrable Acidity
TSS	Total Soluble Solids
USDA	United States Department of Agriculture
WAT	Weeks after transplanting
WNI	Water Content in Next Irrigation
WP	Water Productivity
WUE	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Almost half of Africa's economic activity is carried out by agriculture. According to a report released by the World Bank (2021), if the continent's farmers and businesses can access the necessary resources and technology, they can create a food market worth a trillion dollars by 2030. Agriculture in Ghana mainly involves smallholders, rain-fed, and traditional practices. According to the FAO (2015), 15% of the farms are over 2 hectares, 25% is between 1.2 and 2 hectares, and the remaining 60% is under 1.2 hectares. The farming systems in Ghana vary depending on the region's agro-ecological zones (Kemausuor *et al.*, 2013). The country's agricultural sector strengths include a well-established research facility and proximity to the EU market (Ministry of Business Development, 2020).

Ghana's agricultural land area is about 13.5 million hectares. Out of this, approximately 50 percent is under cultivation, while over 200,000 hectares are under irrigation. The agricultural sector is a crucial contributor to Ghana's economy and is vital to the country's export earnings. It also produces employment opportunities for over 50% of the country's population (GIDA, 2020).

Compared to other sectors, the agricultural industry is known to impact poverty reduction in Ghana significantly. It is also essential for rural development and plays a role in stabilizing the country's social and environmental conditions. One of the most prominent examples of this is the Planting for Food and Jobs (PFJ), which was launched in 2017. Through the PFJ program, farmers receive tools and resources to improve agricultural production and living conditions. Additionally, it motivates investors to participate in the nation's agricultural export business.

One of the most critical components of the diet of Ghanaian households are tomatoes, with consumption estimated to around 440,000 tons annually (Van Asselt *et al.*, 2018). Despite the government's efforts to support the country's tomato production, the importation of tomato has remained relatively high (IFPRI, 2020). According to UN Comtrade (2019) statistics, Ghana imports about 8,000 tons of tomatoes annually. However, a study by Van Asselt *et al.*, 2018 estimated that the country imports about 100,000 tons annually. This means that tomatoes' supply and demand patterns are unclear. Therefore, the government and private sectors must work together to develop effective marketing policies.

Ghana has the right topographical and agro-ecological conditions for tomato production, and one of the largest agricultural dams in West Africa, the Tono Irrigation Dam, is located in a tomato farming region, making it possible to produce tomatoes all year round (Research Desk Consult, 2022). The tomato production calendar varies depending on the region and the type of production system used. Irrigated production occurs in the northernmost regions from December to April, followed by rainfed tomato production from the forest zone. Irrigated production in the Volta and Greater Accra regions occurs during the last quarter of the calendar year (IFPRI, 2020). Roma VF, Laurano, Raki, Chocó TP, Power Reno, Rasta, Italy Heinz, and Petomech are the common tomato varieties grown in Ghana, primarily suitable for processing. Tomato production in Ghana involves around 90,000 farmers. At the same time, more than 300,000 individuals are employed in the retail and wholesale of raw and processed tomato products, according to Research Desk Consulting's report in 2022. Tomato products are in high demand throughout the country, as they are considered a dietary staple in households, hotels, and restaurants. This demand is constantly increasing across all regions. The rise of the middle class in Ghana and the population's increasing urbanization have led to an insatiable hunger for convenience foods among consumers. As a result, the demand for tomato paste used to prepare both local and foreign cuisines have increased (Goodman AMC, 2016). The sub-region is also experiencing an increasing demand for both quantity and quality of tomato paste, which could serve as a significant customer base for locally processed tomatoes. However, unfortunately, the tomato processing industry in Ghana remains small and heavily reliant on imports. According to estimates, Ghana spends more than USD 100 million annually to import over 100,000 metric tonnes of tomato paste.

Despite a year-round supply, there are periods of deficit when traders turn to neighbouring markets, especially Burkina Faso, which supplies the Ghanaian market, particularly during the first half of the year (Robinson and Kolavalli, 2010; Gonzalez *et al.*, 2016). The Ministry of Food and Agriculture (MoFA) estimates that tomato yield potential in Ghana could reach 20 tons per hectare with improved seed use, adoption of good agricultural practices, and reliable rainfall. This is about two-and-a-half times the current average yield of 7.5 tons under irrigated and rainfed systems combined (MoFA, 2017). Tomato yields in Burkina Faso are significantly higher, with about 10 tons per hectare. If Ghanaian farmers could achieve these yields, they would add 100,000 tons to their annual output, which is the number of tomatoes they currently import. However, tomato farmers in Ghana face various challenges, such as the absence of improved seeds, a lack of credit, and high transaction costs due to poor infrastructure (Arah *et al.*, 2015). Additionally, the fragility and perishability of tomatoes pose significant challenges to value chain agents, with losses in post-harvest handling, transport, storage, and processing potentially comprising up to half of total production.

The majority of imported tomato in Ghana comes from Burkina Faso, with Burkinabé tomatoes forming an essential part of the supply chain, especially in the first half of the year. The popularity of Burkinabé tomatoes can be attributed to higher yields, competitive transportation costs, a well-established supplier network, and a good reputation. However, estimates of the total amount of tomatoes imported into Ghana vary according to data sources. UN Comtrade reported an average of 9,400 tons per year between 2010 and 2016, mainly from Burkina Faso. Meanwhile, Ghana's estimates supplied to UN Comtrade and FAOSTAT put the number at

7,000 tons annually over the same period. These international statistical agencies do not routinely reconcile trade statistics.

In the past decade, policies and programs have been implemented to improve tomato production and marketing in Ghana, including USAID's Trade and Investment Program for a Competitive Export Economy (TIPCEE) from 2005 to 2009, which aimed to increase productivity and introduce smaller crates and grade tomatoes. The Planting for Food and Jobs (PFJ) initiative in 2017 also aimed to boost the agricultural sector by providing subsidized inputs and value chain interventions, prioritizing tomatoes and several other crops.

Over time, various international agreements and strategies have been developed to advance horticulture. For instance, India and Ghana launched a project in 2017 to boost tomato production (CSIR, 2017).

Tomatoes are rich in nutrients like lycopene, which is known to reduce the risk of chronic diseases and cancer. They also help lower the risk of cardiovascular diseases and osteoporosis (Rao *et al.*, 1998; Frusciante *et al.*, 2007; Bhowmik *et al.*, 2012). The presence of these nutrients and other antioxidant properties in tomatoes is significant for global human nutrition. Tomatoes being a climacteric fruit are sensitive to ripening hormone ethylene. The higher antioxidant activity of tomato could mitigate the effect of ethylene as ripening process involved series of physiological and biochemical changes in which antioxidant properties play fundamental role (Jimenez *et al.*, 2002).

Tomato's nutritional value, flavour, and colour depend on their antioxidant properties. According to epidemiological studies, the presence of β-carotene and lycopene in tomatoes can be considered functional food substances (Tonucci *et al.*, 1995; Nguyen and Schwartz,1999). It is essential to analyse the effects of different tomato types on synthesizing these compounds. Studies have shown that the amount of antioxidant compounds in tomatoes varies depending on their genotype (George *et al.*, 2004). Viskelis *et al.*, 2907, conducted a study which revealed that the Lithuanian variety known as Rutuliai has the highest amount of lycopene, 1.6-fold more significant than hybrid "Admiro" and 2-fold greater than hybrid "Kassa."A study conducted by Radzevicius and colleagues in 2013 revealed that the ascorbic acid content of different tomato cultivars varied significantly.

Tomato also responds well to fertilizer application and is reported to be a heavy feeder of nitrogen (N), phosphorus (P), and potassium (K) fertilizer. It is partially compatible with drip irrigation, which is a very efficient use of water and nutrients. Nitrogen, phosphorus, and potassium are essential for tomato production and the recommended balanced rates of fertilization include twice as much N as P and K (Xiukang and Yingying, 2016). To obtain high yields and maximum profits in commercial tomato production, the optimal management of both fertilizer and water is required. Therefore, it is necessary to select an optimal combination of irrigation and fertilization to improve agricultural water and fertilizer management practices (Qu *et al.*, 2020).

1.2 Problem Statement and Justification

According to the Business and Financial Times (2022), the imports of tomatoes from Burkina Faso reached about $99.5 million in 2018. The country is expected to produce about 800 metric tonnes of tomatoes annually in 2022. Unfortunately, Ghana has not achieved its full potential in producing tomatoes, with an average yield of less than ten metric tonnes per hectare (Puozaa, 2015; Adongo *et al.*, 2016). The lack of access to markets, the unimodal nature of the production, and the high perishability of fruit contribute to the decline in domestic production. The competition from imports also causes this. Between December and May, the harvest season in Burkina Faso, which can last for several months, can yield up to 100,000 tons annually (Robinson *et al.*, 2010; Van Asselt *et al.*, 2018)

Other factors that can affect the production of tomatoes include soil infertility, inadequate water management, and improper application of fertilizers (Wang *et al.*, 2011). It is essential to thoroughly assess the various growth stages of vegetables to determine optimal water management techniques (Machado and Oliveira, 2005).

The incorrect estimation of water needs can harm crops, reducing quality and yield. Watering plants at the appropriate times can help manage their water requirements (Evan and Sadler, 2008). In some areas of Ghana, particularly the Northern part of the country, there has been an improvement in access to irrigation, which is needed to develop tomato plants to reduce hunger and poverty.

The lack of adequate water supply can affect the production of tomatoes. Water deficiency resulted in a decrease in overall fruit yield, Pascale *et al.* (2011). Surplus moisture can also harm a plant, as excessive amounts can lead to various issues, such as delayed flowering, fruit disorders, and root death. In order to maximize the production of tomatoes, it is essential to schedule irrigation at different times properly.

Scheduling irrigation properly can help replenish soil moisture and accelerate the development of plants. Straw mulch can also be utilized alongside irrigation to improve the plant's growth and produce more fruits (Zhang *et al.*, 2014).

This study aims to identify the physiological effects of varying tomato irrigation regimes on their growth, shelf life, and yield. There needs to be more research on the optimal water regime for hybrid and low-yield cultivars. Limited reports have been on the various aspects of tomato production and irrigation in Ghana's Guinea-Savannah agroecological zone. One of the most critical factors affecting the quality and quantity of tomato production is water availability.

1.3 Objectives of the Study

1.3.1 Main Objective

The study aimed to analyse the impact of irrigation regime and crop variety on the physiological response and shelf life of tomatoes in a field experiment in northern Ghana.

1.3.2 Specific Objectives

The specific objectives of the study were:

i. To determine the crop water requirement of tomatoes at Nyankpala in the Northern region of Ghana.

ii. To determine the influence of different irrigation regimes and variety on the growth and yield of tomatoes.

iii. To determine the influence of irrigation regime and tomato variety on the physiological responses of tomatoes.

iv. To establish the influence of irrigation regimes and variety on the fruit quality of tomatoes.

1.5 Structure of Thesis

The first chapter of the thesis presents the study's background, objectives, justification, and hypothesis. Chapter two covers the literature review, which includes the importance of tomato production, the production of selected tomato varieties in the world and in Ghana, soil quality, variety types and adaptability, growth, yield, physiological responses, and fruit quality. This study examines the effects of crop variety and irrigation regimes on tomatoes' quality and physiological responses. The chapter three introduces the study's materials and procedures, while the fourth provides the results and discussions. The fifth chapter summarizes the study's recommendations and conclusions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Growth Habits and Water Requirements of Tomato

Tomato, scientifically known as *Solanum lycopersicon*, is a popular and widely cultivated vegetable crop that originated from Mexico and Peru (Gould, 1992). This short-lived perennial plant can grow annually to reach a height of 1-3 meters and produce bright, edible fruit rich in the pigment lycopene. Tomatoes can be grown not only for local consumption but also for exportation (OECD, 2017). There are two types of tomatoes: indeterminate and determinate. Determinate plants usually have a short period of fruit setting and flowering. On the other hand, indeterminate cultivars can continue producing fruit until they die (Steduto *et al.*, 2012).

The USDA states that tomatoes are a part of the *Plantae, Magnoliophyta, Solanales, Solanum,* and *Solanaceae* families. They are tolerant to soil pH ranging from 5.5 to 6.8. They have fleshy roots that can extend to 160 cm in height (Welbaum, 2015). Depending on the climate, the soil type, and the irrigation method, the amount of water needed to harvest tomatoes can vary from around 350 to 800 millimetres. They prefer well-drained and deep soils with good water-holding capacity (Steduto *et al.*, 2012). Depending on the growing area's temperature, tomato may start to flower within 25 to 40 days following transplanting or up to 60 days after emergence. According to Steduto *et al.* (2012), the life cycle of a fresh market tomato plant is about 115 to 145 days. Various factors, such as soil water supply and demand, can affect the quality and yield of tomatoes (May and Gonzales, 1994; Sen and Sevgican, 1999). These include physiological disorders like blossom-end rot and fruit cracking (Obreza *et al.*, 1991).

2.1.1 Tomato Varieties

Hybrids were developed to improve the quality and yield of tomatoes in both enclosed and open environments. Different types of tomatoes can be distinguished by their shape, size, color, and flavor (Sacco, 2008). Various tomato varieties can be cultivated in Ghana, and these include the Nimagent F1, Roma, Pectomech, and Tropimech. The cultivated varieties are not significantly different from the ones approved by the country's Ministry of Agriculture (Clottey *et al.*, 2009; Robinson *et al.*, 2010). MoFA (2009) established a variety of tomato varieties that can be cultivated in Ghana. These include the Rio Grande, Roma, Pectomech, Laurano 70, and Wosowoso. In addition, different genotypes, such as the Platinum F1 and the Mongal F1, have shown high-ranking performance in field and greenhouse trials (Ochar *et al.*, 2019).

2.1.2 Fruit Quality

When it comes to choosing a suitable tomato variety, farmers should take into consideration various aspects such as its shape, color, size, and shelf-life. These characteristics can help them determine which variety is ideal for the profitability their business and produce the best marketable yield (NGSSA, 2003).

2.1.3 Variety Reliability and Adaptability

Unpredictable weather can affect the performance of crops, which is why it is essential to minimize the risks involved in the production process. This can be done by selecting varieties that are capable of tolerating pests, diseases, and bad weather which are also high yielding (NGSSA, 2023).

2.1.4 Disease and Nematode Susceptibility

Various diseases can severely affect the production and quality of tomatoes and other crops. To combat the negative impact of disease attacks on crop production, farmers often implement costly control measures that can reduce profitability. As a result, tomato farmers in KwaZulu-Natal prioritize varieties that are resistant and tolerant to diseases and nematodes to avoid yield losses and maintain profitability (NGSSA, 2023).

2.1.5 Growth Indicators

According to Singh and colleagues, growth can be measured by determining the increase in protoplasm levels at a cellular level. However, it is only sometimes possible to measure this phenomenon directly. Instead, we rely on other factors, such as cell count and fresh weight, to identify growth (Singh *et al.*, 2021).

i. Phases of Growth

A plant's growth period comprises three phases: maturation, elongation, and meristematic. During the meristematic stage, the cells at either the shoot apex or root constantly divide. These cells have a large, thin primary cellulose wall and abundant plasmodetal connections.

Next to the meristematic zone, the elongation phase involves the development of new cell walls and increased vacuolation. During this period, the cells also undergo cell enlargement and deposition. The maturation phase takes place further away from the shoot apex. During this stage, the maximum size of the cells is attained through the modification of their wall thickness and the formation of new protoplasmic connections (Gardner *et al.*, 1991).

ii. Growth Rates

A report by Muszta and Pommerening (2015) stated that the term growth rate refers to an increase in the number of cells produced by an organism or a part of it over time. There are various ways that living systems can grow to increase their number of cells. Also, the growth rate can be compared quantitatively. The absolute growth rate measures the increase in the total number of units a given system has per unit of time. On the other hand, the relative growth rate refers to the growth the system has experienced as a percent of its initial value.

iii. Conditions for Growth

The water status of plant cells is also a vital factor that affects their growth and development. Water is required for cell enlargement, while the presence of turgidity helps in extending their growth. Oxygen helps in releasing energy needed for metabolic activities.

Both micro and macronutrients are required for the production of protoplasm and for the energy-producing activities of plant cells. Ensuring that the temperature range at which plants grow is at an ideal level can help them survive. In addition, environmental factors such gravity and light can affect the development of different stages (Garner and Allard, 1920).

2.1.6 Plant Growth Regulators

These small molecules are known as plant growth regulators. They come in various chemical forms and are classified as indole compounds, adenine derivatives, carotenoids, or terpenes. They are also referred to as plant growth substances or phytohormones (Kumari *et al.*, 2018). Two main groups of PGRs are responsible for regulating various plant growth activities. The first one involves promoting the division of cells and other growth-stimulating activities, such as fruiting and flowering. Common PGRs in this group include cytokinins, auxins, and gibberellins (Subandi *et al.*, 2017). The second group of PGRs is responsible for regulating the responses of plants to environmental stresses and wounds. It is also involved in various growth-inhibiting actions, such as abscission and dormancy. Although ethylene can be a component of both groups, it mainly hinders growth activities (Tucker, 1993).

2.1.7 Physiological Effects of Plant Growth Regulators (PGRs)

i. Auxins

The term auxin refers to compounds that regulate the growth of plants. One of the most common types is IAA, produced by the stems and roots' tips. Other types include IBA, found in plants, and synthetic versions of these compounds.

In addition to helping promote plant growth, auxins can also help prevent leaf and fruit drop during the early stages of development. They can also induce parthenocarpy, which occurs when a plant produces fruit without fertilization. In addition to killing weeds, using herbicides known as auxins can also assist in developing monocotyledonous plants. Auxin is involved in controlling the differentiation of the xylem and in the cell division process. This discovery was made by Darwin (1880).

ii. Gibberellins

In addition to helping plants grow, gibberellins are also known to promote growth by producing a variety of physiological responses. They are categorized into various forms, such as GA1, GA2 and GA3. One of the most extensively studied types is Gibberellic Acid (Kurosawa, 1926).

iii. Cytokinins

Plant hormones known as cytokinesis have a particular effect on the division of cells. One of the first known forms of this substance is kinetin, a modified version of adenine found in the DNA of herring sperm. However, it is not native to plants. The discovery of zeatins has led to identifying various naturally occurring cytokinin compounds. In addition to helping with the development of lateral shoots, cytokines also play a vital role in the establishment and maintenance of adventitious shoots and the development of leaves. They can help overcome the apical dominance that can result in leaf senescence (Skoog and Miller, 1950).

iv. Ethylene

The gas ethylene can affect the development and growth of plants. It can be produced in large quantities during the ripening process of fruit and tissue undergoing senescence. It can also affect the development of seedlings by causing apical hook formation and promoting horizontal growth. Ethylene accelerates the process of plant organ aging, especially the leaves and flowers. It can regulate various physiological processes and is widely used in agriculture as a plant growth regulator (Prasanna *et al.*, 2007). The utilization of ether produces ethylene. The plant readily absorbs it and releases it slowly. In order to hasten the ripening of tomatoes, ether is commonly utilized (Cruz *et al.*, 2018).

v. Abscisic acid (ABA)

Although it was first discovered to regulate dormancy and abscission, ABA has various effects on a plant's development. These include its ability to inhibit plant metabolism and seed germination. ABA plays a vital role in the development and maturation of seeds. It can induce dormancy, which helps plants withstand environmental conditions that can negatively affect their growth, such as desiccation (Nonogaki *et al.*, 2014).

2.1.8 Tomato Ripening Impact on Fruit Biochemical Composition

Tomatoes' biochemical composition and fruit quality are closely related to their maturity at harvest. When it comes to identifying which green tomatoes are mature or immature, it is hard to tell because of the varying harvest time. Viskelis *et al.* (2015) noted that advanced green tomatoes have better flavor when fully matured. The thin skin of tomatoes makes them more prone to injury and water loss, affecting their taste. During ripening, they accumulate nutrients such as ascorbic acid and sugars. Their fruit texture also affects how vulnerable they are to physical damage. According to Viskelis *et al.* (2015), this characteristic is very important for consumers as it can be easily tested using their fingertips. Different environmental factors, such as the plant's genotype and the fruit's ripeness, can affect the composition of tomato carotenoids. The level of lycopene found in fully-ripened tomatoes can vary. Some reports indicate that the average amount is around 9.27 mg/100 g-1. Others claim the figure is around 3.1 to 7.7 mg/100 g-1.

Lithuanian researchers investigated to examine the effects of fruit ripening on the quality of tomatoes. They selected five different types of Lycopersicon spp. tomatoes and studied them at varying stages. The researchers discovered that fully-ripened tomatoes had the highest level of lycopene, varying levels ranging from 9.21 mg/100 g-1 in "Milinai" to 12.69 mg/100 g-1 in "Vilina." On the other hand, green tomatoes had the lowest levels, ranging from 0.25 to 0.72 mg/100 g-1. The researchers also observed a similar pattern regarding the- carotene levels in green and fully-ripened tomatoes. The levels ranged from 0.20 to 0.47 mg/100 g-1 in green tomato fruits, while those in fully-ripened tomatoes were from 1.40 to 1.69 mg/100 g-1.

The researchers concluded that the -carotene and lycopene levels increase when tomatoes are at the ripening stage. But, in the "Vilina" and "Milinai" varieties, the small increase in these compounds was insignificant enough to make a statistical difference (Choi *et al*, 2023).

The flavor of tomatoes is mainly affected by the quantity and ratio of sugars and acids in their fruit. During the fruit's ripening stage, the quality of tomatoes changes. There are fewer organic acids and ascorbic acids in them as they start to mature, and there are also higher levels of dry matter and total sugars at the end of the process. However, data regarding tomatoes' ascorbic acid and total sugar content during their ripening stage vary significantly (Andelini *et al.*, 2023).

2.1.9 Effect of Water Supply on Plant Growth, Fruit Quality and Yield

Numerous studies have been conducted on optimizing water use in the production of tomatoes. Yrisarry *et al.*, 1991 found that under and over-irrigation can lead to low solid contents and poor crop yields. In a study conducted by Tuzel *et al.*, (1993), they noted that increasing the irrigation rate of greenhouse tomatoes could help decrease the plants' dry matter and soluble solids. A similar study conducted by Sefara (1994) revealed that increasing the irrigation intervals throughout the season resulted in better fruit quality.

Increasing the deficit irrigation and the partial root-zone drying technique can improve the soluble solid contents of tomatoes (Lang *et al.*, 2003). It is widely believed that optimizing the use of irrigation is a vital part of the production of tomatoes to ensure that they have a high quality and economic return (May and Gonzales, 1994; Obreza *et al.*, 1996; Byari and Al-Sayed, 1999; Sen and Sevgican, 1999; Renquist and Reid, 2001).

Various studies have shown that the amount of nutrients and the frequency of irrigation can affect the quality of fruits and the yield of plants. Increasing the greenhouse tomato plants' irrigation rate can help decrease the soluble solids and dry matter in the fruit (Tuzel *et al.*, 1993). Higher fruit water content can result in reduced soluble sugars, volatile compounds, organic acids, minerals, and vitamins (MxAvoy, 1995; Peet and Wilits, 1995). Pulupol *et al.* (1996) observed that water content reduction can improve the concentration of soluble solids recommended for processed tomatoes.

2.1.10 Effects of Variety, Irrigation Regimes and Mulch Levels on Fruiting of Tomato

Studies were carried out to assess tomato fruit yield under mulch and irrigated conditions. It has been stated that the Mongal F1 tomato variety is one of the most productive and successful varieties that can be grown in greenhouse production and field trials (Ochar *et al.*, 2019). However, studies revealed that increasing the irrigation deficit by about 50% would reduce the number of fruits produced by the plants. The lowest fruit count was around 55 % ETc, and the highest was over 100 %. The researchers noted that the highest fruit count was achieved by tomato plants that had a 100 % ETc during a two-season trial. On the other hand, the most stressed regime had the lowest fruit count during the first and second trials (Ragab *et al.*, 2019; Sibomana *et al.*, 2013).

According to studies, drip irrigation at a 1.0 E pan can produce more fruits than the scheduled irrigation at a 0.6 E pan (Kumar, 2012). However, increased deficits can negatively affect the development of tomatoes (Ganeva *et al.*, 2018; 2019). In addition, moisture stress can reduce the number of fruits the plants produce (Birhanu and Tilahun, 2010).

Using organic mulches is a critical factor that affects tomato fruit count. Using grass, rice straw, and sawdust mulches led to more fruits per plant. On the other hand, the control group had the lowest fruit count (Nkansah *et al.*, 2003). An experiment revealed that Mexican sunflowers (*Tithonia diversifolia*) can increase the fruit count of plants (Liasu and Abdul, 2007). In addition, cocoa husk mulch can reportedly help boost the fruit count after application (Ahmad *et al.*, 2011; Kassahun, 2017).

Using wheat straw, black polyethylene, and rice straw mulches can increase the number of fruits per plant. In addition, irrigation regimes with a 100 to 115 percent ETc could produce more fruits than those with a 50 to 75% Etc (Silva *et al.,* 2021).

2.1.11 Soil Moisture

Unpredictable soil moisture levels can lead to physiological disorders like fruit cracking. This issue can also be caused by frequent watering in a greenhouse. According to reports, higher soil moisture levels can also lead to tomato crop cracking. High irrigation rates can result in fruit quality being affected by the crack (Kamimura *et al.,* 1972. Other studies have shown that plants that receive high amounts of water are more prone to developing cracks. Fruit cracking can also be caused by irregular irrigation, which can occur when the soil becomes moist and dry again. Watering frequency was reduced to four or five times a day, and the total amount of water used per day remained the same. Kamimura *et al.*, 1972 noted that a sudden increase in the water content of the growing media affected the plant's root pressure and cuticle elasticity. The higher the soil's moisture level, the more water uptake will occur, increasing turgor pressure. This causes the cell expansion to pressure the plant's epidermis and cuticle.

Weakness or limited elasticity in the cuticle layer can cause fruit to crack (Pascual *et al*., 1999; Dorais *et al.,* 2004). Changes in the soil's moisture level can affect the strength of tomato fruit's skin. Peet (1992) noted that the soil's moisture content increased when the skin's strength increased and decreased when it went down. In 1997, Emmons and Scott reported that inadequate watering had caused fruit to crack in field-grown tomatoes.

2.1.12 Humidity

Low relative humidity and high temperatures are known to trigger fruit cracking. In 1978, Drews noted that this phenomenon could increase the likelihood of this occurrence. Dorais *et al.* (2004) conducted a study that showed that increased relative humidity can affect the leaf transpiration rate and turgor pressure in fruit. Under these conditions, the fruit's skin may become more stressed, which could lead to a fruit-cracking reaction. Leonardo *et al.,* (2000) noted that misting during the summer can increase the risk of this type of reaction.

According to Guichard in 1999 cited by Dorais *et al.* (2004), misting can improve the plant's water status and reduce the amount of transpiration. It can also increase the water and carbon fluxes going into the fruit.

2.1.13 Temperature and Light

According to Peet's Fruit in 1992, high light intensity can raise the temperature of exposed fruits, leading to fruit cracking. In addition, the growth rates and fruit soluble solids can increase in such conditions. Studies conducted by Pascual *et al.* (1999) revealed that higher radiation and temperatures during the reproductive season can lead to fruit cracking, especially in the upper clusters. Fruits positioned higher in the cluster are more susceptible to direct sunlight and high temperatures. In 1995, studies conducted by Willits and Peet revealed that the number of fruits affected by fruit cracking increased significantly in the upper clusters. From first to seventh clusters, the percentage of affected fruit increased from 21 to 38%. The researchers attributed the rise in fruit cracking to irradiance and temperature. These factors contribute to the development of fruit cracking by increasing the pulp's expansion and weakening the cuticle (McAvoy,1995). Dorais *et al.,* 2001 noted that temperature variations, such as those caused by low nights and high days, can affect the pressure in the fruit's internal organs.

2.1.14 Relative Humidity

Papadopoulos (1991) reported that excessive variation in humidity can lead to a deficiency in calcium in plants. This issue occurs when the water between the fruits and leaves is not evenly distributed. Ho and Adams (1993) believe that high temperature and low humidity during the day can increase transpiration, allocating more calcium to the leaves.

High humidity can also reduce transpiration and lead to less calcium being absorbed from the leaves and more from the fruits. In 1995, Ho and Adams discovered that high humidity during the day can affect the amount of calcium the fruit produces. In 2001, Tadesse noted that the presence of high relative humidity can promote the growth of fruits and encourage the accumulation of calcium. According to Banuelos *et al.*, (1985), although the calcium that fruit absorbs at night is higher than during the day, the amount of calcium the fruit takes at night due to high humidity can increase (Tadese, 2001).

2.1.15 Drip Irrigation

Drip irrigation is one of the most efficient ways to grow quality tomatoes. This method involves slowly watering the plants through a small tube. It does not require wetting the leaves. The tape is usually 8 to 10 millimetres thick and is buried between 4 to 12 inches of dripper spacing. One drip line is needed per row for optimal tomato production. The flow rate of the tape can vary. Growers commonly use medium-flow tapes, delivering around 0.5 to 1.0 gallons per minute. On the other hand, high-flow tapes are more effective at reducing the time it takes to water the plants. Another advantage of this method is that it allows the plants to receive nutrients through fertigation. Fertigation is a technique that allows crops to receive nutrients and water throughout their growth cycle instead of at the same time prior to or after planting. It is an efficient way of conserving both resources (Cherlinka, 2023).

2.1.16 Watering

When tomatoes are not watered properly, their quality and yield will decline. Insufficient water can reduce the number of blossoms per truss, produce fewer fruits, and lead to the development of blossom-end rot. Ensuring that plants receive the necessary amount of water during critical growth stages is very important to ensure that they reach their optimal development. The development of fruits and the flowering of tomatoes usually begin around six to eight weeks after transplanting. On the other hand, indeterminate and determined varieties of tomatoes have a shorter flowering period. They need around 2 to 2.5 quarts of water a day to grow their fruit. A greenhouse with several hundred tomato plants requires over a thousand gallons of water per week to maintain proper development and growth (Jett, 2014).

2.1.17 Fertilization

Although tomatoes can be fertilized with a wide range of water-soluble fertilizers, it is generally advised to avoid using too much potassium and phosphorus through drip irrigation. Before planting, the soil must be thoroughly tested. The decision to add more nutrients to the drip irrigation system should be based on the tissue test results.

The nitrogen required to develop tomatoes is vital for the plants' growth. If the plants are not getting enough nutrients, they will develop stunted and misshapen leaves and produce fewer fruits. It is recommended that the total amount of nitrogen applied at planting is around 40 to 50 percent. The remaining portion can be applied through drip irrigation (Jett, 2014).

Various organic materials, such as compost and alfalfa meal, can be mixed with the soil before planting. The volume of water that has been used for irrigation can determine the amount of nitrogen that is applied. Compared to soil application, applying nutrients such as potassium, nitrogen, and phosphorus is less effective when producing fruit. Regarding tomatoes' response to nitrogen, it is readily available in nitrate or ammonium fertilizers. Compared to ammonium fertilizers, nitrate nitrogen has a lower salt level (Jett, 2014).

2.2 Tomato-Based Systems in Ghana

In Ghana, there are five major ecological zones. These include the Northern, Southern, Transition, Coastal, and disorganized forests. The tomato plant can be grown in different areas of the country depending on the available resources. According to the Ministry of Food and Agriculture (2011), plants can flourish in different environments.

Tomato can be cultivated in two ways: the irrigated and the rain-fed systems. With the latter, the plant's survival hinges on moisture availability.

In 2010, studies conducted by Kolavalli and Robinson revealed that the Upper East and Burkina Faso regions can produce fresh tomatoes throughout the year using irrigation. This allows Ghana to receive tomatoes from December to May. On the other hand, the production of tomatoes in the country's Southern regions occurs in June and November.

The exact production method and cost of tomatoes are two of the most important factors that affect the plant's success. In the case of rain-fed production, the low yields are attributed to the lack of inputs. On the other hand, in irrigated production, the high yields are attributed to using an irrigation system (Namara *et al.*, 2010; Robinson *et al.*, 2010).

2.3 Physical, Chemical and Biological Properties of soil

The characteristics of a soil type are characterized by its mineral matter, which is decomposed organic matter, and its physical composition. A well-drained soil can yield optimal vegetable production. Although tomatoes can tolerate various soil types, they are not ideal for heavy clay soils. It is recommended to avoid using heavy clay or organic soils. Although soil is the foundation of all modern agricultural systems, it is still neglected. Soil health is very important in organic farming as it affects various plant and animal life cycle aspects.

An organic producer should prioritize the health and quality of the soil when it comes to maintaining its sustainability. Table 1 highlights the different characteristics of the soil that can affect its productivity.

Table 2. 1 Soil Indicators

Physical properties	Chemical properties	Biological properties
• Bulk density • Rooting depth • Water infiltration rate • Water holding capacity • Aggregate stability	• pH • Electrical conductivity • Cation exchange capacity • Organic matter • Mineralizable nitrogen • Exchangeable K • Exchangeable Ca	• Microbial biomass carbon • Earthworms • Enzymes • Disease • Suppressive

(Usharani *et al.*, 2019)

2.4 Growth (number of leaves, plant height, branching, etc) and Yield Components

An event in any living creature is called growth, and it involves the irreversible expansion of various body parts, such as the size, length, height, volume, and cell count. This happens in meristems, typically involving the growth of protoplasmic material. The apical and intercalary meristems accomplish the growth of the plant's axes.

High plants have indeterminate growth rates. It may be geometrical or arithmetical and cannot sustain a high rate throughout an organism's lifespan.

The development of a plant is carried out in three phases: the lag, senescent, and log phases. When a cell stop being able to divide, it goes through differentiation, allowing it to develop structures similar to its function. This process is the sum of both development and differentiation.

Both extrinsic and intrinsic factors regulate the development and growth of a plant. The latter refers to the chemicals produced within a plant's various parts and control its developmental activities. The five major groups of PGRs are ethylene, abscisic acid, cytokinins, and auxins. These diverse PGRs have physiological effects on a plant and can act in antagonistic or synergistic ways. Some external factors that influence a plant's development and growth are temperature, light, oxygen status, and nutrients.

Some plants can induce flowering by getting exposed to a specific photoperiod duration. Depending on their requirements, these are called day-neutral, short-day, or long-day plants. Some plants also need low temperatures to hasten their flowering, referred to as vernalization.

2.5 Physiology of Growth and Yield Components

The way plants grow and how they distribute their biomass among various parts of the pla nt are the factors that determine the yield of crops. This is because the development of the crops and biomass distribution is influenced by the physiological processes involved in their growth. Knowledge about these processes is very important in maximizing crop yield.

Understanding the definition of growth is very important to ensure that the plants can maximize their biomass. It can be measured by various characteristics such as the plant's height, leaf area, and shoot. These measurements can then be used to compare the different cultivars (McCauley, 1990). Another important aspect of growth is the quantitative changes that happen during plant development.

Wareing and Phillips (1981) defined growth as an irreversible change in an organism's size. In 1995, Wilhelm and McMaster explained that growth merely refers to an increase in an individual's physical dimension. This can be seen in the elongated leaf blade or the increase in the leaf area. The environment, such as plants, soil, and climate, affects growth. Although growth is often confused with development, both concepts are interrelated.

The development of plants refers to the sequence of events that happen during a plant's life cycle (Landsberg, 1977). These include the development of its morphological and functional characteristics. Development is typically measured over time and includes the various processes related to organogenesis. A functional definition of this concept refers to the progression of an organism or cell through its lifespan.

The concept of phyllochrons, which refers to the intervals between the successive growth stages of a plant's leaves, has been used to describe the development of grasses (Wilhelm and McMaster, 1995). Although development can be affected by environmental factors, it is mainly related to the accumulation of heat units (Stansel, 1975).

The development of crops does not always follow a predictable path. Various environmental factors, such as temperature, duration, light intensity, and nutrients can affect it.

The ability of plants to grow throughout their lives is unique. This is because the plant's body contains meristems capable of self-perpetuating and dividing. When the product loses its ability to divide, these cells become the plant's body. The open growth stage involves adding new cells to the plant body. Gymnosperms and dicotyledonous plants develop lateral meristems, cork-cambiums, and vascular cambium during their lifetime. These meristems then cause the plant's organs to expand. This is referred to as secondary growth.

2.6 Physiological Indices (Chlorophyll Fluorescence)

The crop variety and irrigation regimes used to cultivate tomatoes in Ghana's Northern region are vital factors affecting their physiological responses. When the plants are given the proper amount of water, they can efficiently utilize the nutrients and produce optimal levels of photosynthesis. Conversely, irregular or insufficient irrigation can result in water stress, which can affect the plants' growth, leaf area, photosynthesis, and overall production. In addition, water stress can trigger tomato susceptibility to a wide range of diseases, decreasing their fruit quality and yield.

Different tomato varieties have varying genetic makeups that affect their water efficiency, root depth, heat tolerance, and overall productivity. With that in mind, choosing cultivars with high heat tolerance or drought resistance can be beneficial. For instance, varieties with deep root systems are more resilient during dry periods.

The physiological responses of different tomato varieties can be affected by their interaction with irrigation systems. For instance, drought-tolerant cultivars perform better when compared to those that require more water. The alignment of irrigation schemes and crop varieties can yield optimal results and reduce water usage (Alordzinu *et al.*, 2022).

External factors can also affect tomato physiological responses, like the soil type, pests, and availability of nutrients. Understanding the effects of varying types and irrigation systems can help improve the tomato cultivation process in the region. According to studies, regular and sufficient irrigation can help improve the growth and yield of tomato crops. Physiological responses like transpiration, leaf conductance, and photosynthesis can be improved by giving the plants consistent water.

The increased stomatal conductance and carbon dioxide influx from adequate watering can help boost the plant's photosynthetic rate and produce higher yields (Li *et al.*, 2022).

2.6.1 Initial Fluorescence of the Dark-Adapted Sample (Fo)

Chlorophyll fluorescence is a widely used method to study plant physiology. Initial fluorescence at the dark-adapted stage (Fo) is the minimal fluorescence yield when all Photosystem II (PSII) reaction centers are open. Changes in the Fo value can indicate alterations in the structure and function of PSII under different irrigation conditions, including water stress.

Kalaji *et al.* (2011) investigated the effect of different irrigation regimes on the Fo of tomato plants. They found that under drought conditions, there was a marked increase in the Fo value, suggesting a disruption in the PSII reaction centers due to induced oxidative stress. Conversely, Guo *et al.* (2017) observed that well-watered tomato plants had lower Fo values, indicating a more efficient energy transfer within PSII reaction centers. Thus, maintaining an optimal water supply is crucial for efficient photosynthetic activity. However, excessive irrigation can also lead to an increase in Fo values, similar to the effects of drought stress. Over-irrigation can cause waterlogging conditions that decrease oxygen supply and increase Fo. This suggests damage to the PSII complex due to increased production of reactive oxygen species under low oxygen conditions.

These studies indicate that both under-irrigation and over-irrigation can impair PSII function, leading to an increase in Fo values. Therefore, it is important to maintain an appropriate irrigation regime to preserve the integrity of the PSII complex and ensure efficient photosynthetic activity in tomato plants.

2.6.2 Maximum Fluorescence after Illumination of a Dark-Adapted Sample

The fluorescence yield of a dark-adapted sample after illumination is measured to determine the plant's photosynthetic potential. The maximum Fm value is displayed when the reaction facilities of the PSII are closed. This provides a comprehensive view of the plant's photochemical efficiency.

Oukarroum *et al.*, (2007) studied tomato plants to determine how different irrigation regimes affected their Fm. The plants declined their fluorescence due to drought stress and decreased chlorophyll content. The researchers concluded that these conditions could lead to photoinhibition, potentially damaging the reaction facilities of the PSII.

A study conducted by Zivcak *et al.* (2013) revealed that an irrigation regime that provides a balanced water supply can increase the plant's fluorescence parameters and improve photosynthesis. Unfortunately, this finding also highlighted the risks of over-watering, as this can result in a reduction in Fm due to the emergence of an anaerobic condition in the root zone. Flexas *et al.* (2002) linked the presence of FM to the health of the plant's photosynthetic apparatus. According to their study, a balanced irrigation system can provide an optimal Fm and a healthy photosynthetic index. But deviations from this pattern can disrupt the processes involved in photosynthesis.

2.6.3 Maximum Quantum Yield of PSII Photochemistry

A chlorophyll fluorescence analysis is a valuable technique for assessing the health of a plant. It can provide insight into how a plant responds to specific irrigation regimes. In addition, it can be used to examine how water stress affects a plant's photosynthetic performance (Murchie and Lawson, 2013).

According to a study by Cornic in 2000, drought can decrease a plant's photosynthetic efficiency. It can also lead to a reduction in the amount of carbon dioxide that the plant absorbs. The study noted that the water deficit conditions can cause stomatal closure, leading to decreased photosynthesis activity. In 2018, a study by Kalaji and colleagues revealed that an optimal irrigation system can help improve tomato plants' photosynthetic efficiency. They noted that the system maintained high fluorescence parameters, such as Fv/Fm, and the ability of the open PSII reaction centers to capture energy. These findings indicated that the plant's overall health and performance were better.

Zhang *et al.* (2009) noted that excessive irrigation can result in waterlogging, which can reduce the plant's root oxygen supply and decrease its photosynthesis activity. The researchers noted that the waterlogging conditions affected chlorophyll fluorescence parameters.

2.6.4 Maximum Primary Yield of PSII Photochemistry

The PSII photochemistry's primary maximum yield is shown in terms of its quantum efficiency. The system can absorb this maximum amount of light under certain conditions.

Kalaji *et al.* (2016) revealed that optimal irrigation settings can help tomato plants produce a stable and high Φ _P0, indicating that they use light energy efficiently in the photochemistry process. On the other hand, when the water deficit conditions were applied, the Φ _P0 level dropped significantly.

The researchers noted that the damage to the reaction centers of the PSII system might cause the reduction in Φ_P0 under water stress. Mathur *et al.* (2011) studied the relationship between irrigation regimes and PSII photochemistry. They discovered that both under and over-irrigation resulted in a reduction in the Φ_P0 level. The study also emphasized how important it is to maintain water availability to operate the photochemistry process efficiently. Although it was found that water stress can induce photoinhibition, excessive water can lead to various metabolic disturbances and anaerobic conditions. Studies also indicated that the Φ_P0 parameter can reflect the plant's response to long-term stress by acting as a proxy for the plant's adaptive mechanisms (Oukarroum *et al.*, 2009).

2.7 Effects of Maturity

The stage at which a produce is harvested is very important to determine its quality. For instance, fully matured fruits have a higher rate of ripening than immature or partially matured fruits. Different respiration rates are observed depending on the stage of maturity, type, and age of the produce. At the ripe stage, the respiration rate peaks compared to the senescent and immature stages (Adaskaveg *et al.*, 2002).

When tomatoes are still in their mature-green stage, they should be harvested. This indicates that they have developed green-colored blossoms and that seeds are enclosed in jelly-like substances (Tiwari *et al.*, 2002). They can also be harvested when the fruit turns pink. According to Wills and colleagues, about a quarter of the blossom's surface is pink (Wills *et al.*, 2004).

28 Tomato Growth, Ripening and Postharvest Physiology

The development process of fruits can be divided into the following stages:

- Cell Division
- Cell Expansion
- Maturation
- Ripening
- Senescence

The tomato starts small and complex, and it has organic acids inside. As it grows, it begins to develop from the inside out, and by the time it reaches the maturity stage, it has wholly formed its seeds. During the ripening stage, it stores volatiles, aromas, and sugars.

The starch hydrolysis process begins when the tomato reaches its maturation stage. The accumulation of Lycopene pigment causes the red color of the tomato. As the cell structure of the tomato deteriorates, it becomes vulnerable to pathogens.

The development of the seed is the most critical aspect of the tomato's growth process. Its genetic makeup determines how it responds to environmental factors and growth. In tomatoes, its mesocarp tissues have a vascular network and are composed of giant cells.

When fertilization and pollination are performed, the plants can develop their fruit. They are assisted by various hormones, such as those produced by the auxins and gibberellins. These hormones play an essential role in the cell division process (De Jong M *et al.*, 2009).

The accumulation of cytokinins by the seeds of tomatoes affects the division of the surrounding pericarp tissue (Gillaspy G, *et al.*, 1993).

i. Cell Division and Development

The process of cell enlargement in fruit needs to be more consistent. For instance, the cell size can vary in different directions and rates. This causes mature fruits to have vertical solid gradients in their overall size. Even though fruit development is complex, specific patterns can be observed in its cell division and growth. When the cell division process causes the embryo to grow, its volume remains small for the first few weeks. During this period, the flesh begins to increase. The endosperm and fertilized embryo then start to develop.

The pericarp's development resumes once it stops growing and continues until it grows larger. This phase of the fruit's growth begins through its cells' expansion. This process happens in the radial, tangential, and longitudinal directions. After anthesis, the cell division stops, marking this phase's end.

ii. Changes during Fruit Ripening

- Changes in carbohydrate composition result in sugar accumulation and increased sweetness.
- Change in color.
- Flesh softening and textural change.

- Formation of aroma volatiles.
- Accumulation of organic acids with associated development of flavor.

iii. Fruit Growth Requirement

The fruit's growth affects various factors, such as the composition of organic acids, lipid distribution, and carbohydrate economy. In practical terms, the economy of carbohydrates is the most vital. They are initially utilized for tissue expansion, cell division, and differentiation. The remaining carbohydrates are then stored in starch or sugars. Different types of tomatoes have varying amounts of these sugars, such as sucrose or hexoses. The vascular networks and leaves also transport other nutrients into the fruit.

The texture, taste, and aroma of tomatoes depend on various factors, such as their size, maturity, and growth rate. During the hotter months, thick-skinned tomatoes are commonly harvested, while thin-skinned ones are available in other seasons. The skin texture of tomatoes is affected by their fluid components' retention properties during hot weather.

iv. Firmness and Colour of Tomatoes

Consumers and buyers highly value the skin color and texture of fruits. As they soften and ripen, they become more vulnerable to damage. The degree to which the fruit's skin and flesh firm up indicates its quality (Tijskens *et al.,* 1994).

The firmness of tomatoes is also linked to their visual properties, such as their shape and color (Kader *et al.,* 1978). Color is a vital factor that consumers consider when choosing a fruit. A color difference meter or a color chart produced by the USDA (Minolta Chromo Meter) can help them determine the exact shade of tomato.

A study conducted by Batu in 2004 suggested that the firmness of fruits should be at least 1.45 N/mm. Although this figure is ideal for supermarkets, tomatoes grown at home should have readings of over 1.28 N/mm. The values of the pink and turning stages were higher than 0.08 Minolta. On the other hand, those of the light red varieties were around 0.60 and 0.95.

2.9 Tomato Aging, Ripening, and Metabolic Changes

A type of fruit known as tomatoes undergo various changes during their ripening process. These changes include changes in their acidity, firmness, and sweetness. One of the enzymes involved in this process is tomato PG, which can accumulate as the process continues. It is also known that ethylene is a vital component of the process (Rhodes, 1980; Jeffery D *et al.*, 1984). The degradation and synthesis of proteins are two primary components of the tomato's ripening process (Biggs *et al.*, 1986). This process can be observed in the various protein levels observed in the fruit at various stages. One of the most critical factors that can affect the development of this process is the stimulation of protein synthesis (Grierson, 1983).

2.10 Fruit Biochemical Composition of Tomato

Since tomatoes are a global plant, they can be used to compare the quality of fruits grown in organic and conventional systems. Unfortunately, organic farming can negatively affect the yield of fruits, and they tend to have more defects. Nonetheless, consumers still expect organic food to be safer, better for their health, and contain higher nutritional value.

According to studies, conventional crops are known to have higher levels of various nutrients, such as vitamin E, protein, and carotenoids. On the other hand, organic crops are more likely to contain phenolic compounds, vitamin C, and phytic acid.

By preventing the use of chemical fertilizers and pesticides, organic farming can enhance the soil's natural fertility and minimize pollution. This practice can also have positive effects on the well-being of humans and livestock. Fruits and vegetables are rich in antioxidants and other nutrients that can help improve their health.

The quality of tomatoes varies depending on their species, growth stage, and environmental factors. Aside from temperature and light, other factors, such as fertilization and soil fertility, can also affect the fruit's development. One of the most important factors that can affect the nutritional value of a ripe tomato is its total and soluble solids content.

A number of studies have shown that organic tomatoes contain higher levels of dry matter than their conventional counterparts. In fact, according to the studies, organic tomatoes have a dry matter content of around 7.86%, while those from conventional farms have a dry matter content of about 5.07%.

2.11 Climatic Effect on Quality of Tomatoes

i. Temperature

Once the pollination process has been completed, tomatoes can reach full maturity in six to eight weeks. The ideal temperature for this fruit is between 70- and 75-degrees Fahrenheit. High temperatures can prevent the production of carotene and lycopene, the main components of the fruit's orange-red color. Because of this, tomatoes can stay in a green stage for a long time. Direct sunlight can also affect the development of pigments in tomatoes. Sunscald can occur if the fruit is exposed to high temperatures. On the other hand, low temperatures can destroy the enzymes that are responsible for the fruit's ripening process. Yellow shoulder disorder can occur if the plant has too much potassium and magnesium.

Pick tomatoes when the first signs of their ripening appear. They should be exposed to temperatures around 70 to 75 degrees Fahrenheit to ensure their color and flavor develop naturally.

ii. Humidity

High-quality crops require the appropriate level of relative humidity. An increase in this factor can boost calcium levels in tomatoes but also lead to a shorter shelf life. Once fully matured, they can be kept in a climate with a 90 to 95 % relative humidity level to help prevent evaporation (Adams P *et al.*, 1992). The degradation of various nutrients and carbohydrates through a variety of processes can lead to a reduction in the quality of food. These can occur at high temperatures, which can cause a loss of nutrients, flavor, and texture. As a tropical country, India's temperature can significantly affect these processes.

2.12 Proximate analysis (TTA, pH, TSS) and shelf-life

Fresh tomatoes are very perishable and can last for only a short time. The storage and handling of this fruit can affect its nutritional value and quality. A proximate analysis determines the various ash, moisture, crude protein, and carbohydrate levels found in tomatoes. The environmental factors affecting the quality and life of fresh vegetables and fruits include temperature, frost, soil type, and rain (Bachmann and Earles, 2000). When fully ripe tomatoes are stored at 2 to 5 degrees Celsius, they can prevent chilling (Passam *et al.*, 2007).

When fresh tomatoes are stored at 5 degrees Celsius, their volatile compounds can lose their properties, which can cause them to produce unpleasant (Maul *et al.*, 2000). The changes during the ripening process can also affect the flavor and aroma characteristics of the fruits (Krumbein *et al.*, 2004). Plastic packaging materials can help delay the shelf life of tomato (Srinivasa *et al.*, 2006). Because of succulence of tomatoes, proper storage methods are essential to enhance their physical attributes and shelf life. According to Anju-Kumari *et al.* (1993) certain tomato cultivars require harvesting at the green stage to extend their shelf life.

In order to extend the shelf life of tomatoes, Kapsiya *et al.*, 2015 recommended using moist sawdust. The composition of this material can affect its ability to retain water. In addition, the microorganisms that can infect tomatoes when treated with preservatives can vary depending on the wood species (Johnson and Hodari-Okae, 1999).

According to Aborisade (2003), wood ash has antifungal and insecticidal properties. In However, Akomolafe and Aborisade (2007) noted that earthenware pots can be used for preserving vegetables and fruits. The improper handling and handling of fruits and vegetables can lead to postharvest losses. This can also affect the quality of the fruits and their nutritional value (Gil *et al.*, 2006). During the storage period, certain biosynthetic routes can be utilized to develop the organoleptic properties of the fruits. This study analyses the synergy between two tomato varieties' structures and phytotherapeutic properties.

2.13 Physiological Disorders of Tomatoes

Tomatoes are prone to several diseases and physiological disorders, which are often caused by environmental stresses.

i. **Blossom Drop**

Unfavourable weather and high temperatures can result in poor pollination and blossom drop. If nighttime temperatures fall below 55 degrees Fahrenheit, tomato plants may experience this phenomenon. This can cause the blossoms to fall off without producing fruit. According to a study by Jauron in 1997, this issue could be caused by the lack of nutrients.

ii. **Blossom-End Rot**

A black or brown spot on the blossom end of a fruit indicates that it has suffered from blossom-end rot, which usually occurs when the plant does not have enough calcium to support its development. The fluctuating levels of soil moisture can cause this condition. Watering the plants regularly and mulching them is recommended to prevent this from happening (Jauron, 1997).

iii. **Sunscald**

In 1997, Jauron noted that the initial signs of sunscald are yellow or shiny spots on the fruit's sides. Over time, the affected tissue will dry out and turn into wrinkled and sunken areas. Secondary organisms will then enter the affected regions and cause the fruit to rot. Sunscalds usually occur in fruits exposed to high temperatures.

iv. **Fruit Cracks**

The development of concentric and radial cracks at the fruit stem can be caused by prolonged dry periods or heavy rainfall. Those exposed to direct sun are more prone to experiencing fruit cracking. This condition usually occurs in larger fruit varieties such as beefsteaks (Jauron, 1997).

v. **Catfacing**

When the weather is cloudy and cool during the blooming period, the blossom may stick to the developing fruit, causing the fruit to become puckered and scarred. This condition is known as "cat facing" and is typically observed in large-fruited varieties (Jauron, 1997).

i. **Puffiness**

When the weather is cloudy and cool during the blooming period, the blossom may stick to the developing fruit, causing the fruit to become puckered and scarred. This condition is known as "cat facing" and is typically observed in large-fruited varieties (Jauron, 1997).

2.14 Tomato Response to Deficit Irrigation

In order to produce tomatoes, which are commonly grown in areas with limited water supplies, irrigation is required (Steduto *et al.*, 2012). Although it is not necessary to water the plants excessively, waterlogging can affect their functioning and cause various problems (Benton, 1999; Patanè *et al.*, 2011). Due to the high-water content of tomato, they are prone to experiencing various problems such as fruit drop, low fruit yield, and blossom end rots (Tsige *et al.*, 2016).

To prevent these issues, optimal tomato growth can be achieved through surface drip irrigation and plastic film mulching (Wang *et al.*, 2018). Deficit irrigation can lead to economic losses, decreasing crop marketability (Shinohara *et al.*, 1995). According to this study, water stress can affect the growth and yield of plants by preventing photosynthesis and the transport of photosynthate to different parts of the plant. On the other hand, researchers discovered that stress could promote the photosynthate's movement into the fruit.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area

The study was conducted at the University of Development Studies' Nyankpala Campus. The town of Nyankpala is situated in the Tolon Kumbungu District of the Northern Region. It is located 167 m above sea level and 16 km away from the regional capital, Tamale. The area lies within latitude 9°24' N and longitude 0° 59'W which shares borders with the Kumbungu and North Gonja Districts. Figure 3.1 shows the district map.

Figure 3. 1: Map of Ghana Showing the District of Tolon and the Experimental Area

(Field Experiment, 2023)

The study area experiences a unimodal rainy season of approximately 950 to 1200 mm (Denkyirah *et al.*, 2016). The rainy season starts from May to October and peaks from August to September. The seasons runs for about 140 to 190 days. The dry season last from November to March with temperatures ranging between 32 – 42 °C during the day and nighttime temperatures between 20 – 22 °C. This situation highlights the limited opportunities for crop cultivation due to the short duration of rainfall. The soils in the study area were classified under the Ghana soil classification as savanna ochrosols with granite, sandstone and shale as parent material and subsoil classified as sandy -loam (Adjei-Gyapong and Asiamah, 2002).

3.2 Experimental Design and Treatments

This experiment was presented in a two-factorial split-plot design with three replicates. The main plot factor is the irrigation regime with a sub-plot factor as crop variety, as presented in Table 3.1

Table 3. 1: Factors and Factor Levels Used for Field Experiment

Irrigation Regime	Crop Variety
60% CWR	Cobra 26 F1
80% CWR	Mongal F1
100% CWR	

Where: CWR-Crop Water Requirement(Field Experiment, 2023)

3.2.1 Treatments

Each treatment was assigned randomly to eliminate bias. The labels for each treatment were placed in the experimental unit to make identification easy. For optimal plant establishment, the plots received even amounts of water before introducing the irrigation regime. The experimental design layout is presented in the following section (Figure 3.2).

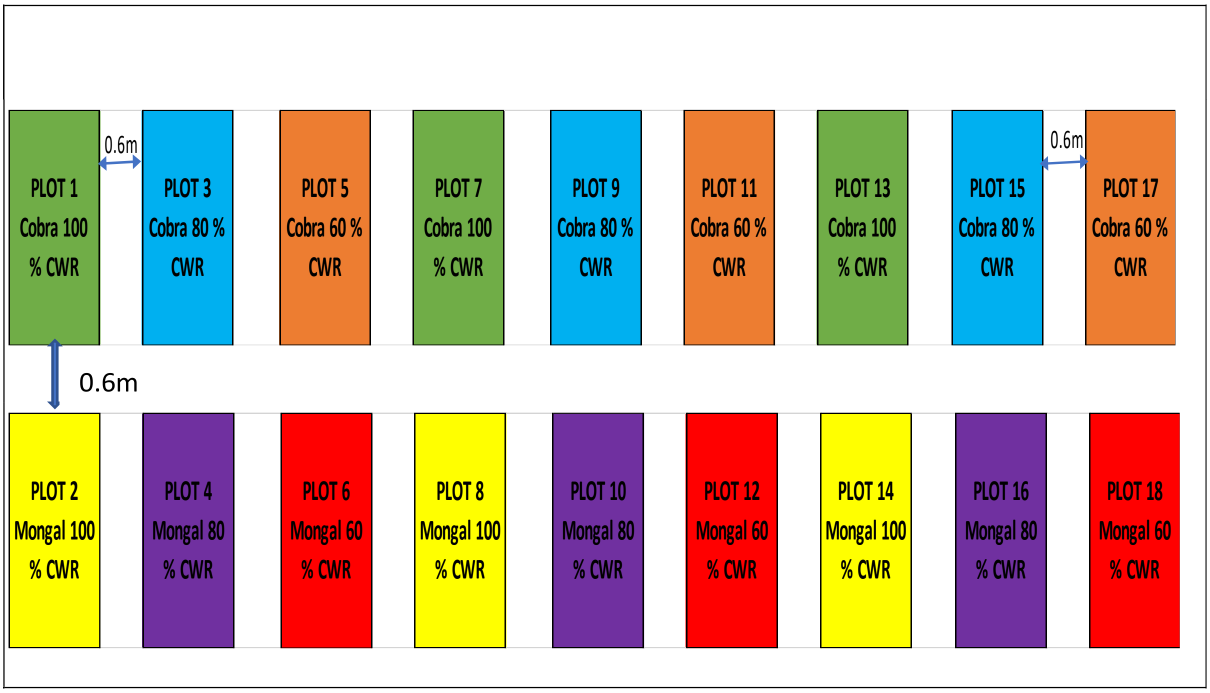

Figure 3. 2: Experimental Design of Irrigation Regimes

(Field Experiment, 2023)

3.2.2 Tomato Variety

The varieties used in the study were the Mongal F1 and the Cobra 26 F1, adapted to the weather conditions in the study area.

Cobra 26 F1 is a robust and productive variety for every season. The variety has an early maturity of about 65-70 days, with an average fruit weight of about 80-90 grams. The variety has excellent tolerance to tomato yellow leaf curl virus and bacterial wilt while resistant to fusarium, verticillium, and tomato mosaic virus (Technisem seed catalog, 2023).

Mongal F1 is a productive variety for every season, especially hot weather seasons. The average weight is 100 grams, with the fruit slightly flattened round with medium firmness. This variety has excellent resistance to bacterial wilt and tomato mosaic virus, with a maturity of approximately 65 days after transplanting. The average number of days between Transplanting and Harvesting varies depending on condition and growing region (Technisem seed catalog, 2023).

3.2.3 Irrigation Regimes

The experiment was conducted using three different irrigation regimes. The 60 %, 80 %, and 100 % CWR levels were utilized to determine the hybrid varieties tolerance to drought as a means of conserving water whilst increasing yields. These levels were applied randomly according to the treatment in the potted experiment.

3.3 Nursery Preparation and Field Management

3.3.1 Nursery Preparation and Management

The tomato was seeded in two (2) different seed trays for each variety on 14 February 2023. Each seed tray has a dimension of 51 cm x 20 cm with one hundred and twenty-eight (128) seedling cells. The seedling cell shape is in the form of a hexagon. Compared to chemical pruning, air root pruning techniques are more effective at producing high-quality root systems, the rooting media used in the nursery is cocopeat.

Two tomato seed varieties, namely Mongal F1 and Cobra 26, were drilled using a method known as drilling. The plants were then covered with a layer of cocopeat and placed on trays with polyethylene sheets. This method eliminates the need for irrigation once the seeds have emerged. After five days of planting, the tomato seedlings emerged. They were raised to allow the polyethylene material to be removed from the surface. They were then irrigated twice daily with light showers to maintain their field's capacity.

3.3.2 Field Layout

The tomato seedlings were potted using random sampling. A 6-liter capacity bucket of twenty-two (22) centimetres depth with a radius of 12.5 centimetres served as the potting material with four (4) holes drilled beneath each bottom to allow drainage. The field was laid out with six (6) treatments with three (3) replicates. The main plot was three levels of irrigation regimes (60 %, 80 %, and 100 % CWR) with crop variety (Cobra 26 F1 and Mongal F1) as the sub-plots. Each experimental unit contained five pots, summing up to 90 banks. The pots were filled with topsoil and watered to meet its field capacity.

3.4 Soil Sampling

The objective of the experiment was to determine the characteristics of the soil's properties due to its abundance of minerals and nutrients. Tomatoes require a pH level between 6.0 and 6.5, which is slightly acidic. We collected samples from four different locations.

The soil analysis results allowed the decision-maker to estimate the amount of water required for the crop and determine the appropriate fertilizer application rate. The samples were then analyzed at the institute's soil laboratory. Some of the analyzed parameters included the soil's texture, saturation, and organic matter.

3.4.1 Infiltration Test

The water's infiltration rate into the soil can be determined by the depth of the layer of water that can penetrate the ground in just an hour. A miniature disc infiltrometer was utilized for the test. The top and bottom chambers of the device were filled with water.

The top chamber was used to regulate the suction, while the lower one was used to determine the water volume that could enter the soil. A stainless-steel disk with a porous inner surface was used as the infiltrometer's base. This material prevented water from leaking into the air. After the infiltrometer was placed on the ground, the water that exited the chamber rapidly flowed into the soil at a rate determined by the ground's hydraulic parameters. The volume of water that entered the soil varied by 30 seconds (Mini Disk Infiltrometer, 2006).

3.4.2 Soil Texture

The hydrometer technique is used to determine the texture of the soil and its classification based on the USDA's textural triangle (Beretta *et al.,* 2014; Kebede, 2019). Once the distribution of the particles has been determined, a suitable surface can be identified.

The method utilized was Bouyoucos (1962) for accurately determining the soil's particle size distribution was refined using specific reagents. Some of these included Calgon, a 5% sodium hexametaphosphate liquid solution, hydrogen peroxide, at least 30%, and amyl glycol or methanol, which is around 95%. A total of 51 grams of air-dried soil was wetted with distilled water. A total of 20 ml of hydrogen peroxide was added to the mixture. This chemical destroyed the soil's organic matter, allowing the different classes to be freed. Other substances, such as amyl alcohol and sodium hexametaphosphate, were added to the mixture.

Shake the mixture for two hours and place it in a sedimentation cylinder with distilled water. A hydrometer's first reading was carried out after 40 seconds. The temperature was also recorded using a thermometer. After three hours, the sample was allowed to remain undisturbed (Andrés *et al.*, 2014) as stated in equations 3.1 to 3.3:

$$Percentage\ Sand\ (\%\ sand) = 100 - [H1 + 0.2\ (T1 - 20) - 2]\ x\ 2 \ldots\ldots\ldots\ldots\ldots Eqn\ 3.1$$

$$Percentage\ Clay\ (\%\ clay) = [H2 + 0.2\ (T2 - 20) - 2]\ x\ 2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.2$$

$$Percentage\ Silt\ (\%) = 100 - (\%\ Sand + \%\ clay) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.3$$

Where:

WT - Total Weight of air-dried soil,

H1 - 1st Hydrometer reading at 40 seconds,

T1 - 1st Temperature reading at 40 seconds,

H2 - 2nd Hydrometer reading at 3 hours,

T2 - 2nd Temperature reading at 3 hours,

– 2 - Salt correction to be added to hydrometer reading and

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

3.4.3 Bulk Density

The dry weight fraction was determined by collecting undisturbed soil samples from a sample point. They were then dried at 105 degrees Celsius until a stable weight could be achieved (Hillel, 2004). The estimated Bulk Density was computed by considering the soil volume in the core sampler and as shown on equation 3.4.

$$Bd - Ms/Vc \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eqn\ 3.4$$

Where:

Bd - Bulk Density (g/cm3),

Ms. - Dry weight of the soil (g) and

Vc - Total volume of the ground in the sampler (cm3).

3.4.4 Field Capacity of the Soil

A 24-hour soak was performed to determine the moisture content of the soil samples. The extracted water was then used for analysis using the pressure plate method.

3.4.5 Permanent Wilting Point

The amount of water held by forces stronger than 15 bars in the soil is known as its permanent wilting point. This point represents the minimum amount of water that plants can use (Judy, 2004). A semi-disturbed soil sample was placed in a synthetic ring to determine the permanent wilting point. For 24 hours, the samples were subjected to a pressure membrane extractor, which revealed an overpressure. On reaching equilibrium, the pieces had been weighed, dried at 105 degrees Celsius, and weighed again. The permanent point was estimated using equation 3.5.

$$PWP = W1 - W2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.5$$

Where:

PWP - Permanent wilting point (%),

W1 - Initial weight of soil before oven drying (g) and

W2 - Final weight of soil after oven drying at 105 ^{0}C (g).

3.4.6 Soil Chemical Analysis

Four (4) soil samples were gathered from various parts of the heap. They were analyzed to determine the application rate of fertilizer. These samples were taken to the Nyankpala soil research laboratory. The CSIR SARI laboratory in Nyankpala analyzed the samples for various parameters, including pH, N, P, CEC, organic carbon, and Ca. The Kjeldahl method was used to determine the nitrogen content of the soil (Bremner and Mulvaney, 1982). The Bray-P method was also utilized to determine the phosphorus level. On the other hand, the 1954 flame photometer technique was used to determine potassium. The soil's COD, pH, salinity, and organic carbon content were evaluated using the Walkley and Black method (1934). A similar technique was also utilized to analyze the magnesium and calcium levels (Motsara and Roy, 2008; Ogundare *et al.*, 2015; Peters, 2018).

3.5 Irrigation Water Requirement

The quantity of water the plants require throughout their growing season was calculated using these estimations.

3.5.1 Estimation of Crop Water Requirement

The reference ETO was computed using the daily data collected from 1970 to 2023 at Savannah Agriculture Research Institute weather station in Nyankpala. The various meteorological parameters were used to calculate the ETO, such as maximum temperature, minimum temperature, wind speed, and sunshine hours. The instrument used for calculating the reference ETO was the CROPWAT 8.0 program of the Food and Agriculture Organization of the United Nations (2012). The Kc was derived from the irrigation paper of the FAO for tomato (Allen *et al.*, 1998). The values for the different growth stages were as follows: 0.85, 0.87, and 1.08. The daily crop coefficient was calculated using the Kc values and the length of the various growth stages. The 20-day growth stage for the initial, 30-day, 40-day, and 20-day products, as well as the late season and mid-season, were calculated based on the equation 3.6.

$$ETc = ETO \ x \ Kc \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn \ 3.6$$

Where:

ETO - evapotranspiration (mm), and

Kc - e crop coefficient.

For localized (drip) irrigation, the equation by Keller and Bliesner (1990) was used to adjust the ETc to ETcrop-loc for localized irrigation systems with a ground cover (Pd) of 95 %. So, the adjusted ETc was calculated using the formula as given in equation 3.7.

$$Td = Ud \ x \ [0.1 \ (Pd)0.5] \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn \ 3.7$$

Where:

Td - ETc-localized,

ETc-localized - estimated ETcrop at peak demand for localized irrigation,

Ud - conventionally estimated peak ETcrop, and

Pd - percentage ground cover (%).

3.5.2 Estimation of the Net Irrigation Requirement (IRn)

The irrigation net requirement for this study was adjusted based on crop water availability, the degree of leaching, and adequate rainfall. However, losses occurred during the application of water (Savva and Freken, 2002).

The irrigation net is calculated by considering the formula in equation 3.8.

$$IRn = ETc - Pe \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Eqn\ 3.8$$

Where:

Pe – 0, and

IRn – ETc -localized.

3.5.3 Estimation of the Gross Irrigation Requirement (IRg)

The gross water losses that can occur during the application and conveyance of water in a field are the factors that determine the need for gross irrigation. The method of application used to calculate this requirement, the drip method, had an Ea of 95%.

According to Coolong (2016), the efficiency of drip irrigation varies between 90 and 95 percent. The total amount of water required for irrigation was calculated using equation 3.9.

$$Rg = \frac{IRn}{Ea} \dots\dots\dots\dots\dots.\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\ Equation\ 3.9$$

Where:

IRg - Gross irrigation requirement (mm),

IRn - Net irrigation requirement (mm), and

Ea - Field application efficiency (distribution uniformity, %).

3.5.4 Irrigation Scheduling

The following steps were utilized to calculate the water used for irrigation.

The quantity of water used for irrigation was estimated using the AWC.

According to Yitayew and Waller (2016), the difference between the capacity of the field and the permanent wilting point is the quantity of available water as shown in equation 3.10.

$$AWC = FC - PWP \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.10$$

Where:

AWC - Available water content,

FC - Field Capacity, and

PWP - Permanent Wilting Point.

The total amount of water that the soil has available is computed by taking into account the equation 3.11.

$$TAW = (\theta FC - \theta WP)\ Zr \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn.\ 3.11$$

Where:

Zr - Root zone depth (mm) derived from Doorenbos and Pruitt, 1977,

θFC = Water content at field capacity (%), and

θWP - Water content at wilting point (%).

ii. Estimation of Readily Available Water (RAW) of the Soil

The availability of readily available water was determined by multiplying the depletion allowed by management in equation 3.12.

$$RAW = AWC * MAD \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.12$$

Where:

RAW - Readily available water to plant always, AWC - Available water content, and

MAD - Management allowable depletion that was selected concerning soil texture, crop, and climate, and it should not affect the yield.

The RAW was multiplied by the crop area to convert it to volume as shown in equation 3.13.

$$RAW\ (litres) = RAW\ (mm) x\ Crop\ Area\ (m2)\ x\ 1000\ litres\ \ldots\ldots\ldots\ldots\ldots Eqn\ 3.13$$

Estimating the Maximum Irrigation Interval (days) as given in equation 3.14.

$$RAW\ ID = IRn \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.14$$

Where:

ID - The maximum irrigation interval or the irrigation frequency (days),

RAW - The readily available water (liters) and

IRn - The net irrigation requirement in (l/day).

All irrigations were completed to restore the field's capacity, as given in equation 3.15.

$$Estimation\ of\ the\ Irrigation\ Run\ Time\ (hours)\ IRg\ Ta = Q \ldots\ldots\ldots\ldots\ldots Eqn\ 3.15$$

Where:

Ta - Irrigation run time (hours),

IRg - The gross irrigation requirement (l), and

Q - Emitter discharge (l/h).

To convert the time spent on the irrigation run into minutes, the values were multiplied by 60.

iii. Estimation of Water Content for Next Irrigation as given in equation 3.16.

$$WNI = FC - (AMC)\ MAD \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.16$$

Where:

WNI - Water content for next irrigation (liters),

FC - Field Capacity (%),

AMC - Available Moisture Content and

MAD = Management Allowable Depletion (%).

iv. Estimation of Irrigation Water Productivity

The WUE is the water utilization efficiency of a given amount of water. It can be calculated by taking into account the formula below and adding kg ha to the equation 3.17.

$$IWP \ = \ Y \ x \ ETc \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots Eqn \ 3.17$$

Where:

IWP - Irrigation water productivity (kg ha mm-1),

Y - Crop yield in (kg ha-1), and

ETc - The water used (mm).

3.5.5 Installation and Testing of Drip Irrigation System

The system included various components, such as a water supply, control head, emitter drippers, and laterals. The water supply came from a borehole and was then stored in two tanks of 4,000 l each. The system's primary line, a 1.5" pipe, delivers water to three sub-mains. The fittings were made from low-density polyethylene. The fittings and pipes were cleaned-how was this done? Describe!! to ensure uniformity. A screen filter was utilized to remove pollutants from the drip irrigation system. It was designed to prevent emitter clogging.

After it was installed, the system was checked to ensure no leaks or differences in pressure.

The uniformity of the drip irrigation system was then tested to see how it performed. A distribution uniformity measurement was carried out by collecting the collected water from the emitters. In 30 minutes, the highest and lowest water flow was recorded at 418 and 340 ml. The measurement results revealed that the distribution and uniformity coefficients were 86.9 percent and 99 percent, respectively. High uniformity of drip irrigation systems can help improve water use efficiency. According to studies, having a 99 percent uniformity coefficient can influence the quality and yield of crops (Fernandez *et al.*, 2016; Smith *et al.*, 2020).

3.6 Cultural Practices

3.6.1 Transplanting

The pots were weed-free and irrigated on the day of transplanting. The seedlings were placed in the mud pots on March 9, 2023. They were then set upright in the holes 10 cm deep to minimize shock stress and transpiration losses.

3.6.2 Fertilizer Application

The fertilizer application was done split, with a minimum of 400 kg/ha of nitrogen, phosphorus, and potassium being applied at a rate of 2 to 5 WATP.

3.6.3 Plant Protection Measures

To protect tomato plants from spider mites and thrips, Mektin 1.8 EC was applied with Abamectin at 10 ml per 16 liters of water. Leaf spots and Blights were also treated with Azoxystrobin and Difenoconazole at 200 and 125 grams per litre. One week of every week, this activity was carried out. Soiling up and removing weeds were done once every week. To protect the plants, fall due to the weights of the fruit, they were secured using twines and sticks designed to support them as they were set up.

3.6.4 Harvesting

The harvesting of fruits takes place once the fruits have been ripened weekly. The plots and weights used in the computation of the yield will help with accuracy.

3.6.5 Weather Conditions During Crop Growth Season

The study utilized a mini station known as ATMOS to monitor the weather conditions during the growing season. The data it collected included temperature, wind speed, relative humidity, and solar radiation.

3.7 Data Collection

3.7.1 Crop Water Productivity (CWP)

The productivity of crop water is computed by considering the number of marketable tomatoes that are about the amount of water that's required to produce them. It is usually expressed in terms of kilograms per cubic meter (kg/m^3) as shown in equation 3.18.

$$CWP = Yact/ETact \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Eqn\ 3.18$$

Where:

CWP - Crop Water Productivity,

Yact - Marketable Product and

ETact - Actual Evapotranspiration.

3.7.2 Agronomic Data

Three (3) tomato plants were randomly selected and tagged during each treatment. They were monitored throughout the season to ensure they would not develop unevenly. Fifty-four (54) plants were ordered for each experimental block, and the data collected from the field was analyzed.

i. Plant Height

Height measurements of the plant were made at different growth stages. They were taken at 2, 4, 6, 8, and 10 weeks after transplanting. The measurement of this parameter was carried out using a metal meter rule that extends from the plant's base to the bud.

ii. Stem Diameter

A digital caliper was used to measure the stem's diameter, which was 5cm above the ground. The measurements were performed at various ranges, such as 2 to 10 WAT.

iii. Number of Branches Per Plant

The count of the branches per plant was carried out manually. The records indicated that the number of weeks after transplanting to be captured were 2, 4, 6, 8, 9, and 10.

v. Days to Flowering

The days to flowering were calculated by counting the number of days that the plants bloomed after transplanting to a certain percentage. The abortion was calculated by taking into account the fruit and flower count. The data was then gathered weekly. The count started when the flowers began to bloom and continued until the flowering period's end.

vi. Days to Harvesting (Earliness)

This was measured by counting the number of days after transplanting to the day of the first harvest at the fully ripened stage.

vii. Fruit Number, Fruit Weight, and Yield Per Plant

Each experimental plot's fruits were harvested and weighed using an electronic scale. The fruits were counted and weighed at the full-mature stage between 60 to 69 days after transplanting. The yield parameters of the experiment were evaluated by comparing the number of fruits produced per plant, the weight of the fruit, and the total yield.

3.7.3 Physiological Indices of Tomato

Chlorophyll Fluorescence was determined using Opti-Sciences Pulse Modulated Chlorophyll Fluorometer (OS5p+) with dark-adaptation clippers between the 4:00 AM - 5:00. JIP test (Strasser protocol) is a dark-adapted test that was used in detecting and measuring the plants stress. Kautsky, 1957 first described the Straasser protocol as helping measure the stress that affects PSII photochemistry. The parameters considered using the fluorometer included:

- Initial fluorescence was obtained in a dark-adapted sample (Fo).
- Maximum fluorescence after illumination of the dark-adapted sample (Fm).
- Maximum quantum yield of the PSII photochemistry (FvFm).
- Maximum primary yield of PSII photochemistry.

- The chlorophyll content meter (CCM 200) was used to collect data on the chlorophyll content. Three plants will be sampled for each treatment plot. Three leaves from the apical bud per plant were sampled randomly from the tagged place where data was collected. The average of the three leaves of each of the three plants was considered as the representative of each treatment.

3.7.4 Fruit Quality Analysis

The three (3) samples were stored under varying degrees of humidity and ambient temperature. The shelf life of the fruits was determined by comparing the number of days they were stored to the days when they were softened. The various characteristics of fruits, such as their firmness, vitamin C, and pH, were analyzed using ten samples. They were then extracted and analyzed using a blend method. The Brix percentage determined by a portable refractometer was also considered.

The study aimed to determine the degree to which tomato extract was titrated using a burette containing 1M NaOH at pH 8.1. The results indicated that the percentage of citric acid in the juice was equivalent to 10mg/100 ml. Different parameters, such as the fruit firmness, pH, and vitamin C levels, were then measured using a pH meter, a penetrometer, and ascorbic acid.

The content of the antioxidant tomato extract was determined using a spectrophotometric analysis. The results indicated that it had a total of 0.372 A505 and 0.0806 A453.

i. The firmness of the fruit was assessed by feeling its texture and rated on a 1-5 scale, with 0-1 being substantial, 1-2 firm, 2-3 soft, and 3-4 and above very soft.

ii. For proximate analysis, the fresh tomato was cleaned and divided into two parts. The first part was used to determine the moisture content, and the sample was blended into a paste. The second part was used to analyze the elemental, proximate, and vitamin content. After cutting it into pieces, it was placed under the sun and dried. The tomato was then crushed. It was then ground into fine powder using a mortar and pestle. The substance was kept at room temperature until the study was finished.

3.8 Data Analysis

The collected data was organized in Microsoft Excel. The analysis was carried out using the ANOVA technique, which involves a significance level of 5%. The results were then analyzed using the 12th edition of GenStat software. The LSD test was also utilized for comparisons. The count data underwent a square root transformation. Mean values were differentiated using the at a 5 % probability level, calculate the Least Significant Difference (LSD) for cases where significant differences exist. Tables, pictures, and graphs were utilized as required to convey the results.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical and Chemical Properties of the Growing Medium

The soil used for the study was characterized by a sandy-loam texture based on the particle size distribution of Bouyoucos in 1962. The soil's infiltration and bulk density were 134.78 and 1.27 grams per centimeter, respectively. The moisture level at the wilting point and the field capacity were 19.8 percent and 8.9 percent, respectively. The potting media used had an aggregate content of 77.1%, a silt content of 18.6%, and a low clay content of 4.24 percent. The surface of soils in the savanna zones characterized by their Vegetation and climate are primarily sandy soils with insufficient water-holding retention, drainage, and nutrient availability (Amusan *et al.*, 2019; Adepetu *et al.*, 2021).

Bulk density values, which are considered suitable for agriculture production, often range from 1.2 to 1.4 g/cm3, which indicates a well-structured soil with appropriate pore spaces that promotes water movement and root development, as reported by Sulemana *et al.* (2019) that aligns with the Bulk Density in this study as presented in Table 4.1. Sandy soils have a field capacity ranging between 15 to 25 % volumetric water content, which results in rapid drainage (Hillel, 2004; Brady and Weil, 2016). The field capacity from the current research (19.8%) is within the cited range. Soil moisture at the permanent wilting point was at 8.9 %. The pH value recorded was 7.03, which, according to Motsara and Roy (2008), classified the current study's pH as neutral. Potassium recorded a value of 245 mg/kg which was within the range of 141 to 370 mg/kg which is sufficient for crop production as reported by Akbas *et al.*, 2017. Phosphorus recorded a high concentration of 54.45 mg/kg which supported a healthy plant growth. Ma *et al.*, 2016 reported a range of phosphorus content of 7.4 to 24 mg/kg to have increased yield.

Table 4. 1: Physical and Chemical Properties of Soil Used for the Experiment

Physical Property	Values	Chemical Property	Values
Bulk Density (g/cm^3)	1.27	pH (1:2.5 H_20)	7.03
Infiltration 'mm/hr)	134.78	0rganic Carbon (g/kg)	44.1
Field Capacity (%)	19.8	Nitrate Nitrogen (mg/kg)	96.53
Permanent Wilting Point (%)	19.8	Ammonia (mg/kg)	23.8
Sand (%)	77.12	Phosphorus (mg/kg)	54.45
Silt (%)	18.64	Potassium (mg/kg)	245
Clay (%)	4.2		

(Savannah Agriculture Research Institute, 2023)

4.2 Analysis of Weather Parameters

Table 4.2 summarizes the parameters of the weather forecast for the experiment. The mean relative humidity level during the crop growth was around 0.86 %. The monthly wind speed was around 1.2 to 1.77 meters per second. The solar radiation and monthly precipitation amounts ranged from 0.02 to 0.03 mm. The average monthly air temperature was between 27.6 and 31 °C. The relative humidity level during this period was at 3.63 %. The monthly wind speed was between 1.2 and 1.7 meters per second. Table 4.2 also summarizes the monthly solar radiation and precipitation amounts.

According to Asante and colleagues, the temperature values indicated in this study were consistent with the recommended range for successful tomato cultivation in Ghana's northern region, which is between 25 and 35 °C (Asante *et al.*, 2017). A report by Kwakye *et al.*, 2013 indicated that the wind speeds in the region were between 1.5 and 2.5 m/s. Air circulation is beneficial to prevent the build-up of moisture, promoting the healthy growth of tomato plants. The total rainfall for March, April, May, and June were 9.3, 103.7, 73.1 and 130.4 mm respectively. Irrigation was done daily in March, while irrigation was applied according to the soil moisture content from April to June. Precipitation affects tomato productivity due to inadequate or excessive rainfall, reducing yield and fruit quality (Gao *et al.*, 2019).

The results of the weather parameter during the experiment as presented showed; the mean relative humidity during the crop growth stages ranged from 0.86 to 3.63 %. The mean monthly wind speed was between 1.23 to 1.77 m/s. The mean monthly precipitation and solar radiation ranged from 0.0 to 0.03 mm and 182.22 to 228 w/m^2, respectively. The mean monthly air temperature ranged between 27.6 to 31 °C. The mean relative humidity during the crop growth stages ranged from 0.86 to 3.63 %. The mean monthly wind speed was between 1.23 to 1.77 m/s. The mean monthly precipitation and solar radiation ranged from 0.0 to 0.03 mm and 182.22 to 228 w/m2, respectively. The mean monthly air temperature ranged between 27.6 to 31 °C.

The stated values of Temperature aligned with Asante *et al.*, 2017. The average range for successful cultivation of tomatoes in the northern part of Ghana is between 25 and 35°C (Asante *et al.*, 2017). Kwakye *et al.*, 2013 reported wind speeds of around 1.5 to 2.5 m/s are suitable for vegetable production in the northern part of Ghana. Air circulation is beneficial to prevent the build-up of moisture, promoting the healthy growth of tomato plants.

The total rainfall for March, April, May, and June were 9.3, 103.7, 73.1 and 130.4 mm respectively. Irrigation was done daily in March, while irrigation was applied according to the soil moisture content from April to June. Precipitation affects tomato productivity due to inadequate or excessive rainfall, reducing yield and fruit quality (Gao *et al.*, 2019).

Table 4. 2: Weather Parameters During the Crop Growing Season

	Week 1		**Week 2**		**Week 3**		**Week 4**	
Month	Tmin	T max	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
March	25.3	40.9	23.1	39.8	20.8	37.8	23.8	38.7
April	21.6	38.4	25.7	35.0	23.4	37.0	20.8	36.3
May	21.9	36.7	23.5	36.9	21.6	34.8	25.0	35.2
June	21.6	34.9	22.8	34.8	20.7	35.7	20.3	31.9

	RHmin	RHmax	RHmin	RHmax	RHmin	RHmax	RHmin	RHmax
March	0.86	2.97	1.09	2.94	1.09	3.01	1.91	2.96
April	1.91	3.24	2.28	3.28	2.52	3.32	2.34	3.63
May	2.30	3.54	2.37	3.59	2.43	3.53	2.84	3.58
June	1.77	3.50	1.55	1.88	1.47	3.19	2.30	3.36

Tmin = minimum Temperature, Tmax = maximum Temperature, RHmin = minimum relative humidity, RHmax = maximum relative humidity.
(ATMOS 41 All-in-one Weather Station, 2023)

4.3 Crop Water Requirement

4.3.1 Crop Water Requirement of Tomato and Irrigation Regimes

The amount of water that tomato plants need was estimated using the FAO's CROPWAT 8.0 model. Table 4.3 shows the results of the highest amount of water used was 481 mm, while the lowest was 288.5 mm.

The irrigation water requirement for tomato plants is based on the season's water application. The highest amount of water was obtained from a control treatment of 481 mm, while the lowest was 288.5 mm. The requirements for tomato plants are mainly influenced by various factors such as climate, management practices, and variety.

The gross irrigation water requirement for tomato plants was calculated using the efficiency of the field application method, which is based on drip irrigation. The highest amount of water that was required was about 505.1 mm.

Table 4. 3: Crop Water Requirement of Tomato at Different Irrigation Regimes

Month	Kc	ETo (mm/day)	100 % CWR (mm/day)	80 % CWR (mm/day)	60 % CWR (mm/day)
February	0.6	1.84	12.9	10.32	7.76
February	0.6	1.94	15.8	12.64	9.48
March	0.6	2.11	21.1	16.88	12.66
March	0.62	2.3	23	18.4	13.8
March	0.73	2.8	30.8	24.64	18.48
April	0.85	3.37	33.7	26.96	20.22
April	0.97	3.94	39.4	31.52	23.64

April	1.06	4.25	42.5	34	25.5
May	1.07	4.2	42	33.6	25.2
May	1.07	4.13	41.3	33.04	24.78
May	1.07	4.16	45.7	36.56	27.42
June	1.07	4.17	41.7	33.36	25.02
June	0.98	3.86	38.6	30.88	23.16
June	0.86	3.17	31.7	25.36	19.02
July	0.75	2.59	20.7	16.56	12.42
Total			**481**	**384.7**	**288.5**

CWR- Crop Water Requirement

(CROPWAT Output, 2023)

4.3.2 Crop Water Productivity

The interaction effect between variety and irrigation regimes did not significantly (p>0.083) affect the productivity of crops. There were significant differences between the irrigation regimes (p<0.0037) For instance, the 80 % CWR irrigation regime had the highest productivity at 2133 kilograms per metric ton of water, while the 60 % CWR irrigation regime had the lowest at 1401 kg/mm (Figure 4.1). The interaction between irrigation regimes and crop variety is a critical factor in determining tomato water productivity. Research conducted by Tari *et al.* (2015) demonstrated the combining effects of irrigation practices, such as deficit irrigation with drought-tolerant tomato varieties, can maximize water use efficiency while minimizing water consumption. It was observed that deficit irrigation with drought-tolerant tomato varieties can maximize water use efficiency while reducing water consumption. The result of this experiment is similar to Smith *et al.* (2017) and Patel and Kumar (2018); they documented substantial improvements in tomato yield and water use efficiency when adopting drip irrigation systems by precise scheduling of water considering the crop's growth stage can further optimize water usage and overall crop water productivity.

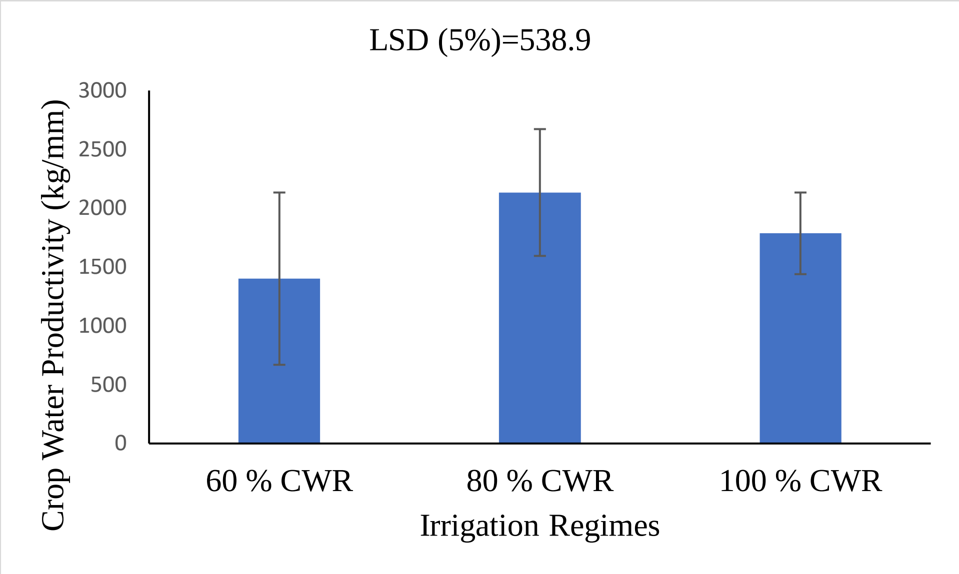

Figure 4. 1: Effects of Irrigation Regimes on the Crop Water Productivity

(Field Experiment, 2023)

4.4 Effects of Irrigation Regimes and Crop Variety on the Growth and Yield of Tomato

4.4.1 Effects of Irrigation Regimes on Plant Height (cm) of Two Tomato Hybrids at 2, 4, 6 and 8 WAT

Although the plant height was not significant different ($p>0.05$), there were significant differences ($p<0.005$) in the 4 to 8 WAT irrigation regimes. Nonetheless, irrigation regimes at 4, 6, and 8 WAT showed a significant difference ($p<0.005$). Similarly, crop variety had significant differences ($p>0.05$). At 4 WAT, there was a significant difference between 60 % CWR and 100 % CWR. The latter was 12.3 % taller. At 6 WATP, there were significant differences ($p<0.004$) between irrigation regimes. 100 % CWR was the tallest, with a 9.7 % difference. Similarly, at 8 WATP, 100 % CWR was 13 % taller than 60 % and 80 %, with a significant difference ($p<0.001$). From 2 to 8 WAT, plant height exhibited an increase according to the week of data collected. 100 % of CWR gave the highest plant height (56.49 cm), while 60 % of CWR gave the least (48.54 cm), as shown in Figure 4.2. The data similarity during the weeks was because of rain that occasionally occurred, causing soil moisture to exceed its field capacity of 19.8 %.

Smith *et al.* (2017) found results similar to this study. Their observations showed that different irrigation regimes alter soil moisture content, affecting plant nutrient availability. Tomato plants grew slowly with a deficit irrigation strategy, while an optimal irrigation regime enhanced both growth and fruit quality. Johnson and Anderson (2015) also found that a well-regulated irrigation system supported robust tomato growth and high yield. Crop varieties are also a significant factor in tomato development. Jones *et al.* (2015) reported that certain tomato varieties exhibit greater tolerance to varying water conditions, while others require specific irrigation schedules for optimal yield. Cobra F1 and Mongal F1, both hybrids, have good drought tolerance.

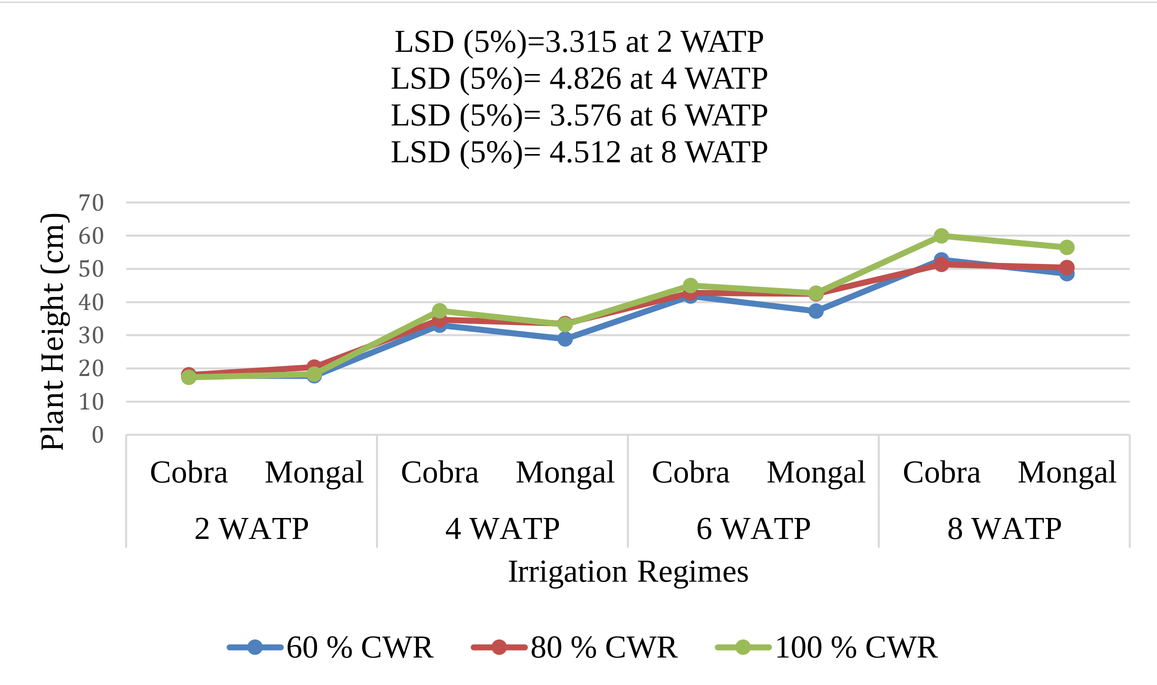

Figure 4. 2: Interaction of Irrigation Regimes and Crop Variety on Plant Height

(Field Experiment, 2023)

4.4.2 Effects of Irrigation Regimes and Crop Variety on Stem Girth (mm)

Interaction effect was significant (p>0.005) of irrigation regimes and crop variety on the stem girth at 6 WAT. Thickest stem circumference was recorded at Mongal (100 % CWR) with a value of 13.56 mm, while the most negligible thickness was given at Mongal (60 % CWR) with a value of 8.09 mm, as shown in Figure 4.3. The difference in stem girth between 60 % CWR and 100 % CWR was higher, where 100 % CWR was 32.3 % wider in stem girth. The experiment revealed that adequate availability of water increases the soil's moisture content, improving the plant's physiology by enhancing cell tumor, nutrient transport, and metabolic activities, leading to an increase in stem girth (Smith *et al.*, 2017). Johnson and Brown (2018) conducted a study that demonstrated that drip irrigation promotes efficient water distribution to tomato plants, minimizing water wastage and maintaining soil moisture, which fosters favorable conditions for stem girth.

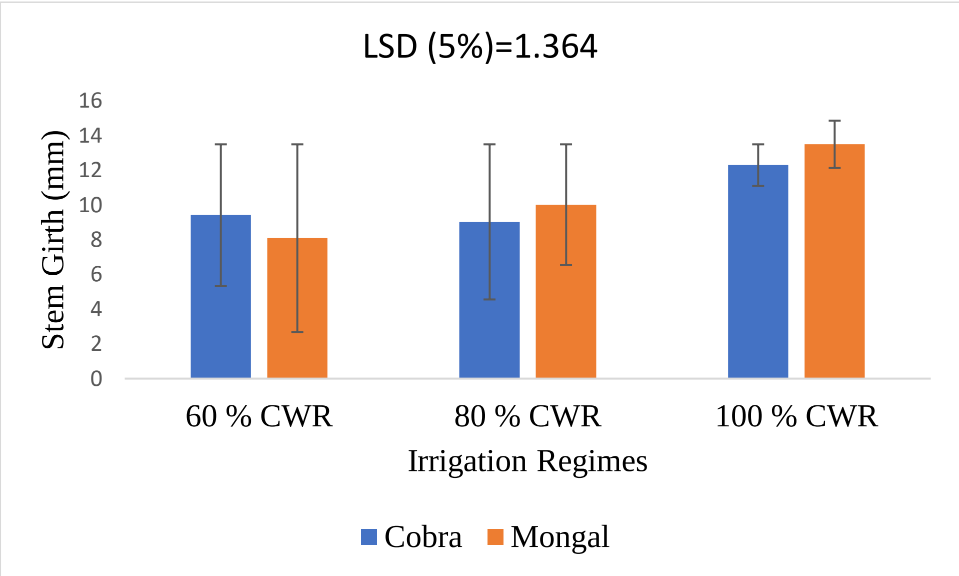

Figure 4. 3: Interaction Effects of Irrigation Regimes and Crop Variety on Stem Girth (mm) at 6 WAT

(Field Experiment, 2023)

4.4.3 Effects of Irrigation Regimes and Crop Variety on the Flowering of Tomato

At 6 WAT, no significant interaction effect was observed between irrigation regimes and crop varieties (p>0.05). However, irrigation regimes exhibited significant differences (p<0.05). 100 % CWR irrigation regime had the highest number of flowers while 80 % CWR had the lowest number while the lowest number of flowers with 38.9 % fewer flowers (Figure

4.4). It was observed that Mongal produced more flowers than Cobra due to its genetic makeup, as shown in Figure 4.5. Appropriate irrigation regimes increased flower numbers. However, drought stress induced a higher rate of production of flowers under 60 % CWR compared to 80 % CWR, indicating that it protects the plant from unfavourable weather conditions. According to studies conducted by Smith *et al.*, 2017, a balanced irrigation system can help enhance the plant's signalling pathways to produce robust flowering.

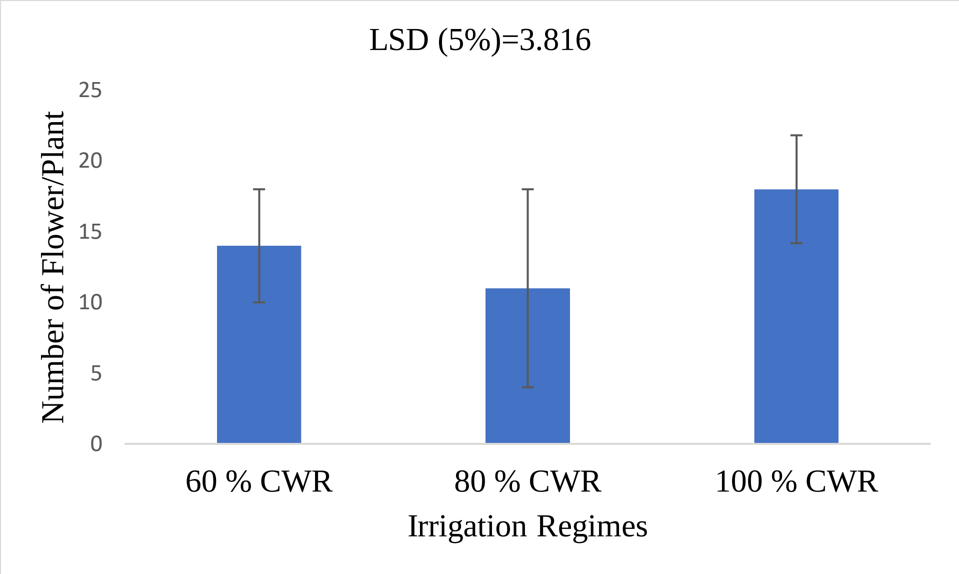

Figure 4. 4: Effect of irrigation regimes of Flowering at 6 WATP

(Field Experiment, 2023)

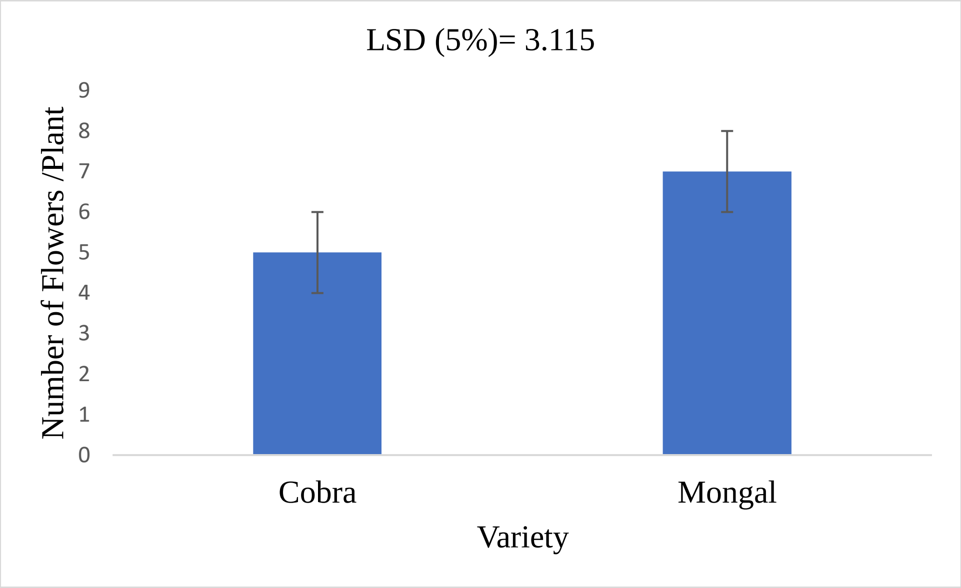

Figure 4. 5: Effect of Crop on Flowering at 6 WATP

(Field Experiment, 2023)

4.4.4 Effects of Irrigation Regimes and Crop Variety on the Fruit Yield of Tomato

Although there was no combination of irrigation regimes and crop variety (p>0.005) on the total fruit yield (Table 4.4). The irrigation regimes had a considerable impact on the total yield of tomato (p<0.037). The irrigation regime at 80 % CWR resulted in the highest fruit yield of 15,020 kg/ha, while the irrigation regime at 60 % CWR had the lowest yield of 9,860 kg/ha (Table 4.5). The irrigation regime at 60 % CWR produced 34.3% less fruit yield compared to 80 % CWR.

Irrigation regimes with 100 % CWR were found to cause fungal diseases and blossom end rot, which reduced the yield. This finding was consistent with a study conducted by Steduto *et al.* (2012). Therefore, an irrigation regime of 80 % CWR resulted in the highest profit. According to research by Smith *et al.* (2017), excessive water application through traditional irrigation systems can lead to waterlogging, which can adversely affect root health and reduce yield potential. The results indicated that Mongal F1 performed best at 80 % CWR irrigation regime, while Cobra performed best at 100 % CWR irrigation regime. Mongal was found to have higher drought tolerance than Cobra, which caused it to perform best at 80 % CWR irrigation regime (Patel and Micra, 2018; Fernandez *et al.*, 2020). Hybrid varieties have been bred for their superior genetic traits, which include improved yield potential, disease resistance, and shelf life, as indicated by studies conducted by Johnson and Smith (2019).

Table 4. 4: Interaction Effects of Irrigation Regimes and Crop Variety on Yield (kg/ha)

Irrigation Regimes	Cobra F1	Mongal F1
60 % CWR	10310	9410
80 % CWR	12300	17730
100 % CWR	13990	11160
LSD (5%)	**0.083**	
p-Value	**5.365**	

CWR=Crop water requirement

(Field Experiment, 2023)

Table 4. 5: Main Effect of Irrigation Regimes on the Fruit Yield of tomato

Irrigation Regime	Yield (kg/ha)
60 % CWR	9860
80 % CWR	15020
100 % CWR	12580
LSD (5%)	**3.793**
p-Value	**0.037**

CWR= Crop water requirement

(Field Experiment, 2023)

4.5 Interaction Effect of Irrigation Regimes and Crop Variety on the Physiological Responses of Tomato

4.5.1 Interaction Effect of Irrigation Regimes and Crop Variety on the Initial The fluorescence in the dark-adapted sample (Fo)

Initial Fluorescence was found to have a significant difference ($p<0.001$) due to the interaction between the crop variety and irrigation regimes at 4 WAT to 10 WAT. The highest initial fluorescence at 4 and 10 WAT was gave by Mongal (100 % CWR), while the least was given by Mongal (60 % CWR). There was a considerable increase in the Fo value from 4 to 10 WAT, which was 57.4 % within the weeks. At 10 WAT, Mongal (100 % CWR) showed the highest Fo of 161.4 µmols, followed by Cobra (80 % CWR) with 139.2 µmols, and Mongal (60 % CWR) with the lowest value of 89.7 µmols (Table 4.6).

Cobra showed an increasing Fo value with deficit irrigation, while Mongal showed a decreasing Fo value with the same type of irrigation. Chen *et al.*, 2014 reported that excessive irrigation can increase Fo values, which is similar to how drought stress can affect them. Drought stress was found to cause waterlogging conditions, leading to a decline in the oxygen supply to the roots and a higher Fo. This suggests damage to the PSII complex, which may be due to the increased production of reactive oxygen species under low oxygen conditions. Additionally, different tomato varieties have varying levels of resistance or tolerance to biotic and abiotic stressors. Some types may possess greater drought or heat stress resilience, making them more suitable for cultivation in Northern Ghana.

Table 4. 6: Interaction Effects of Irrigation Regimes and Variety on Initial Fluorescence

	4 WAT		6 WAT		8 WAT		10 WAT	
IR	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	**Mongal**
60 % CWR	54.7	38.5	95.46	65.5	95.46	63.62	127.2	89.7
80 % CWR	59.19	55.07	83.28	92.5	82.42	84.44	139.2	129.6
100 % CWR	43	68.81	96.89	155.37	92.22	163.75	90.9	161.4

LSD (5%)	**2.843**	**1.661**	**1.661**	**1.66**
p-value	**0.001**	**0.001**	**0.001**	**0.001**

CWR= Crop water requirement, WATP= Weeks after transplanting

(Field Experiment, 2023)

4.5.2 Interaction Effects of Irrigation Regimes and Crop Variety on the Maximum Fluorescence in the Dark-Adapted Sample

Interactions between irrigation regimes and crop variety influenced a significant difference at 4 ($p<0.023$), 6 ($p<0.026$), and 10 ($p<0.007$) WAT. The highest significance ($p<0.001$) of the maximum fluorescence at 8 WAT was shown, and Mongal (100 % CWR) gave the highest Fm value of 578 µmols while Cobra (80 % CWR) gave the least (369 µmols).

The fluorescence values of tomato plants increased significantly from 4 to 8 WAT. However, the value decreased from 8 to 10 WAT due to the fruiting and flowering of the plants at 72.3 %, while there was a decrease of 3.7 % from 8 to 10 WATP. The plants' growth was also observed to be good. Figure 4.7 shows that the maximum number of fluorescence units exhibited by the plants at 8 WAT increased significantly.

Oukarroum *et al.* (2007) noted that changes in Fm in tomato plants were a result of different irrigation regimes, where drought stress or water deficit conditions led to a decrease in Fm, which agreed with the Fm values recorded in the variety Mongal. This finding emphasized water stress leading to photoinhibition, where excessive light energy could not be used effectively, potentially damaging the PSII centres. However, Zivcak *et al.* (2013) illustrated that an optimal irrigation regime fosters higher Fm values in tomato plants. Optimal fluorescence parameters were consistently showcased by plants receiving a balanced water supply, indicating that their photosynthetic machinery was operating at its maximum potential. The research also accentuated the perils of over-irrigation, showing that excessive watering could lead to decreased Fm values, possibly due to the onset of anaerobic conditions in the root zone, which could impact overall plant metabolism and PSII functionality, as observed in a variety of Cobra.

Table 4. 7: Interaction Effects of Irrigation Regimes and Variety on Maximum Fluorescence (Fm)

	4 WAT		6 WAT		8 WAT		10 WAT	
IR	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	**Mongal**
60 % CWR	136.4	121.3	500	451	498	414	452	451
80 % CWR	131.7	137.7	422	548	369	456	427	480
100 % CWR	143.9	160.2	552	623	500	578	433	559
LSD (5%)	**13.7**		**69.5**		**39.7**		**57.6**	
p-value	**0.023**		**0.026**		**0.001**		**0.007**	

CWR= Crop water requirement, WATP= Weeks after transplanting, IR= Irrigation regimes

(Field Experiment, 2023)

4.5.3 Interaction Effect of Irrigation Regimes and Crop Variety on Maximum Quantum Yield of PSII Photochemistry (FvFm)

Table 4.8 shows the influence of the crop variety and irrigation regime on the variance. The maximum quantum yield had a slight significance ($p<0.042$) at 4 WAT and a high significant difference at 6 and 8 WAT ($p<0.001$), with a substantial difference at 10 WAT ($p<0.004$). Cobra (100 % CWR) and Mongal (100 % CWR) gave similar figures of 0.690 µmols at 4 WAT, which is the highest maximum quantum yield of PSII photochemistry. This result was due to the adaptability of both varieties to the environment. At 6WAT, Mongal (100 % CWR) maintained the highest significant difference from Cobra (100 % CWR), while Mongal (80 % CWR) had the highest significant difference from Cobra (80 % CWR). Lastly, Cobra (6O % CWR) achieved the highest significance difference as compared to the figure obtained for Mongal (60 % CWR). The genetic makeup of the varieties caused them to react differently to the irrigation regimes, as reported by Galmès *et al.* (2007). The highest value was exhibited by

Cobra (60 percent CWR) at 8WATP, while the lowest value was recorded by Mongal (80 percent CWR). In terms of the quantum yield of the photochemistry of the PSII, Mongal's 100 percent CWR recorded the highest at 10 WATP, while the lowest was by Cobra (60 percent CWR).

Maxwell and Johnson (2000) found similar results in their study on tomato plants under various irrigation regimes. They observed that optimal watering conditions fostered a stable and high FvFm value, indicative of a healthy PSII system. In contrast, under-irrigation and over-irrigation led to a decreased FvFm. Drought conditions can directly inhibit PSII through oxidative stress, whereas over-irrigation might induce root hypoxia, leading to metabolic disturbances that affect the overall health of the photosynthetic machinery.

Table 4. 8: Interaction Effects of Irrigation Regimes and Variety on Maximum Quantum Yield of PSII Photochemistry

	4 WAT		6 WAT		8 WAT		10 WAT	
IR	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	**Mongal**
60 % CWR	0.669	0.598	0.795	0.734	0.842	0.709	0.719	0.666
80 % CWR	0.648	0.671	0.678	0.888	0.655	0.797	0.689	0.713
100 % CWR	0.69	0.69	0.787	0.799	0.802	0.816	0.74	0.803
LSD (5%)	**0.045**		**0.014**		**0.012**		**0.029**	
p-value	**0.042**		**0.001**		**0.001**		**0.004**	

CWR= Crop water requirement, WATP= Weeks after transplanting, IR= Irrigation regimes(Field Experiment, 2023)

4.5.4 Interaction Effect of Irrigation Regimes and Crop Variety on the Maximum Primary Yield of PSII Photochemistry (FvFo)

There were significant differences between 6 ($p<0.002$) and 10 ($p<0.042$) WAT. But not between 4 and 8 WAT ($p>0.05$). At 6 WAT, variety Mongal outperformed variety Cobra with regards to the primary yield of PSII photochemistry. The highest maximum primary yield was recorded for Mongal (100 % CWR), followed by Mongal (80 % CWR), while Cobra (80 % CWR) gave the lowest. Results suggest that the value of FvFo decreased at 10 WATP, with

Mongal (100 % CWR) giving the highest, followed by Mongal (80 % CWR), while Cobra (80 % CWR) gave the lowest FvFo valves (Table 4.9). This decrease in FvFo suggests a disruption in the PSII reaction centres, likely due to induced oxidative stress under water deficit conditions. A study similar to Kalaji *et al.* (2016) indicated that under optimal watering conditions, tomato plants maintained a relatively high and stable FvFo, suggesting the efficient utilization of light energy for photochemistry in PSII. In the case of water deficit conditions, the FvFo of light energy usage decreased significantly. This suggests a reduction in its efficiency. The authors suggested that the decline in FvFo under water stress could be due to PSII reaction centre damage or alterations in the distribution of absorbed light energy. Mathur *et al.* (2011) found that over-irrigation and deficit irrigation led to a reduction of FvFo, emphasizing the importance of optimal water availability in maintaining PSII photochemistry efficiency. Water stress induced photoinhibition and oxidative damage of PSII photochemistry, while excessive watering led to the onset of anaerobic conditions and metabolic disturbances detrimental to PSII functionality.

Table 4. 9: Interaction Effect of Irrigation Regimes and Variety on the Maximum Primary Yield of PSII Photochemistry

	4 WAT		**6 WAT**		**8 WAT**		**10 WAT**	
IR	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	**Mongal**	**Cobra**	Mongal
60 % CWR	2.035	2.051	4.267	4.007	4.01	3.93	3.59	3.35
80 % CWR	2.178	2.273	3.579	4.364	3.26	3.94	3.34	3.69
100 % CWR	2.256	2.1	4.125	4.383	3.96	3.48	3.48	3.86
LSD (5%)	**0.308**		**0.194**		**0.404**		**0.534**	
p-value	**0.558**		**0.002**		**0.054**		**0.042**	

CWR= Crop water requirement, WATP= Weeks after transplanting, IR= Irrigation regimes

(Field Experiment, 2023)

4.6 Effect of Irrigation Regimes and Crop Variety on Fruit Quality of Tomato

4.6.1 Effects of Irrigation Regimes and Crop Variety on the Dry Matter Content (%)

The dry matter was affected by varying irrigation regimes and variety. The interaction effect ($p>0.05$) between variety and irrigation did not affect dry weight. The variance analysis revealed that the irrigation regimes had significant ($p<0.009$) effects on the dryness of the tomato whilst variety had a higher significant ($p<0.001$). For instance, 60 % CWR used in the irrigation regime produced the driest tomato at 12.5 %, while 80 % CWR used in the irrigation regime produced the driest matter at 11.52 %. The difference between the Mongal and Cobra varieties was due to their tolerance to high temperatures and genetic makeup.

The consistency of this observation with the study conducted by Dorais et al. in 2008 indicates that the selection of tomato varieties affects the amount of dry matter they produce. Varying abilities in how they can accumulate dry matter can affect the overall quality of the fruit. Excessive irrigation can also dilute the dry weight of tomatoes.

In 2001, Howell and his colleagues noted that deficit irrigation increased the dry matter concentration in tomatoes. This irrigation occurs below the crop's evapotranspiration demand.

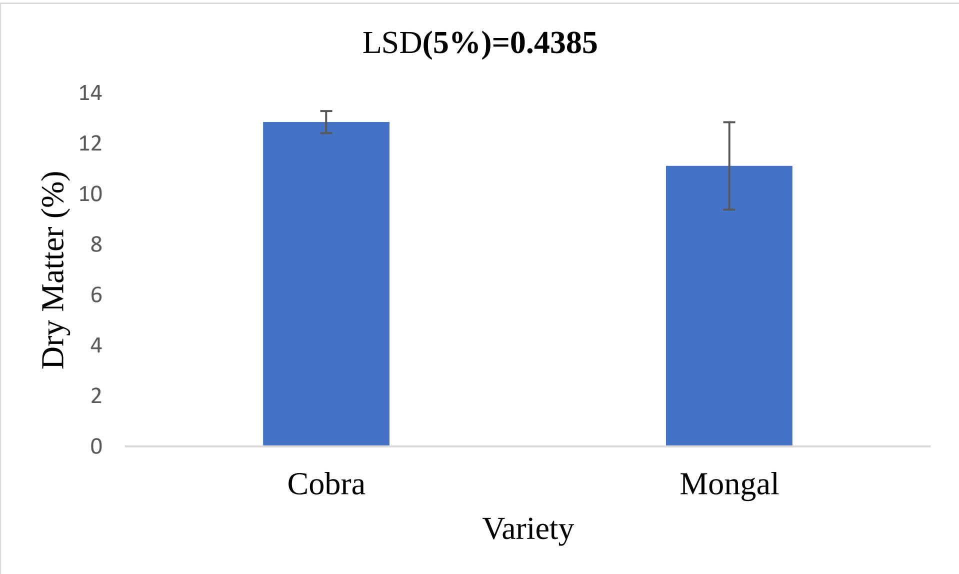

Figure 4. 6: Effect of Dry Matter Content (%). Bar=SEM

(Field Experiment, 2023)

4.6.2 Effect of Irrigation Regimes and Crop Variety on Moisture Content (%)

The higher significant difference ($p<0.001$) in total moisture content was attributed to the variety. There were individual interactions between the irrigation regimes. The moisture content of fruits and vegetables was not affected by the interaction between variety and irrigation regimes ($p>0.05$). According to the fruit moisture content, the highest proportion (94.5 %) was observed for 80 % CWR On the other hand, the lowest (93.1 %) was observed for 60 % CWR.

Cobra F1 had the lowest moisture content of 93.1 %, while Mongal F1 had the maximum moisture content of 94.9 % (Figure 4.7). Cobra and Mongal showed different behaviours concerning moisture due to their adaptability to irrigation regimes. The experiment's observation aligns with Albrizio *et al.* (2016) study, which found that tomatoes' fruit moisture content decreases under deficit irrigation compared to full irrigation. Thompson and Lee's (2015) studies suggested that tomato varieties respond differently to irrigation regimes, depending on their resilience to changes in irrigation. Davis *et al.* (2013) showed that proper irrigation management could control moisture content, and reduced irrigation rates resulted in optimal moisture content that aligns with the varieties' moisture content. Lee and Taylor (2016) demonstrated that the combination of suitable irrigation regimes and variety optimization leads to a moisture content that is in line with the variety.

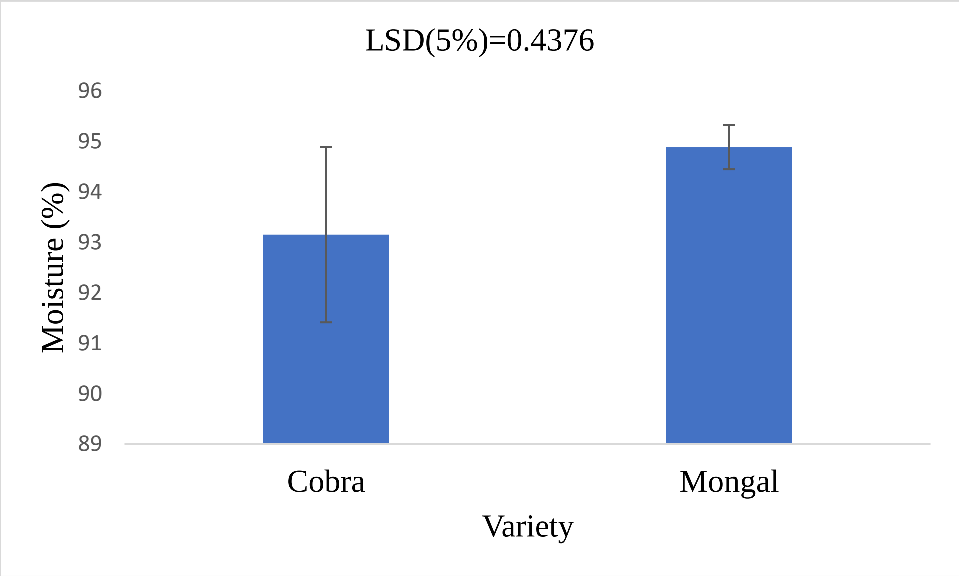

Figure 4. 7: Effect of Irrigation Regimes on the Moisture Content (%). Bar=SEM

(Field Experiment, 2023)

4.6.3 Interaction Effect of Irrigation Regimes and Crop Variety on Colour (a* redness content) of Tomato

The interaction effect between irrigation regimes and variety significantly ($p<0.001$) affected the redness (a*) of the colour. The deepest red colour was observed under the irrigation regime of 60 % CWR, whereas the colour was less deep under the irrigation regime of 100 % CWR. The varieties showed a significant difference in their coloration, with Mongal having a redder shade compared to Cobra. Mongal at 60 % CWR showed a deeper colour, while Cobra at 100 % CWR had a minor deep colour (Figure 4.8). The outcome of the experiment is consistent with the findings of Robinson and Collins (2010), who studied the impact of irrigation practices on tomato colour. Their research indicated that water stress resulting from insufficient irrigation could accelerate the colour development process, leading to a deeper red shade. The study also revealed that controlled deficit irrigation, where water is strategically withheld at specific growth stages, enhances the red coloration of tomatoes. On the other hand, over-irrigation was found to delay colour development, resulting in tomatoes with a pale or uneven coloration (Thompson *et al.*, 2014; Smith, 2016). Thompson and Lee (2017) demonstrated that different tomato varieties exhibit varying capacities for colour development under identical irrigation conditions. Some varieties have been specifically bred to display vibrant colours under certain watering regimes, while others may require irrigation strategies to achieve optimal coloration (Martinez *et al.*, 2018).

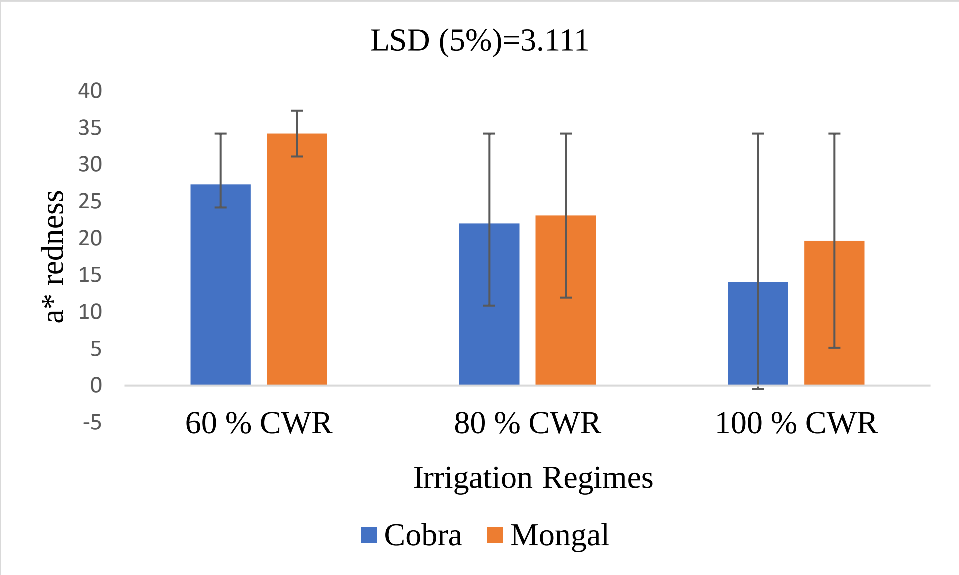

Figure 4. 8: Interaction Effect of Irrigation Regimes and Crop Variety on a* redness Content. Bar=SEM

(Field Experiment, 2023)

4.6.4 Effects of Irrigation Regimes and Crop Variety Tomato Variety on pH Content

The pH level of tomato fruits varied significantly between the variety ($p<0.016$) and irrigation regimes ($p<0.001$) individually. But the interaction between the variety and irrigation regimes did not significantly affect the respective power of hydrogen or pH. Figure 4.9 shows that the irrigation regime at 60 % CWR had the highest pH of 4.54, while the irrigation regime at 100 % CWR had a lower pH content of 3.86. As for the tomato varieties, Mongal F1 had a higher pH of 4.26 compared to Cobra, which had a pH of 4.13. This suggests that tomato pH level is significantly influenced by genetic factors. A previous study by Jackson and Johnson (2015) found that different tomato varieties have unique genetic characteristics that react differently to irrigation practices, resulting in a broad range of pH levels, as observed with Mongal and Cobra in this experiment.

The results of this study support the findings of a study conducted by Martinez and colleagues in 2016, who noted that certain types of plants can grow under certain irrigation conditions and contribute to stable pH levels. Different practices can also cause pH levels to change. The appropriate pH range for mature tomatoes is between 4.5 and 5.5, with slight variations depending on the variety. However, to prevent the growth of pathogens and microbes, the pH level needs to be below 4.6 (Barringer, 2004; Anthon and Barrett, 2012).

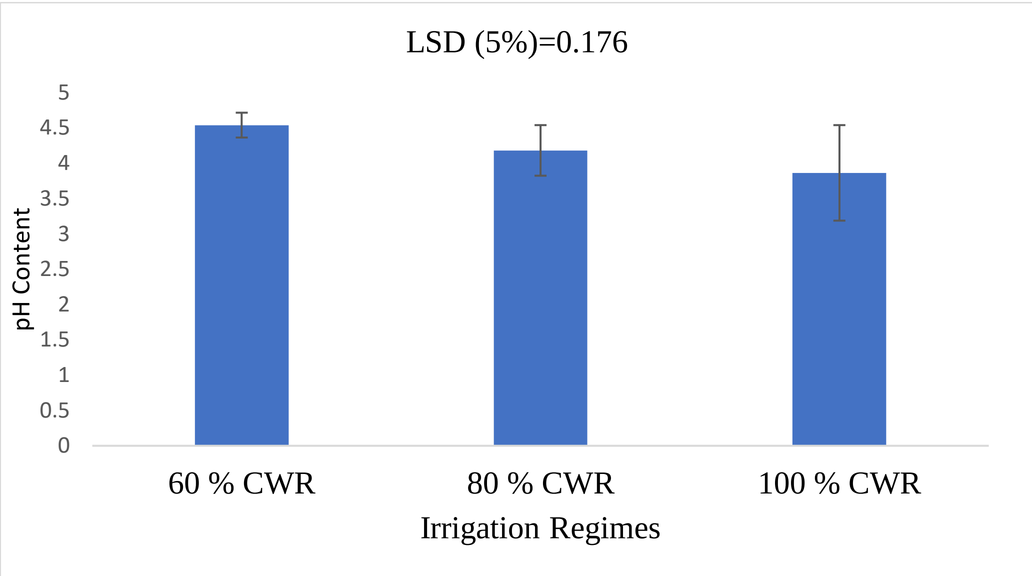

Figure 4. 9: Effects of Irrigation Regimes and Variety on the pH Content. Bar=SEM

(Field Experiment, 2023)

4.6.5 Effects of Irrigation Regimes and Crop Variety on Acidity (%)

The study revealed that the irrigation regimes ($p<0.001$) and varieties ($p<0.001$) varied significantly. But the interaction effect between the variety and irrigation regimes did not lead to significant ($p>0.053$) changes in the acidity content of the water. The highest acidity content of 0.87 % was recorded under the 60 % CWR irrigation regime, while the lowest acidity content of 0.60 % was recorded under the 100 % CWR irrigation regime. The Mongal variety had a maximum sharpness of 0.75 %, while Cobra had an acidity of 0.69 % (Figure 4.10).

Research conducted by Garcia *et al.* (2012) supports this finding, showing that controlled deficit irrigation can enhance flavour attributes by increasing acidity levels, while over-irrigation can reduce acidity levels, potentially affecting taste and shelf-life (Harris & Thompson, 2014). However, a study by Moore and Johnson (2016) found that different tomato varieties respond differently to irrigation practices in terms of acidity levels. Some varieties may require customized water management to achieve desired acidity levels, while others have been bred to maintain or enhance acidity under specific irrigation regimes (Clark *et al.*, 2018).

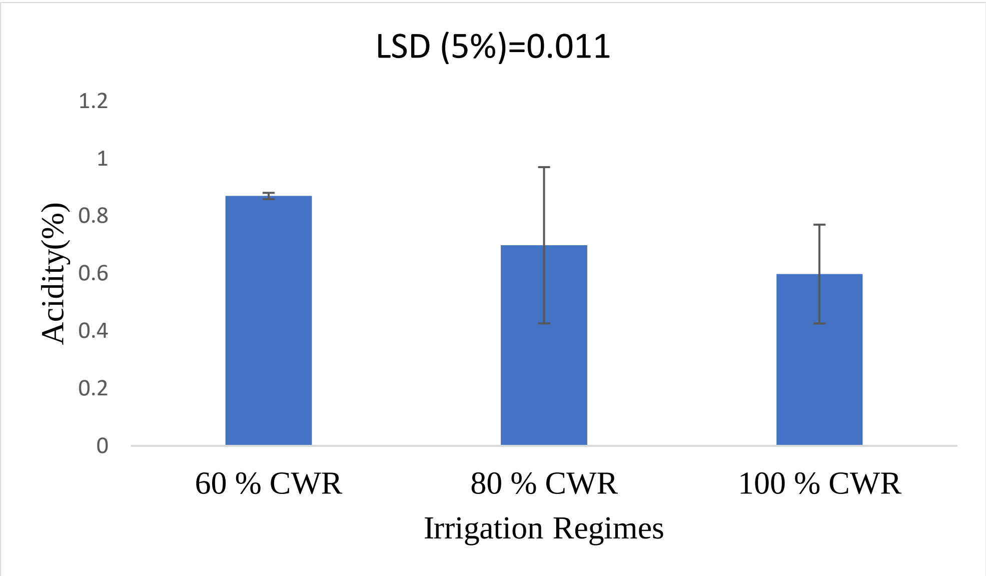

Figure 4. 10: Effects of Irrigation Regimes on the Acidity. Bar=SEM

(Field Experiment, 2023)

4.6.6 Effects of Irrigation Regimes and Crop Variety Tomato Variety on Ash Content of Tomato

Individual differences were observed in the irrigation regimes ($p<0.001$) and varieties ($p<0.004$), as shown in Figure 4.11. The ash content of the tomato fruit did not indicate significance (p<0.120) as a result of the varying irrigation regimes and variety. Ash content was higher in 100 % CWR at 21.2 % compared to 60 % CWR. In addition, Mongal exhibited a higher ash content compared to Cobra.

The results of this experiment support Stevens and Carter's (2013) findings that controlled irrigation, where water is supplied according to the plant's specific growth stage requirements, results in higher ash content, which indicates an increase in mineral accumulation. Furthermore, Anderson and Taylor's (2018) research suggested that specific tomato varieties have a genetic inclination to accumulate different mineral levels, as observed with the performance of Mongal and Cobra. Ash content in tomatoes refers to the remaining inorganic mineral content after the organic matter has been incinerated. It plays a significant role in determining the flavor and nutritional quality of a fruit. In 2020, a study conducted by Roberts and Lewis revealed that the relationship between crop varieties and irrigation regimes affects the amount of tomato ash.

They concluded that a well-matched combination of irrigation strategy and tomato variety could optimize ash content, contributing to improved nutritional quality and fl avour.

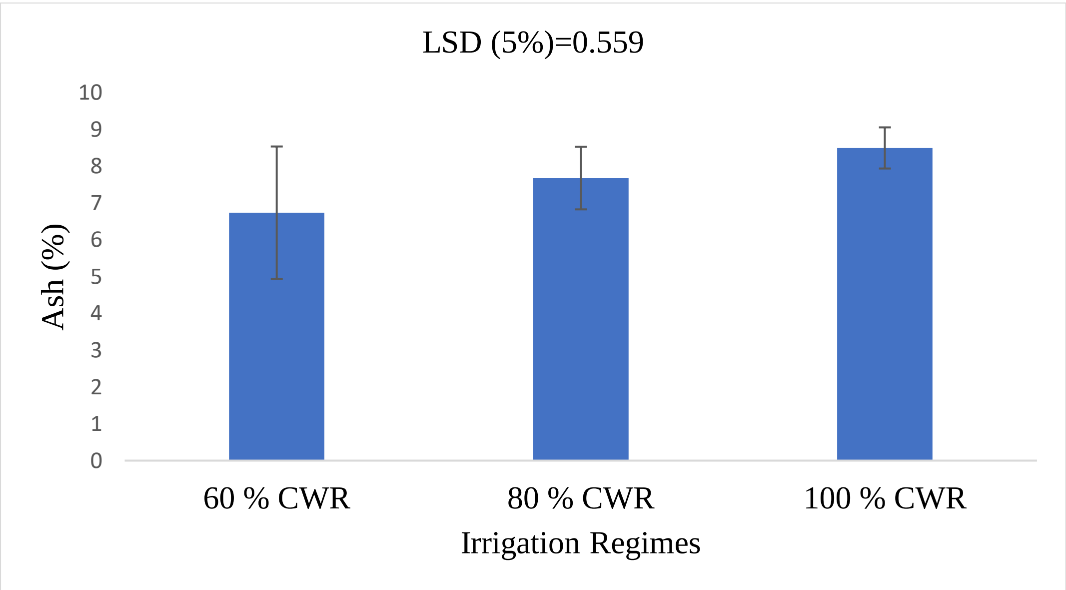

Figure 4. 11: Effects of Irrigation Regimes on Ash Content of Tomato. Bar=SEM

(Field Experiment, 2023)

4.6.7 Effects of Irrigation Regimes and Crop Variety tomato variety on Lycopene of Tomato

The tomato's lycopene content was significantly influenced by irrigation regimes ($p<0.001$) and varieties ($p<0.008$) in isolation (Figure 4.12). The interactions between various varieties and irrigation regimes were not significant.

The highest lycopene content was observed in the 60 % CWR irrigation regime with 150.4 mg/kg, followed by 80 % CWR with 133 mg/kg and 100 % CWR with 114.5 mg/kg. The lycopene content in 60 % CWR was 23.9 % higher than in 100 % CWR. According to the study, the deficit irrigation resulted in a significant increase in the amount of lycopene in the tomatoes. This finding supports the findings of Martinez *et al.*, 2013, observed a similar increase in the concentration of this nutrient in specific growth stages. In contrast, Johnson and Lewis (2016) investigated the genetic traits of different tomato varieties and their response to irrigation regimes. They found that some varieties retained or increased lycopene under controlled irrigation regimes, while others decreased when exposed to specific watering authorities.

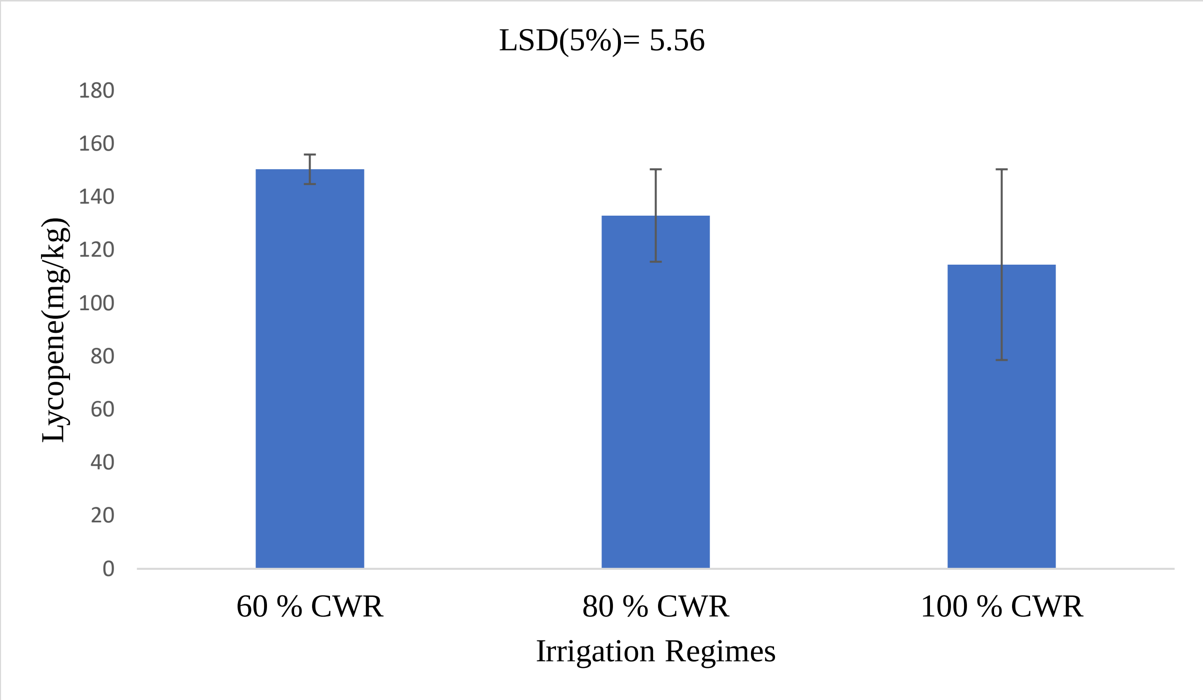

Figure 4. 12: Effects of Irrigation Regimes and Crop Variety on Lycopene. Bar=SEM

(Field Experiment, 2023)

4.6.8 Interaction Effect of Irrigation Regimes and Crop Variety on the Fibre Content (%)

Table 4.10 shows a significant difference ($p<0.03$) in the fibre content when comparing the crop variety and irrigation regimes of tomato. The highest fibre content was found in Mongal (100 % CWR), while the lowest was found in Mongal (60 % CWR). Mitchell and Patel (2019) conducted a study that aligned with the observations made in this experiment. They concluded that the optimal fibre content of tomatoes could be achieved by selecting the right tomato variety and irrigation strategy. Their research highlights the importance of understanding both irrigation practices and crop variety selection in achieving the desired fibre content.

Table 4. 10: Interaction Effect of Irrigation Regimes and Variety on the Fibre Content of Tomato

Irrigation Regimes	Cobra	Mongal
60 % CWR	5.491	6.370
80 % CWR	6.686	7.075
100 % CWR	7.771	7.865

LSD (5%)	**0.391**
p-value	**0.03**

(Field Experiment, 2023)

4.6.9 Interaction Effect of Irrigation Regimes and Crop Variety on the Total Soluble Salts (TSS)

The total soluble salts had a significant difference ($p<0.001$) in their composition due to the interaction between crop variety and irrigation regimes. TSS content was highest in Irrigation regimes with 100 % CWR, followed by 80 % CWR, and lowest with 60 % CWR. Mongal F1 was found to have more TSS than Cobra. The highest TSS content was recorded in Mongal (100 % CWR) and the lowest in Cobra (60 % CWR) (Figure 4.13).

The total soluble salt (TSS) content in tomatoes is a crucial factor that affects their taste, texture, and nutritional value, and it is influenced by dissolved salts of sodium, potassium, calcium, and magnesium. This experiment's results align with Nelson and Thompson's (2019) research, which showed that selecting a suitable tomato variety and a compatible irrigation system can lead to optimal TSS content, enhancing overall quality and consumer appeal. This study highlights the importance of considering both crop variety selection and irrigation practices when aiming to manage TSS content in tomatoes.

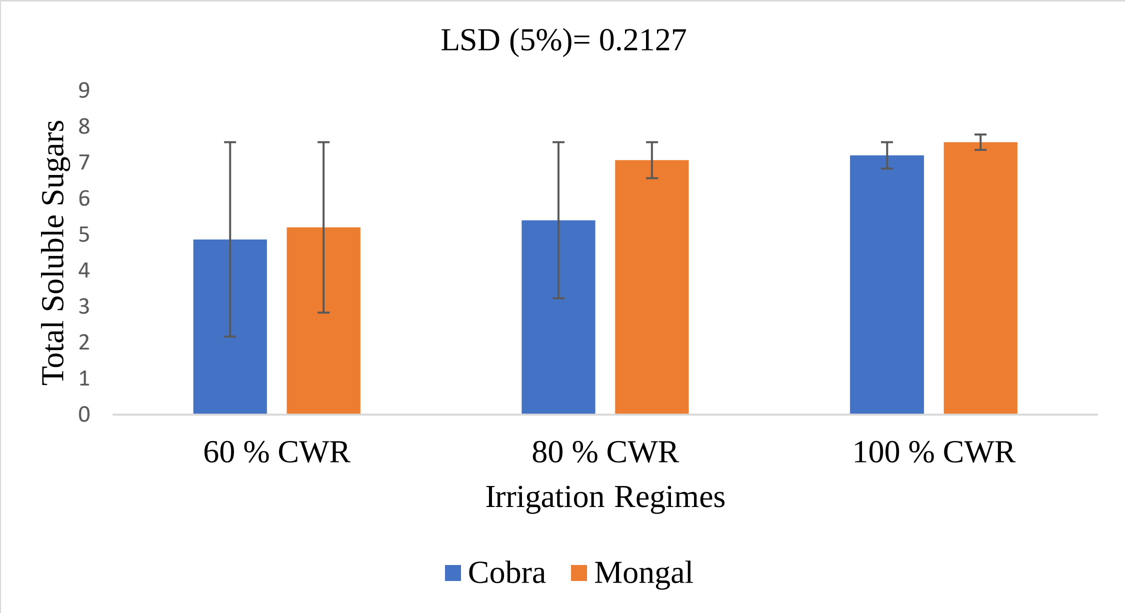

Figure 4. 13: Effects of Irrigation Regimes and Crop Variety on TSS. Bar=SEM

(Field Experiment, 2023)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Northern Region is characterized by high temperatures and warm weather, which can lead to significant evapotranspiration loss. It also has limited water resources, though its water demand is high for agricultural and domestic purposes. The study found that the Northern Region's warm weather and high temperatures can lead to significant evapotranspiration loss. The findings revealed that higher water stress impacts tomato growth and physiological responses, causing a decrease in yields. The following conclusions are drawn from the findings of the study:

I. The seasonal crop water requirement of tomatoes was estimated at 481 mm. The crop water productivity showed a significant difference with irrigation regime at 80 % CWR, with 2,133 kg/mm achieving the highest yield of 15,020 kg/ha while minimizing the inputs required for crop cultivation. The findings revealed that higher water stress impacts tomatoes' growth and physiological responses, causing a decrease in yield.

II. The irrigation regime at 80 % CWR produced the highest yield of 15,020 kg/ha, while 100% ETc recorded an average yield of 12,580 kg/ha.

III. Irrigation regime at 100 % CWR showed a high chlorophyll fluorescence significance, indicating a healthy plant.

IV. Irrigation at 100 % CWR produced good quality fruits.

5.2 Recommendations

Following the findings, recommendations can be formulated for further consideration.

I. 80 % CWR is recommended to farmers since it is water conserving and the water saved can be used to expand the irrigable area eventually increasing yields.

II. Irrigation at 80 % CWR is recommended for high yields and to meet the demand of scarcity of tomato during the dry season.

III. Irrigation regime at 100 % CWR is recommended good physiological response such as maximum fluorescence of the tested hybrids.

IV. Irrigation at 100 % CWR is recommended for higher fruit quality such as lycopene content and total soluble salts influencing the nutritional value of tomato.

The experiment should be repeated under a different environmental condition to validate the research findings.

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APPENDICES A

Appendix 1. Variate: Stem Girth of Tomato at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	177.76	88.88	42.9	<.001
VARIETY	1	1.23	1.23	0.59	0.445
IRRIGATION.VARIETY	2	18.323	9.162	4.42	0.017
Residual	48	99.449	2.072		
Total	53	296.762			

Appendix 2. Variate: Flowering of Tomato at 6WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	640.16	320.08	5.8	0.004
VARIETY	1	260.1	260.1	4.71	0.033
IRRIGATION.VARIETY	2	2.47	1.23	0.02	0.978
Residual	84	4638.93	55.23		
Total	89	5541.66			

Appendix 3. Variate: Fruit Yield of Tomato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	79.706	39.853	4.38	0.037
VARIETY	1	1.454	1.454	0.16	0.696
IRRIGATION.VARIETY	2	56.131	28.065	3.09	0.083
Residual	12	109.124	9.094		
Total	17	246.415			

Appendix 4. Variate: Initial Fluorescence at 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	205.44	102.72	10.57	
REP.IRRIGATION stratum					
IRRIGATION	2	1191.33	595.66	61.27	<.001
Residual	4	38.89	9.72	13.46	

REP*IRRIGATION*VARIETY stratum					
VARIETY	1	45.68	45.68	63.25	<.001
IRRIGATION*VARIETY	2	4208.02	2104.01	2913.24	<.001
Residual	6	4.33	0.72	0.04	
REP*IRRIGATION*VARIETY	36	690.55	19.18		
Total	53	6384.24			

Appendix 5. Variate: Initial Fluorescence at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	309.59	154.80	47.77	
REP.IRRIGATION stratum					
IRRIGATION	2	21604.83	10802.41	3333.32	<.001
Residual	4	12.96	3.24	2.87	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	2136.09	2136.09	1890.96	<.001
IRRIGATION*VARIETY	2	17675.55	8837.78	7823.61	<.001
Residual	6	6.78	1.13	0.04	
REP*IRRIGATION*VARIETY	36	1082.79	30.08		
Total	53	42828.59			

Appendix 6. Variate: Initial Fluorescence at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	309.59	154.80	47.77	
REP.IRRIGATION stratum					
IRRIGATION	2	26083.21	13041.60	4024.27	<.001
Residual	4	12.96	3.24	2.87	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	2608.49	2608.49	2309.15	<.001
IRRIGATION*VARIETY	2	24993.42	12496.71	11062.66	<.001
Residual	6	6.78	1.13	0.09	
REP*IRRIGATION*VARIETY	36	439.51	12.21		
Total	53	54453.96			

Appendix 7. Variate: Initial Fluorescence at 10 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	309.6	154.8	47.77	
REP.IRRIGATION stratum					
IRRIGATION	2	6326.6	3163.3	976.10	<.001
Residual	4	13.0	3.2	2.87	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	823.2	823.2	728.69	<.001
IRRIGATION*VARIETY	2	28271.3	14135.6	12513.52	<.001
Residual	6	6.8	1.1	0.00	
REP*IRRIGATION*VARIETY.	36	17795.9	494.3		
Total	53	53546.2			

Appendix 8. Variate: Maximum Fluorescence at 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	893.	446.	2.69	
REP.IRRIGATION stratum					
IRRIGATION	2	5240.	2620.	15.81	0.013
Residual	4	663.	166.	1.08	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	77.	77.	0.50	0.504
IRRIGATION*VARIETY	2	2293.	1147.	7.49	0.023
Residual	6	919.	153.	0.15	
REP*IRRIGATION*VARIETY	36	37307.	1036.		
Total	53	47392.			

Appendix 9. Variate: Maximum Fluorescence at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	10488.	5244.	1.44	
REP.IRRIGATION stratum					
IRRIGATION	2	138304.	69152.	18.98	0.009

Residual	4	14573.	3643.	0.71	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	32762.	32762.	6.41	0.045
IRRIGATION*VARIETY	2	72363.	36182.	7.08	0.026
Residual	6	30681.	5113.	0.33	
REP*IRRIGATION*VARIETY	36	559788.	15550.		
Total	53	858959.			

Appendix 10. Variate: Maximum Fluorescence at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2887.	1444.	0.80	
REP.IRRIGATION stratum					
IRRIGATION	2	148312.	74156.	40.92	0.002
Residual	4	7250.	1812.	2.38	
REP.*RRIGATION*VARIETY stratum					
VARIETY	1	9933.	9933.	13.02	0.011
IRRIGATION*VARIETY	2	83541.	41771.	54.77	<.001
Residual	6	4576.	763.	0.06	
REP*IRRIGATION*VARIETY.	36	458495.	12736.		
Total	53	714994.			

Appendix 11. Variate: Maximum Fluorescence at 10 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	11910.	5955.	1.54	
REP.IRRIGATION stratum					
IRRIGATION	2	22736.	11368.	2.94	0.164
Residual	4	15473.	3868.	2.68	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	47438.	47438.	32.88	0.001
IRRIGATION*VARIETY	2	36162.	18081.	12.53	0.007
Residual	6	8656.	1443.	0.06	
REP*IRRIGATION*VARIETY.	36	921499.	25597.		

Total	53	1063873.			

Appendix 12. Variate: Maximum Quantum Yield at 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.006133	0.003066	1.80	
REP.IRRIGATION stratum					
IRRIGATION	2	0.029401	0.014700	8.64	0.035
Residual	4	0.006803	0.001701	0.89	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.003367	0.003367	1.76	0.233
IRRIGATION*VARIETY	2	0.021523	0.010762	5.63	0.042
Residual	6	0.011466	0.001911	0.26	
REP*IRRIGATION*VARIETY.	36	0.263373	0.007316		
Total	53	0.342066			

Appendix 13. Variate: Maximum Quantum Yield at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.00002	0.00001	0.04	
REP.IRRIGATION stratum					
IRRIGATION	2	0.00761	0.00380	17.75	0.010
Residual	4	0.00086	0.00021	1.57	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.03890	0.03890	285.03	<.001
IRRIGATION*VARIETY	2	0.17732	0.08866	649.71	<.001
Residual	6	0.00082	0.00014	0.01	
REP*IRRIGATION*VARIETY	36	0.42120	0.01170		
Total	53	0.64671			

Appendix 14. Variate: Maximum Quantum Yield at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.00031	0.00015	1.39	
REP.IRRIGATION stratum					

IRRIGATION	2	0.06236	0.03118	282.29	<.001
Residual	4	0.00044	0.00011	0.68	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.00072	0.00072	4.47	0.079
IRRIGATION*VARIETY	2	0.17017	0.08508	524.79	<.001
Residual	6	0.00097	0.00016	0.01	
REP*IRRIGATION*VARIETY.	36	0.54845	0.01523		
Total	53	0.78343			

Appendix 15. Variate: Maximum Quantum Yield at 10 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.00072	0.00036	0.65	
REP.IRRIGATION stratum					
IRRIGATION	2	0.06688	0.03344	60.46	0.001
Residual	4	0.00221	0.00055	0.56	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.00176	0.00176	1.79	0.229
IRRIGATION*VARIETY	2	0.03143	0.01571	15.99	0.004
Residual	6	0.00590	0.00098	0.04	
REP*IRRIGATION*VARIETY	36	0.85508	0.02375		
Total	53	0.96398			

Appendix 16. Variate: Maximum Primary Yield at 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.4485	0.2242	4.03	
REP.IRRIGATION stratum					
IRRIGATION	2	0.3232	0.1616	2.90	0.166
Residual	4	0.2226	0.0556	0.48	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.0031	0.0031	0.03	0.876
IRRIGATION*VARIETY	2	0.1480	0.0740	0.64	0.558
Residual	6	0.6894	0.1149	0.40	
REP*IRRIGATION*VARIETY	36	10.3592	0.2878		

Total	53	12.1939

Appendix 17. Variate: Maximum Primary Yield at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
REP stratum	2	0.1068	0.0534	4.76	
REP.IRRIGATION stratum					
IRRIGATION	2	0.7276	0.3638	32.42	0.003
Residual	4	0.0449	0.0112	0.21	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.9175	0.9175	17.27	0.006
IRRIGATION*VARIETY	2	2.4596	1.2298	23.14	0.002
Residual	6	0.3188	0.0531	0.18	
REP*IRRIGATION*VARIETY	36	10.6747	0.2965		
Total	53	15.2499			

Appendix 18. Variate: Maximum Primary Yield at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0582	0.0291	0.22	
REP.IRRIGATION stratum					
IRRIGATION	2	1.4495	0.7247	5.56	0.070
Residual	4	0.5210	0.1303	0.79	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.4622	0.4622	2.81	0.145
IRRIGATION*VARIETY	2	1.6187	0.8093	4.92	0.054
Residual	6	0.9870	0.1645	0.25	
REP*IRRIGATION*VARIETY	36	23.3119	0.6476		
Total	53	28.4085			

Appendix 19. Variate: Maximum Primary Yield at 10 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.235	0.118	0.34	
REP.IRRIGATION stratum					

IRRIGATION	2	0.385	0.192	0.56	0.608
Residual	4	1.363	0.341	3.48	
REP*IRRIGATION*VARIETY stratum					
VARIETY	1	0.364	0.364	3.72	0.102
IRRIGATION*VARIETY	2	1.095	0.548	5.60	0.042
Residual	6	0.587	0.098	0.09	
REP*IRRIGATION*VARIETY	36	37.336	1.037		
Total	53	41.364			

Appendix 20. Variate: Dry Matter Content (%) of Tomato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.5346	0.2673	1.53	
REP.*Units* stratum					
IRRIGATION	2	2.7115	1.3558	7.78	0.009
VARIETY	1	13.5373	13.5373	77.67	<.001
IRRIGATION.VARIETY	2	0.2411	0.1206	0.69	0.523
Residual	10	1.743	0.1743		
Total	17	18.7676			

Appendix 21. Variate: Moisture Content (%) of Tomato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.5346	0.2673	1.54	
REP.*Units* stratum					
IRRIGATION	2	2.6925	1.3463	7.76	0.009

VARIETY	1	13.5547	13.5547	78.09	<.001
IRRIGATION.VARIETY	2	0.244	0.122	0.7	0.518
Residual	10	1.7358	0.1736		
Total	17	18.7616			

Appendix 22. Variate: a*Redness Content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	68.691	34.346	11.75	
REP.*Units* stratum					
IRRIGATION	2	609.054	304.527	104.14	<.001
VARIETY	1	85.849	85.849	29.36	<.001
IRRIGATION.VARIETY	2	24.554	12.277	4.2	0.047
Residual	10	29.243	2.924		
Total	17	817.391			

Appendix 23. Variate: pH Content of Tomato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0157	0.00785	0.84	
REP.*Units* stratum					
IRRIGATION	2	1.375233	0.687617	73.81	<.001
VARIETY	1	0.077356	0.077356	8.3	0.016
IRRIGATION.VARIETY	2	0.006544	0.003272	0.35	0.712
Residual	10	0.093167	0.009317		

Total	17	1.568

Appendix 24. Variate: Acidity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0026081	0.0013041	3.55	
REP.*Units* stratum					
IRRIGATION	2	0.2264968	0.1132484	307.97	<.001
VARIETY	1	0.0183042	0.0183042	49.78	<.001
IRRIGATION.VARIETY	2	0.0029308	0.0014654	3.99	0.053
Residual	10	0.0036772	0.0003677		
Total	17	0.2540171			

Appendix 25. Variate: ASH Content (%) of Tomato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0026081	0.0013041	3.55	
REP.*Units* stratum					
IRRIGATION	2	0.2264968	0.1132484	307.97	<.001
VARIETY	1	0.0183042	0.0183042	49.78	<.001
IRRIGATION.VARIETY	2	0.0029308	0.0014654	3.99	0.053
Residual	10	0.0036772	0.0003677		
Total	17	0.2540171			

Appendix 26. Variate: Lycopene (mg/kg fresh wt)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	43.13	21.56	1.15	
REP.*Units* stratum					

IRRIGATION	2	3870.39	1935.19	103.52	<.001
VARIETY	1	207.33	207.33	11.09	0.008
IRRIGATION.VARIETY	2	9.56	4.78	0.26	0.779
Residual	10	186.94	18.69		
Total	17	4317.35			

Appendix 27. Variate: Fibre Content (%) of Tomato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.48114	1.74057	37.69	
REP.*Units* stratum					
IRRIGATION	2	10.68813	5.34407	115.73	<.001
VARIETY	1	0.92798	0.92798	20.1	0.001
IRRIGATION.VARIETY	2	0.47161	0.23581	5.11	0.03
Residual	10	0.46178	0.04618		
Total	17	16.03063			

Appendix 28. Variate: TSS Content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.12333	0.06167	4.51	
REP.*Units* stratum					
IRRIGATION	2	16.57	8.285	606.22	<.001
VARIETY	1	2.80056	2.80056	204.92	<.001
IRRIGATION.VARIETY	2	1.73444	0.86722	63.46	<.001

Residual	10	0.13667	0.01367
Total	17	21.365	

Appendix 29. Variate: Crop Water Productivity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	1608168.	804084.	4.38	0.037
VARIETY	1	29347.	29347.	0.16	0.696
IRRIGATION.VARIETY	2	1132441.	566220.	3.09	0.083
Residual	12	2201914.	183493.		
Total	17	4971870.			

APPENDICES B

Appendix 1: Perforated potting material **Appendix 2: Seeded tomato at 7 DAS**

Appendix 3: Field Layout after transplanting **Appendix 4: Tomato plant at 4 WATP**

Appendix 5: Maintenance of GAP's **Appendix 6: Weighing of oven dried leaves.**

Appendix 7: Water stressed tomato plants according to the irrigation regimes

Appendix 8: Fruiting at 10 WATP   **Appendix 9: Experiment at the maturity stage**

Appendix 10: Harvesting of tomato   **Appendix11: First harvest of tomato**