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EFFECTS OF VAREITY, DEFICIT DRIP IRRIGATION AND RICE STRAW MULCH ON FLOWERING, FRUITING AND YIELD OF TOMATO (*LYCOPERSICON ESCULENTUM* L.)

BY

KYRIA NGIAH-SAH KAH

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DECLARATION

Student

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:

Candidate's Signature:……………..…………… Date:………………….……………………

Name: **KAH KYRIA NGIAH-SAH**

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.

Principal Supervisor's Signature:…………………………. Date:………………………….

Name: **PROF. ABDUL-HALIM ABUBAKARI**

Co-Supervisor's Signature: .………………………….……… Date:……..…………………..

Name: **PROF. ISRAEL K. DZOMEKU**

Head of Department Signature:………………………….. Date:………………………….

Name: **ING. PROF. ABDUL GANIYU SHAIBU**

WACWISA Director Signature ………………………..… Date……..……………………

Name: **ING. PROF. FELIX K. ABAGALE**

ABSTRACT

Tomato (*Lycopersicon esculentum* L.) is one of the world's most significant vegetables and its demand has increased making factors affecting its production very key for evaluation. The yields of tomato in Ghana are generally low and are being supplemented by imports from neighbouring countries. This study investigated the effects of deficit drip irrigation and rice straw mulch levels on flowering, abortion, fruiting and yield of two tomato varieties. The experiment was carried on sandy loam soil at the Council for Scientific and Industrial Research- Savanna Agricultural Research Institute (CSIR-SARI) experimental field at Nyankpala, Tamale in the Guinea Savanna zone of Ghana from November 2020 to March 2021. The experiment was a 2 x 3 x 3 factorial study laid out in a split-split plot design with two tomato varieties (Pectomech and Mongal F1), three irrigation regimes (50, 75 and 100 % of ET_c) and three levels of rice straw mulch (0, 3 and 6 tha^{-1}) with four replications. The output of the CROPWAT model indicated that the highest seasonal water requirement of tomato was 564 mm at 100 % ET_c whilst the lowest of 282 mm at 50 % ET_c. Soil analysis revealed that the soil textural class was sandy loam. The top-soil had a field capacity of 18.2 %, whilst the subsurface soil had a value of 18 %. The analysis of variance revealed significant ($p<0.05$) differences in flower count and flower abortion, fruiting and total fruit yield as influenced by irrigation regimes and mulch levels. The highest total fruit yield of 13.46 tha^{-1} was obtained from the use of Mongal F1 and 100 % of ET_c, whilst the lowest of 2.04 tha^{-1} was recorded from Pectomech tomato variety and 50 % ET_c. Deficit drip irrigation is a productive method of water application. In the Northern Region of Ghana where water is a scarce resource, deficit irrigation in combination with mulching could be adopted to produce high value vegetables.

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DEDICATION

To my mother, my siblings and myself.

TABLE OF CONTENT

CONTENT
PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS AND ACRONYMS

AMC	Available moisture content
Bd	Bulk density
Ca	Calcium
CEC	Cation exchange capacity
Cmol	Centimole
CSIR	Council for Scientific and Industrial Research
DU	Distribution uniformity
DI	Deficit irrigation
DAP	Days after planting
EC	Electrical conductivity
ETc	Crop water requirement
FAO	Food and agricultural organization
FC	Field capacity
GDP	Gross domestic product
IRg	Gross irrigation requirement
IR_n	Net irrigation requirement
K	Potassium
Kc	Crop factor
kg	Kilogram
MAD	Manageable allowable depletion
Mg	Magnesium
MoFA	Ministry of Food and Agriculture
N	Nitrogen
O.C	Organic carbon P

Phosphorus pH Power of

hydrogen PWP Permanent

wilting point

RAW	Readily available water
SARI	Savanna Agricultural Research Institute
SEM	Standard Error of Means
TAW	Total available water
WATP	Weeks after transplanting
WNI	Water content in next irrigation
WP	Water productivity

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is fast becoming an increasingly scarce resource, with droughts becoming serious due to changing climate conditions, especially in the arid and semi-arid regions. Agriculture is the world's largest water user, accounting for 70 % of all freshwater withdrawals (Oweis and Hachum, 2014; FAO, 2017). Over time there has been evidence to proof that the agricultural sector has been a significant source of livelihood by contributing to food security and employment (FAO, 2016; Yeboah and Jayne, 2018). Ghana's agricultural sector accounts for more than 40% of the country's gross domestic product (GDP) (MoFA, 2011). Globally, with available fresh water, irrigation accounts for about 60 to 70% withdrawals and 80 % of consumptive use (Döll *et al*., 2014; Gleick, 2014). In the past 40 years, area of land that was under irrigation has doubled (Siebert and Döll, 2010; FAO, 2012; Siebert *et al*., 2015) and recently about 24% of total harvested cropland which is irrigated produces more than 41% of cereal yield globally (Portmann *et al*., 2010). In numerous parts of the globe, increasing use of irrigation systems have the capacity to save and redistribute water to underperforming systems and increase yield (Fishman, 2015; Jägermeyr *et al*., 2016).

Drip irrigation systems have proven to be a strategy to minimize water losses, augment the quantity and quality of fruits and vegetables via decreased water application (Evans and Sadler, 2008; Berihun, 2015; Biswas *et al.,* 2015). Drip irrigation systems can also help boost crop productivity while using less water (Biswas *et al.*, 2015). The drip system are considered to have an application efficiency of 90% and above especially for vegetable crops in the semi and arid regions (Nikolaou *et al*., 2020).

Vegetables are important in building human immunity because they contain antioxidants, vitamins, fiber, and minerals, and consuming them in required amounts can help boost the immune system in this era of the coronavirus pandemic (Baidya and Sethy, 2020). Tomato is a popular vegetable with very high nutritive content and health benefits. The tomato fruit contains essential amino acids, minerals, vitamin C, organic acids, and also lycopene which serves as a powerful antioxidant that prevents the proliferation of cancer cells (Bhowmik *et al*., 2012; Bratianu and Schwontkowski, 2013; Ilić *et al.*, 2014; Xiukang and Yingying, 2016). Agronomic practices like mulching have the potential to reduce the demand for irrigation water by conserving moisture (Kirda *et al*., 2002). Mulching is an effective practice or measure in crop production that can be used to manipulate the environment of the crop in order to enhance yield and quality by controlling weed population (Steffen *et al*., 2015). In both developed and developing countries, tomato cultivation offers tremendous benefits. Tomato fruit quality and quantity potentials are still being worked on, therefore issues affecting tomato production have piqued people's curiosity. (Agbemafle, 2015; Xiukang and Yingying, 2016).

1.2 Problem Statement and Justification

One factor that limits growth and yield of tomato is water deficiency even though surplus moisture can be unfavourable as well (Nangare *et al*., 2016; Ganeva *et al.*, 2019; Ragab *et al*., 2019). Tomato plants have a high-water requirement throughout their growing life cycle (Benton, 1999; Patanè *et al*., 2011) but excess water can be harmful to the plant because the roots will not function properly under waterlogging conditions (Benton, 1999) leading to root death, delayed flowering and fruit disorders (Tsige *et al.*, 2016). Above 90% of the tomato fruit is made up of water and so insufficient water during the reproductive (flowering and fruiting) stages can lead to flower and fruit drops, blossom end rots which will translate to low fruit yield (Tsige *et al*., 2016). The reproductive stage of the tomato is critical and can be adversely influenced by stress. Negative changes in moisture levels like during plant development and reproduction have instant and prolonged effects. In addition, research show that the reproductive stage is the most vulnerable to moisture stress (Sivakumar and Srividhya, 2016), the flowering stage is the highest consumer of water (Steduto *et al.*, 2012).

In times of insufficient rainfall, and also off-seasons, irrigation is required for optimal development of tomato plants (Kuşçu *et al*., 2014) especially in areas like the Northern parts of Ghana. Irrigation access has improved in recent years as a result of the Ghana government's efforts, particularly in the northern portions of the country where hunger and poverty are more prevalent (Yilma and Berger, 2006). Lack of adequate water to replenish the crop water requirement of plants can lead to a decrease in yield, especially in vegetable production. Limited irrigation water has shown to have unfavourable effects on quality of vegetable crops thus contributing to a reduction in the total fruit yield. Some vegetable crops are very sensitive to suboptimal irrigation while others are less sensitive with differences among varieties (Pascale *et al*., 2011).

Production of tomato is limited by several factors like water scarcity, soil infertility, over or under application of fertilizers and mismanagement of water (Wang *et al.*, 2011). In terms of yield potential, the farmers in Ghana have failed to reach their potential of producing 20 tha^{-1} of tomato (Robinson *et al*., 2010; MoFA, 2020). Average yields remain low at less than 10 tha^{-1} (AsareBediako *et al*., 2007; Puozaa, 2015; Adongo *et al.*, 2016) because of the one seasonal production, high perishability of the fruit, poor access to markets, and competition from imports. From the 2000s, production of tomato appears to be slowly declining so domestic production is supplemented by imports from neighbouring countries like Burkina Faso during the December to

May harvest season, estimated to be as high as 100,000 tons per year (Robinson *et al.*, 2010; Asselt *et al*., 2018).

Accurate assessments of specific growth stage stress tolerances like vegetative and reproductive stages for vegetable crops are very necessary to establish deficit irrigation levels (Machado and Oliveira, 2005) and be able to deal effectively with the crop water requirement at sensitive and precise stages with support from modern irrigation systems for optimal water management (Evans and Sadler, 2008). Outcomes such as reduced yield, low fruit quality, unpleasant physiological responses in plants can be a result of errors in estimating evapotranspiration. For irrigation to be properly scheduled and implemented, soil moisture should be monitored (Evans and Sadler, 2008). Fruit number and yield are affected by the quantity of moisture available to the crop (Benton, 1999). In recent times, deficit irrigation (DI) is being widely adopted. Under deficit irrigation, the crop experiences stress by applying less irrigation water or withholding irrigation application at certain stages, without major yield reduction to an extent. Deficit irrigation has proven to be a strategy that can be used to improve crop productivity and water efficiency (Liu *et al*., 2019).

Irrigation is significant and a major integrant of the wellbeing and development of the world (Evans and Sadler, 2008). It is key that the technique of deficit irrigation continues to encounter upgrade (Kirda *et al.*, 2002). Jägermeyr *et al*. 2015 suggested that the potential of irrigation refinement can be more sustainable if combined with practices like mulching. Water is an important component that impacts tomato development and yield (Wang *et al*., 2011) and so proper irrigation scheduling at different stages is crucial for high tomato fruit production (Wang *et al*., 2011; Tsige *et al.*, 2016). It is obvious that replenishing soil water by proper irrigation scheduling is crucial to crop development and plant optimum growth (Arah *et al*., 2015; Hott *et al.*, 2018;

Ragab *et al*., 2019). Irrigation combined with straw mulch have positive effects on plant development and can be used as an efficient technique to improve yield (Zhang *et al*., 2014). However, there are few reports which relate tomato variety, irrigation regimes, and mulching rates to flowering, fruiting and yield in the Guinea savannah agro-ecological zone. Therefore, because of existing water scarcity and low tomato yield, this study needed to be carried out.

1.3 Main Objective of the Study

The main aim of this experiment was to assess the effects of deficit irrigation and rice straw mulch on the flowering, fruiting and yield of two tomato varieties.

1.4 Specific Objectives

The specific objectives of the study were:

- To evaluate the effects of tomato variety, irrigation regimes, and mulch levels on flower and abortion count in tomato.
- To assess the effects of tomato variety, irrigation regimes, and mulch levels on fruiting of tomato.
- To determine the effects of tomato variety, irrigation regimes, and mulch levels on yield and water use efficiency of the tomato crop.

CHAPTER TWO

LITERATURE REVIEW

2.1 History, Classification and Growth Conditions of the Tomato Plant

The tomato plant is an origin of the costal highlands of western South America even though it grows in all the temperate climates worldwide. There is evidence to support the fact that it was a domesticated plant with a yellow fruit which also moved from Peru and found its way to Central America and the people in that area used the fruit in their cooking. The plant was cultivated in southern Mexico and other locations by the 16th century (Miller, 2003). Tomato (*Solanum lycopersicon*) can be described as a short-lived perennial plant that can be grown annually in the Solanaceae or nightshade family. It can grow up to the height of 1 - 3 m tall, having a weakly woody stem that usually scrambles over other plants. The fruit has a bright colour which is as a result of the pigment lycopene and it is edible, the crop can be grown for both local and exportation purposes worldwide (OECD, 2017). Though botanically classified as a berry, which is a type of fruit, the tomato is nutritionally classified as a vegetable. Tomatoes are of two types, determinate and indeterminate. Indeterminate cultivars generate vines that never die and continue to bear fruit until they are killed. The determinate type of tomato usually rests on the ground and has concentrated flowering and fruit setting which last for about three weeks as compared to the indeterminate type (Steduto *et al.*, 2012). According to classification by the United States Department of Agriculture (USDA) in 1893, tomato belongs to the kingdom: Plantae, phylum: Magnoliophyta, class: Magnoliopsida, order: Solanales, family: Solanaceae, genus: *Solanum*, Species: *Solanum lycopersicon* L. Tomato is moderately tolerant to soil pH of 5.5 - 6.8 and it is a deep-rooted plant with its roots reaching up to 160 cm (Welbaum, 2015). Tomato is moderately sensitive to salinity, requires about 350 - 800 mm of water from the transplanting stage to the harvest, the amount of water required depends on climate, soil type, irrigation method, and crop management. The type of soil required is usually one with good aeration, well drained, deep and an adequate water holding capacity, of which sandy loam soils are preferred (Steduto *et al.*, 2012). The optimal depth of planting is usually 2 - 4 cm. Tomato plant generally starts to flower as early as twenty-five (25) to forty (40) days after transplanting or between thirty-five (35) to sixty (60) days after seed emergence, this largely depends on the temperature of that area. The whole life cycle of the plant ranges between 115 and 145 days for fresh market tomato (Steduto *et al*., 2012).

2.2 Importance of Tomato and Vegetables

Generally, vegetables are important in building human immunity because they contain antioxidants, vitamins, fibre, and minerals and thus consuming them in required amounts can help fight against certain diseases (Baidya and Sethy, 2020). With the recent happenings of the COVID19 pandemic, it can be used as strategy for increasing overall vegetable intake and also boost food production (Baidya and Sethy, 2020; Moseley *et al*., 2020). In Ghana, a wide range of vegetables are consumed; carrots, onions, chilies and tomatoes, among others. The recent estimate consumption from the Ghana Living Standards Survey (GLSS) indicate that spending on vegetables was 12.8 % of total food expenditure with tomatoes being the highest (35 %), followed by 19% from onions, 10 % from chillies and the least carrots (1 %) (Asselt *et al*., 2018). Tomato, eggplant, pepper are all members of the Solanaceae family and are very important vegetables in the world (Welbaum, 2015). The tomato fruit can be consumed fully cooked, half-cooked, fresh in salad, as paste in soups and stews all over the world due to its status as a basic ingredient in a wide variety of foods (Dhaliwal, 2014; Welbaum, 2015; OECD, 2017). Tomatoes are packed with many health benefits (Bhowmik *et al*., 2012; Baidya and Sethy, 2020). Lycopene is a powerful antioxidant found in tomato fruits and it helps in resisting cancerous cell formation and also prevents other diseases (Bhowmik *et al.*, 2012; Ilić *et al.*, 2014). Tomatoes play a significant role in the human diet and thus health because the tomato fruit contains vitamins such as vitamin C and vitamin A which are immune boosters. The fruits also contain vitamin B, Phosphorus, Magnesium, Potassium, and Iron which are effectively lowering blood pressure, reducing cholesterol levels, and normalizing nerve activity in the body of humans (Bhowmik *et al.*, 2012).

2.3 Irrigation Potential and Development in Sub-Saharan Africa and Ghana

Data suggests that the irrigation potential in sub-Saharan Africa is reasonable even though unexploited to a greater extent (Sijali, 2001). Irrigated agriculture has made enormous contributions to Africa's and the world's food and economic development (FAO, 2003; Swamikannu and Berger, 2009). In semi-arid countries, irrigation farming is a significant rural development investment that can have both direct and indirect impacts on food security, poverty and rural development (Bhattara and Narayanamoorth, 2004; IFPRI, 2008). Irrigation also allows farmers to grow high-value crops such as tomato, onion, green pepper, and leafy greens. Farmers can diversify their planting patterns and earn better incomes under favourable economic conditions, improving their overall livelihood (Swamikannu and Berger, 2009).

Irrigated agriculture in Ghana started over a century ago, the practice in 1960 and 1980 covered up to 19,000 ha of land and by the year 2007, it had increased to 33, 800 ha (Namara *et al.*, 2011). The irrigation potential keeps increasing, ranging between 0.36 and 1.9 million hectares under irrigated cultivation (FAO, 2005). Ghana Irrigation Development Authority (GIDA) has built 22 public irrigation schemes covering up to 14,700 acres, 60 % of which were constructed in 2003. There are currently 56 irrigation schemes managed by farmers and GIDA (MoFA, 2011). The irrigated area under private small-scale is about 1,850,000 ha (Giordano *et al.*, 2012). Common irrigation methods used in Ghana are watering cans, buckets, motorized pumps with hosepipe, surface, and sprinkler irrigation methods (Obuobie *et al*., 2006). Studies have revealed that the pH of soils at Tono and Vea dam sites in the Upper East region are within acceptable limits for optimum crop growth and development, also the pH of the soils at Libga are too alkaline for crop growth and development translating to low yield (Adongo *et al*., 2015).

Irrigation is a means of augmenting crop production to meet the increasing demand in Ghana. Expanding irrigation development on various scales is one of the finest options for dependable and sustainable food supply. To improve national food security, more emphasis is placed on Farmer Led Irrigation (FLI) and small-scale irrigation involving farmers in different phases. This demonstrates that there are plans of ongoing irrigation development activities for accelerated and sustained development to end poverty in the country (Kebede, 2019).

The Northern region of Ghana is known to have high evapotranspiration rates with a short rainfall season and farming period of about four (4) to five (5) months coupled with extended dry season of about seven (7) to eight (8) months. This proves that irrigation is necessary for agricultural throughout the extended dry season (Namara *et al*., 2011). Generally, rain-fed agriculture cannot sustain the demand of the future population unless production goes hand in hand with irrigation. Yields of several crops have been recorded to be significantly greater with irrigated farming as compared to rain-fed (Swamikannu and Berger, 2009).

2.3.1 Vegetable Production in Ghana

Ghana has ideal environmental conditions for the development of a diverse range of crops, including vegetables, cereals, fruits, legumes, root and tuber crops (Puozaa, 2015).

There are over fifteen types of vegetables cultivated in Ghana ranging from exotic to traditional leafy vegetables. Non-traditional vegetables such as lettuce, cabbage, and spring onions are imported and generally eaten raw in salads, but traditional vegetables such as "ayoyo" (Corchorus sp.) and "alefu" (Amaranthus sp.) or less perishable veggies such as tomatoes and garden eggs are cultivated locally. Availability of water is one of the factors influencing vegetable production. In the rainy season, vegetable supply increases since there is no need for irrigation and prices also drop. This gives irrigation a lot of potential considering the fact that more profit can be made from vegetable production during the dry season (Drechsel and Keraita, 2014).

In the Northern region of Ghana, the tomato industry can be competitive and stimulate wealth creation (Clottey *et al*., 2009). Production of tomato across the regions of Ghana depends on the type of system, that is either irrigated or rain fed and also based on seasonality. The fact that tomato production is seasonal in Ghana has a detrimental impact on the amount and value of output produced and exchanged on an annual basis. The perishability of fruits and vegetables observed in their production usually forces producers to trade their produce at prices offered, This scenario is most common during major harvesting seasons when there is a lot of rain (Yilma and Berger, 2006; Puozaa, 2015).

Tomato production in Ghana has consistently been on the decline and not meeting with domestic demand, so the gap is usually supplemented by imports from neighboring countries (Robinson *et al*., 2010; Puozaa, 2015). Smallholder farmers are the main producers of tomato in Ghana, this is a contributing factor to the deficit supply due to their lack of resources to expand their production.

2.3.2 Tomato Based Systems in Ghana

Ghana has five major ecological zones; Guinea Savannah in the Northern part; in the south we have the rain forest, transitional zone, coastal savannah zones and the deciduous forest. The tomato plant has proven to thrive over different ecological zones making it possible for the plant to be cultivated in any part of the country with the appropriate resources (MoFA, 2011).

The cultivation of tomato can be classified into two (2) production systems (irrigated and rainfed). With the rain fed system, the crop's survival entirely depends on rainfall as a source of moisture. Relevant studies by Robinson and Kolavalli in 2010 concluded that production in the Upper East Region of Ghana and the neighboring country Burkina Faso is year-round with the use of irrigation hence can supply Ghana with fresh tomato during the December to May periods. Meanwhile production picks up in the southern regions of Ghana around the period of June to November and mostly done under rain-fed conditions. The production type (rain-fed or irrigated) has significant effects on the cost of production and yield level. Usually, production under rain-fed is characterised by low yields because of low inputs, depending on the region of production and the type of irrigation system, irrigated production is classified as either high input-low yield or high inputhigh yield (Namara *et al.*, 2010; Robinson *et al*., 2010)**.**

2.4 Drip Irrigation

This irrigation method necessitates the administration of water to the root zone area in a steady and precise manner, with minimal runoff, deep percolation and evaporation losses. The drip system of irrigation has been widely accepted as one of the most efficient irrigation techniques, this is because it allows water and nutrient to be uniformly distributed to the plants. It is suitable for undulating and steep slopes, shallow soils, porous soils fields with varying soils (Sijali, 2001; Coolong, 2016). Drip irrigation methods are also known to save water by significantly lowering soil evaporation and increasing crop water productivity. Alternative cropping systems, such as winter crops and deep-rooted cultivars that maximize the use of stored soil water and nutrients, could be employed to take advantage of such an advantage (Evans and Sadler, 2008). The drip system normally consists of;

- Water source which provides the required amount of water to the system

- A control valve that aids in opening and shutting water into the system
- Injection equipment which is used to apply fertilisers and other additives into the system
- Flowmeter used to quantify the amount of water that passes through the system
- Filter used to remove contaminants from the irrigation water that can cause emitter clogging
- Pressure gauges used to regulate and control the pressure of irrigation water
- Main lines carry water to the sub-main lines which subsequently distribute it to the laterals (Introduction to Microirrigation System, 2019).

Drip irrigation systems have been known to account for an application efficiency of up to 90 % and it is a more effective way of water management than the dug-out irrigation method (Swamikannu and Berger, 2009; Giordano *et al.*, 2012), and furrow, basin, or border strips which have records of excessive deep percolation losses, low uniformity in water distribution and efficiencies of less than 70 % (Burt *et al.*, 1997; Nikolaou *et al.*, 2020). Subsurface drip irrigation has also been used successfully in vegetable cultivation and tree planting maintenance in the arid and semi-arid regions (El-Attar *et al*., 2019; Nikolaou *et al.*, 2020). When compared to the furrow technique of irrigation, the output of onions practically doubled with subsurface drip irrigation. This was due to the fact that the subsurface drip irrigation system allowed for more frequent irrigation with smaller water depths and greater efficiency than the furrow approach (Enciso *et al*., 2015). Drip irrigation systems are usually used for row crops like vegetables and fruits (Sijali, 2001).

2.5 Deficit Irrigation Systems

Deficit irrigation is a method of maximizing the quantity of water applied to a crop by lowering the amount necessary for the entire growing season or for specific growth stages. The different types of irrigation methods can be used for deficit irrigation. Water deficit irrigation is a technique used in agriculture to increase water use efficiency and increase yields per unit of irrigation (Geerts and Raes, 2009; Nagaz *et al*., 2012). Applying deficit irrigation to crops is exposing them to stress of some degree for a specific period or the entire season of growth, ensuring that yield is not compromised significantly (FAO, 2000). The benefits of redirecting the saved water to irrigate extra cultivated land should outweigh any yield drop from exposing crops to water stress (Kirda *et al*., 2002; Steduto *et al.*, 2012; Liu *et al*., 2019). In Ethiopia, deficit irrigation has had a favorable impact on tomato marketable production, with yield dropping as the deficit water level increased (Birhanu and Tilahun, 2010). Significant water savings can be generated by applying deficit irrigation properly (Kirda *et al*., 2002). Cotton, maize, potato, sunflower, wheat, and sugar beet are among the crops that benefit from deficit irrigation. Deficit irrigation can be used on these crops at any time during the growth season or at moisture-sensitive phases. Deficit irrigation, for example, during the flowering and boll formation stages of cotton, wheat flowering and grain filling stages, soybean vegetative growth, sunflower vegetative and reproductive stages, and sugar beet vegetative and reproductive stages, provides acceptable and feasible irrigation options for minimal yield reductions with limited irrigation water supplies (Kirda *et al.*, 2002). Crop sustainability can be an advantage of deficit irrigation strategies (Al-Ghobari and Dewidar, 2018).

2.6 Irrigation Requirement

2.6.1 Reference Evapotranspiration (ET_o)

The evapotranspiration from the reference surface is dealt with via reference evaporation. A hypothetical grass reference crop with a crop height of 0.12 m, a fixed surface resistance of 70 sm^1, and radiation of 0.23 is used as the reference surface. The reference surface is a large expanse of green, well-watered grass of uniform height that is actively growing and totally shadowing the ground. The fixed surface resistance of 70 sm^{-1} indicates that the soil surface is relatively dry, owing to a weekly watering frequency (Allen *et al*., 1998).

Blaney-Criddle, Radiation, Pan evaporation, and the Penman-Monteith methods are the four conventional methods used to estimate reference evapotranspiration. For the computation of ET_o from meteorological data, the FAO Penman-Monteith approach is maintained as the sole standard method. The evaporation loss from a water surface can also be used to estimate ET_o (Allen *et al*., 1998). The Penman-Monteith equation has been derived as:

$$ET_o = \frac{0.408\Delta(Rn-G) + \gamma\frac{900}{T+273}U^2(e^s-e^a)}{\Delta+\gamma(1+0.34U_2)}$$ ……………………………….. Equation 2.1

Where;

ET_o = Reference evapotranspiration (mm/day),

Δ = Slope of saturation vapour pressure curve at temperature (kPa / ºC)

R_n = Net radiation at the crop surface (MJ /m^2 /day)

G = Soil heat flux density (MJ /m^2/ day)

T = Mean daily air temperature at 2 m height (ºC)

u_2 = Wind speed at 2 m height (m/s) e_s =

Saturation vapour pressure (kPa) e_a = Actual

vapour pressure (kPa) e_s - e_a = Saturation vapour

pressure deficit (kPa) γ = psychometric constant

(kPa / ºC)

2.6.2 Crop Water Requirement (ET_c)

The total amount of water needed by a crop during evapotranspiration is its water demand. Doorenbos and Pruitt (1977) defined ET_c as ‘the depth of water required to meet the crop’s water loss through evapotranspiration while being disease-free, growing in large fields under nonrestricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment’. It is denoted as ET_c and it refers to the amount of water that is needed to make-up for the loss (Savva and Frenken, 2002). In order to properly design any irrigation system, knowledge on the crop water requirement is necessary.

Direct measurement procedures of crop water requirements are burdensome, time-consuming and complicated. The model CROPWAT, is being used widely because it is able to combine climate, crop, soil, rainfall and irrigation inputs into a water balance model (Allen *et al.*, 1998). The CROPWAT model is a computer programme developed by FAO, it was designed to help in the calculation of crop water and irrigation requirements, development of irrigation schedules (Smith, 1992).

Estimating the Net Irrigation Requirement (IR_n): Doorenbos and Pruitt (1984) defined net irrigation requirement (IR_n) as the depth or the volume of water that must be delivered through an irrigation system to ensure that the crop receives its complete crop water need throughout the course of a production period. IR_n usually excludes losses that occur during the process of applying water. Inaccurate estimation of the net water requirement can lead to system performance failures and waste of water resources, the net irrigation requirement can be estimated using the formular below (Savva and Frenken, 2002).

$IR_n = ET_c - (Pe + Ge + Wb) + LR$ ………………………...Equation 2.2

Where:

IR_n = Net irrigation requirement (mm)

ET_c = Crop evapotranspiration (mm)

Pe = Effective dependable rainfall (mm)

Ge = Groundwater contribution from water table (mm)

Wb = Water stored in the soil at the beginning of each period (mm)

LR = Leaching requirement (mm)

Estimating the Gross Irrigation Requirement (IR_g): It is net irrigation plus water losses and operational wastes that occur during application of irrigation water (Doorenbos and Pruitt., 1984; Savva and Frenken, 2002).

2.7 Irrigation Scheduling

For sustainable irrigation water management, irrigation scheduling has been noted to be a key factor for crop growth. Irrigation scheduling is based on elements such as climate, soil, and plant features that may affect water uptake by the crop, and thus scheduling takes into account the irrigation system and the amounts of water to be delivered. To successfully compute an irrigation schedule, direct yield measurements as a function of irrigation application must be documented from carefully designed and conducted field experiments carried out under known conditions (Jägermeyr *et al.*, 2015; Nikolaou *et al.*, 2020).

Supplying plants with the right amounts of water at the appropriate time is the main goal of irrigation scheduling (Steduto *et al*., 2012). The process of deciding "when to irrigate" and "how much to water" crops is known as irrigation scheduling. Proper scheduling is required to properly regulate use of irrigation water, manage inputs such as seeds, fertilisers and labour. Appropriate scheduling of irrigation not only saves water but also, saves energy besides, higher crop yield (Tsige *et al*., 2016)**.**

Soil Water Availability: This refers to the soil's ability to retain water and make it available to plants. The amount of water available in a soil after rainfall or irrigation has occurred and the soil has been well-drained is known as its field capacity. The amount of water a soil can contain is proportional to how much it can deliver to plants. The amount of water supplied to a soil at wilting point in order for it to meet field capacity is known as available water content (Allen *et al*., 1998).

Estimating Total Available Water (TAW) of the Soil: The difference in soil moisture between field capacity and wilting point determines the total available water in the root zone. TAW refers to the total amount of water available to a crop, and it depends on factors such as the texture, structure, and organic content of the soil (Doorenbos and Pruitt, 1977; Savva and Frenken, 2002). TAW is computed using the formula;

$$TAW = (\Theta FC - \Theta WP)\, Zr \qquad \text{Equation 2.3}$$

Where:

TAW = Total available water in the root zone of soil (mm)

Zr = Root zone depth (m)

θFC = Soil water content at field capacity

θWP = Soil water content at wilting point

Moisture in the soil is low and not readily available to plants at permanent wilting point, hence the term "readily available moisture," which refers to moisture in soil that is easily extracted by plants.

Most crops can't quickly take up enough water from the soil to replenish water lost via transpiration when the available moisture is less than 75% (ICE, 1983; Kassahun, 2017).

Estimating the Readily Available Water (RAW) of the Soil: The amount of water that is readily available to the plant at all times is referred to as RAW. The easily available soil water is the portion of total available water that a plant can collect from the root zone without incurring moisture stress. The RAW is calculated following the equation set forth by Allen *et al.* (1998); Benjamin *et al*. (2014) as;

$$RAW = (\theta FC - \theta WP)P * Zr$$ ………………..…..………………...Equation 2.4

Where:

P = Fraction of available soil water content that can be depleted from the root zone before moisture stress and yield reduction,

θFC = Fraction of soil water content at field capacity,

θWP = Fraction of soil water content at wilting point, and

Zr = Crop rooting depth.

Irrigation Interval

It is the maximum period for which the next irrigation must occur. Mishra and Ahmed (1990) proposed that irrigation interval should be calculated using the formula below:

$$Tmax = \frac{AMD}{ETc}$$ ………………………...Equation 2.5

Where:

Tmax = Maximum irrigation interval (days)

AMD = Allowable soil moisture depletion (cm) and ETc

= Daily water use (cm/day).

2.8 Tomato Variety Types

Numerous cultivars and hybrids have resulted through tomato selection and breeding over the years. Tomato hybrids were created to increase yields and improve fruit quality in both open and enclosed growing settings (OECD, 2017). Tomato is categorised as one of the vegetables with a wide range of varieties (Sacco, 2008). Due to the large range of planting kinds available, farmers have the flexibility to select their preferred varieties for cultivation. To increase the productivity of tomato farmers, research institutions introduce new varieties. Tomato cultivars varies in colour, flavor, size, shape, plant type (determinate or indeterminate), pest resistance and disease susceptibility, and maturity length (Anderson, 2019). When picking from a pool of tomato varieties, there are various aspects to consider, and this can be rather difficult for farmers. Some factors to be considered in the selection process of tomato varieties for cultivation were recommended by the KwaZulu-Natal Department of Agriculture and Environmental Affairs (2003).

1. Fruit Quality: Fruit quality features like colour, shape, size, firmness, shelf-life and uniformity are some of the key determinants that have the potential to influence the preference of a particular variety over another by customers. Tomato farmers need to consider the aforementioned quality traits in order to make decisions in selecting the appropriate variety to be cultivated to better suit demand and the output market available (KwaZulu-Natal, 2003).
2. Variety Reliability and Adaptability: Factors affecting production of crops cannot be fully controlled, so farming thereby considered a risky adventure. Due to the fact that crop

performance can be affected by unpredictable weather and other uncertainties, it is therefore very necessary to reduce risk associated with the production process. This can be done by selecting varieties with high adaptability to bad weather, pests and disease infestation, and stand a better chance of yielding higher even under unfavourable conditions (KwaZulu-Natal, 2003).

3. Disease and Nematode Susceptibility: Tomato and other crops are affected by a wide range of diseases which usually translates to yield reduction. To counteract yield losses resulting from disease attacks, control measures are usually put in place and the latter exercise is usually expensive thereby reducing profitability of production. This pushes cultivators of tomato farmers to give priority to varieties that are disease and nematode resistant and tolerant (KwaZulu-Natal, 2003).

In Ghana, a wide range of tomato varieties are suggested (Clottey *et al*., 2009; Adubofuor *et al*., 2010; Robinson *et al*., 2010). Tomato cultivars planted include Pectomech, Tropimech, Roma, Bolga, Ashanti, Nimagent F1, Wosowoso, Rasta, and Power Rano. The cultivated varieties do not differ significantly from those approved by the Ministry of Food and Agriculture (MoFA). MoFA (2009) also set aside several varieties that are suitable for cultivation in Ghana, examples of such varieties include; Pectomech, Roma VF, Rio Grande, Tropimech, Cac J, Wosowoso, Pectomech VF, and Laurano 70 (Puozaa, 2015). Also genotypes like Mongal F1, Platinum F1, and Sumo F1 have exhibited high-ranking performance for fruit yield for both greenhouse and field trials (Ochar *et al*., 2019).

2.9 Mulching Practices

Mulch is a protective layer used to retain moisture by reducing evaporation from sunlight and also the wind, suppress weeds, improve soil conditions, reduce compaction from heavy rains. The mulch material can either be organic from plant or animal residues or inorganic from synthetic (Ramakrishna *et al.,* 2006; Kassahun, 2017)**.**

Mulching can be used to regulate soil temperature there by encouraging root growth of plants and prevents soil erosion. Mulching crops improves water-nutrient retention in the soil and has also been known to promote plant health and vigour. As compared to bare soil, mulching when properly implemented has the potential to improve the welfare of the plants significantly. (Ramakrishna *et al.,* 2006; Anonymous, 2008; Kassahun, 2017). Mulch was observed to maintain soil moisture, it was observed that mulched plots had more moisture as compared to un-mulched plots (Su *et al.*, 2014).

An investigation by Tariq *et al*. (2012) proved municipal waste are very effective mulch materials in the production of horticultural crops.

2.9.1 Types of Mulches

According to Wild (1988) there are two main mulch types; organic and inorganic. The organic materials obtained from plant and animal residues and inorganic materials which are usually synthetic (Kassahun, 2017). They are laid out on the soil's surface to protect it from the full power of the sun, rainfall, and wind, which would otherwise cause crusting, freesing, and evaporation. Another definition by Norman *et al*. (1992) described mulching as an application of a covering layer of material to the surface of a soil. Organic mulch materials such as cereal straw and stalks, agricultural debris, sawdust, grass, maize stover, weeds, manure, Spanish moss, and various water plants are used by farmers. Aluminum foil, asphalt, paper, glass wool, petroleum mulch, and various polythene mulches such as black or translucent polythene sheets are examples of inorganic mulches (Thurston, 1997).

2.10 Effects of Deficit Irrigation and Organic Mulch on Reproductive and Yield Traits of Crops

Restricted water supply can repress new leaf development and reduced yield (Steduto *et al*., 2012). A wide fluctuation in the moisture level in soil coupled with reduced water availability for some varieties during critical periods like fruit setting can have adverse effects on the tomato crop. Varied shape and size, blossom end rot, fruit cracking and blotchy ripening are some of the results (Steduto *et al*., 2012). In a positive light, Kang *et al*. (2000) discovered that regulating deficit irrigation during specific periods of maize growth saved water whilst preserving yield.

2.10.1 Tomato Response to Deficit Irrigation

Irrigation is very important in the production of tomatoes, especially in water scarce areas (Steduto *et al*., 2012). Tomato plants have a high-water requirement throughout the growing season (Benton, 1999; Patanè *et al*., 2011) but not excess because the roots will not function properly under waterlogging conditions (Benton, 1999) leading to root death, delayed flowering and fruit disorders (Tsige *et al.*, 2016). Above 90 % of the tomato, fruit is made up of water and so insufficient water access for the plant during sensitive stages like flowering and fruit development can lead to flower and fruit drops, blossom end rots which will translate to low fruit yield and quality (Tsige *et al.*, 2016). Surface drip irrigation combined with plastic film mulching has been demonstrated to be an excellent combination for optimum tomato growth and production in studies (Wang *et al*., 2018).

2.10.2 Effects of Irrigation and Mulch on Flowering and Abortion of Plants

Flowering is part of the reproductive stage of tomato growth, it is important because it is a prerequisite for fruit formation and a delay in flowering can translate to low yields (Atherton and

Harris, 1986). Flowers are the most complex structures in flowering plants, they make up the reproductive organ (stamens and carpels) (Alvarez-Buylla *et al*., 2010).

Findings from a two-seasoned study concluded that as deficit irrigation increased from 100 % ET_c to 55% ET_c reduced flower count per plant with conclusions that, the highly stressed irrigation (55% ET_c) recorded the least flower count in comparison to 100 % ET_c (Ragab *et al.*, 2019).

A study on the gladiolus plant indicated that irrigation treatments significantly affected flowering percentage and flower number with highest percentage (86%) obtained in 1.0 Epan followed by 75 % in 0.75 Epan and the least (58%) recorded with 0.50 Epan (Bastug *et al.*, 2006).

A research study was implemented to assess the response of growth and yield parameters of the carnation plant (Dianthus *caryophyllus* L.) to irrigation intervals (1, 2 and 3 day) and amounts (0.25kcp, 0.75 kcp, 1.0 kcp and 1.25 kcp). The highest number of flowers (90) was recorded with the irrigation interval of one day and the 1.0 kcp amount of irrigation water supplied with the lowest flower (10) number observed with the interval of three days and least irrigation amount (Kazaz *et al.*, 2010).

Investigations of a study revealed that flower number was significantly reduced by deficit irrigation irrespective of the genotype (Ganeva *et al*., 2019).

Irrigation regimes of the range 100 to 115 % ET_c produced more flowers per cluster, but regimes higher than 115 % ET_c and lower than 75 % ET_c recorded reduced flowers per cluster and high abortion rates (Silva *et al.*, 2021).

Results from an experiment concluded that flower number, length and width were increased as the irrigation water was increased compared to low amounts of water. The study revealed low frequency of irrigation water helped improve water use efficiency (Aydinsakir *et al*., 2011).

Ragab *et al*. (2019) considered the effect of four (4) deficit regimes: 100, 85, 70, and 55 % of ET_c on vegetative development and yield of tomato plants, the findings from the study concluded that the regime of 55 % ET_c noted a significant reduction in the number of flowers and fruits per plant.

In another study carried out on freesia plants, straw mulch produced highest number of flowers per spike as compared to no mulch, the experiment also concluded that straw mulch encouraged flower production (Younis *et al.*, 2012).

Runkle (2018) reported that flower buds can abort due to certain environmental causes like unsuitable photo period, availability of ethylene, nutrient deficiency, high temperatures and drought stress. Excessive or deficient irrigation had negative effects on the flower number, fruit count and flower abortion of tomato plants, which affected yield traits of processing tomato as reported by Silva *et al*. (2021).

Sivakumar and Srividhya (2016) noted that water stress during flowering reduced flower number and also increased flower abortion. Nangare *et al*. (2016) reported that the different crop growth stages are not equally sensitive to moisture stress and so identifying the critical stages can be beneficial.

2.10.3 Effects of Environmental Factors on Flower Number, Abortion, and Yield of Crops.

Tomato flowers are perfect and depending on the specie, they can either be indeterminate (racemose) or determinate (cymose). The number of flowers produced by a tomato plant depends on environmental factors (OECD, 2017).

Environmental factors such as light, water, temperature, humidity and nutrient deficiency are very important for plant growth and development. Plants growing at temperatures at 16°C produces flowers four times more than a plant growing at 24°C and also plants under conditions of less than

12 hours of light and temperatures below 10°C were noted to undergo flower abortion leading to reduced yield (OECD, 2017). Plants transpire more at high temperatures and this can cause reduced pollen and anther development hence yield reduction. Being able to adapt to environmental changes is key in crop production, thus genotype identification with higher yield potential at high temperatures is necessary (Vijayakumar *et al*., 2021). In an experiment with nine (9) indeterminate tomato varieties, Ganeva *et al*., (2019) reported that flower abortion rates were observed highest in water stressed conditions. Vijayakumar *et al*. (2021) reported that under high temperatures, flower number, fruit number and total fruit yield reduced in all tomato genotypes.

Pereira *et al*. (2017) concluded in a research study that one of the primary factors causing reduced yield in watermelon was loss of female flower via abortion which was increased during adverse weather conditions. Environmental factors influenced the performance of the genotypes evidenced. Ochar *et al*. (2019) carried out a research evaluating eight (8) tomato genotypes under field conditions which revealed low fruit yield, the results were attributed to high temperatures and poor rainfall.

Sandip *et al*. (2015) noted that flowering is a key factor in mango production and climatic conditions such as very low and very high temperature during the flowering stage was harmful and caused abortion.

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

According to Ochar *et al*. (2019), the Mongal F1 is amongst the best performing tomato variety that is satisfactory for optimum field trials and green house production.

Studies for two seasons revealed that increasing deficit irrigation from 100 % ET_c to 55 % ET_c reduced fruit number per plant significantly with the lowest fruit count recorded with 55 % ET_c

and the highest count with 100 % ET_c (Ragab *et al.*, 2019). The number of chili fruits per plant was positively affected by organic mulched plots as compared to plots that were un-mulched (Ahmad *et al*., 2011).

A two seasoned trial reported the highest number of fruits from 100 % ET_c (46) in the first trial and 48 fruits in the second trial with least recorded by the most stressed regime (40 % ET_c) recording 35 fruits and 31 in the first and second trial respectively (Sibomana *et al.,* 2013).

Findings by Kumar (2012) who noted that drip irrigation scheduled at 1.0 E pan obtained significantly higher number of fruits per plant (50) as compared to 0.6 E pan (46). Also in conformity with studies carried out by Ganeva *et al.* (2018;2019) reported that increased deficit irrigation has negative effects on fruit formation of tomato.

Birhanu and Tilahun (2010) reported a decrease in fruit number from tomato plants that were exposed to moisture stress.

In comparison to the control, organic mulches produced the highest number of tomato fruits per plant, with rice straw mulch generating more fruits than grass straw and sawdust mulches (Nkansah *et al.*, 2003). In another experiment, the highest number of fruits per tomato plant was recorded with grass mulch followed by wood chip mulch with the control recording least fruit number (Awodoyin *et al.*, 2007). Fruit count per plant observed with pots that were mulched using the Mexican sunflower (*Tithonia diversifolia*) was higher as compared to un-mulched pots (Liasu and Abdul, 2007).

According to experimental findings, the mulch material; cocoa husk had a very positive influence on fruit number of tomato when compared to treatments that were un-mulched (Ahmad *et al.*, 2011; Kassahun, 2017). Tomato fruit number was positively affected by irrigation and mulch with mulched plots recording fruit number of 13 per plot compared to un-mulched plots with 10 fruits (Okal, 2015).

Mulch also increased the amount of fruits per plant, with the maximum number of fruits per plant (61) noted from treatment with black polyethylene mulch, followed by sugarcane mulch (51), then rice straw (47) which was statistically same as wheat straw (46) and the least fruit count per plant was recorded in the control (38) (Ahmad *et al.*, 2011).

Irrigation regimes of the range 100 to 115 % ET_c (459 to 528) recorded more fruits as compared to regimes of range 50 to 75 % ET_c, nevertheless, regimes above 115 % ET_c reduced fruit number (Silva *et al.*, 2021).

2.10.5 Effects of Deficit Irrigation and Mulch on Yield Traits of Crops

Irrigation has been demonstrated to boost tomato fruit yield significantly in studies (Kumar, 2012; Patanè *et al*., 2011).

According to results of a study revealed that the mulch material significantly influenced chilli fruit weight with sugarcane, rice straw and wheat straw all recording higher weights as compared to unmulched plots (Ahmad *et al.*, 2011).

In the temperate region of Uttarakhand, tomato yield recorded an increase (20.7 to 29.8 %) as compared to yields of un-mulched soils (Kamal and Shashi, 2012). Studies also carried out on crops like okra gave an increase in yield from treatments with black plastic mulch by 30 % over treatments that were un-mulched (Patel *et al*., 2009).

A two seasoned study revealed that when deficit irrigation increased from 100 % ET_c to 55 % ET_c reduced fruit number per plant significantly with the lowest flower count recorded with 55 % ET_c and the highest count with 100 % ET_c (Ragab *et al.*, 2019).

With respect to mulch types, findings by Berihun (2011) disclosed that treatments with black plastic mulch recorded 48.02 and 55.32 tha^{-1} in the first year, 65.44 and 70.85 tha^{-1} in the second year of marketable and total fruit yield respectively. The results were followed by yields obtained with treatments of straw mulch; 38.92 and 47.72 tha^{-1} in the first year and 50.02 and 59.0 tha^{-1} in the second for marketable and total fruit yield respectively.

Biswas *et al*. (2015**)** carried out an investigation and concluded that drip irrigation combined with a practice like mulch was an adequate option for saving water and at the same time improving the yield of the tomato plant. The maximum yield of 79.49 and 81.12 tha^{-1} were recorded under straw and polyethylene mulch, respectively. The drip system saved 50 % of irrigation water and increased fruit yield (25 – 27 %) compared to yields obtained from un-mulched control treatment**.**

Results from an experiment conducted in Ethiopia implied that yields of tomato from the treatment combination of 80 % ET_c and sugarcane mulch recorded a yield of 44.04 tha^{-1}, which was higher than 30.19 tha^{-1} recorded from the treatment combination of 90 % ET_c and bulrush mulch. The combination of the irrigation level (90 % ET_c) combined with bulrush mulch also recorded a higher yield as compared to treatments of no mulch and sugarcane leaf mulch, 21.48 tha^{-1} and 28.45 tha^{1} respectively (Kassahun, 2017). Also irrigation treatments without mulch recorded the least yield , the findings indicated that deficit irrigation without mulching is not very effective in contributing to optimum yield production (Kassahun, 2017).

In Tanzania, the research findings from a study concluded that planting two tomato varieties in the dry season with mulch recorded more yield compared to treatments that were not mulched and this practice was considered to be very appropriate for domestic consumption (Okal, 2015).

In an investigation to find out the effects of drought on tomato flowering, yield, and quality parameters in several genotypes, the analysis of variance showed higher fruit weight (20.25 tha^{-1}) in treatments without stress as compared to drought conditions (13.75 tha^{-1}) (Sivakumar and Srividhya, 2016).

In an experiment carried out on onions, the analysis of variance demonstrated high significance ($p<0.01$) due to the interaction effect of deficit irrigation and straw mulching levels Correspondingly, the maximum total yield of 34.71 tha^{-1} was achieved from the plot that received 100 % ET_c and 6 tha^{-1} straw mulch, followed by plots with 80 % ET_c and 6 th^{-1} straw mulch which recorded 32.52 tha^{-1}. The least total bulb yield of 21.10 tha^{-1} was noted from the treatment combination of 60 % ET_c with no mulch. It is important to note that the highest marketable and unmarketable yield were achieved from plots received 100 % ET_c and 6 tha^{-1} straw mulch which contributed to total yield (Kebede, 2019). Mubarak and Hamdan (2018) concluded that the onion crop is vulnerable to moisture stress, with full irrigation treatments producing the best bulb yield (19 tha^{-1}) when compared to deficit conditions (7 tha^{-1}).

There was a yield increase of up to 100 % amongst management options with bare soil recording least yield compared to mulched plots (Osei-Bonsu and Asibuo, 2013; Kassahun, 2017).

Tegen *et al*. (2016) obtained maximum yield (60.90 tha^{-1}) from treatments with grass straw mulch, followed by black film and white plastic mulches, with the lowest yield (43.76 tha^{-1}) recorded in treatments of no mulch.

In Nigeria, Igbadun *et al*. (2012) investigated the impacts of managed deficit irrigation and mulch on onion yield and crop water productivity. Results revealed that bulb yield was reduced by 50 % when the crop was irrigated at 25 % of weekly ET_c. Applying 50 % ET_c caused a yield reduction of 15.5 – 23 %. However, 75 % ET_c was not significant in yield reduction compared to 100 % ET_c. Also, treatments with mulch recorded an increase in yield (12 - 15 %) as compared to non-mulched conditions.

The impact of deficit irrigation and mulch on drip-irrigated onion crop water use and productivity was investigated by Ramalan *et al*. (2010) and the findings confirmed that an increase in the level of water deficit led to a decrease in onion bulb yield whilst crop water consumption and irrigation use efficiencies augmented with an increase in the level of deficit water. The results also indicated that bulb yield was increased with the use of mulch (30.3 tha^{-1}) compared to yield from un-mulched plots (28 tha^{-1}). Similarly, mulch can be used as an efficient technique that is applicable for enhancing maize production and water use efficiency in arid areas (Shen *et al*., 2012).

In an experiment with the cultivation of sesame seed, there was an observation of a higher yield of 664 $kgha^{-1}$ with mulched plots compared to 190 $kgha^{-1}$ in un-mulched plots (Teame *et al*., 2017).

Zhang *et al*. (2014) concluded in an experiment carried out on grapevine that mulching combined with surface irrigation is an effective technique for improving the yield of grapevine and also to maximise its water use efficiency compared to treatments with no mulch.

It was evident from the results of an experiment carried out on sugar beet that mulched plots produced increased root yield from 11.96 to 19.45 % compared to treatments that were not mulched. The study also revealed that using mulch has the ability to enhance the water productivity and boost the yields of sugar beet in areas of limited water (Malik *et al*., 2018).

In strawberry production, mulching was observed to improve on the fruit growth, weight, yield and quality (Fan *et al*., 2012). Oliveira *et al*. (2011) also concluded that the reproductive stage was more sensitive to water stress with dramatic yield reduction compared to the vegetative stage.

2.10.6 Effect of Deficit Irrigation and Mulching on Water Productivity of Crops

Water productivity looks at producing more crops with lesser amounts of water. It is the ratio of output, yield derived from input, water (Kassahun, 2017). Berihun, (2011) concluded that in tomato production, the water use efficiency on the crop was significantly affected when using drip irrigation in combination with mulching. Kassahun (2017) had findings that revealed that without mulching, deficiting irrigation alone was not effective in yield production and improving water use efficiency.

Increased agricultural water productivity is widely regarded as a fundamental strategy for addressing water scarcity and reducing environmental problems in arid and semiarid countries (Kebede, 2019). Increasing water productivity can be considered as an alleyway for reducing poverty, especially in developing countries. Crop water productivity is a key variable that can be used to assess the performance of irrigated and rain fed systems of production in agriculture (Kassahun, 2017).

Geerts and Raes (2009) confirmed that deficit irrigation could serve as a strategy to increase crop water productivity without compromising on yield, decrease the amounts of nutrients leached out and also control salt build-up.

Research results from several authors have revealed that irrigation water use efficiency (IWUE) significantly decreased with increasing irrigation water (Kirda *et al.*, 2002; Molden and Oweis, 2007; Patanè *et al.*, 2011; Nagaz *et al.*, 2012; Tadesse *et al.*, 2017; Mubarak and Hamdan, 2018; Ragab *et al.*, 2019).

Shen *et al*. (2012) reported that in arid regions, using straw mulch could be a very effective way of improving water use efficiency and maize production.

Mubarak and Hamdan (2018) revealed that in onion production, water productivity was significantly greater for mulched treatments compared to those that were not mulched.

Zwart and Bastiaanssen (2004) defined irrigation water productivity as the ratio of yield of crop to the water used to produce that yield.

Deficit irrigation combined with time of application of water also significantly enhanced the water productivity of onion (Nurga *et al*., 2020).

Water productivity can also be used to describe the relationship between the quantity of water used to grow the crop and the amount of water utilized to grow it, It is measured in terms of crop yield per unit volume of water. The yield can be quantified in terms of wet or dry yield, nutritional value or economic return. In dry areas, deficit irrigation has been intensively studied and found to be a profitable and long-term crop production method. By restricting water delivery to droughtintolerant development stages or throughout the growth period, deficit irrigation is aimed at maximising water productivity and stabilizing yields (Kebede, 2019).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Study Location

The study was carried out from November 2020 to March 2021. The experiment was conducted at the on-station research field of the Council for Scientific and Industrial Research (CSIR) -Savanna Agricultural Research Institute (SARI), Nyankpala which is located on N 9˚023.321', W 01˚000.140 in Tolon-Kumbungu district of the of Ghana's Northern Region. Figure 3.1 shows a map of the experimental field. The average annual precipitation in the area is 1100 mm with daily temperatures ranging from 19 to 37 °C. Agro ecological zone is Guinea savanna, with short drought-resistant trees and grassland which provide the vegetative cover. The site has a fairly flat topography and is devoid of trees. The sandy loam soil type is prevalent in the area. The site had an installed drip irrigation system which was modified to deliver the volume of water required by the study. The Wambong dam, which is roughly 22 kilometers from the location, provided water for cultivation. Water was pumped via a sub-surface pipe network to the facility and stored in a 30,000 liters capacity tank as a night storage.

3.1.2 Climate

The Guinea Savanna Agro-ecological Zone includes Ghana's Northern Region. It is associated with an annual rainfall total of 1000-1300 mm. The rainy season lasts roughly 140-190 days. whereas the projected reference evaporation, ETo, is around 2000 mm/year, resulting in a significant seasonal shortfall. August and early September are the wettest months of the year. Approximately 60 % of the rainfall falls in three (3) months (July to September), with severe storms causing serious drainage issues. In most cases, the soil's absorptive capacity is insufficient to survive the intensity of the rain, resulting in enormous volumes of runoff and erosion, which is one of the area's most severe agricultural restrictions. The dry season usually lasts from November to March with daytime temperatures ranging from 32 – 42 ºC and nighttime temperatures ranging from 20 ºC – 22 ºC.

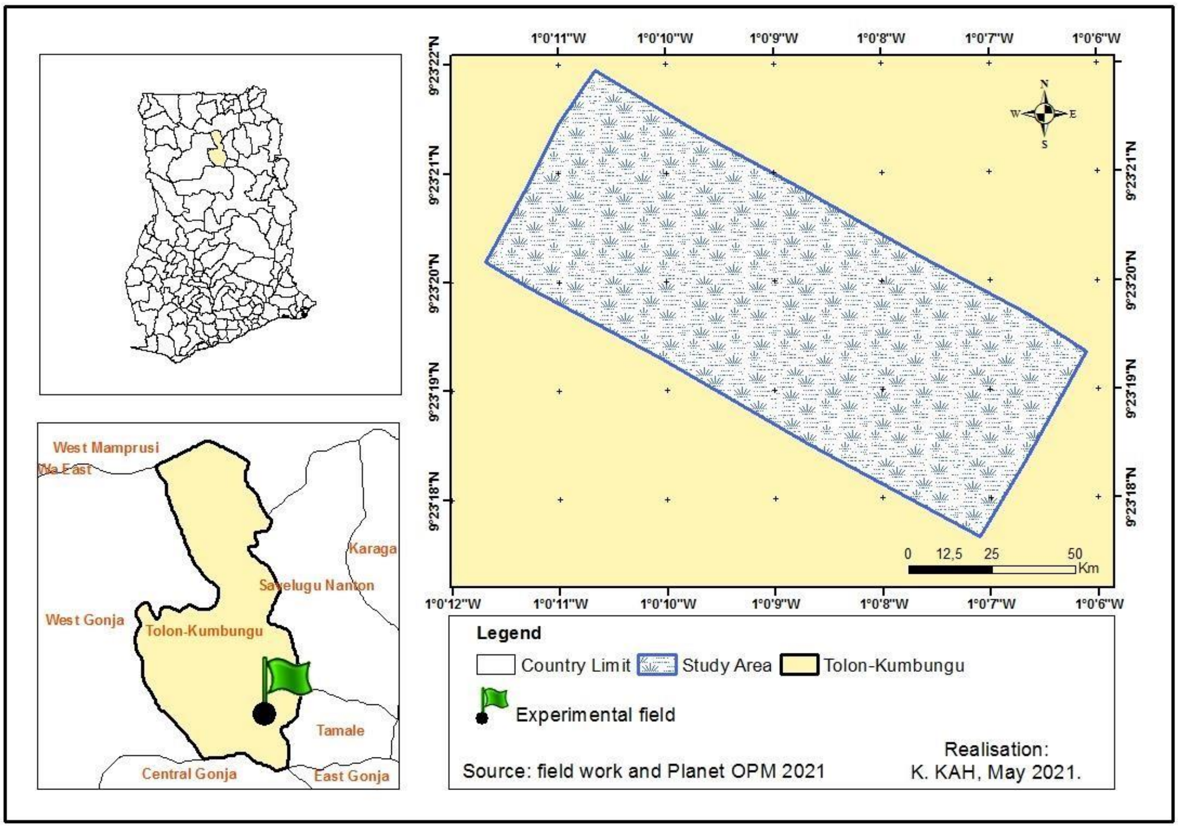


Figure 3.1: Map Showing Location of Study Area

(Field Experiment, 2021)

3.2 Experimental Design and Treatments

This was a 2 x 3 x 3 factorial experiment laid out in a Split-split-plot design and replicated four (4) times. The main plot factor was tomato variety, with the sub-plot factor being drip irrigation regimes and the sub-sub-plot factor was the levels of rice straw mulch (Table 3.1).

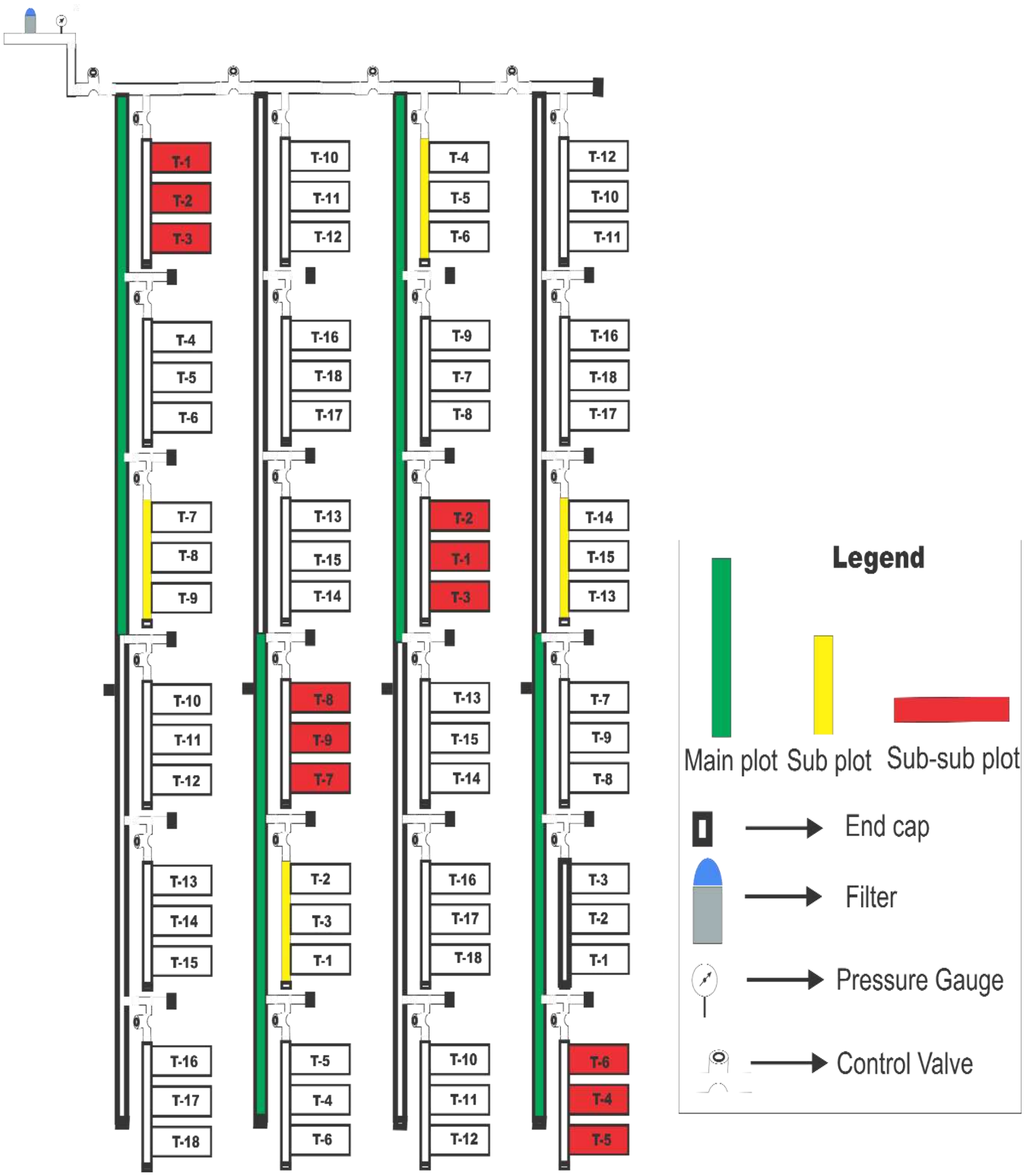
Table 3.1: Factor and Factor Levels Used in Factorial combination.

Variety	Irrigation Regimes	Rates of Rice Straw Mulch
Pectomech	50 % Crop water requirement (ET_c)	0 tha^{-1}
Mongal F1	75 % ET_c	3 tha^{-1}
	100 % ET_c	6 tha^{-1}

(Field Experiment, 2021)

3.2.1 Treatment Assignment

Treatments were randomly assigned to eliminate bias, with each treatment labeled at the beginning of each plot for easy identification. To establish the plants, all plots received equal amounts of water for the first two (2) weeks after transplanting that brought the field-to-field capacity, and then treatments were applied. Figure 3.2 is the layout of the experimental field design with randomly assigned treatments.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T-14
T-15
T-13
T-7
T-9
T-8
T-3
T-2
T-1
T-6
T-4
T-5
Legend
Main plot
Sub plot
Sub-sub plot
End cap
Filter
Pressure Gauge
Control Valve

Figure 3.2: Experimental Field Layout Indicating Drip Setup and Randomization of Plots

(Field Experiment, 2021)

3.2.1.1 Mulching

Three mulching levels of rice straw were used for the experiment; 0 tha^{-1}, 3 tha^{-1}, and 6 tha^{-1}. The different levels were superimposed randomly, according to treatments. The mulch levels were reduced to plot dimensions of 8.1 m^2; 4.8 kg and 2.4 kg were applied for 6 tha^{-1} and 3 tha^{-1}, respectively.

3.2.1.2 Irrigation

The three (3) irrigation regimes used for the experiment were 50 % ET_c, 75 % ET_c, and 100 % ET_c. The levels were then applied randomly according to treatments using the plot size which was 8.1 m^2.

3.2.1.3 Variety

The two (2) tomato varieties used for the experiment were Pectomech and Mongal F1. These varieties were selected based on their availability and adaptability to the local weather.

3.3 Nursery Preparations and Practices

Nursery beds of dimension; 1 m x 6 m were constructed using a hand hoe. Fifty grams (50 g) of two (2) tomato seed varieties i.e. Pectomech and Mongal F1 were sowed by the drilling method with 37 drills of 15 cm of intra row spacing and a thin layer of soil was used to cover the seeds. The surface of the nursery bed was covered with a layer of rice straw mulch to help retain soil moisture and regulate soil temperature within the root zone for effective and uniform seed germination and emergence. Irrigation was done twice daily as light showers using a watering can to meet the field capacity of the soil. The tomato seedlings emerged five (5) days after planting (DAP), after which the mulch material was removed from the surface and raised to allow the seedlings to be well established. A hand-fork was used every 4 days to loosen the soil to enable enhanced soil water storage.

3.4 Land Preparation and Field Layout

The area for the experiment was ploughed, harrowed and hand leveled. The layout of the field was done using a measuring tape, a rope line, wooden pegs, and a wooden hammer to hammer pegs into the soil. The different blocks and plots were separated with wooden pegs. Plot size consisted of three (3) rows of 4.5 m long and 1.8 m wide, giving an area of 8.1 m^2 for each plot with alleys of 1 m separating plots and blocks respectively, giving rise to 1037.4 m^2 as the total area of the experimental field.

Plate 3.1: Experimental Field Layout with Drip lines

(Field Experiment, 2021)

3.5 Soil Sampling and Analyses

3.5.1 Analysis of Soil Physical Properties

Soil samples were taken in a zigzag manner across the experimental plot from 0 - 20, 21- 40, and 41- 60 cm soil depth and analyzed for its physical properties by adopting standard procedures.

Results of soil analysis served as a decision tool in estimating the water requirement of the crop, computing the irrigation scheduling, and fertilizer application rate. The collected samples were taken to the University for Development Studies, Nyankpala Campus soil laboratory for determination of soil texture, initial soil moisture content, saturation, bulk density, total available water, organic matter, soil pH, porosity, and saturated hydraulic conductivity.

i. Infiltration Test

The infiltration rate which is the speed at which water enters into the soil is measured by the depth of the water layer that can enter the soil in one hour. Using a mini-disc infiltometer, an infiltration test was performed on two (2) separate places of the field, upstream and downstream. The infiltrometer's top and lower chambers were both filled with water. The suction was regulated by the top chamber while the lower chamber contained the volume of water that seeped into the soil at a rate determined by the bubble chamber's suction. A porous sintered stainless-steel disk at the bottom of the infiltrometer prevented water from leaking into open air. The small diameter of the disk allows for undisturbed measurements on relatively leveled soil surfaces.

Water began to exit the bottom chamber and infiltrate into the soil at a pace specified by the hydraulic parameters of the soil once the infiltrometer was put on the soil. The volume was recorded at particular time intervals of 30 seconds while the water level decreased (Mini Disk

Infiltrometer, 2006).

ii. **Soil Texture**

The hydrometer method for analyzing soil particle size distribution was used to determine the soil texture (Beretta *et al*. 2014) and the textural class was assigned using the USDA textural triangle (Kebede, 2019), the appropriate texture was obtained based on the particle size distribution (Beretta *et al*., 2014).

iii. **Bulk Density**

It was determined using undisturbed soil samples collected from four (4) points to represent the experimental plot at four different depths (0 - 20, 21- 40 and 41 – 60 cm) using core samples. To measure the dry weight fraction, the soil samples were oven-dried for 24 hours at 105 ºC to a consistent weight and weighed. By dividing the weight of the dried soil by the volume of the soil in the core sampler, the bulk density was estimated (Hillel, 2004).

$$Bd = \frac{M_s}{V_c}$$ ………………………………… Equation 3.1

Bd = Bulk density (g/cm^3)

M_s = Dry weight of the soil (g)

V_c = Total volume of the soil in the sampler (cm^3) iv.

Field Capacity of the Soil

The moisture content at field capacity was determined after soil samples were saturated for 24 hours and water from the saturated soil was extracted using the pressure plate apparatus at 0.33 bars (Protocol for Analysis, 2021).

v. **Permanent Wilting Point**

The amount of water in soil held by forces stronger than 15 bars is considered its permanent wilting point, it represents the minimum point of plant available water (Judy, 2004). This was determined using the membrane apparatus. In this setup, the semi-disturbed sample was saturated and placed in a synthetic ring. After saturation of the samples for 24 hours, an overpressure was realized in the pressure membrane extractor using the compressor at 15 bars. On reaching the equilibrium the samples were removed, weighed (W_1), oven-dried at 105 ºC, and weighed (W_2) again.

$PWP = W_1 - W_2$ ………………………………..……………… Equation 3.2

Where:

PWP = Permanent wilting point (%)

W_1 = Initial weight of soil before oven drying (g)

W_2 = Final weight of soil after oven drying at 105 ºC (g)

3.5.2 Soil Chemical Analysis

Over the entire experimental area, soil samples were taken in a diagonal pattern and downwards in the soil profile, at depths of 0 - 20 cm, 21 - 40 cm, and 41 - 60 cm. In each block, soil samples were obtained and composite samples were created by layering them together.

The soil samples were tested for N, P, K, Ca, Mg, CEC, pH, EC, and organic carbon at CSIRSARI Nyankpala's laboratory. The Kjeldahl method was used to determine the total nitrogen available in the soil (Bremner and Mulvaney, 1982). The Bray-P solution method was used to determine phosphorus (P), whereas the United States Salinity Laboratory Staff's (1954) flame photometer method was utilized to determine potassium (K). The Walkley and Black technique

(1934) was used to determine pH, salinity (EC meter), and organic carbon (OC) content; the Ammonium acetate method was used to determine calcium (Ca) and magnesium (Mg) (Motsara and Roy, 2008; Ogundare *et al*., 2015; Peters, 2018).

3.6 Drip System Installation and Testing

- **Installation of Drip Irrigation System**

A water supply, control head, main and sub-main lines, laterals, and emitter drippers were all included in the system. The source of the water for irrigation was the Wambong dam, the water was pumped from the dam into a three (3) PVC Polytanks of 10,000liters which served as the storage reservoir. The system was installed using low-density polyethylene pipes (LDPEP) with their respective fittings. The field was cleared of any sharp-edged objects or stones. The drip irrigation system consisted of a screen filter that was used to remove contaminants from the water to avoid emitter clogging, a mainline of 1.5" that supplied water to four (4) sub-mains of 1", four (4) sub-mainlines that carried water to the four (4) replications, and 216 laterals that carried water to the plants. As a result of land elevation changes, the laterals were laid along the slope to minimize changes in emitter discharge while the sub-main lines were laid across the slope. All the pipes and fittings were clear of dirt to avoid clogging and ensure uniformity.

3.7 Irrigation Water Requirement

The following estimations were done to determine the quantity of water required by the plants throughout the growing season.

Estimation of Crop Water Requirement.

Reference ETo was calculated using daily meteorological data collected over a period 1970 to 2019. Maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (RH), wind speed (at two meters), and sunshine hours were the climatic parameters that were employed (hrs).

Using the FAO Penman-Monteith method, the ETo was calculated using the CROPWAT program (FAO, version 8.0) (Allen *et al*., 1998).

The crop coefficient (Kc) used was adopted from FAO Irrigation and Drainage Paper 56 for tomato (Allen *et al*., 1998). The Kc values for respective growth stages were 0.9, 1.12 and 0.83 for initial, mid and end stage, respectively. Based on the Kc values of the crop and length of each growth stages, daily crop coefficient was interpolated for development and late season. Length of growth stages of 20, 30, 40 and 20 days for initial, development, mid-season and late.

$ET_c = ET_o \times K_c$ ……………………………………………………......Equation 3.3

Where:

ET_o is the evapotranspiration (mm)

K_c is the crop constant

For localized (drip) irrigation, the equation by Keller and Bliesner (1990) was used to adjust the ET_c to $ET_{crop\text{-}loc}$ for localized irrigation systems with a ground cover (P_d) of 95 %. so, the adjusted ET_c was calculated using the formula.

$Td = Ud \times [0.1 (Pd)^{0.5}]$ …………………………………………………… Equation 3.4

Where:

$Td = ETc_{\text{-localized}}$

$ET_{c\text{-localized}}$ = estimated ET_{crop} at peak demand for localized irrigation

Ud = conventionally estimated peak ET_{crop}

Pd = percentage ground cover (%)

Estimation of the Net Irrigation Requirement (IR_n)

Assuming no effective rainfall (Pe), no leaching (LR), the net irrigation requirement for this experiment became the adjusted crop water requirement (ET_c) (Savva and Frenken, 2002). The Net Irrigation Requirement (IRn) did not account for losses that happened during the water application procedure. The Net irrigation was calculated using the formula;

$IR_n = ET_c - Pe$ ……………………………………………………… Equation 3.5

Note, Pe = 0, therefore, IRn = $ET_{c\text{-localized}}$

Estimation of the Gross Irrigation Requirement (IR_g)

The gross irrigation requirements accounted for water losses that occurred during conveyance and application in the field. The gross irrigation requirement was computed by adopting a field application efficiency (E_a) of 95 % because of the usage of the drip method of application. As stated by Coolong (2016) drip irrigation application efficiencies normally vary between 90 and 95 %. the gross irrigation requirement was calculated using the formula;

$IR_g = \frac{IRn}{Ea}$ ……………………………………………………… Equation 3.6

Where:

IR_g = Gross irrigation requirement (mm)

IR_n = Net irrigation requirement (mm)

E_a = Field application efficiency (distribution uniformity, %)

3.7.1 Irrigation Scheduling

To be able to schedule the irrigation water, the following steps were taken to arrive at the estimations.

Estimation of Available Water Content (AWC)

The difference between the amount of water at Field Capacity (0.3 bar) and Permanent Wilting Point is the available water (15 bars) (Waller and Yitayew, 2016).

AWC = FC – PWP ……………………………………Equation 3.7

Where:

AWC = Available water content

FC = Field Capacity

PWP = Permanent Wilting Point

Estimating Total Available Water (TAW) of the soil: TAW was computed using the formula;

$TAW = (\Theta_{FC} - \Theta_{WP}) Zr$ ……………………………………Equation 3.8

Where:

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

θ_{FC} = Water content at field capacity (%),

θ_{WP} = Water content at wilting point (%)

Estimation of Readily Available Water (RAW) of the Soil:

For this experiment the readily available water was calculated by multiplying the available water content by the management allowed depletion

$$\mathrm{RAW} = \mathrm{AWC} * \mathrm{MAD} \quad \text{.........Equation 3.9}$$

Where:

RAW = Readily available water to plant at all times,
AWC = Available water content,

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

For the RAW to be converted to the volume it was multiplied by crop area (intra spacing x interspacing).

RAW (liters)= RAW (mm)x Crop Area (m^2) x 1000 liters ……………………...Equation 3.10

Estimation of the Maximum Irrigation Interval (days)

$$ID = \frac{RAW}{Rn} \quad \text{.........Equation 3.11}$$

Where:

ID = The maximum irrigation interval or the irrigation frequency (days)

RAW = The readily available water (liters)

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

All irrigations were completed in order to restore the field's capacity.

Estimation of the Irrigation Run Time (hours)

$$Ta = \frac{IRg}{Q} \quad \text{.........Equation 3.12}$$

Where:

T_a = Irrigation run time (hours),

IR_g = The gross irrigation requirement (l),

Q = Emitter discharge (l/h),

Converting the irrigation run time from hours to minutes was done by multiplying the values by 60.

Estimation of Water Content for Next Irrigation

WNI = FC - (AMC) MAD ……...………………………………. Equation 3.13

Where:

WNI = Water content for next irrigation (liters),

FC = Field Capacity (%),

AMC =Available Moisture Content,

MAD = Management Allowable Depletion (%).

Estimation of Irrigation Water Productivity

The yield that may be produced from a given amount of irrigation water is known as water use efficiency (WUE). It was calculated using the formula below and represented as kg ha mm^{-1}.

$$IWP = \frac{Y}{ETc}$$ ………………………...…………………………Equation 3.14

Where:

IWP = Irrigation water productivity (kg ha mm^{-1}),

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

ET_c = The water used (mm).

- **Testing of Irrigation System**

The system was tested after installation to make sure there are no leaks, pressure differences, and non-uniformity.

- **Distribution Uniformity Test**

A distribution uniformity test was done by measuring the volume of water flow recorded against per specific time. Catch cans were randomly placed across the whole field and the volume of water was recorded against time, then catch cans were placed in each replication for the four (4) replications and the volume recorded per unit time. Catch cans were also placed in two (2) replications each and volume of water collected recorded per unit time. The values were recorded and arranged in descending order, from the recorded values, the lower ¼ of the values and all the values were averaged and the distribution uniformity test was done using the formula below. A Distribution uniformity values of above 80 % are accepted (Irrigation Evaluation and Maintenance, 2017).

$$DU = \frac{\text{Average of the lowest } 1/4}{\text{Total Average}}$$ ……………………………Equation 3.15

Where:

DU = Distribution uniformity (%)

3.8 Cultural Practices

3.8.1 Transplanting

Healthy and vigorous seedlings of height 12 - 15 cm or 3 - 4 true leaf stages were carefully uprooted from the seedbed Lemma and Shimeles (2003) for transplanting. The field was clean and free from weeds and irrigated to field capacity before transplanting. Transplanting of tomato seedlings was done with planting distances of 30 cm apart, 15 plants per row and a total of 45 plants per plot. The seedlings were transplanted with a pot of soil and placed in holes of 10 cm deep at and the soil hardened to maintain verticality of seedling posture and mostly in the evening to reduce transpiration losses and shock stress associated with transplanting.

3.8.2 Fertilizer Application

Fertisol, an organic fertilizer was applied as soil amendment across the field at a rate of 6 tha^{-1} three (3) days before seedlings were transplanted. Yara Mila Grower fertilizer 17:10:10, 3 % S + 0.3 % Zn and Yara Mila Activa fertilizer 23:10: 5, 2% MgO + 3 % S + 0.3 % Zn were applied at a rate of 75 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} to the tomato plants in a split manner with basal dose at two (2) WATP and top dressing at five (5) WATP to all the treatments.

3.8.3 Plant Protection Measures

Tomato plants were protected against whiteflies and thrips by applying insecticides; Methyl demeton 25 EC at 1 ml per litre of water and also controlled from blights and leaf spots by applying Bicarbonate fungicides at 60 ml per 15 liters. This was done twice every week. Agronomic practices like weeding and earthing up were done once in two (2) weeks.

Staking of tomato plants was done by using iron stakes planted as pegs and with stakes pegged at 5 cm from each plant and carefully bound to plants using nylon twines.

Harvesting

Harvesting of the fruits was done when the fruits ripened and was done on weekly basis and according to plots and also weighed to enable yield computations.

3.9 Data Collection

3.9.1 Weather Conditions During Crop Growth Season

- Weather conditions were monitored during the crop growing season using a mini weather station (Decagon Weather Station, EM50 data logger coupled with an ECRN1000 Rain Guage) set up at the study site. The weather data collected included air temperature (°C), solar radiation (W/m^2), relative humidity (%), wind speed (m/s) and precipitation (mm) at 30 minutes' interval.

3.9.2 Agronomic Data

In each plot, ten tomato plants were chosen at random and tagged and monitored throughout the growing season to ensure uniformity. 30 plants per block were tagged and a total of 720 plants were tagged for the entire field and the following data sets were collected from the field.

- **Flower Count:** the number of flowers within each plot were counted and recorded weekly.
- **Flower abortion Count:** the number of aborted flowers were counted and recorded weekly.
- **Fruit Count per plant:** Total fruit number on the tagged plants were counted weekly and averaged.
- **Fruit Yield:** Total fruits per plant and also per plot were harvested and weighed in kilograms (kg) using an electronic weighing scale. Weights were converted to tons per hectare (tha^{-1}).

3.10 Data Analysis

Data collected was arranged in Microsoft Excel and subjected to Analysis of Variance (ANOVA) at a significance level of 5 % appropriate for split-split-plot using 12th edition of the GenStat software. The count data was transformed using the square root method. Where significant differences were observed, the means were separated using Least Significant Difference (LSD) at 5% probability. The results were presented in Tables and Figures where appropriate. Appropriate pictures were also taken and used were necessary.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Physical Properties of Experimental Soil

The soil textural class of the experimental field was sandy loam, according to laboratory analysis of the particle size distribution of the experimental soil (Table 4.1) (USDA soil textural classification, 1987). Soil bulk density varied from 1.48 to 1.68 g/cm^3 across soil depth of 0 – 60 cm with the topmost layer recording the least bulk density. The top-soil at the depth 0 - 20 cm had a field capacity of 18.2 %, whilst the subsurface soil (21-40 cm) recorded field capacity of 18 %. The soil moisture content at the permanent wilting point also varied with soil depth between 6 % to 9 % on dry weight basis (Table 4.1). Total available water (TAW) computed gave a value of 26.94 mm/m at 0 - 20 cm depth, whilst 36.85 mm/m was noted at 21 - 40 cm depth (Table 4.1).

Table 4.1: Soil Physical Properties of the Experimental Site

Soil Physical Properties	Soil Depth (cm)		
	0 – 20	**21 - 40**	**41 - 60**
% Sand	70.12	60.24	59.35
% Silt	21.2	29.24	30.02
% Clay	8.68	10.52	10. 63
Soil Texture	Sandy loam	Sandy loam	Sandy loam
% Gravel by mass > 2mm	30.10	39.30	41.20
Total organic matter (%)	2.88	1.44	1.21
Field capacity (%)	18.20	18.00	20.40
Permanent Wilting Point (%)	9.10	6.90	9.60
Saturation (% V)	45.80	41.90	38.10
Available water (%)	9.10	11.10	10.80
Bulk density (g cm^{-3})	1.48	1.68	1.69
Porosity	44.12	36.51	29.97
TAW (mm/hr)	26.94	36.85	36.50

Saturated Hydraulic 0.081 0.044 0.041 conductivity (Ks cm/min)

(Field Experiment, 2021)

The soil at the experimental field had a sandy loam texture with a high sand percentage of 70 % and a low percent of clay (8 %) across the soil depths. This result is in harmony with Buri *et al*., 2012; Shaibu *et al*., 2017 who reported that soil textures within the savannah zones are dry and vary from sand through sandy loam to silt and are relatively poor in clay content.

The bulk density of the soil varied from 1.48 to 1.68 g/cm^3 and the top surface soil layer (0-20 cm) had a lower bulk density value than the subsurface layer and this could be ascribed to the topsoil's high organic matter concentration. In general, the bulk density was within the desirable range and considered satisfactory for maximum air and water flow in the soil for crop root growth as reported by Hunt and Gilkes (1992); Waller and Yitayew (2016). This results are in agreement with Waller and Yitayew (2016) who clearly stated that organic matter is able to decrease bulk density and also with Pervaiz *et al*. (2009**)** who reported that mulching increased soil organic matter (1.32 g kg^{-1}) but decreased bulk density (1.35 Mg m^{-3}). Hitimana *et al.* (2021) reported a lower value of 1.22 g cm^{-3} of bulk density from treatments with rice straw mulch compared to a higher value of 1.34 g cm^{-3} obtained from treatments with bare soil.

Determining moisture content at field capacity did not vary much with the soil depth on a weight basis. The soil at the top depth (0 - 20 cm) had a field capacity of 18.2 % based on weight basis, while the sub-surface soil (21 - 40 cm) had a field capacity 18%. According to Hillel (2004), the field capacity (FC) of sandy soils ranges from 15 to 25 % on a weight basis. Thus, the values obtained in the current study were within the range expected for sandy soil. The moisture content at the permanent wilting point also showed variation with soil depth between 6 % and 9 % on a weight basis (Table 4.1). The soil depth at 0 - 20 cm had a permanent wilting point value on weight basis of 9.1 % and 6.1 % at depth of 21 - 40 cm, this was in agreement with the range reported by Busscher (2009).

A value of 26.94 mm/m was found as the total available water at 0 - 20 cm depth, while 36.85 mm/m was found at 21 - 40 cm depth. It was in line with the total available water of sandy loam soils which ranges from 30 to 70 mm/m (Cotching, 2001).

Infiltration Rate

In this experiment, the soil water infiltration rate was found to be 33.73 mm/hr (Figure 4.1) at the upstream and 26.27 mm/hr (Figure 4.2) at the downstream with an average of 30 mm/hr.

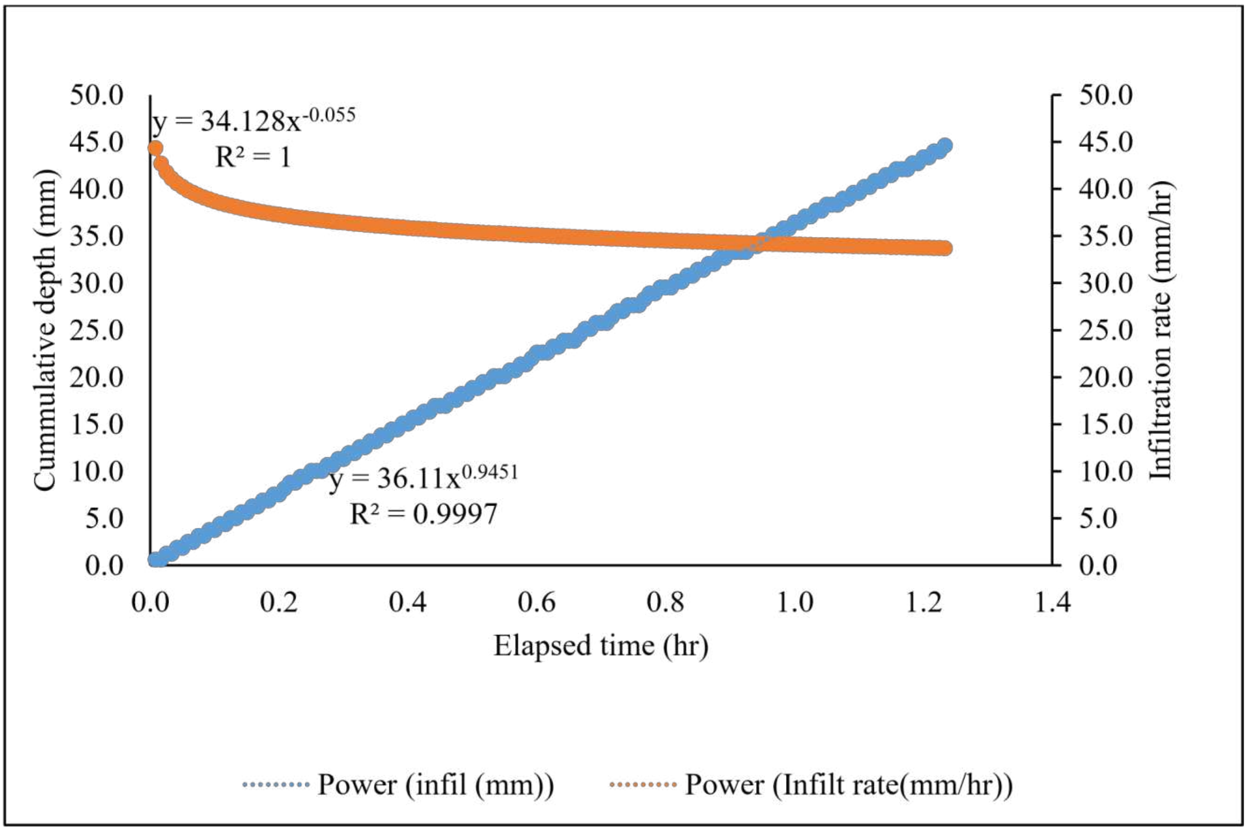

Figure 4.1: Cumulative Depth and Infiltration Rate for Upstream of the Experimental Site
(Field Experiment, 2021)

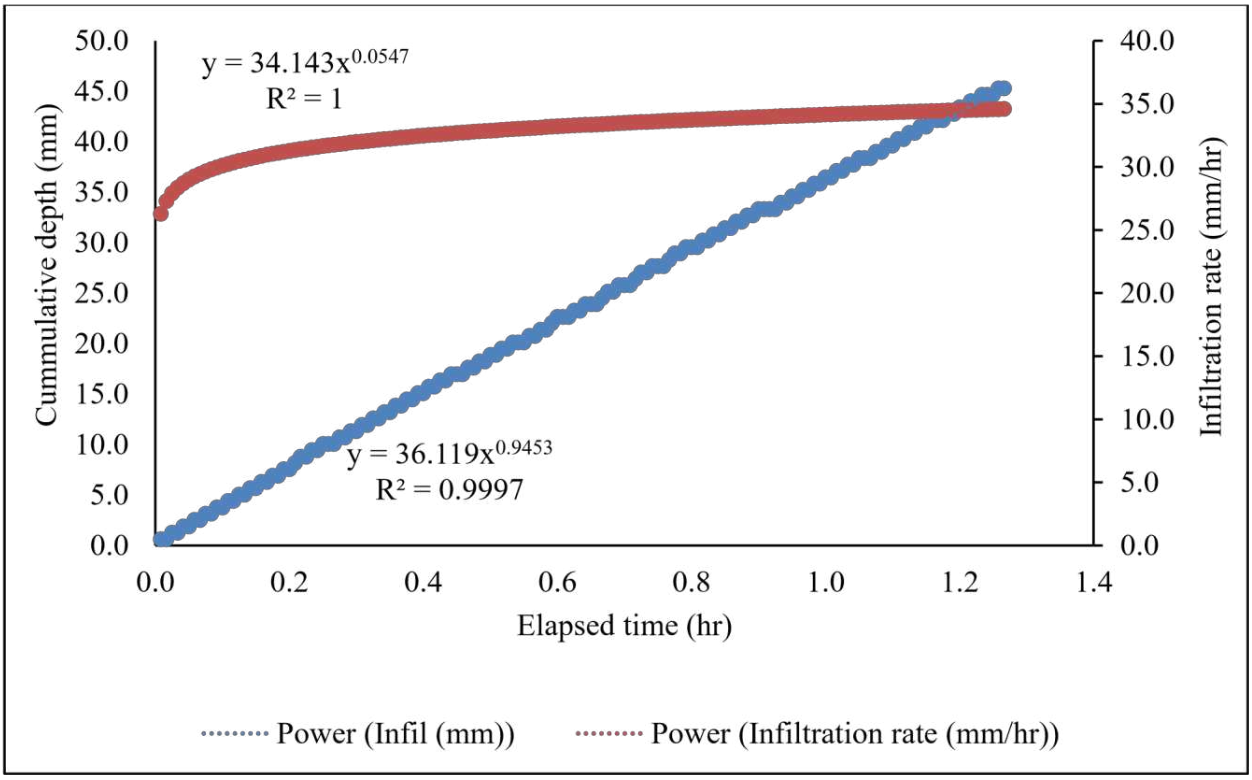

Figure 4.2: Cumulative Depth and Infiltration Rate for Downstream of the Experimental Site *(Field Experiment, 2021)*

In this experiment, the average infiltration rate was 30 mm/hr which was in the lower range of infiltration of vegetated sandy loam soil (Hunt and Gilkes, 1992). This means that a 30 mm layer of water on the soil surface will infiltrate in one hour. This value (30 mm/hr) was also described as infiltrating moderately by Hunt and Gilkes (1992). This rate also falls within 13 - 76 mm/hr which was stated by Waller and Yitayew (2016) to be the range of sandy loam soils.

4.2 Chemical Properties of Soil and Irrigation Water

The pH of the soil, according to chemical analysis, ranged from 5.42 to 5.45 with the topmost layer recording the highest pH value. The soil electrical conductivity (EC) varied from 1.36×10^{-2} dS/m within the soil depth of 0 - 20 cm to 6.98×10^{-3} dS/m for 41 - 60 cm (Table 4.2). Organic carbon level decreased with increasing soil depth from 0.975 to 0.5265 % whilst soil total nitrogen varied from 0.08 to 0.04 % across soil depths (Table 4.2). The irrigation water's chemical analysis revealed a pH of 6.70, which was considered normal. Table 4.2 shows that the irrigation water's electrical conductivity (EC) was 0.1 dS/m.

Table 4.2. Analysis of Chemical Properties of Soil and Irrigation Water

Soil Chemical Properties	**Soil Depth (cm)**			
		0 - 20	21 - 40	41 - 60
EC (µS/cm)		13.06	8.32	6.98
pH		5.45	5.42	5.42
O.C (%)		0.975	0.741	0.5265
% N		0.0898	0.0659	0.0482
P (mg/kg)		3.684	2.348	2.296
K (mg/kg)		78	56	44
Ca (Cmol+/kg)		3.4	2.4	2.2
Mg (Cmol+/kg)		0.4	1.8	1.6
CEC (Cmol+/kg)		5.8	5.64	4.93
Irrigation Water chemical properties	pH	EC (µ/cm)	Salinity (µS/m)	TDS (mg/kg)
	6.7	104.4	105.2	63.3

(Field Experiment, 2021)

The pH value of the soil ranged from 5.42 to 5.45, according to the results of soil chemical analysis. According to Motsara and Roy (2008) soil reaction (pH) classification, the soil of the study area was classified as strongly acidic (4.6 - 5.5). Also, most nutrient elements were made available to plants in the pH range of 5.5 – 6.5 of which the values of the experimental field were very close to Motsara and Roy (2008). The electrical conductivity of the soil at the experimental field varied from 6.98 x 10^{-3} dS/m to 1.36 x 10^{-4} dS/m (Table 4.2). According to classifications of soil by Motsara and Roy (2008) and USDA (1954) non-saline, slightly saline, moderately saline, strongly saline, and severe salinity are defined by electrical conductivity of 0 - 2 dS/m, 2- 4 dS/m, 4 - 8 dS/m, 8 - 16 dS/m, and >16 dS/m, respectively. This shows that the soil of the experimental site was non-saline or sodic. The organic carbon (O.C) varied from 0.5265 to 0.975 % (Table 4.2). Maximum O.C was obtained in the topsoil layer, while minimum value was measured in the lower soil profile. Soils with organic carbon values between 0.5 and 1.5 % are considered to be low in O.C by Tadese (1991). Thus, the soil of the site was found to be less than 3 % indicating the soil health to be poor (Tequam and WSP, 2017).

Analysis of results of soil total nitrogen (TN) varied from 0.04 to 0.08 % across soil sampling depths (Table 4.2). Soil TN availability of < 0.05 % as very low, 0.05 - 0.12 % as low, 0.12 - 0.25 % as moderate and > 0.25 % as high was classified by Tadese (1991). According to this classification, analysis of soil samples indicated a very low level of total N indicating that the nutrient is a limiting factor for optimum crop growth. This is in agreement with similar studies which reported Nitrogen to be the most limiting soil nutrient because of its high volatility and the fact that it can be easily leached (Kebede, 2019). The chemical analysis of the irrigation water indicated a pH value of 6.70 and thus, in a normal range. The electrical conductivity of the irrigation water showed 0.1 dS/m (Table 4.2) and thus considered to be in the salinity class C1 indicating suitability for irrigation and low in salinity hazard (Zaman *et al*., 2018). Also, irrigation water's electrical conductivity (EC) was observed by FAO (1985) when in the range of 0.7 – 3 ds/m was considered slight to moderate to salinity effect.

4.3 Crop Water Requirement of Tomato

The highest net irrigation water application was 564 mm obtained from the irrigation regime of 100 % ET_c and the minimum was 282 mm from the highly stressed regime of 50 % ET_c (Table

4.3). The highest gross irrigation seasonal water requirement calculated by using 95 % field application efficiency, was obtained from 100 % ET_c (593 mm) and the lowest was 297 mm from 50 % ET_c.

Table 4.3: Crop Water Requirement and Deficit Irrigation Regimes of Tomato

Month	K_c	ET_o (mm/day)	100 % ET_c (mm/dec)	75 % ET_c (mm/dec)	50 % ET_c (mm/dec)
Nov	0.9	4.43	39.87	29.90	19.94
Dec	0.9	4.03	36.27	27.20	18.14
Dec	0.9	4.03	36.27	27.20	18.14
Dec	0.94	4.03	37.88	28.41	18.94
Jan	1	4.46	44.60	33.45	22.30
Jan	1.06	4.46	47.28	35.46	23.64
Jan	1.11	4.46	49.51	37.13	24.75
Feb	1.12	5.16	57.79	43.34	28.90
Feb	1.12	5.16	57.79	43.34	28.90
Feb	1.12	5.16	57.79	43.34	28.90
Mar	1.01	5.36	54.14	40.60	27.07
Mar	0.83	5.36	44.49	33.37	22.24
Total			564	423	282

(Field Experiment, 2021)

According to the soil physical and chemical properties, irrigation was very necessary to allow plants to reach optimum growth and mulching played a pivotal role sustaining moisture in the soil. Seasonal crop water requirement of tomato was determined based on the seasonal water application depth from transplanting to harvest and varied based on treatments. The highest net irrigation water application was 564 mm obtained from the control treatment (100 % ET_c) and the minimum was 282 mm from the highly stressed treatment (50 % ET_c). The highest gross irrigation seasonal water requirement that was calculated by using 95 % field application efficiency was obtained from 100 % ET_c as 593 mm and the lowest was 297 mm from 50 % ET_c. The result of tomato seasonal water demands of 561 mm that was obtained from optimal irrigation agrees with Kuşçu *et al*. (2014) and Kizza *et al*. (2016). As expected, the highest seasonal ET_c was recorded in the full irrigation regime (100 % ET_c), clearly owing to favourable soil moisture over the cropping period, whereas the treatment with a prolonged water deficit had the lowest seasonal crop water requirement (50 % ET_c). The estimated seasonal ET_c values for tomato (512.2 mm for the full irrigation treatment in 2010 and 502.5 mm for the same treatment in 2011) are consistent with the results obtained by Doorenbos and Pruitt (1992). These authors stated that the water requirements of tomatoes varied from 400 to 600 mm Birhanu and Tilahun (2010); Kumar (2012); Berihun (2015); Biswas *et al.* (2015); Kassahun (2017) and Kebede (2019) depending on the climate and the total length of the growing period. Many different authors provide a wide range of values for tomato water requirements. Under open field conditions, the water demand of tomatoes was shown to vary between 215 and 841 mm in a comparable experiment conducted in Ethiopia (Kassahun, 2017).

4.4 Weather Paramaters of the Crop Growing Season

During the period of the crop growth that is from December 2020 to March 2021 the mean monthly maximum temperature ranged from 30 to 33.7 ºC for the months of December 2020 to March 2021 respectively and also the mean monthly minimum temperature ranged between 27.6 and 29.4 ºC (Table 4.4).

Table 4.4: Average Weekly Temperature (ºC) and Relative Humidity (%) Weather Conditions of the Experimental Site

	Week 1		Week 2		Week 3		Week 4	
Month	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
Dec	0.0	0.0	0.0	0.0	0.0	0.0	29.3	30.0
Jan	29.5	31.4	29.5	30.8	28.6	29.7	27.6	30.6
Feb	29.7	31.8	31.2	32.2	28.5	32.5	29.9	31.8
Mar	32.3	31.8	30.0	33.0	29.4	33.0	30.4	33.7
	RH min	RH max	RH min	RH max	RH min	RH max	RH min	RH max
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.24	0.27
Jan	0.23	0.51	0.25	0.54	0.2	0.3	0.18	0.24
Feb	0.18	0.36	0.17	0.47	0.1	0.5	0.14	0.34
Mar	0.17	0.5	0.51	0.53	0.5	0.6	0.32	0.66

Source: Decagon Weather Station model Em-50 Datalogger

Tmin = minimum temperature, Tmax = maximum temperature, RH min = relative humidity, RH max = maximum relative humidity.

The mean relative humidity during the crop growth stages was ranging from 14 – 66 %. The mean monthly wind speed was between 1.74 to 2.43 m/s for the months of December to January, respectively. The air temperature ranged from 27.6 to 33.7 ºC during the tomato crop's growth phase, relative humidity varied from 14 to 66 % whilst, wind speed was between 1.74 and 2.43 m/s (Table 4.4). The stated values are inline with the report by Kumar (2012) who stated that the crop requires a mean maximum temperature of 29 to 32.8 ºC, with relative humidity of 24 to 91 %. The total amount of precipitation during the whole period of the crop growth was only 26.8 mm. It was therefore evident that the soil moisture was in short supply for the optimum growth of the tomato plant admiting the need for irrigation (Kumar, 2012)**.** Several findings have revealed that the optimum productivity of any crop depends on weather and climatic conditions that are ideal (Ozores-hampton *et al*., 2012; Puozaa, 2015; Arthanari and Dhanapalan, 2019; Vijayakumar *et al*., 2021)**.** To be able to modify agro-techniques**,** knowledge on weather conditions of a particular region is necessary.

4.5 Effect of Irrigation Regimes and Mulch Levels on Tomato Varietal Flower Count and Abortion

The interaction of mulch and variety on flower count at 7 WATP was significantly (*p <0.01)* different. The Pectomech variety recorded the highest flower count of 4 at mulching rate of 6 tha[1] which was closely followed by mulching rate of 3 tha^{-1} with flower count of 3 and mulching rate of 0 tha-1 having the lowest count of 2. Mongal F1 registered the lowest flower count of 2 at 3 tha[1] with 0 tha^{-1} having the highest count of flower of 2 (Table 4.5). The main effect of irrigation significantly (*p <0.01*) influenced the number of flowers produced with irrigation regime at 100 % ET_c recording the highest number of flowers (3) compared to 50 % (2) (Figure 4.3).

The main effects of mulch, interaction of irrigation by variety, interaction of irrigation by mulch were not significant at (*p>0.005*).

Table 4.5: Interaction of Variety by Mulch Levels on Flower Count at 7 WATP

Variety	Mulch Level (tha^{-1})		
	0	3	6
Mongal F1	2.320	2.054	2.061
Pectomech	2.947	3.182	3.396
LSD (5%)		0.2803	
p-value		0.005	

(Field Experiment, 2021)

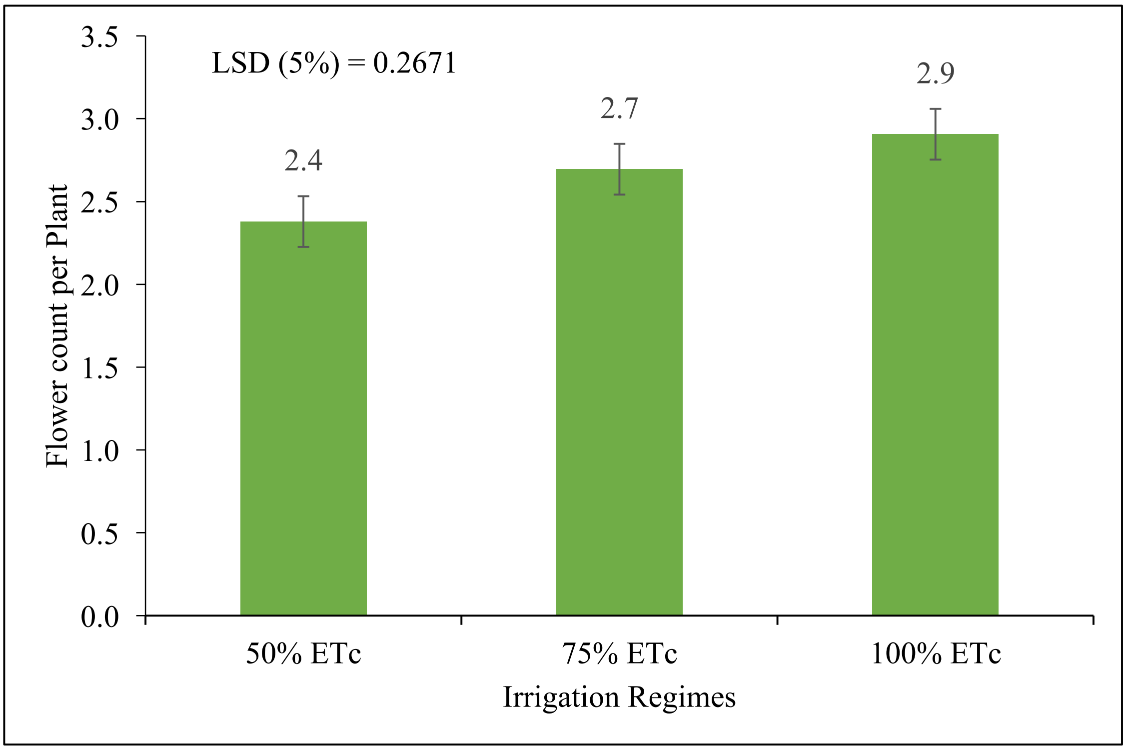

Figure 4.3: Effect of Irrigation Regimes on Flower Count at 7 WATP. Bar = SEM *(Field Experiment, 2021)*

At 8 WATP, interaction effects of irrigation and mulch, variety and mulch, variety and irrigation on flower number was not significant (*p>0.05*). However, main effects of variety and mulch on flower number were significant at *p< 0.001*. The variety Pectomech had the highest number (2) and Mongal F1 had the lowest (1) (Figure 4.4). Mulch Levels at 0 tha^{-1} produced more flowers (2) in comparison to levels 3 tha^{-1} and 6 tha^{-1} that recorded statistically the same number of flowers (1) (Figure 4.5).

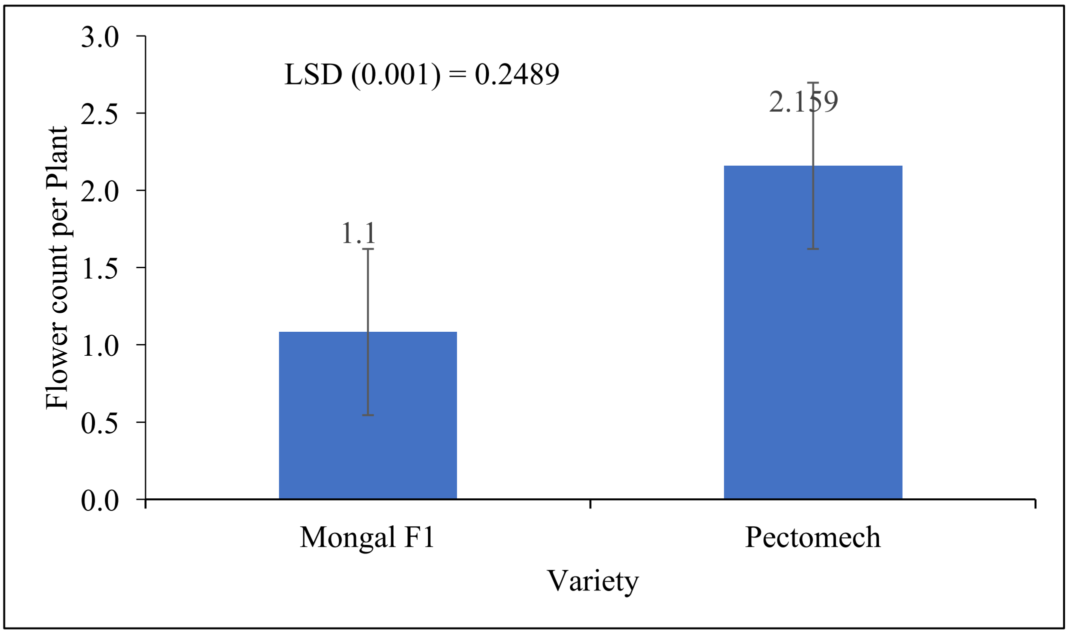

Figure 4.4: Effect of Variety on Flower Count at 8 WATP. Bar = SEM

(Field Experiment, 2021)

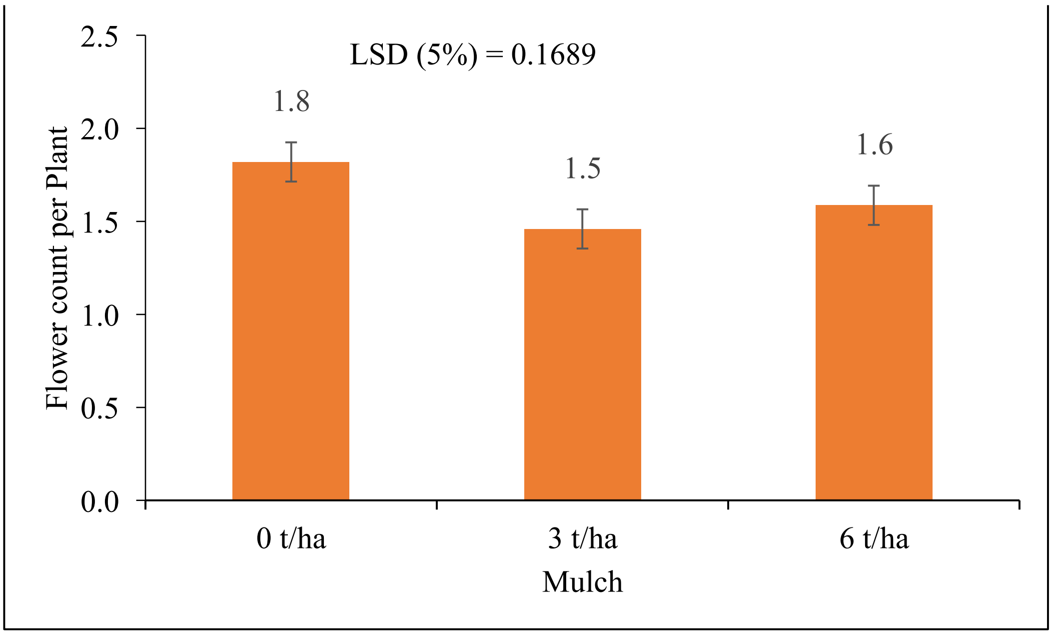

Figure 4.5: Effect of Mulching Levels on Flower Count at 8 WATP. Bar = SEM
(Field Experiment, 2021)

Tomato flower count was not significantly (*p> 0.05*) affected by the interaction between irrigation regimes and mulch levels at 9 WATP. However, the interaction between variety and mulch levels significantly (*p< 0.001*) influenced flower count and also the interaction between variety and irrigation significantly (*p< 0.05*) influenced flower number. The number of flowers was also significantly affected by the main effects of mulch (*p< 0.001*) and irrigation (*p< 0.05*). Pectomech at 0 tha^{-1} and 6 tha^{-1} mulching level produced more flowers (2) and least flower count was produced by the Mongal F1 variety at 0 tha^{-1} (1) as presented in Figure 4.6. The Pectomech variety at 50 % ET_c irrigation regime recorded more flowers (2), followed by Pectomech at 75 % ET_c irrigation regime (2) and least flower count was recorded by the Mongal F1 variety at 75 % irrigation regime (1) (Figure 4.7).

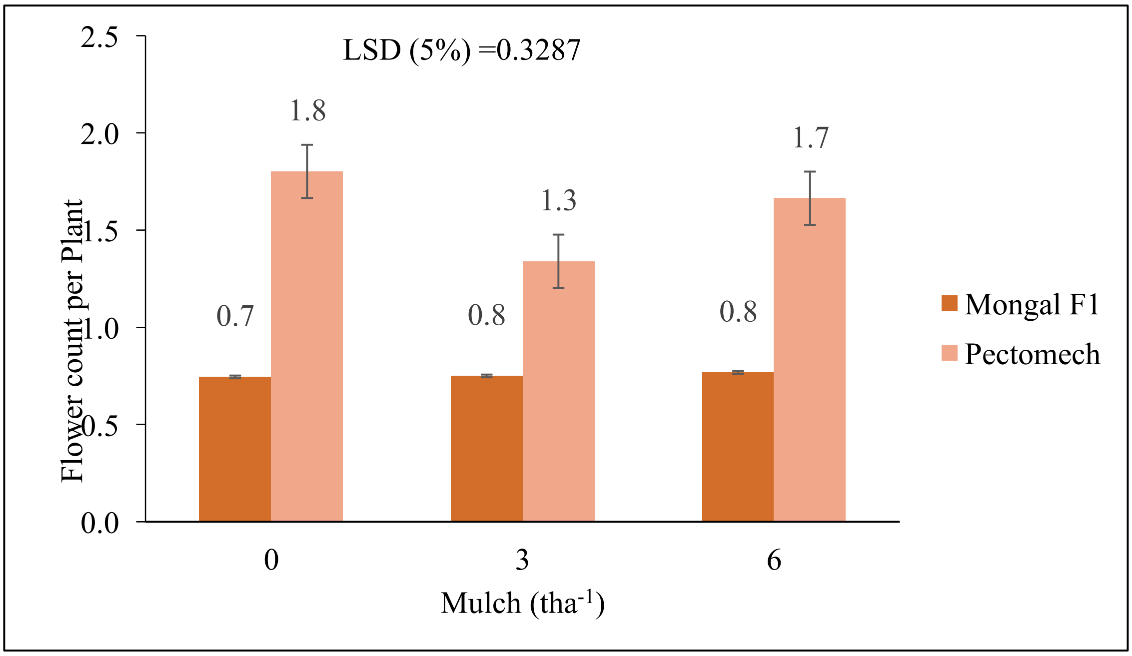

Figure 4.6: Effect of Variety and Mulching Levels on Flower Count at 9 WATP. Bar = SEM
(Field Experiment, 2021)

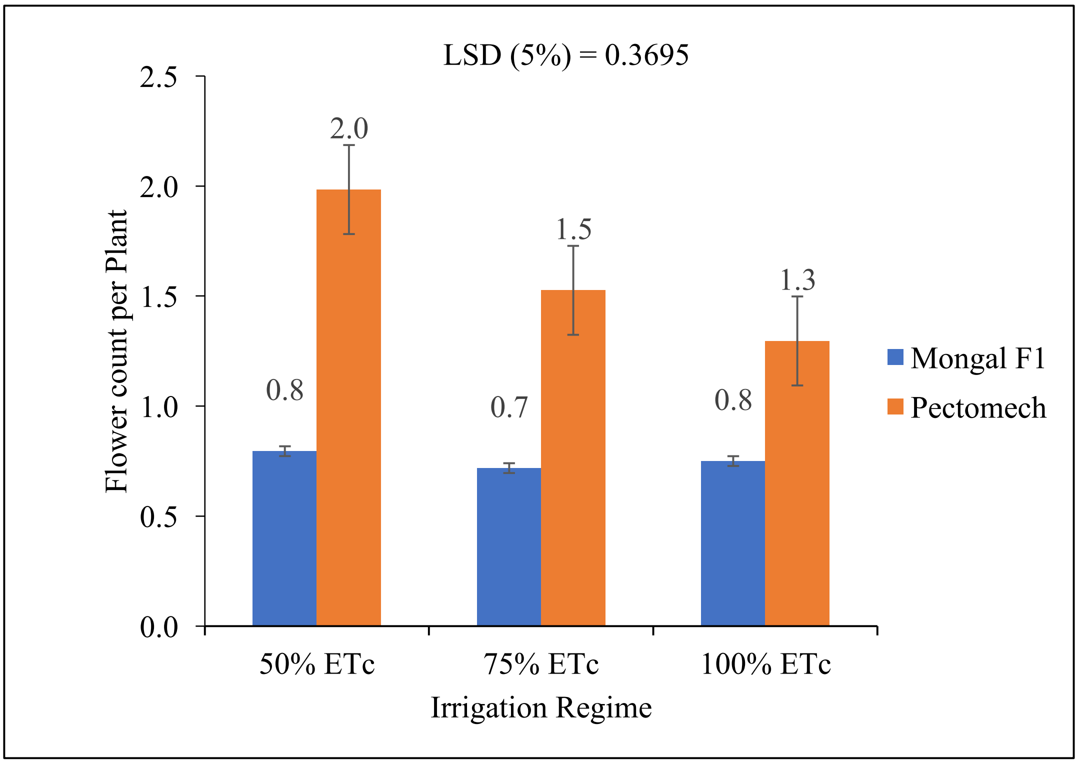

Figure 4.7: Interaction Effect of Variety and Irrigation Regimes on Flower Count at 9 WATP. Bar = SEM
(Field Experiment, 2021)

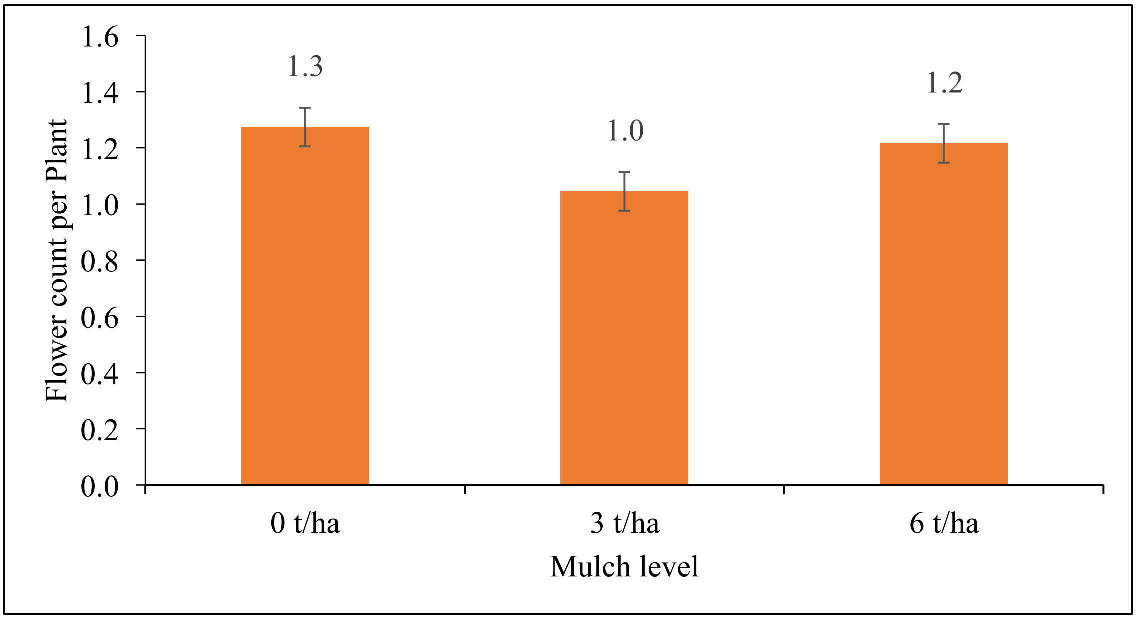

Figure 4.8: Effect of Mulch Levels on Flower Count at 9 WATP. Bar = SEM

(Field Experiment, 2021)

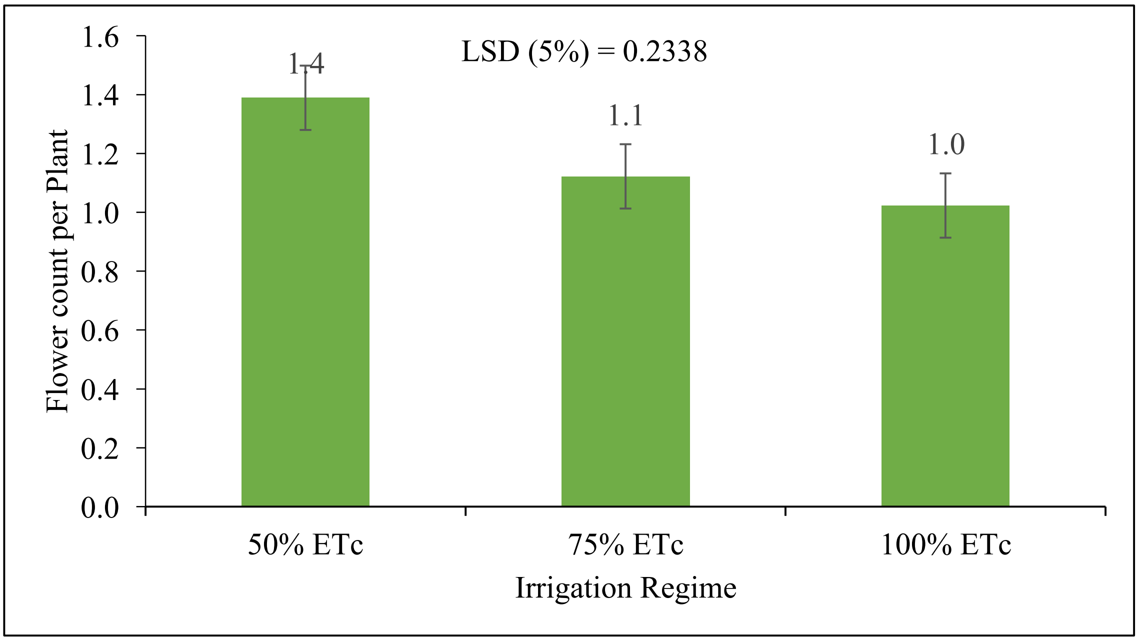

Figure 4.9: Effect of Irrigation Regimes on Flower Count at 9 WATP. Bar = SEM

(Field Experiment, 2021)

The interaction of variety by mulch on flower count at 7 WATP was significantly different. The results clearly indicated the potential of mulch to improving reproductive growth. This was in line with a study carried out on freesia plants by Younis *et al.* (2012), who reported that straw mulch produced highest number of flowers per spike as compared to no mulch, the experiment also concluded that straw mulch encouraged flower production .

Irrigation regime as the main effect influenced the number of flowers with irrigation regime at 100 % ET_c recording the highest number of flowers as compared to 50 % ETc. The results are in consensus with findings of Silva *et al*. (2021) who reported that irrigation regimes that ranged from 100 to 115 % ET_c recorded more flowers as compared to regimes of 50 % ET_c. Also the results of the current study are similar to that of Ganeva *et al*. (2019) who reported that water stress at 50 % ET_c negatively affected flower number by 25 % as compared to 100 % ETc which was the control. Also, Hott *et al*. (2018) indicated that increase in the number of flowers was promoted by higher moisture availability. It was observed that the total number of flowers decreased with an increase in deficit irrigation (50 % ET_c). Flowering has been noted to be the most susceptible stage and a reduction in water availability could lead to flower abortion (Jaimez *et al*., 2000). The increased number of flowers could be attributed to the plants receiving an adequate supply of water.

At 8 WATP, there was a significant difference in flower number due to mulching rates, with the highest number of flowers being recorded in experimental plots that received 0 tha^{-1} of mulch compared to plots that received 3 and 6 tha^{-1}. This can possibly be as a result of the effects of the unfavourable conditions faced by the un-mulched plots and the plants wanting to end their life cycle as reported by Sivakumar and Srividhya (2016) and that led to the plots flowering more. The results are in disagreement with conclusions by Zakari *et al*. (2020) who reported mulched plots to have recorded more flowers as compared to un-mulched plots. The results were also not in unison with Kumar (2012) who recorded highest number of flowers per plant (51) with mulched treatments as compared to 43 from plots with no mulch application. The results however do not agree with Birhanu and Tilahun (2010) who reported a decrease in flower number from tomato plants that were exposed to moisture stress.

At 9 WATP, there was a highly significant difference in flower number due to the interaction effect of the Pectomech variety and mulch level of 0 tha^{-1}. This increased flower count under drought conditions might be due to rapid phenological development to complete the life cycle under an unfavourable environmental condition (Sivakumar and Srividhya, 2016). The findings of this study were not in unison with those of Younis *et al.* (2012) who concluded that straw mulch enhanced flower production.

The possible reason for increased flower number, under higher rates of irrigation and straw mulching levels, was that optimal irrigation and higher levels of straw mulching helped to create a more conducive soil micro-environment for reproductive growth of tomato plant development over an extended time (Tegen *et al.*, 2016).

Flower Abortion

The main effects of mulch, interaction of irrigation and variety, interaction of irrigation and mulch on flower abortion were all significant ($p<0.001$) at 7 and 8 WATP. On the 9 WATP only the main effects of irrigation and mulch were statistically significant ($p<0.001$) and variety was significant at ($p<0.01$).

The interaction of variety, irrigation regimes and mulch levels at 7 and 8 WATP was significantly different ($p< 0.01$) and also significantly ($p< 0.05$) different at 9 WATP. Pectomech variety treated with 50 % ET_c and 0 tha^{-1} recorded maximum flower abortion count of 39 at 7 WATP. At 8 WATP and 9 WATP, Pectomech with 50 % ET_c and 0 tha^{-1} recorded flower count of 35 and 32 respectively. The least tomato flower abortion count was 11, 6, and 5 which were observed with Mongal F1 at 100 % ET_c at 6 tha^{-1} at 7, 8 and 9 WATP respectively (Table 4.6).

Table 4.6: Interaction Effect of Tomato Variety, Irrigation Regimes and Mulch Levels on Flower Abortion at 7, 8 and 9 WATP

Variety	Irrigation Regimes (% ET_c)	7 WATP			8 WATP			9 WATP		
		Mulch Levels (tha^{-1})								
		0	3	6	0	3	6	0	3	6
Mongal F1	50	25.5	22.3	27.0	21.8	18.3	23.0	18.8	15.8	19.5
	75	27.3	24.5	21.0	23.5	20.8	17.0	20.5	17.8	14.0
	100	19.0	12.0	10.8	14.3	8.3	6.0	11.3	5.8	4.8
Pectomech	50	38.5	31.5	30.8	35.3	27.8	27.0	32.3	24.8	24.0
	75	29.3	25.8	25.3	26.0	21.8	21.3	23.0	19.0	18.3
	100	19.5	16.0	13.5	15.8	12.3	9.8	12.8	9.0	6.8
LSD (5%)		5.172			5.109			5.163		
p-value		0.006			0.005			0.041		

(Field Experiment, 2021)

The interaction effect of variety, irrigation and mulch were all significant. The Pectomech tomato variety aborted more flowers than the Mongal F1 tomato variety and this could be as a result of the adaptability of the variety to the environment. The findings suggest that the difference might be due to the adaptability of the variety in the local environment and tolerance to high temperatures (Ochar *et al*., 2019). The results are in harmony with the results of Mends-Cole *et al*. (2019) who reported that environmental conditions and genotype significantly affected flower abortion. The results also are in consensus with Melomey *et al.* (2019), who reported that some tomato varieties currently cultivated in Ghana have poor performances such as susceptibility to blossom end rot, tomato yellow leaf curl virus, and intolerance to heat.

The highly stressed irrigation regime (50 % ET_c) significantly aborted more flowers than 100 % ET_c and this can be attributed to stress levels and with the results agreeing with Ragab *et al*. (2019) who reported that irrigation regime of 55 % ET_c significantly reduced flower number and increased abortion of flowers compared to the irrigation regime of 100 % ET_c. The results also corroborate that of Silva *et al*. (2021) who reported irrigation regimes of 100 to 115 % ET_c which recorded lower abortion rates of tomato flowers. The flower abortion rates indicated that increased deficit water increased abortion which is in agreement with studies by Nangare *et al.* (2016); Sivakumar and Srividhya (2016) and Giuliani *et al.* (2018) who reported increased deficit irrigation increased the flower abortion rate. Also, an increased rate of flower abortion and decreased crop yield was observed with the irrigation regime that was most stressed. The above result findings were found to be in unison with those of Ganeva *et al*. (2019) who concluded that moisture stress significantly reduced flower and fruit count, also increased flower abortion.

According to studies carried out by Ganeva *et al.* (2018;2019), deficit irrigation coupled with high temperatures had adverse influence on flowering of tomato. Even though they may produce flowers, all of them may not translate to fruits due to abortion because the flowers wither and dry up, after which they fall off the plant preventing the flower from fruiting. Environmental causes like high temperature, heat and humidity can lead to reduction in flower number, increase in fruit drop, blossom end rot and also fruit abortion (Steduto *et al.*, 2012; Puozaa, 2015). Extremely high temperatures essentially cause tomato plants to give up on producing fruit, and focus instead on survival. High humidity impedes pollination, which can cause the flowers to wither and drop off the plants (Atherton and Harris, 1986; Vijayakumar *et al*., 2021). Irrigation is required to be sufficient to enable canopy growth and yet not excessive to avoid flower and fruit droppings (Steduto *et al*., 2012).

The temperature during the study period ranged from 27.6 - 33.7 ℃ and it was in alignment with work done which indicated that high daytime temperatures of above 29 ℃ and low night temperatures below 13 ℃ can cause flower drop in tomato plants. The plants do best with temperature ranges from 21 ℃ to 29 ℃, it can tolerate more extreme temperatures for short periods but temperatures out of the ideal range will lead to flower abortion and allow the plant to focus on survival (Arthanari and Dhanapalan, 2019)**.** Relative humidity plays an important role in pollen transfer, the ideal range is between 40 % and 70 %. If the relative humidity is lower or higher than the ideal range, it interferes with the release of pollen because the pollen is dry and unable to stick to the stigma (Ozores-hampton *et al*., 2012; Arthanari and Dhanapalan, 2019). The **r**elative humidity during the study ranged from 14 to 66 %, with the lower limit being way below the ideal of 40 %, this could be the reason why even though Pectomech tomato variety flowered more, it had a higher flower abortion rate compared to Mongal F1 tomato variety and also considering that Mongal F1 was more adaptable to the adverse weather conditions.

4.6 Effect of Tomato Variety, Irrigation Regimes, and Mulch Levels on Tomato Fruiting.

At 7 WATP, tomato fruit count was not significantly affected at $p > 0.05$ by the main effect of variety and the interaction between variety and mulch levels, variety and irrigation regimes. However, the interaction between irrigation and mulch significantly influenced the fruit count at $p < 0.05$. The number of fruits was also significantly affected by the main effects of mulch ($p < 0.001$) and that of irrigation ($p < 0.05$). The highest number of fruits (11) recorded by plants treated with 100 % ET_c irrigation and 6 tha^{-1} of mulch and the lowest of 5 fruits at 50 % ET_c irrigation regime and mulch level of 0 tha^{-1}. The highest number of 9 fruits was recorded by plants treated with 3 tha^{-1} and 6 tha^{-1} whilst the 0 tha^{-1} mulch level recorded the least of 7 fruits.

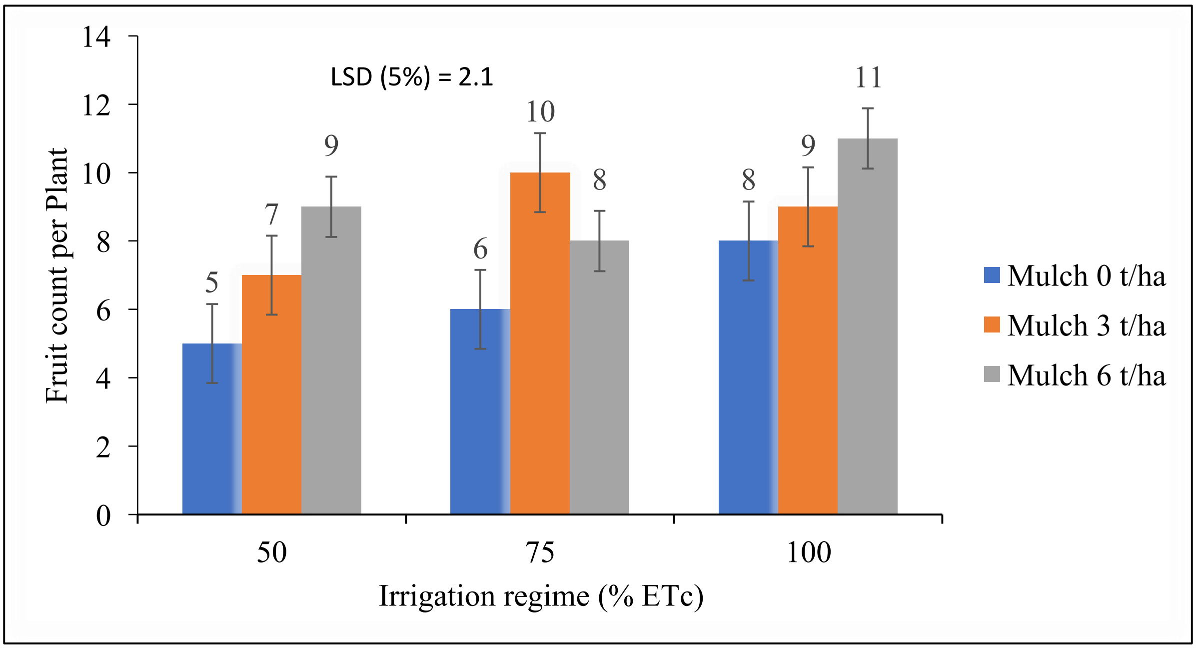

Figure 4.10: Interaction Effect of Irrigation Regime and Mulch Levels on Fruit Count at 7 WATP. Bar = SEM

(Field Experiment, 2021)

At 8 WATP, tomato fruit count was not significantly ($p>0.05$) influenced by the interaction between irrigation and mulch, variety and mulch and variety and irrigation. Tomato Fruit count was however influenced by the main effects of mulch significantly ($p< 0.001$), irrigation ($p<0.05$) and variety ($p<0.01$). Mulch levels at 3 and 6 tha^{-1} both recorded 9 number of fruits whilst 0 tha^{-1} mulch level recorded 7 fruits. Irrigation at 100 % and 75 % ET_c recorded more and similar number of fruits (10) as compared to 50 % ET_c which recorded 8 tomato fruits (Table 4.7). The Mangal F1 variety recorded 13 tomato fruits whilst Pectomech recorded a number of 6 tomato fruits as seen in Figure 4.11.

Table 4.7: Effect of Irrigation Regimes on Fruit Count at 8WATP

Irrigation (% ET_c)	Number of fruits
50	8
75	10
100	10
LSD (5%)	1.6
p-value	0.021

(Field Experiment, 2021)

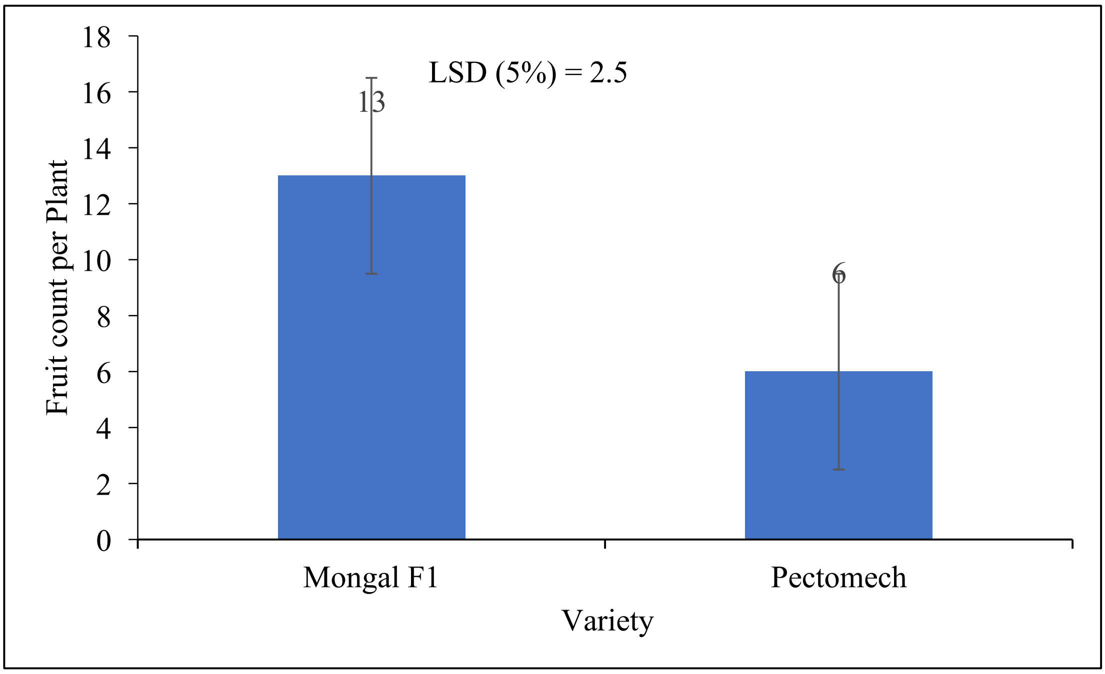

Figure 4.11: Effect of Two Tomato Varieties on Fruit Count at 8 WATP. Bar = SEM

(Field Experiment, 2021)

Table 4.8: Effect of Mulch Levels on Tomato Fruit Count at 8 WATP

Mulch Level (tha^{-1})	Flower Count
0	8
3	10
6	10
LSD (5%)	0.9

p-value	<0.001

(Field Experiment, 2021)

At 7 WATP, irrigation at 100 % ET_c recorded the highest number of fruits with the least from the most stressed regime of 50 % ET_c. This conclusion corresponded to the findings of a study conducted by Sibomana *et al.* (2013) who reported the highest number of fruits from 100 % ET_c (46) in the first trial and 48 fruits in the second trial with the least recorded by the most stressed regime (40 % ET_c) recording 35 fruits and 31 in the first and second trial respectively.

However, the interaction between irrigation and mulching significantly ($p< 0.05$) influenced the fruit count. The highest number of fruits was recorded for the interaction between 100 % ET_c irrigation regime and 6 tha^{-1} of mulch and the lowest at 50 % ET_c irrigation regime at 0 tha^{-1} of mulch. This results were in agreement with results by Al-Suhaibani (2009) who recorded highest fruit count from treatments that were mulched and received high amounts of moisture compared to treatments that were under deficit conditions. The results also agreed with findings by Ayankojo and Morgan (2020) who reported reduced fruit number caused by increased temperatures, no mulch plots were exposed to higher temperatures compared to the mulched plots.

Similarly at 8 WATP irrigation at 100 and 75 % ET_c recorded maximum fruit count with least fruit count recorded at 50 % ET_c, this result was in agreement with research findings by Kumar (2012) who reported that drip irrigation scheduled at 1.0 E pan obtained significantly higher number of fruits per plant (50) compared to 0.6 E pan (46). The outcomes were also consistent with the findings by Ganeva *et al.* (2018;2019), who reported that increased deficit irrigation negatively affects fruit number by 58 % as compared to the control plants.

At 7 and 8 WATP, mulching had a positive effect on fruit number with 3 and 6 tha^{-1} significantly recorded higher fruit number compared to no mulch. This result was in unison with Kumar (2012) who recorded highest number of fruits per plant (51) with mulched treatments compared to 43 from plots with no mulch application. The results are in consensus with Birhanu and Tilahun (2010) who reported a decrease in fruit number from tomato plants that were exposed to moisture stress. The Mongal F1 tomato variety recorded more fruits than the Pectomech tomato variety and with similar results as Ochar *et al*. (2019) who recorded Mongal F1 to be a high performing genotype suitable for both greenhouse and open field trials.

Deficit watering was found to play a significant role in the fruit count of tomato plants, as evidenced by the findings. The highest fruit number might be due to optimum water and mulch application.

4.7 Effect of Variety, Irrigation Regimes and Mulch Levels on Tomato Fruit Yield

Total fruit yield was not significantly ($p>0.05$) influenced by the interaction between irrigation and mulch, and variety and mulch.

The main effect of variety and irrigation regimes caused a substantial variation in total fruit yield, according to the analysis of variance. at $p< 0.01$ and mulch levels at $p< 0.001$. Accordingly, with the main effect of variety, Mongal F1 tomato variety recorded the maximum total fruit yield of 10.65 tha^{-1} with Pectomech registering the minimum of 2.67 tha^{-1}. The irrigation regime of 100 % ET_c recorded maximum total fruit yield of 8.08 tha^{-1} followed by 6.44 tha^{-1} for 75 % ET_c and a minimum of 5.46 tha^{-1} for 50 % ET_c. The plants treated with 6 tha^{-1} of mulch recorded a maximum total fruit yield of 7.43 tha^{-1} and a minimum of 5.34 tha^{-1} from the mulch level of 0 tha^{-1}.

The interaction between variety and irrigation significantly ($p<0.05$) affected total tomato fruit yield with a maximum fruit yield of 13.46 tha^{-1} recorded for Mongal F1 tomato variety with 100 % ET_c and a minimum of 2.04 tha^{-1} recorded from the interaction of the Pectomech variety with 50 % ET_c.

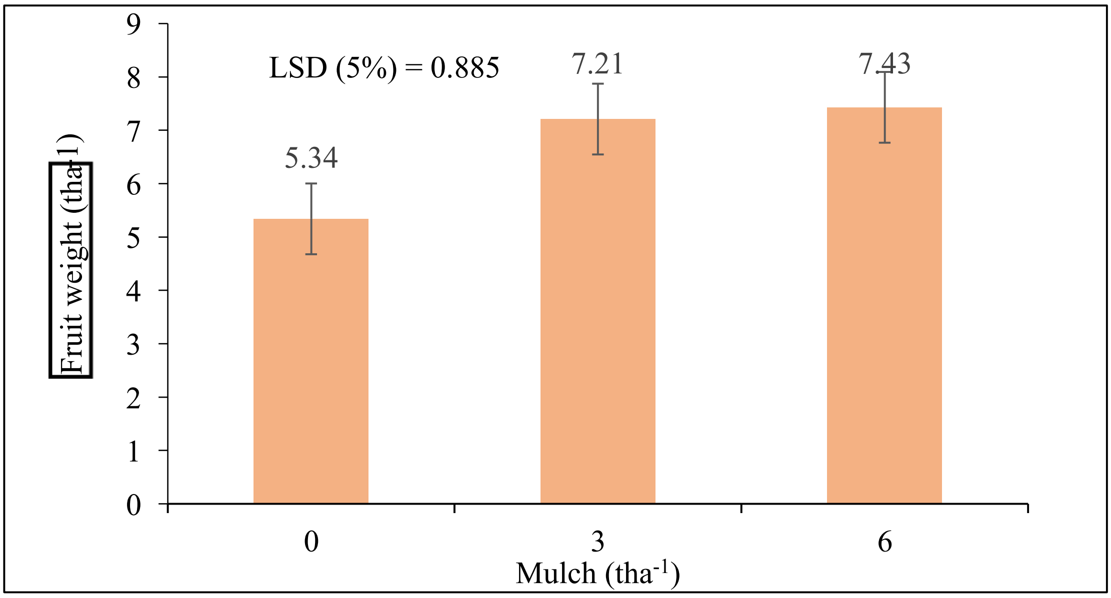

Figure 4.12: Effect of Mulching Levels on Total Fruit Weight. Bar = SEM

(Field Experiment, 2021)

Table 4.9: Effect of Tomato Variety and Irrigation Regime on Total Fruit Weight

Irrigation (% ET_c)	Variety	
	Mongal F1	Pectomech
50	8.87	2.04
75	9.63	3.26
100	13.46	2.7
LSD (5%)	3.818	
p-value	0.015	

(Field Experiment, 2021)

The analysis of variance indicated that there was a significant difference in the total fruit yield due to the main effects of variety, irrigation regimes and mulching rates. Accordingly, the maximum total fruit yield was recorded from the main plot that was assigned with the Mongal F1 tomato variety with the minimum from the Pectomech tomato variety. The research results suggested that the difference might be due to the adaptability of the Mongal F1 tomato variety to the local environment and tolerance to the high temperature of the study area. Again, the Pectomech tomato variety was noted to be susceptible to blossom end rots thereby translating to lesser fruit yield compared to the Mongal F1 tomato variety. Ochar *et al.* (2019) observed that the tomato variety Mongal F1 is better acclimatized to cultivation than the Pectomech variety , and also Melomey *et al.* (2019) reported the Pectomech tomato variety to be intolerant to heat, susceptible to blossom end rots and tomato yellow leave curl disease. This results also corroborate findings that indicated particular cultivars being resistant to immediate adverse environmental conditions like high temperature (Lekshmi and Celine, 2015). The results also agree with findings that revealed that for some tomato varieties, variations in soil moisture during flowering, fruiting can lead to fruit cracking, blossom end rot and varied shape and size (Steduto *et al*., 2012). Also temperatures greater than 27 °C combined with high relative humidity can negatively influence pollen germination which can translate to reduced yield (Steduto *et al*., 2012)**.**

Concerning the main effect of irrigation regimes, maximum total fruit yield was obtained from plots that received 100 % ET_c and a minimum from the regime of 50 % ET_c. The increase in yield could be due to the soil moisture being at the required level. The results are in accordance with investigations by various authors who all reported that increase in deficit water reduced fruit mass which was directly related to fruit yield (Nangare *et al*., 2016; Sivakumar and Srividhya, 2016; Giuliani *et al*., 2018; Ganeva *et al*., 2019). The results were also noted to be similar to Berihun (2011), Patanè *et al*. (2011), Kamal and Shashi (2012), Kumar (2012), Biswas *et al*. (2015) and Hott *et al*. (2018) who reported higher yields from favourable conditions in terms of moisture availability to the plants.

These results are in line with studies done by Kebede (2019) which recorded the highest bulb yield of onion from treatment plots that received 100 % ET_c compared to yield from 60 % ET_c Kumar (2012) that indicated the highest fruit yield of 36.78 tha^{-1} from drip irrigation at 1.0 Epan and lowest value of 27.25 tha^{-1} from drip irrigation at 0.6 Epan. The outcome of this study were also in consensus with results by Sibomana *et al*. (2013) who recorded the lowest yield in the most stressed plants (25 tha^{-1}) compared to the control (69.5 tha^{-1}).

The effect of mulching levels recorded a maximum total of fruit yield from the rate of 6 tha^{-1} compared to 0 tha^{-1} and noting that the results were in line with Kebede (2019), who reported the highest yield with the rate of 6 tha^{-1} of straw mulch. Kebede (2019) and Kumar (2012) also recorded a minimum yield of 21.99 tha^{-1} of onion and 27.25 tha^{-1} of tomato respectively with treatments of 60 % ET_c and no mulch owing to the fact that mulching positively affected crop yield. The results of the study were also similar to Tegen *et al.* (2016) who recorded 60.9 tha^{-1} as the highest marketable yield from treatments with grass mulch and the lowest of 43.76 tha^{-1} with no mulch treatment in a polyhouse. The increase in overall fruit yield achieved by using rice straw mulch was ascribed to its beneficial effect on soil moisture and temperature, which created a favourable environment for tomato plant growth and development. Rice straw mulch was therefore more suitable for improving the conditions of the soil compared to un-mulched plots. This agrees with studies conducted by Ayankojo and Morgan (2020) who reported that increased temperatures resulted in lower yield.

4.8 Effects of Variety, Irrigation and Mulch on Crop Water Productivity

Water use efficiency was not significantly (*$p>0.05$*) influenced by the main effect of irrigation and also interaction effects of all treatments. The Analysis of variance indicated that there was a significant difference in the water use efficiency due to variety main effect at $p< 0.05$ and mulch levels at $p< 0.001$. Accordingly, Mongal F1 had the maximum water use efficiency of 26.03 kg/ha/mm whilst the Pectomech tomato variety registered the least with 6.58 kg/ha/mm. The plants treated with 6 tha^{-1} of mulch recorded maximum 18.52 kg/ha/mm followed by 17.50 kg/ha/mm for plants treated with 3 tha^{-1} of mulch and a minimum of 12.88 kg/ha/mm from 0 tha^{-1}.

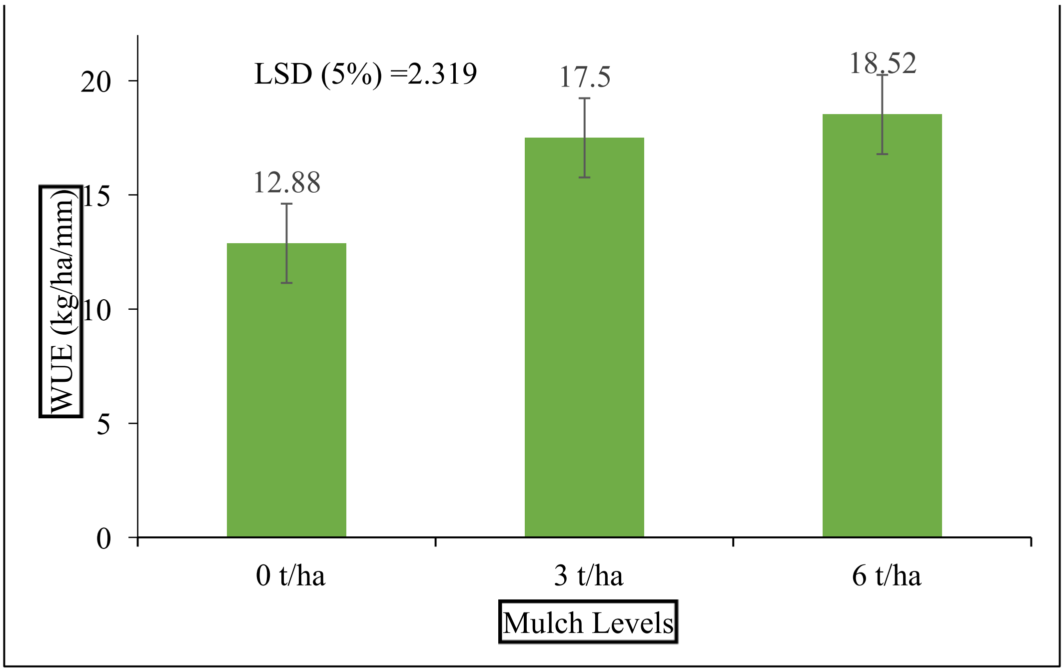

Figure 4.13: Effect of Mulching Levels on Water Use Efficiency (WUE). Bar = SEM

(Field Experiment, 2021)

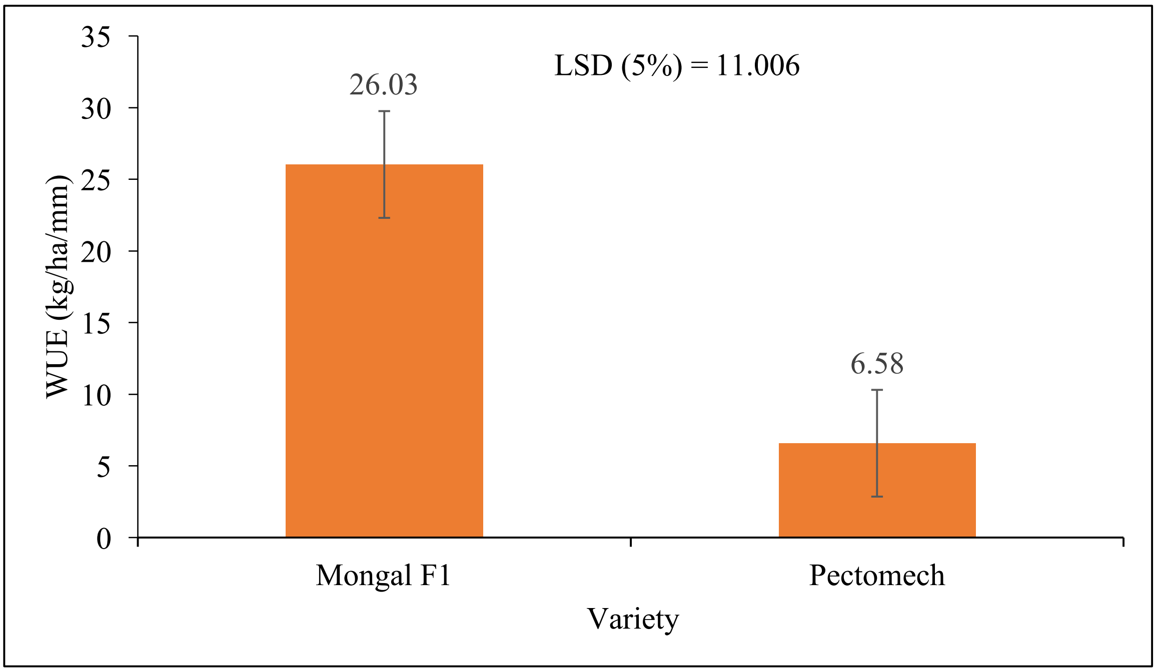

Figure 4.14: Effect of Tomato Variety on Water Use Efficiency. Bar = SEM

(Field Experiment, 2021)

The analysis of the results indicated that irrigation did not significantly affect water use efficiency and this was in harmony with the results obtained by Nurga *et al.* (2020) who observed that water productivity was not significantly affected by irrigation levels. The findings also contradict research that found that irrigation water use efficiency (IWUE) declined significantly as irrigation water was increased (Kirda *et al.*, 2002; Molden and Oweis, 2007; Patanè *et al*., 2011; Nagaz *et al.*, 2012; Tadesse *et al.*, 2017; Mubarak and Hamdan, 2018; Ragab *et al.*, 2019).

Accordingly, with the main effect of variety, Mongal F1 recorded a higher water use efficiency as compared to Pectomech. This is consistent with the findings of Ochar *et al.* (2019) who concluded that the tomato variety Mongal F1 performed better than Pectomech tomato variety. Also Melomey *et al*. (2019) concluded that Pectomech tomato variety was not tolerant to heat. Mulching significantly affected the water use efficiency and this was because mulch has the potential to conserve moisture. This result agreed with other findings that have revealed that increasing moisture decreased irrigation water use efficiency (Ramalan *et al*., 2010; Kuşçu *et al*., 2014; Tadesse *et al*., 2017; Mubarak and Hamdan, 2018; Ragab *et al*., 2019). This result also strongly aligned with that of Kassahun (2017) whose findings demonstrated that in the absence of mulching, deficit irrigation alone was ineffective in yield production and improving water use efficiency. The results were also in agreement with Giuliani *et al*. (2018), who reported that tomato genotype coupled with their water stress tolerance level affected water use efficiency.

4.9 Correlation Analysis

Flower count at 7 WATP correlated highly and positively with flower count at 8 WATP. Flower count at 8 WATP correlated highly positively with flower count at 9 WATP, highly and negatively with fruit count at 8 WATP and total fruit yield. Flowering at 9 WATP was correlated highly and negatively to fruit count at 8 WATP. Fruit count at 8 WATP correlated highly and positively with total fruit yield. The coefficients of correlation were; r = 0.73, 0.82, 0.78, 0.77, 0.80 and 0.86 respectively.

Table 4.10: Pearson's Correlation Coefficient (r) Between Tomato Flowering, Fruiting and Yield

	Fl 7	Fl 8	Fl 9	Fr 7	Fr 8	TFY
Fl 7	1					
Fl 8	0.729593**	1				
Fl 9	0.511674	0.815876**	1			
Fr 7	-0.19622	-0.35661	-0.25183	1		

Fr 8	-0.52058	-0.78183**	-0.77092**	0.397558	1	
TFY	-0.55623	-0.79746**	-0.69908	0.376761	0.85795**	1

Fl **7** = flower count at 7 WATP, Fl 8 = flower count at 8 WATP, Fl 9 = flower count at 9 WATP, Fr 7 = fruit count at 7 WATP, Fr 8 = fruit count at 8 WATP, TFY = total fruit yield, ** = highly correlated

(Field Experiment, 2021)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Northern Region of Ghana is a semi-arid region with limited water resources and increasing water demand, as well as high evapotranspiration losses, which limit crop production and water productivity. Improving water productivity (WP) represents a critical issue for agricultural water management and as a result, sustainable crop production. An adaption of economically sound and scientifically proved procedures is a viable instrument for improving water productivity. Water scarcity and its repercussions may make deficit irrigation (DI) with mulching one of the most desired management strategies. As a result, the current study was designed to look into the impacts of tomato variety, deficit watering, and rice straw mulch levels on tomato flowering, fruiting, and yield. The findings from this study revealed that;

a) Stress conditions (Pectomech in combination with 50% ETc, Pectomech combined with no mulch) produced the highest number of flowers.

b) Irrigation at 100% ETc by 6 t/ha mulch produced highest fruit number which was similar to 75% ETc at 3 t/ha. Mongal F1 recorded highest fruit count compared to Pectomech.

c) Mongal F1 irrigated at 100% ETc obtained the maximum fruit yield (14 t/ha) which was noted to bridge the farmer's average yield by 86%.

The findings from this study revealed that water stress was directly related to reproductive development of tomato plant. Stress conditions positively influenced the flower number, variety, irrigation and mulch positively affected fruit number and fruit yield of tomato. The decrease in yield was caused by a decrease in the number of fruits per plant and the mean fruit weights.

Pectomech was established to be the variety with the lower fruit yield as compared to Mongal F1. In this experiment, mulching played a significant role in retaining moisture and variation in mulch levels indicated a difference in fruit count and yield. Deficit irrigation and straw mulch levels resulted in significant effects on flowering, abortion, yield, and crop water productivities of the tomato crop.

5.2 Recommendations

Based on the above findings, the following recommendations could be made for further consideration and improvement of tomato production in the study area.

1. Pectomech with no mulch and Pectomech at 50% ETc could be adopted at flowering stage to enable maximum flower production.

2. Mongal F1 irrigated with 75% ETc could be adopted at the fruiting stage and Mongal F1 irrigated with 100% ETc for optimum yield could be recommended.

3. Further investigation could be carried out on the effects of other mulching materials available for tomato production, especially in water stress areas of the country.

4. The experiment should be repeated under different environmental conditions so as to validate the research findings.

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APPENDICES

Appendix 1: Crop Water Requirement for Tomato Plant with Deficit Levels

Month	Decade	Stage	Kc	ETo	ETc (mm/d)	ETc (mm/dec.)	100 % ETc mm/dec	75 % ETc mm/dec	50 % ETc mm/dec
Nov	3	Ini	0.9	4.43	3.99	39.87	39.87	29.90	19.94
Dec	1	Ini	0.9	4.03	3.63	36.27	36.27	27.20	18.14
Dec	2	Ini	0.9	4.03	3.63	36.27	36.27	27.20	18.14
Dec	3	Dev	0.94	4.03	3.79	37.88	37.88	28.41	18.94
Jan	1	Dev	1	4.46	4.46	44.60	44.60	33.45	22.30
Jan	2	Dev	1.06	4.46	4.73	47.28	47.28	35.46	23.64
Jan	3	Mid	1.11	4.46	4.95	49.51	49.51	37.13	24.75
Feb	1	Mid	1.12	5.16	5.78	57.79	57.79	43.34	28.90
Feb	2	Mid	1.12	5.16	5.78	57.79	57.79	43.34	28.90
Feb	3	Mid	1.12	5.16	5.78	57.79	57.79	43.34	28.90
Mar	1	Late	1.01	5.36	5.41	54.14	54.14	40.60	27.07
Mar	2	Late	0.83	5.36	4.45	44.49	44.49	33.37	22.24
Total						563.67	564	423	282

Kc = crop coefficient, ETo = evapotranspiration of reference crop, ETc = crop evapotranspiration, mm/d = millimeter per day, mm/dec = millimeter per decade, Ini = initial stage, Dev = development stage

Appendix 2: Description of Treatments used for experiment.

Treatment N0.	Treatment Label	Description of Treatments
T-1	V1 100 M2	Pectomech, 100 % ET_c, 3 tha^{-1} straw mulch
T-2	V1 100 M1	Pectomech, 100 % ET_c, 6 tha^{-1} straw mulch
T-3	V1 100 M3	Pectomech, 100 % ET_c, 0 tha^{-1} straw mulch

T-4	V1 75 M2	Pectomech, 75 % ET_c, 3 tha^{-1} straw mulch
T-5	V1 75 M3	Pectomech, 75 % ET_c, 0 tha^{-1} straw mulch
T-6	V1 75 M1	Pectomech, 75 % ET_c, 6 tha^{-1} straw mulch
T-7	V1 50 M2	Pectomech, 50 % ET_c, 3 tha^{-1} straw mulch
T-8	V1 50 M3	Pectomech, 50 % ET_c, 0 tha^{-1} straw mulch
T-9	V1 50 M1	Pectomech, 50 % ET_c, 6 tha^{-1} straw mulch
T-10	V2 50 M1	Mongal F1, 50 % ET_c, 6 tha^{-1} straw mulch
T-11	V2 50 M2	Mongal F1, 50 % ET_c, 3 tha^{-1} straw mulch
T-12	V2 50 M3	Mongal F1, 50 % ET_c, 0 tha^{-1} straw mulch
T-13	V2 75 M2	Mongal F1, 75 % ET_c, 3 tha^{-1} straw mulch
T-14	V2 75 M3	Mongal F1, 75 % ET_c, 0 tha^{-1} straw mulch
T-15	V2 75 M1	Mongal F1, 75 % ET_c, 6 tha^{-1} straw mulch
T-16	V2 100 M3	Mongal F1, 100 % ET_c, 0 tha^{-1} straw mulch
T-17	V2 100 M1	Mongal F1, 100 % ET_c, 6 tha^{-1} straw mulch
T-18	V2 100 M2	Mongal F1, 100 % ET_c, 3 tha^{-1} straw mulch

T = Treatments, ETc = Crop water requirement, V = Variety, M = Mulch Level

Appendix 3: Distribution Uniformity Test values

Replication	DU (%)	Q (l/h)
Replication 1	0.84	0.9
Replication 2	0.87	0.74
Replication 3	0.87	0.75
Replication 4	0.85	0.79

DU = distribution uniformity, Q =discharge, l/h = liter per hour

Appendix 4: Effect of Irrigation Levels on Fruit Number at 7WATP

Irrigation (% ETc)	Number of fruits
100	9a
75	8ab
50	7b
LSD	1.7
p-value	0.039

Appendix 5: Effect of Mulching Levels on Fruit Number at 7WATP

Mulch (tha-1)	Number of fruits
6	9a
3	9a
0	7b
LSD	0.9
p-value	< .001

Appendix 6: Effect of Variety on Total Fruit Weight (tha-1)

Variety	Fruit weight (tha^{-1})
Mongal F1	10.65
Pectomech	2.67
LSD	4.137
p-value	0.009

Appendix 7: Effect of Irrigation Levels on Total Fruit Weight

Irrigation (% ETc)	Fruit weight (tha^{-1})
50	5.46b
75	6.44b
100	8.08a
LSD	1.511
p-value	0.008

Different letters show different means according to Duncan test results at 5% confidence interval.

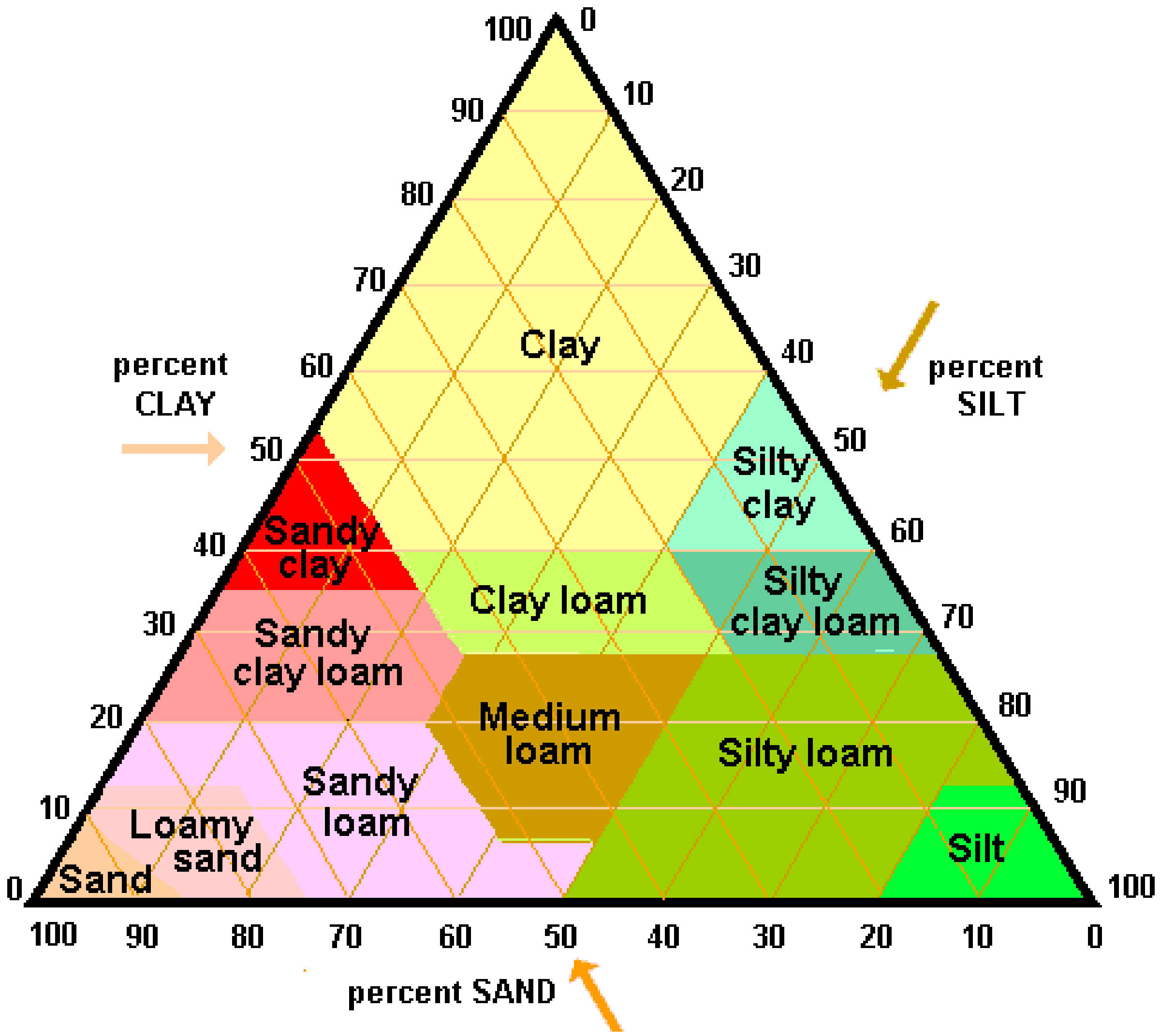
Appendix 8: Average Weekly Temperature (ºC) and Relative Humidity (%) Weather Conditions of the Experimental Site

	Week 1		Week 2		Week 3		Week 4	
Month	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
Dec	0.0	0.0	0.0	0.0	0.0	0.0	29.3	30.0
Jan	29.5	31.4	29.5	30.8	28.6	29.7	27.6	30.6
Feb	29.7	31.8	31.2	32.2	28.5	32.5	29.9	31.8
Mar	32.3	31.8	30.0	33.0	29.4	33.0	30.4	33.7

	RH min	RH max	RH min	RH max	RH min	RH max	RH min	RH max
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.24	0.27
Jan	0.23	0.51	0.25	0.54	0.2	0.3	0.18	0.24
Feb	0.18	0.36	0.17	0.47	0.1	0.5	0.14	0.34
Mar	0.17	0.5	0.51	0.53	0.5	0.6	0.32	0.66

Source: Decagon Weather Station model Em-50 Datalogger

Tmin = minimum temperature, Tmax = maximum temperature, RH min = relative humidity, RH max = maximum relative humidity.



Appendix 9: United States Department of Agriculture (USDA) Soil Textural triangle

Appendix 10: Tomato Seedlings at the Nursery at 21 Days after Transplanting.

Appendix 11: Driplines Laid on the Field

Appendix 12: Tomato Seedlings Two Hours after Transplanting

Appendix 13: Field Picture with Tomato at the Fruiting Stage (left) and Data Collection (right)

Appendix 14: Mini Decagon Weather Station mounted at the center of the Experimental Field

Appendix 15: Tomato Fruits Affected by Blossom End rot

Appendix 16: Mature Healthy Tomato Plant


Appendix 17: Harvested Tomato Fruits