UNIVERSITY FOR DEVELOPMENT STUDIES

WEST AFRICAN CENTRE FOR WATER IRRIGATION AND SUSTAINABLE AGRICULTURE

EFFECTS OF DRIP IRRIGATION REGIME AND RICE MULCH ON GROWTH AND YIELD OF YAM (*Dioscorea rotundata* L.*)* SEEDLINGS IN NORTHERN GHANA

TIKU CHANTAL ATUT

SEPTEMBER 2021

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BY

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

SEPTEMBER 2021

DECLARATION

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: 27/09/2021

CHANTAL ATUT TIKU

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

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ABSTRACT

Yam (*Dioscorea rotundata* L.) vines have similar potential in terms of seed multiplication and water productivity with other food crops such as cereals. The experiment was conducted at Nyankpala in the Guinea savannah agro-ecological zone of Northern Ghana during the 2020-2021 dry season. The objectives were to investigate the response of yam seedlings generated from vines to the combined effects of drip irrigation regime and rice mulch and evaluate their crop water productivity (CWP). The 3 x 3 factorial experiment was laid out in Randomized Complete Block Design with three replications. The irrigation regime was at 50%, 75% and 100% crop water requirement (ETc) combined with rice mulch at without mulch (NO), 1 t/ha of rice straw (RS) and 3 t/ha of partially decomposed rice husk (PDRH). The soil of the experimental site was sandy loam in texture with bulk density, field capacity, permanent wilting point, N, P and K as 1.69 g/cm^3, 18.4% volume, 4.9%v/v, 0.07 %, 4.65 mg/kg, and 64 mg/kg for 0-20 cm depth respectively. Application of irrigation level at 100% ETc and PDRH mulch maximized plant height with 160 cm at 12 weeks after transplanting (WATP) and attained the highest LAI (0.2) and leaf chlorophyll content (53 spads). The yield of yam mini tubers increased with an increasing amount of irrigation water in combination with mulch. The highest total tuber yield of 1105 kg/ha and maximum water CWP of 3.83 kg/ha per L were obtained from 100% ETc under PDRH. However, the application of 50% ETc with RS exhibited 50% of the maximum total tuber yield and also, a similar CWP of 3.69 kg/ha per L of the best treatment. Mini tuber yield correlated positively with marketable yield, mini tuber length, mini tuber circumference, number of mini tubers harvested, and CWP, with respective coefficients of correlation as r = 0.99**, 0.95**, 0.99**, 0.82**, and 0.89**. The study revealed drip irrigation regime of 100% ETc with PDRH mulch exhibited an explicit role for optimum growth, yield and water productivity of yam seedlings generated from single node vines in Northern Ghana. Overall, however, application of 50% ETc drip irrigation regime in combination with 1 t/ha RS is recommended for ideal mini tuber growth and yield in seed yam production using rooted single vine nodes in this agro-ecology for profitable seed yam production whilst minimizing water use and maximizing yield in the dry season.

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DEDICATION

This piece of work is dedicated to Dr. Chamba Baoche Emmanuel for his relentless support in seeing me through this course.

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CWP: crop water productivity

RCBD: randomized complete block design

NO: no mulch

RS: rice straw

PDRH: partially decomposed rice husk

LAI: leaf area index

WAPT: weeks after transplanting

N: Nitrogen

P: Phosphorous

K: potassium

ETc: crop water requirement

TIBs: temporary immersion bioreactor system

IITA: International Institute of Tropical Agriculture

YIIFSWA: Yam Improvement for Income and Food security in West Africa

RH: Relative humidity

WUE: Water use efficiency

EC: electrical conductivity

FAO: Food and Agricultural Organization

PVC: Polyvinyl chloride

LDPE: low density polyethene

FC: field capacity

PWP: permanent wilting point

Zr: Root zone depth

Bd: Bulk density

TAW: total available water

AWC: available water content

RAW: Readily available water

MAD: management Allowable Depletion

NIR: Net Irrigation

GIR: Gross Irrigation

DAP: days after planting

ID: Irrigation duration

$ID_{100\%ETc}$: Irrigation duration for 100%ETc

$ID_{75\%}ETc$: Irrigation duration for 75%ETc

$ID_{50\%}ETc$: Irrigation duration for 50%ETc

ANOVA: Analysis of Variance

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Small-scale farming in Africa is dependent on yam (*Dioscorea rotundata* L.) tuber production. Due to its high calorific content, it is grown and consumed throughout Africa's subtropics and tropical regions. It improves the lives of at least 60 million people in West Africa (Maroya *et al*., 2017). Yams have a long shelf-life and enhance food security and the fight against hunger for small households in Ghana (Degef and Anbessa, 2017). It contributes about 17% of the gross agricultural domestic product of the country. It has a significant socio-cultural impact on the life of many homes. It is used in traditional rituals such as fertility, marriage, and annual festivals, making the crop a measure of wealth (Sanginga, 2015).

Despite the low rate of seed yam multiplication, traditional production methods fail to meet farmer demand, and seed tubers are susceptible to pest and pathogen contamination. Researchers and farmers use a variety of methods to address the issue of inadequate seed yam production, including whole tubers from ware yam, milking, 'Anambra', minisetts, and vine cuttings. However, because new methods have not been widely adopted to address the challenges of quantity and quality of seed tubers, farmers continue to use traditional methods and save seeds from a previous harvest to plant for ware yam (Aighewi *et al*., 2015).

However, irrigation affects the soils properties and the availability of plant nutrients, which either enhance or could mar crop productivity. Irrigation is the process of giving suitable amounts of water to a crop when it is needed, according to the depth of its roots. Irrigation can shorten the yam's growth cycle by reducing the dormancy period and total growth cycle (Oladipo, 2013).

Anything placed on top of the soil to conserve moisture, keep temperatures around plant roots at a comfortable level and discourage weeds or other pests from invading is considered mulch. Organic or inorganic materials can be used to make mulches. Mulches can also be used to improve crop yield and quality by reducing weed growth (Bhakar *et al*., 2017). The use of rice husks at 1 t/ha to increase the total tuber yield of potatoes in Turkey by Güler, (2009) have been reported. Adekiya *et al*., (2015) found that using siam weed (*Chromolaena odorata*) as a mulch on yam plants in Nigeria kept the soil moist and cool while also improving bulk density, soil organic matter, and yam plant vine length, leaf area, and tuber yield.

1.2 Problem Statement

For a long time, yam cultivation has been sustained by traditional methods of seed yam production (Aighewi *et al*., 2015). The traditional seed production method however limits the rapid expansion of farm size and high productivity of yams because of the low seed yam multiplication rate of 1:10. Also, improved traditional multiplication methods such as the minisett technique still give very low output, as compared to cereals like maize, with a seed multiplication ratio of about 1:250-300. Modern rapid multiplication techniques of seed yam production like conventional tissue culture, aeroponics, Temporary Immersion Bioreactor systems (TIBs) and the use of vivipacks using single node vine cuttings have bridged this multiplication gap by increasing the seed multiplication ratio to 1:300, where a single yam plant can produce up to 300 single nodes which are all potential yam tubers.

However, this increase in propagation ratio using yam vines and cuttings has its challenges especially when the rooted single node cuttings (plantlets) are ready for the field to produce micro-tubers (Foundation seed). This coincides with the dry season when precipitation is limited for almost six months resulting in inadequate availability of soil moisture. Producing the Foundation seed yam during the dry season is, however, essential in maintaining the seed yam cycle for timely mass production for farmers. High temperatures, little or no rain, and high evaporation define the dry season in Northern Ghana (especially November-May). If a favorable environment for crop growth and development is not created, this results in large crop losses. CSIR-SARI yam improvement program has recorded up to 100% losses of rooted yam vines(plantlets) grown in the field during the dry season. Inadequate mulching and irrigation resulting in high evapotranspiration rates because of the high temperatures are probably the major contributory factors responsible for the low survival rates of yam plantlets in the field.

However, there is an abundance of rice straw (from earlier harvests of the crop) and rice husk (from rice milling) throughout the growing period of the yam seedlings, posing waste management issues for the environment. To remedy this scenario, this might be utilized as mulching material to conserve the limited soil moisture and carefully employ irrigation water for crop growth.

1.3 Justification

There is no distinction between seed and ware yam in traditional yam production systems. The yam farmer cultivates for ware yam to generate setts for the following cropping season (Aighewi *et al*., 2015). Smaller harvested tubers that are disease-infested are often left as setts for the following season. The propagation ratio is usually 1:5. The minisett technique is a method with a propagation ratio of 1: 25 or 1: 30 that is an advancement on the classic method of seed yam production (Aighewi *et al*., 2015). This increase in yam multiplication has not resulted in a significant degree of competitiveness with other crops like maize (cereal), which has a multiplication ratio of 1: 300, making yam a laggard in seed production.

The rapid seed yam multiplication technology was developed by the International Institute for Tropical Agriculture (IITA) for the YIIFSWA (Yam Improvement for Income and Food Security in West Africa) project. Tissue culture and aeroponics are combined to create clean seed yam in this process. Single-node vines are grown in a soilless medium in a controlled environment using a well-planned and tested water-nutrient mix delivered through regular root zone misting (Maroya *et al*., 2014; Aighewi *et a*l., 2015).

The yam vine production cycle delivers yam vines at the onset of the dry season. The fragility of the plantlets coupled with the unfavorable climate hinders seedling's sustainability in the field. The dry season in Northern Ghana is usually characterized by high diurnal temperature, low relative humidity (RH) and no precipitation. This characteristic weather pattern leads to excessive water loss from the soil and results in seedlings withering in the field. CSIR-SARI has reported up to 100% losses of vines planted in the field during this period (Chamba, 2019).

Irrigation systems that require less labor and energy have been increasingly popular in recent years. These needs are easily met by drip irrigation (micro-irrigation) systems (Kebede, 2019). Drip irrigation reduced the amount of water applied to the crop by 47 to 62 % when compared to furrow irrigation. When compared to furrow irrigation, drip irrigation has been shown to boost crop productivity and water usage efficiency (WUE) by 19 and 20%, respectively. Furthermore, researchers discovered that using supplemental irrigation increased yam tuber output by 49.5 percent (Oladipo, 2013).

Making efficient use of water and irrigating more land with available water resources is wise (Kebede, 2019). This goal can be achieved with better irrigation and water management strategies. One of the most efficient strategies to optimize the water management process is to combine drip irrigation with mulch. Drip-applied water penetrates the soil through small holes on the soil surface (Inusah, *et al*., 2013). Drip irrigation is a viable choice for farmers due to its capacity to deliver small but regular doses of water at a lower cost than other pressurized systems.

Rice straw and rice husk have the potential to support crop growth throughout the year. They are widely available as a byproduct to resource-poor farmers in Northern Ghana and can be utilized to conserve soil moisture. When mulch is utilized, several workers have observed positive effects on soil physical, chemical, and biological qualities, soil moisture, temperature, growth, and yield (Eruola *et al.*, 2012; Agbede *et al*., 2013).

The production of seed yams includes a long chain that starts with cleaning, goes through breeding, foundation seed production, and ends with certified seed being supplied to farmers. This experiment seeks to produce foundation seeds. The average size of yam seed for ware yam production is about 25-500 g in weight (Aighewi *et al*., 2015). Hence the size of seed tuber produced from cleaning to certified seed is not a challenge because they will go through a seed production cycle to attain the required seed yam size.

1.4 Main Objective

To evaluate the growth, yield components and seed yam production of single node yam vines under drip irrigation regime and rice mulch.

1.4.1 Specific Objectives

The specific objectives of the study are to:

- Evaluate how drip irrigation affects the growth and yield components of single node yam vines, as well as seed yam production.
- Examine the effect of rice mulch on yam and seed yam production in single node yam plants' development and yield components.
- Investigate the effects of irrigation and rice mulches on single node yam vines in terms of soil moisture conservation, temperature regulation, and water use.
- Assess the combined effects of a drip irrigation system and rice mulch on the growth and productivity of single node yam vines.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Yam Taxonomy and Distribution

According to the United States Department of Agriculture (USDA) classification, yam belongs to the kingdom *Plantae*, subkingdom *Tracheobionta* (vascular plants), super division *Spermatophyta* (seed plants), division *Magnoliophyta* (flowering plants), class *Liliopsida* (monocotyledons), subclass *Lilidae*, order *Liliales*, family *Dioscoreaceae* and genus *Dioscorea*.

Yam originated from the tropical parts of the world. Of the 750 existing yam species, there exist 750 yam species with eight to nine genera of which only six are cultivated for food in the tropics. The edible species include *D. rotundata* (white guinea yam), *D. cayenensis* (yellow guinea yam), *D. bulbifer*, (aerial or bulbils yam), *D. alata* (water yam), *D. esculenta* (Chinese or lesser yam), *D. trifida* L., *D. japonica*, *D. dumetorum* (trifoliate or bitter yam), *D. hispida*, and *D. oposita*. Predominant yam cultivars in Ghana are *D. rotundata* and *D. alata*, *D. cayensis* as well as some wild species of *D. praehensilis* (Otoo *et al*., 2012).

2.2 Climatic and Field requirements for yam production

Temperature, light, and photoperiod are the most important climatic conditions for yam production (Eruola, *et al*., 2012). For the development of vines and leaves, tuber commencement and bulking, and overall crop development. However, in the tropics, moisture and temperature remain the most important agro-meteorological parameters for crop performance (Vaillant *et al*., 2005). The ideal temperature for yam growth is 25^{o}C to 30^{o}C. Growth rate increases as the temperature increases. Low temperatures during the night favor tuber formation, and high temperatures by day favor vegetative development. Yam reacts the duration of daylight. Shorter days encourage tuber production, whilst longer days encourage vine growth (Vaillant *et al*., 2005). Tuberization is stimulated by several variables, such as environment, mother tuber, genetics. For optimum plant growth, and development, adequate water, nutrients, temperature, RH and soil are required among light, oxygen and carbon dioxide for respiration and photosynthesis.

Yams are upland plants and require well-drained and deep (400 mm) soils. Soils with high organic matter concentration, such as sandy loam and silt loam, produce the best yields. Yams are grown at both low and high elevations. Yields decrease over 900 meters, though yams have been reported to be grown up to 2700 meters (Anonymous). Yams are planted on ridges or mounds. Soil pH (H_2O) of 5.5 to 7.0 isis preferable (Maroya *et al*., 2017). Soil salinity affects yam growth. The production of yams will be reduced if the soil has electrical conductivity (EC) of 1,500µS m^{-1}. Certain nematode, fungus, and virus species that infect the tuber and foliage can also impair yam productivity. Crop management in terms of weed control, fertilizer application, staking or trailing and mulching are prerequisites for maximum yield and optimum crop performance. Yam crop needs about two to three weeding for crop optimum growth. The crop takes 6 to 9 months to senesce.

2.3 Ware yam production and Utilization in Ghana

Yam is grown in many tropical areas outside West Africa, even though it accounts for 93% of global production Together with cassava and sweet potatoes, yam is the important tuber crops in Ghana. it is cultivated throughout Ghana under diverse environments. There is an increase of 1% of total agricultural land used for yam cultivation from 4.9% in 2010 in Ghana (FAO, 2020). Ghana produced 8,288,198 tons of yam cultivated on 464,253 ha of land in 2019 (FAO, 2020). Ghana is a leading exporter of yam, contributing 36% of the world’s yam export. Yam is ranked second after pineapple among Ghana's non-traditional exports.

The fight against food insecurity includes the use of yam as a weapon. More than 60 million people along the yam belt benefit from it (Sanginga, 2015; Maroya *et al*., 2017). Yam is one of the most germane dietary sources of energy produced within the tropics and plays a vital role as a food and trade commodity in Ghana (Oteng-Darko, 2016). Yam is a major source of nutrients (carbohydrates, phosphorus calcium) and vitamins and minerals (Oteng-Darko, 2016). It is often regarded as the richest and most nutrient-dense tropical root crop. Yams are used in the preparation of local dishes such as fufu, a common staple. It can also be fried or boiled and eaten with sauce or roasted/boiled and mashed into Ɛtɔ.

Ware yam is physiologically mature tuber of 500g weight and above. It takes between six to nine months to mature and senescence from the sett. Yam is in high demand both domestically and abroad. It is a key source of income for both farmers and dealers of the crop, as well as a staple food for the entire country. A market exists for the crop (Oteng-Darko, 2016). The yam value chain has a rewarding opportunity for various actors. Despite all the attractive opportunities, more needs to be done on the yam value chain for its full potentials to be exhibited (Oteng-Darko, 2016).

2.4 Seed Yam Production

Seed production is a vital component in any crop production system and serves as a key source of germplasm for clean genetic resource conservation, crop improvement and management. Seed yam constitutes over 45% of total yam production cost as compared to other inputs. Yam productivity is dependent on seed quality together with complementary inputs. The scarcity of quality and quantity seed yam in the yam production belt of West Africa is a major hindrance to yam production. In the past, farmers were obliged to rely on conventional ways of seed multiplication, such as using sections of cut yam tubers and milking, due to the lack of a certified seed yam system. Seed yam makes up 30% of total yam production but traditional seed yam multiplication systems are faced with a low propagation ratio of 1:6-10 coupled with the spread of anthracnose and other disease-infested yam planting material.

Until 2017, the seed yam subsector in Ghana was in the hands of the local and smallholder producers who use rudimentary methods to provide the seeds. In traditional yam production systems, sole seed yam growers are rare and 30% of the harvested tuber is reserved for setts (Aighewi, *et al*., 2020). Yams are produced sexually by botanical seeds and asexually through: aerial tubers, tubers and vine cuttings. Propagation by botanical seeds and aerial tubers is done by researchers for breeding purposes. Propagation through vines is gaining attention with commercial seed farmers. The most common method of propagation is by tubers. Several rapid multiplication techniques have been developed. These include the mini sett, vine multiplication, tissue culture and aeroponics (Aighewi *et al.*, 2015; Aighewi *et al*., 2020).

2.5 Methods of rapid seed yam production

Rudimentary methods of seed yam production often produce poor quality and costly seeds due to disease infection, low multiplication ratio and high labor needs (Aighewi *et al.,* 2015). Despite these difficulties, traditional systems have been able to sustain production throughout the year. The quality, yield (numbers versus weight), percentage survival after planting, cost, and multiplication ratio per unit time in a specific agro-economy should all be considered when determining which technology to utilize, regardless of how it is propagated (Balogun and Gueye, 2013).

Because they have no exposed surface, whole seed tubers sorted from ware crops are perfect for sowing. They suit quite well with farmers' labor management strategy of planting early in the dry season. They suit quite well with farmers' labor management strategy of planting early in the dry season. In addition to full seed tubers, some varieties produce 1–3 smaller tubers together with a big ware tuber that is utilized for food. The little tubers are separated and set aside for planting (Aighewi *et al*., 2015).

The minisett yam multiplication technology was created to boost the quantity and quality of seed yam available to farmers. In the minisett technique, 500–1000 g 'mother seed' yams that have broken dormancy are chopped into 25 g pieces (minisetts) (Aighewi *et al.,* 2015). As soon as the minisetts are cut, they're treated with a mixture of pesticide and fungicide, then spread out to dry for 1–2 days in the shade. The minisetts are then planted in the field went the rains are well established (Aighewi *et al.,* 2015).

African yam experts have turned to vine cuttings as an alternative to traditional seed production. Healthy vines 30-60 days after shoot emergence and before the onset of tuber growth are utilized as mother plants in the production of tubers (Kikuno *et al.*, 2007). Agele *et al*., (2010) found that 20 cm long-rooted vine cuttings with 1 to 3 nodes produced mini-tubers of 50–600 g after 8 months, resulting in a 1:30 propagation ratio.

Before being transplanted into the ground or planted directly in the garden's top soil, cuttings are rooted in a chamber with high humidity or in carbonized rice husk. This new technology makes better use of available space during the seed production process. Other studies have found that yams can multiply hundreds of times in a year using single node cuttings. However, although vine cuttings root well in an aeroponics system, effective and inexpensive ways of rooting *D. rotundata* on a large scale have not yet been established. (Maroya *et al*., 2014).

This technique of propagation has the significant advantage of preserving the entire tuber for food, increasing the crop's economic worth. Furthermore, if a sterilized medium or pest-free soil is utilized for propagation, the setts generated are devoid of nematodes and soil-borne diseases.

The YIIFSWA initiative uses aeroponics seed yam to propagate seeds (Maroya *et al*.2014). IITA has successfully grown the first seed yam in an aeroponics system (IITA). A mix of pre-rooted and newly cut unrooted single nodes was used for this experiment. These plants were transplanted into aeroponics boxes that had been set up in a screen house (Aighewi *et al.,* 2015).

Aeroponics is an efficient, profitable technology for growing plants without soils (Pardossi *et al*., 2011). The aeroponic technology has improved immensely on the plant density of crops due to its ability to eliminate competition among plants. Compared to hydroponics, aeroponics gives room for optimized root aeration and consequently, increased yields (Maroya *et al.*, 2014). The technology is also efficient in its water and nutrient uses (Mugundhan *et al.,* 2011; Mbiyu e*t al.*, 2012).

2.6 Irrigation potential and development in Ghana

Ghana has abundant water resources that can be used to increase irrigation. the irrigated land area under cultivation in Ghana ranges from about 33,000 hectares (ha) to about 0.36-1.9 million hectares (FAO, 2005). The development of Ghana's irrigation system has been justified as a means of achieving food security, reducing poverty, and creating rural jobs. Rainfall distribution in the northern hemisphere is characterized by a single, highly variable mode. Even though significant irrigation initiatives date only from the last 50 years, records show that irrigation began around a century ago. There was a high point in irrigation development in Ghana in the 1970s, which coincided with the worldwide investment pattern. Even yet, the overall level of progress has been very modest (Namara *et al*., 2011; Thomas, 2015).

Out of the total estimated irrigable land area of 2.9 million hectares, less than 2 % has been developed. Around 19,000 acres of irrigated land were developed between 1960 and 1980. The irrigated land area had grown to 33,800 acres by 2007 (Namara *et al*., 2011). This indicates that there are potential opportunities to boost the amount of irrigated land ((Namara *et al*., 2010; Thomas, 2015; Kebede, 2019).

Irrigation is one method of raising agricultural output to meet Ghana's growing needs. One of the finest options to consider for reliable and sustainable food security is to expand irrigation development on various scales. To improve national food security, more emphasis is placed on Farmer Led Irrigation (FLI) and small-scale irrigation involving farmers in different phases. This shows that irrigation development operations are being carried out to accelerate and sustain development to eradicate poverty in the country (Kebede, 2019).

There are only 4 to 5 months of farming time in the Northern region due to short-duration unimodal rainfall and high evapotranspiration rates, while the extended dry season lasts for 7 to 8 months. To cultivate throughout the extended dry season, you'll need irrigation (Namara *et al*., 2011). In general, rainfed agriculture will be unable to feed the country's future population unless it is accompanied by irrigation projects. Rainfed farming routinely produces lower crop yields than irrigated farming (Swamikannu and Berger, 2009).

2.7 Crop Water Requirement

Knowing the crop's water needs (ETc) is essential for irrigation system design. ETc is the evaporation rate of an uninfected crop growing in a field of at least one hectare under optimal soil conditions. As a result of ETc, the crop water need is stated in millimeters of water per day (Allen *et al*., 1998). Laborious and time-consuming, direct measurement processes require a lot of time and effort. The FAO CROPWAT computer program is now commonly used. (Allen *et al.*, 1998). According to FAO Penman-Moneith, CROPWAT is an irrigation planning and management computer program (FAO, 2002). Water requirements for crops can be calculated using inputs from climatic conditions to crop and soil data together with irrigation data. As part of its basic function, it calculates the reference evapotranspiration as well as the crop water and scheme requirements. The FAO penman Monteith method uses data on temperature, humidity, sunshine/radiation, and wind speed to calculate reference evapotranspiration. (Allen *et al.*, 1998).

Equation 1: Reference crop Evapotranspiration (ETo) = $\frac{\left(0.408\triangle(Rn-G)+Y\frac{900}{T+273}U2(es-ea)\right)}{\triangle+Y(1+0.34U2)}$

where: ETo is reference evapotranspiration in mm/day, Rn net radiation at the top surface (MJm-2/day), G is soil heat flux density (MJm^{-2}/day), T is mean daily air temperature (^{o}C), $U_2$is wind speed at 2 m height (m/s), es – ea is saturated vapor pressure deficit (kPa), Δ is the slope vapor pressure curve (kPa/^{o}C), Y is psychrometric constant (kPa/^{o}C) (Allen *et al*., 1998).

A well-established approach for determining agricultural water requirements over the growing season employs ETo and estimates of crop evaporation rates, known as crop coefficient. The following equation generates ETc values using crop coefficient values from (Allen *et al.*, 1998).

Equation 2: Crop water requirement (ETc) = ETo x Kc

ETc is the crop evapotranspiration, Kc is the crop coefficient, and ETo is the reference evapotranspiration in mm/day.

2.8 Irrigation Water Requirement

2.8.1 Water requirement for net irrigation

To meet a crop's evapotranspiration needs during its full growth, irrigation water requirement is calculated.

Equation 3 Net Irrigation water requirement (NIWR) = CWR – Pe where: NIWR stands for Net-Irrigation Water Requirement; where Pe is effective precipitation is derived from an empirical formula using the FAO CROPWAT computer model as a daily soil water balance (Allen *et al.*, 1998).

Equation 4: Effective Rainfall $Pe = P - (C * P)$ or Pe = f* P

where P is the daily rainfall in millimeters (mm), and the constants f and C have values of 0.2 and 0.8, respectively.

2.8.2 Gross amount of water needed for irrigation

Gross irrigation is calculated by multiplying net irrigation by irrigation efficiency. (Allen *et al.*, 1998).

Equation 5: Gross amount of water needed for irrigation (GIWR) = $\frac{NIWR}{Ea}$

GIR, which stands for gross irrigation water requirement, is measured in millimeters. NIWR, on the other hand, is the net irrigation water requirement; and Ea = % application efficiency.

2.8.3 Distribution efficiency

Irrigation distribution uniformity has been described in a variety of ways. There are four commonly used parameters to determine the uniformity of emitter discharge in-field evaluations: DU, qv, UA, UA, and CV stand for uniformity of distribution, Variability in the flow of the emitter, and variation coefficient (CV) (Mizyed and E, 2008). The Distribution uniformity is one of the measures that emphasize the under-watered area and looks at key regions. It indicates the size of the uneven distribution as the proportion of the mean application amount applied in the lowest quarter of the field (Rogers *et al*., 1997). In irrigated agriculture, the United States Department of Agriculture (USDA) has utilized the lowest quarter fraction, dlq (mm), since the 1940s (Burt *et al*., 1997):

Equation 6:Distribution Uniformity (DU) $DU = \frac{Qlq}{Qa} * 100$

where: Qlq = average discharge rate of lowest quarter observed (l/hr): Qa denotes the average discharge rate of the entire field observed (l/hr).

2.9 Irrigation Scheduling

Crop water needs are handled by using a scientific irrigation scheduling strategy, which combines a management and technological approach. As a result of this technology, crops receive water in a more timely and correct manner, saving water and energy, while also improving irrigation performance, crop yield and quality, and the long-term viability of irrigated agriculture (Smith *et al.*, 1996). Soil moisture should be kept near to field capacity to maximize productivity. In a changing environment, irrigation benefits are maximized when the timing and amount of water delivered are adjusted to meet constantly changing crop water requirements.

Water and energy conservation, as well as lower production costs, are some of the benefits of effective irrigation scheduling. Farmers usually rely on their own experience and observations to decide when to irrigate (such as wilting and soil dryness by observation) (Smith, and Munoz, 2002). They claim that providing farmers with "scientific" advice on when to irrigate can result in significant water savings and more prudent irrigation planning. Many approaches are available, but 'Water indicator' and 'Soil budget' are the most popular. To calculate the water budget, we use the following equation:

Equation 7: Irrigation Requirement (I) $I = ET - Pe + ROi + DPi + L + Drz(qf - qi)$

where: I= Irrigation requirement; ET= evapotranspiration; Pe= effective precipitation (cm); ROi, = runoff due to irrigation (cm); DPi= deep percolation due to irrigation (cm); Drz= depth of root zone (cm); qf & qi= final and initial soil moisture contents.

The water budget method has become more popular these days. A large amount of research and studies on crop water requirements has resulted in more accurate ET crop estimation from weather data, making the ETo based on the water balance method the most convenient and reliable way to predict when to irrigate (Smith and Munoz, 2002).

Water content scheduling for soil involves measuring the current soil water content, comparing it to an established minimum water content, and then watering to keep the soil water content higher than the minimum. Soil indicators for when to irrigate provide information on how much water to apply per irrigation as well.

According to (Mishra and Ahmed, 1990) The formula for determining the irrigation interval is as follows:

Equation 8: $\mathbf{Irrigation\ Interval} = \frac{AMD}{ETc}$

where AMD stands for acceptable soil moisture depletion in centimeters; ETc stands for daily water use; and cm/day AMD is the maximum permissible soil moisture depletion.

Irrigation depth refers to the amount of water that can be stored in a root zone between the field capacity and the maximum amount of water that can be withdrawn from the soil's water supply for a specific crop, soil, and climate. It's the same amount of soil water that's readily available to the plant's roots (James, 1988).

Plants can utilize all of the available water (TAW) between 0.1 and 0.33 bar in the root zone (also known as the "field capacity") and 15 bar (the "permanent withering point" or "permanent wilting pressure"). For sandy soils, the TAW is 6 cm/m, while for silt loams it is 25 cm/m (Allen *et al*., 1998).

The moisture deficit (d) in the effective root zone can be calculated when the field capacity moisture contents and bulk densities of each layer of soil are determined (Mishra. and Ahmed, 1990).

Equation 9: Moisture Deficit ($\boldsymbol{d}$) $= \sum_{i=1}^{n} FCi - PWPi)/100XASiXDi$

in which: FCi is the ith layer's field capacity calculated using oven-dry weight as a basis. Asi denotes the apparent specific gravity of the ith layer PWPi is calculated on an oven-dry-weight basis using Di=depth of ith layer and n=number of root zone layers.

2.10 Deficit Irrigation

Yam has always been cultivated under rainfed due to its ability to survive long periods of dryness and its long growing season. Climate, soil moisture retention, and crop water need all influence whether or not irrigation is necessary (Scherer, *et al.*, 2017). A method of irrigation known as localized irrigation involves slowly delivering water to a specific area of soil. This method of water application wets the soil and makes it suitable for crop growth. This method is often pressurized by the use of pumps and delivered to the plant via emitters at regulated and predetermined rates.

Deficit irrigation, on the other hand, refers to the practice of providing the plant with less water than the amount of evapotranspiration expected. Agronomists use irrigation scheduling to optimize water use and increase crop yields per unit of irrigation water applied (Nagaz *et al*., 2012). Deficit irrigation's main objective is to improve production efficiency, which can be accomplished in one of two ways: by reducing irrigation use or by improving fruit quality (Reid and Kalcsits, 2020). Deficit irrigation (or regulated deficit irrigation) is one method of increasing water use efficiency (WUE) and yield per unit of irrigation water applied: The crop is subjected to a certain level of water stress during a specific period or throughout the entire growing season (FAO, 2002; Kebede, 2019). Water restriction is limited to drought-tolerant phonological stages, which are frequently vegetative and late-ripening (Sam and Dirk., 2009). Several studies have demonstrated the importance of water deficits in different stages of crop growth, making it necessary to understand the marginal productivity of water allocated to each crop at different stages of growth before making the best decisions. (Doorenbos and Kassam, 1979) stated the relationship between crop yield and water deficits (Kebede, 2019).

2.10 Crop Response to Deficit Irrigation

Yam production is reliant on adequate rainfall and/or irrigation, evenly distributed and widely spaced all across the growth period, particularly during the tuber bulking phase. However, frequent and too much irrigation delays tuber formation encourages vegetative growth and withholding irrigation results in accelerated tuber bulking and better yields (Vaillant *et al*., 2005).

It was found by Mulovhedzi et al. that ample water supply did not ensure greater sweet potato crop development or yield. Such crops include sweet potato and yam, both of which are considered drought-tolerant (Mulovhedzi *et al*., 2020). Sweet potatoes require an irrigation management strategy based on maximizing soil moisture during the critical storage root initiation period and promoting maximum storage root bulking until harvest.

According to multiple studies, irrigation lowered sweet potato storage roots' percent dry matter, carotenoid concentration, and protein content, but did not alter firmness or root splitting. (Thompson *et al*., 1992) reported that the highest yield in sweet potatoes resulted from maintaining available moisture above 40% to a depth of 0.6 m. Weekly applications of 25mm of water increased yields over no irrigation, but a weekly amount of 38 mm did not increase yield further (Thompson *et al*., 1992).

2.11 Mulch influence on crop growth and yield

Crop residues such as rice husk and wood shavings are effective soil amendments in Nigeria's semi-arid zone, improving soil physical and chemical properties as well as crop growth and yield (Eze *et al*., 2019). Mulches reduce the loss of soil moisture and inhibit weed growth, both of which are important factors in groundnut production (Ramakrishna *et al*., 2006). Mulches are well-known for increasing soil temperature because sunlight passes through the mulch and heats the air and soil beneath it directly, and then the heat is trapped by the "greenhouse effect." Mulches also help crops develop and mature faster, resulting in higher yields (Ossom *et al*., 2001). Mulches help maintain a more consistent and higher level of soil moisture, which reduces the need for frequent irrigation.

Mulch is crucial in the potato production process. When compared to bare soil, plant growth on mulch is often faster. Mulching techniques are widely practiced on a wide range of vegetables while their application has been limited to the production of potatoes (Bharati *et al*., 2020).

Grass mulch outperformed perforated white surface up and the black surface facing down polythene nylon in terms of yam growth, development, and yield. The grass mulch recorded a higher emergence rate than the polythene mulch (Eruola *et al.*, 2012).

2.12 Effects of irrigation and Mulch on Crops

Mulch combined with deficit irrigation is one way to maximize water use efficiency in agriculture, resulting in higher yields per unit of irrigation water used (Nagaz *et al*., 2012). There is a belief that deficit irrigation would not reduce agricultural yields as much as expected since the water saved will be used to irrigate greater cropland instead (Kassahun, 2017).

Soil is protected from direct solar rays that promote evaporation of soil moisture, resulting in a drier soil profile. Mulch prevents this. Mulching minimizes soil evaporation by preventing soil water from evaporating. Increases soil moisture retention as a result (Igbadun *et al*., 2012; Kassahun, 2017). The application of sorghum, cotton, and maize stubbles has been found to increase the soil's ability to retain moisture. There was a higher moisture content in the organic mulched soils compared to the control soils (Kassahun, 2017). When compared to bare soil, organic mulches were more effective at retaining soil moisture. Mulching conserves water in semi-arid areas by reducing evaporation and easing plant development and yield stresses (Kassahun, 2017).

One of the most critical drip irrigation scheduling variables is the frequency of irrigation. The same amount of water applied at different irrigation frequencies may result in different crop yields due to differences in soil moisture and wetting pattern.

2.12.1 Crop growth parameters as affected by irrigation and mulch

Some growth parameters, such as plant height, leaf area index, leaf chlorophyll content, and the number of leaves, are significantly influenced by inadequate irrigation and mulch. Plant height was reported to be higher when deficit irrigation with mulch was used than when deficit irrigation was used without mulch (Biswas *et al*., 2017).

2.12.2 Yield and yield components of yams as affected by irrigation and mulch

According to (Gandhi and Bains, 2006) Straw mulched tomato plants produced more fruit than those that were not. Iftikhar and others found that rice straw and wheat straw mulch had a substantial impact on chili fruit weight. Mulch made from sugarcane bagasse produced the most fruit, followed by a mix of rice straw, wheat straw and control (Iftikhar *et al*., 2011; Kassahun, 2017). According to (Kassahun, 2017) Sweet corn plants with grass mulch had heavier fresh ear weights than control plants. When compared to a control, cocoa husk boosted tomato fruit weight per plant (Ojeniyi *et al*., 2007).

The number of tomato fruits per plant was highest with organic mulches. There were more fruits per plant with rice husk than with other mulches including grass straw, rice straw, and sawdust (Nkansah *et al.*, 2003). Tomato plants treated with grass mulch produced more fruits than those treated with wood chips (Awodoyin and Ogunyemi, 2005). Tomato plants mulched with wild sunflower leaves had the highest fruit production, while plants in no mulched pots had the lowest fruit production during the first week of fruit production (Liasu and Abdul, 2007).

This method enhanced tomato and okra yields compared to control. Mulching boosted the yield in rain-fed settings. Under hairy vetch mulch, tomato yields were significantly higher than in bare soil (Kassahun, 2017).

A yam plant's phenological growth was evaluated using mulching and mulching materials. Generally, the yam was planted under mulched (Eruola *et al.*, 2012) Compared to no mulched plants, mulched plants had considerably higher emergence rate, vine length, stem branch count, leaf count, and Leaf Area Index (LAI). Regardless of the mulching material, it was discovered that mulching increased yam emergence rate by 46 percent and tuber yield by 6-8 tons per season when compared to not mulching (Eruola *et al.*, 2012).

2.12.3 Moisture conservation and Soil temperature regulation

Mulching aid control soil temperature fluctuations. Tillage and mulching improved post-rainy season tomato performance by lowering soil temperature and increasing yields. Mulching with organic materials modifies soil temperatures and, as a result, improves crop yields, according to several studies (Kassahun, 2017). The use of organic mulch was more effective than the control at lowering soil temperatures. This included grass-straw mulches, rice-straw mulch, rice husk mulch, and sawdust mulches (Nkansah *et al.*, 2003;Gandhi and Bains, 2006) as well as the microclimate by changing soil temperature, mulches modulate soil hydrothermal regime (Kassahun, 2017).

Low humidity and high air temperatures during the growing season can reduce crop yields in some of the world's most important agronomic crops. High night air temperature stress that is repeated and prolonged can have negative effects on plant growth and yield. Crop varieties with improved heat tolerance traits and farm-scale crop management strategies are thus required to mitigate climate change.

Organic mulch enhances soil physicochemical properties, subdue soil temperature, decrease evaporation, and increase moisture, resulting in a yam sprouting-friendly soil microclimate. Mulching has been shown to improve soil moisture and temperature, as well as growth and yam yield, according to various researchers (Eruola *et al*., 2012; Agbede *et al*., 2013; Adekiya *et al*., 2015)

Because yams are planted between the end of the rainy season and the beginning of the next, soil moisture becomes critical as soon as planting begins, necessitating the use of an effective soil moisture conservation strategy to optimize soil physical conditions affecting crop yield (Eruola *et al*., 2012; Adekiya *et al*., 2015).

2.12.4 Effects of mulch on Weed control

Mulching is a common practice that is recommended for tropical small-scale farming. Mulching is an important part of the yam production process. Top soil covering has been discovered to be an effective tool for improving natural soil nutrient accumulation and soil health protection (Adekiya *et al.*, 2015). Weed control efficiency of 72 percent was achieved by using old paddy straw in conjunction with green leaf mulch, followed by the application of Lantana camara leaves (Thankamani *et al*., 2016).

The use of paddy straw, coconut leaves, and green leaf mulch significantly reduced dry weed weight. The same treatments achieved the highest weed control efficiency (Thankamani *et al.,* 2016). Rice straw improved ginger's performance by reducing weeds, controlling evaporation losses, increasing soil moisture conservation, and enhancing the plant's uptake of major, secondary, and minor nutrients.

Weeds prefer moist, stable soil because it helps them germinate. Soil moisture fluctuations, especially in the upper soil layers, have a negative impact on seed germination and emergence. However, as evidenced by the results of some authors who showed a positive impact of mulching on weed density, a sufficient layer of mulch can inhibit weed emergence. As a result, mulching can be regarded as an important weed control factor. Weed growth is minimal under mulch because the mulches prevent light penetration or exclude specific wavelengths of light required for weed seedling growth (Ossom *et al.,* 2001).

2.13 Water productivity of crops

Water productivity (WP) focuses on producing more crops from a unit of water. It primarily refers to the ratio of output derived from water use to water input (Clement *et al*., 2011). Rainfed and irrigated agriculture face the same challenge: increasing water productivity. Efficiencies in water use are measured by the amount of water used to generate a unit of dry weight material (Baye, 2011; Kassahun, 2017).

It is widely assumed that increasing agricultural WP is a critical strategy for mitigating water shortages and addressing environmental issues in arid and semiarid regions (Kebede, 2019). Water productivity can be increased to help poor countries like those in Africa and Asia. The crop WP is an important metric in both irrigated and rain-fed agriculture (Kassahun, 2017).

When it comes to crop production systems, WP is used to describe the relationship between the number of crops produced and the volume of water used in the process. The common measure that is emerging to measure water productivity is kilograms of yield produced per meter cube of water. Wet or dry yield, nutritional value, or economic return are all terms that can be used to describe the yield. It's widely accepted that deficit irrigation is an effective and long-term production strategy in dry regions. By restricting water applications to drought-tolerant growth stages or throughout the growth cycle. Deficit irrigation seeks to maximize water productivity while stabilizing rather than producing more (Kebede, 2019).

Deficit irrigation during the growth stage is successful in increasing water productivity for various crops without causing severe yield reductions, according to research findings (Gobena *et al*., 2017). Despite this, a certain level of seasonal moisture must be ensured (Geerts and Raes, 2009). WP can be utilized in the analysis of DI techniques.

Arora *et al*., (2011) found that WP decreased with increase irrigation in soybean crops. (Ughade and Mahadkar, 2016) conducted an experiment on irrigation scheduling on brinjal crops and revealed that 100 % ETc had the highest nutrient uptake over 80%ETc and 60% ETc. (Pandey *et al.*, 2000) investigated the effect of deficit irrigation timing and frequency on maize yield and yield components, as well as the interaction of deficit irrigation and N on evapotranspiration (ET) and water use efficiency (WUE) in semi-arid conditions, and revealed that deficit irrigation during the vegetative and early reproductive stages reduced grain yield (Kebede, 2019).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

This experiment was carried out from December 2020 to May 2021 at the Council for Scientific and Industrial Research-Savannah Agricultural Research Institute (CSIR-SARI) research field in Nyankpala, Ghana's Guinea Savannah agroecological Zone. The study site is located at an elevation of 158.17m above sea level, at latitude 9° 407532N and longitude 0°987150W. The study area has a wet and dry season, with a monomodal rainfall of approximately 1026mm from May to October, with peaks in August and September. The temperature distribution is uniform, with an annual average temperature of 28.3 ^{o}C (MoFA, 2000). The soils belong to the Kumayili series and are commonly classified as Ferric Luvisols.

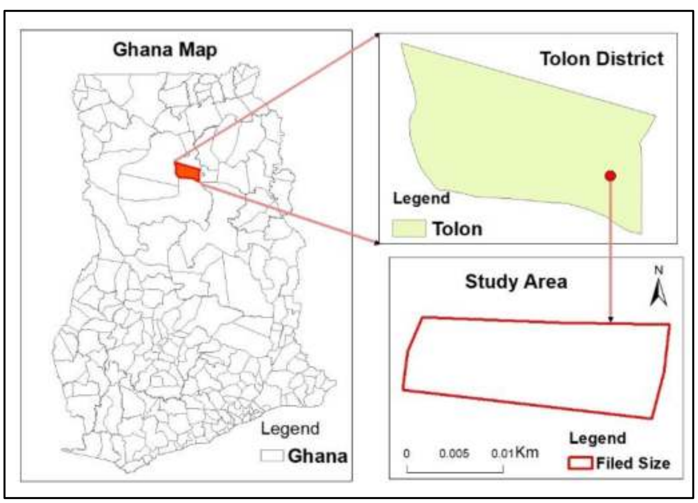

Figure 1: Map of the study area

3.2 Experimental Design and Treatments

The experiment consisted of a 3 x 3 factorial randomized complete block design (RCBD) experiment with three replications. The treatments were drip irrigation regime of 50% crop water requirement (ETc), 75% ETc, and 100% ETc in combination with mulch application of No mulch (NO), Rice straw (RS) and, partially decomposed Rice Husk (PDRH) (**Table 1**). The plot measured 3 m x 1.8 m and was divided into three rows with 0.6 m inter-row and 0.3 m intra-row spacing. The plots and replications were separated by one meter and half a meter, respectively. Irrigation at 50% ETc without mulch served as the control.

Table 1: Experimental treatments

Treatment	Irrigation	Mulch
T1	100%	NO
T2	75%	NO
T3	50%	NO
T4	100%	PDRH
T5	75%	PDRH
T6	50%	PDRH
T7	100%	RS
T8	75%	RS
T9	50%	RS

3.3 Yam Seedlings Preparation (Nursery stage)

Tissue cultured cleaned yam vines were planted in the aeroponics yam facility for two months, the later served as the source of single nodes cuttings for seedlings production. Vines from the Kpamyo variety were collected and single nodes cuttings were extracted by cutting with a sharp scissor and soaking in a solution of fungicide (victory 72WP at a rate of 50 g in 16 L of water or 2 kg/ha for 5 to 10 minutes). The treated vines were planted in growth media (composite mixture of top soil and carbonized rice husk) for one month to develop roots and shoots before transplanting to the field.

Carbonized Rice Husk (CRH) was produced by the incomplete combustion of rice hull or rice husk (RH) using a kuntan-charring apparatus. Fire is set beneath the apparatus and the temperature for charring is kept between 250 – 300 ^{o}C. Raw rice husk is then poured around the apparatus uniformly for incomplete combustion to occur while turning the rice husk around the apparatus from time to time. Each set of charring of about 10 to 15 kg takes about one to two hours to char. After charring, the matured biochar is spread to cool and then stored for use.

The loamy top soil collected was sieved using a 20 mm sieve to get rid of stones and gravel. The soil was wetted and filled in a covered drum and heated with fire for two hours to sterilize it. The fire was removed and the soil was allowed to cool. The CRH and sterilized top soil were then mixed in the ratio of 1:1 by volume using a shovel. The mixture was then filled in cleaned transparent plastic papers (used water sachets) and used for pre-rooting the aeroponics single node vines.

3.4 Soil Sampling

The experimental site which had been under fallow for more than five years was cleared prior to conducting the trial. Before field layout and transplanting, composite soil samples were taken in a zig zag form from the experimental field for analysis of baseline physical and chemical properties. Soil samples were collected at two depths: 0-20 cm and 20-40 cm. The composite samples were allowed to air dry in a well-ventilated area using a shallow tray. The gravel, roots, and organic residues were separated from the soil lumps by crushing them gently. During the smashing, soft gravel was avoided. The soil was sieved through a 2 mm sieve, and then the crumbs were gently rubbed through the mesh, leaving the gravels, roots, and other debris behind.

The physical properties of soil were determined at the AgSSiP University for Development Studies (UDS) soil laboratory, while the chemical properties were determined at the CSIR- SARI soil laboratory. The permanent wilting point of the soil and the field capacity was calculated by (FAO, 2007). With the hydrometer approach, soil texture (particle size distribution) was assessed (Bouyoucos, 1962) and the textural class was assigned using USDA textural triangle. It was then determined what texture class it belonged to depending on how it was classified by the USDA's soil texture triangle. The textural triangle gives various soil textures depending on the relative proportions of soil particles determined above.

To estimate bulk density and porosity, we first measured how much soil was in the core and then dried it at 105°C for 24 hours. The bulk density was calculated by dividing the soil's dry mass by the known cylindrical core volume.

The soil's saturated hydraulic conductivity (Ksat) was measured in the laboratory using an undisturbed soil core and a constant head permeameter. The organic matter was determined using the dichromate digestion method, and the soil pH was determined using the electrometric method. A soil: solution ratio of 1: 2.5 was used in the determination of pH. The total nitrogen in the soil was determined using the micro-kjeldahl technique. Murphy and Riley's method was used to calculate available P. The extraction of exchangeable K+, Ca2+, and Mg2+ was carried out using ammonium acetate. The flame photometer was used to determine potassium, Ca and Mg.

The Infiltration characteristic of the soil was determined with a double ring infiltrometer. The test was conducted at the center of the experimental area. Hammer was used to install the double-ring infiltrometer ring up to the desired depth (usually up to 15 cm) depending on the field condition. The test was conducted by pouring water into the rings (inner and outer) at the same time to approximately up to the same depth. A meter rule was used to record the water level in the inner cylinder. A stopwatch was used to record the time with the corresponding depth of infiltration as determined by the rule. The procedure was repeated until at least three consecutive uniform infiltration depths were recorded. On the other hand, it's possible to employ Kostiakov's Equation (1932), a simplified version of the Infiltration equation that is widely used:

Equation 10: Cumulative infiltration rate (Y) $Y=at^b$

the cumulative infiltration Y, the time from the commencement of infiltration t, and the soil constants "a" and "a".

3.5 Land preparation and Field layout

The experimental field had dimensions of 27 m x 10 m, with plot sizes 3 x 1.8 m consisting of three rows (ridges) each. The distance between replications was 50 cm and between plots was 1 m. The entire field was marked out and the replications and plots were respectively demarcated with ropes and pegged. The 60 cm wide spaces for ridges were tilled to form yam ridges of 30 to 40 cm deep and 3 m long. The ridges were formed manually with the help of the African hoe.

3.5.1 Installation of Drip Irrigation System

Drip irrigation system design

The experimental field was prepared to make ideal growing conditions for the crops as well as to install an on-line surface drip system. The drip system is made up of a main line, lateral line, and dripper made of PVC. The main line was connected to the sub main line, and all drippers were on the laterals.

With the help of a water pump, a small-scale drip irrigation tank was filled with water, and the amount of water released to the field was calculated using the CROPWAT software.

The Polyvinyl chloride (PVC) main pipe line was installed beneath the ground, having "1" diameter. The submain was made up of ¾" PVC pipes.

Lateral lines were made of black low-density polyethylene (L.D.P.E) pipe having 25 mm diameter. Towards the end of each lateral, there was an end stop to prevent the lateral line from crossing over, thereby maintaining the lateral line water within a plot.

The drip tape had emitters spaced so that each emitter may supply water to a single plant, 30 cm is the ideal distance. (The discharge of one emitter was 1 L/h). In order to control the amount of water released from each emitter, the valves had to be opened and closed manually.

3.6 Irrigation

The irrigation system applied for this research work was a localized (drip) irrigation system. The system was powered by gravity and a centrifugal pump when the need arouses. The water source for irrigation was a regularly refilled polytank reservoir mounted on a 1 m metal stands to provide adequate head for running the irrigation system and delivering water at the required flow rate (discharge) to the field. The pumping unit fed the control head which consisted of a filter (disc) and a manually controlled valve. This section functions to filter dirt and particles from the water and to regulate the amount of water flowing to the irrigation facility. The mainline made of Polyvinyl chloride (PVC) pipes and fittings (elbows, tees, reducers and valves) continued from the control head to convey the filtered and regulated water to the submain and thence to the field. The submain carried the irrigation water to the lateral (drip tape) through PVC pipes and fittings at required operating pressure. The laterals were 16 mm diameter pipes with emitter spacing of 30 cm and a flowrate of 1 L/hr, at 10 m with a capacity of 25 m maximum pressure as stated by the manufacturer. This connection was taped from a 25 mm low density polyethene (LDPE) pipe with endcaps. The drip tapes were connected to the 25 mm pipe by 16 mm start connectors and ended with end caps to stop water spillage and end the laterals.

The drip tapes were laid on the ridges and maintained in a straight position with pegs and binding wire. The drip lines were flushed before the endcaps were connected to avoid the emitter clogging with debris. The system was run for an hour to observe for proper system functioning (emitters, joints, valves and fittings) and to check for linkages.

After the installation of the complete system, water distribution uniformity (DU) to the field by emitters was carried out by placing catch cans randomly on rows and for the whole field together (replication one, two and three; replication one; replication two; replication three; replication one and two; replication one and three; replication two and three) and operating the system for 15 minutes for each section to understand the efficiency of water distribution to the field from the emitters.

The amount of water to be irrigated and the schedule were done based on the weather parameters and adjusted crop parameters.

Soil total available water (TAW) was determined from the soil's bulk density, field capacity, permanent wilting point and soil depth as follows

Equation 11:Total available water (TAW), TAW = (FC -PWP) *Bd*Zr.

Where: Bd=bulk density,

FC=field capacity,

PWP=permanent wilting point and

Zr=soil depth (mm)

Available water (AWC) to the plant as delivered by one dripper was computed by

Equation 12:Soil available water content (AWC) AWC =TAW * Aw

Aw is the wetted area (%)

Readily available water (RAW) to the plant was estimated by

Equation 13: Soil readily available Water RAW (mm) = AWC*MAD

Where: MAD is management allowable depletion,

Equation 14:Soil readily available Water RAW (L) = RAW (mm) *A

Where A= area occupied by each plant in state units.

Reference Evapotranspiration (ETo): Long term (1970 - 2019) daily weather data from the CSIR-SARI was collected and used to calculate ETo. Climatic parameters that were used are maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (H), wind speed (at two meter) and sunshine hour (hrs), rain (mm). The conventional ETo was estimated by the CROPWAT software (FAO, version 8.0) using the FAO Penman-Monteith (Allen *et al*., 1998).

ETo was calculated from the assumption that there was no effective rain throughout the experimental period.

Crop coefficient (Kc) and length of growth stages were collected from FAO Irrigation and Drainage Paper 56 for sweet potatoes (Allen *et al.*, 1998) and adjusted with values gotten from (Mulovhedzi *et al.*, 2020) for sweet potatoes. The crop coefficient values for respective growth stages used for this experiment were 0.46, 0.97 and 0.44 for initial, mid and end stages, respectively. Based on the Kc values of the crop and length of each growth stages, the daily crop coefficient was interpolated for development and late season. Length of growth stages of 30, 45, 65 and 50 days for initial, development, mid-season and late season, respectively, were considered based on normal field practice.

Sweet potatoes irrigation and growth parameters were adjusted and used because yam as a crop is under development. Little about yam cultivated under irrigation has been reported as at the trial time.

ET_{C} (mm)=ETo*Kc, for conventional surface irrigation systems.

where ETc is crop evapotranspiration in mm per day, Kc is crop factor in fraction and ETo is reference crop evapotranspiration in mm per day.

For localized (drip) irrigation, we used Keller and Bliesner (1990) equation for estimating the daily ETcrop-loc for localized irrigation systems with a ground cover (P_d) of 95% by

Equation 15: Localized Crop water requirement ($ET_{c\text{-}localized}$) $= U_d\,[0.1(P_d)^{0.5}]$,

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

U_d = conventionally estimated peak ETcrop

P_d= percentage ground cover (%) (Andres and Karen, 2002).

The Net irrigation requirement (NIR) was calculated with the assumption of no effective rainfall (Pe) since the cultivation was done in the dry season and under complete irrigation. Therefore,

NIR=ETc−Pe.

But Pe=0, therefore

NIR(l) = $ET_{c\text{-localized}}$

The gross irrigation requirement was obtained from the following equation:

GIR (L)= $\frac{\mathrm{NIR}}{Ea}$ where;

GIR = Gross irrigation required (mm), NIR = Net irrigation required (mm),

Ea = irrigation application efficiency (%).

The maximum duration before the next irrigation was computed in terms of maximum irrigation interval as readily available water on NIR

Max irrigation interval = RAW/NIR

Irrigation cycle was calculated from GIR/Ea

The computation of the Udo irrigation depth was changed to equivalent amount of water and applied as runtime. From literature, the frequency and irrigation periods were gotten as every day for 100% ETC, after every one day for 75% ETc and after every two days for 50% ETc.

Irrigation run time, the time required to apply irrigation water was computed from the GIR and emitter discharge rate as below.

Irrigation runtime = GIR/emitter discharging rate

Calculated gross irrigation was finally applied to each experimental plot based on the proportion of the treatment in terms of runtime. The volume of water applied for every treatment was determined from plot area and depth of gross irrigation requirement. The time required to irrigate each treatment was calculated from the ratio of GIR to the discharge of the emitters.

Depending on the irrigation regime, the irrigation period per day (hrs/day) was computed as follows

$ID_{100\%ETc}$ =$GIR_{100\%ETc}$/emitter discharge

$ID_{175\%ETc}$ =$GIR_{75\%ETc}$/emitter discharge

$ID50_{\%ETc}$ =$GIR_{50\%ETc}$/emitter discharge

3.7 Cultural Practices

From the nursery, the plantlets were transplanted to the field and all recommended cultural practices were followed: irrigation, mulching, trailing, fertilizer application, weeding, insect- pest control, and reshaping of ridges.

3.7.1 Transplanting

After four weeks of rooting, the vines had developed 2 to 4 leaves and roots to enable the plant proper establishment in the field. The transplants were sorted from the nursery one week before transplanting and exposed to semi-open field conditions to harden the plants before onward transplanting to the field. One day to transplanting they were not watered. The rooted vines were transplanted at 30 days (DAP). The rooted vines were transplanted in the field by removing the transparent plastic and planting the plantlets with their rooting medium in the soil to facilitate crop acclimatization to soil and field conditions.

Transplanting was done on the evening of 2nd of December 2020 when the sun had gone down. One hour to transplanting, the field was thoroughly irrigated to field capacity and allowed for one hour for the irrigated water to penetrate the soil. In transplanting, holes of 5 to 10 cm deep were created beneath the emitters. The transplants and their growing media were planted in the holes and some soil was used to cover the growing medium in the hole and to firm the plantlet base. After transplanting, the plantlets were not irrigated. The field was irrigated to field capacity every day for two weeks to allow proper crop establishment before the experimental treatments of drip irrigation regimes and mulching were imposed. After transplanting, the field was shaded with a layer of shade net to reduce the amount of incident sunlight for 40 days.

3.7.2 Mulching

Mulching materials used in this trial were chopped rice straw (RS) and partially decomposed rice husk (PDRH). PDRH is a partially decomposed rice husk by naturally occurring soil and air micro-organisms or that has been heaped for at least five months. There were two types of mulch used, RS was applied at 1 ton per hectare and PDRH was 3 tons per hectare. These rates were broken down to plot sizes of 0.54 m^2. This rates sufficiently covered the soil. The entire plot was covered with mulch.

3.7.3 Trailing

Yam being a climber was supported by robes hooked to short pegs and planted in the soil around the plant stand and attached above the ground by a horizontal rope. Each plant was supported by one rope and all the plants in a plot were hooked to the horizontal rope above the ground to form a pyramid head. The rope was about 10 mm in diameter.

3.7.4 Fertilizer application

Fertilizer application started at 6 WATP and continued every two weeks till one month to harvesting. The fertilizer type applied was foliar NPK. N-P-K 19-19-19 was applied from 6WATP to 10 WATP. From 12WATP N-P-K 19-19-19 was applied and potassium fertilizer (multi-K; NPK 0- 13-49) was added since potassium encourages tuber bulking. The rate used for this research work was 90 g of NPK 19-19-19 in 15 L of water applied using a knapsack sprayer and 200g of multi-K to 15 L of water.

3.7.5 Weed control

Weeds were regularly controlled from the experimental field by hand picking.

3.8 Data Collection

Data collection began two weeks after transplanting (WATP). Data were grouped into; growth and vegetative parameters, soil parameters and yield parameters. Ten plants per plot were randomly selected and tagged for measurement of growth parameters such as plant height up to 12WATP, stem girth, number of internodes up to 10WATP, internode length, leaf area index (LAI), number of leaves per vine, plant stand per plot, canopy size, weed fresh and dry weight and, chlorophyll content.

The soil parameters included; soil moisture before irrigation, soil moisture after irrigation, percentage of soil total available water depletion, morning soil temperature (between 6:00 and

10:00 am), evening soil temperature (between 4:00 and 7:00 pm). Total N, P, C and K after crop harvest, soil physical properties after harvest.

Yield parameters collected included: number of mini tubers per plot, total mini tuber weight per plot, the average weight of mini tuber, mini tuber length, mini tuber width, grading of mini tubers, below-ground biomass.

3.8.1 Plant height

The height of each tagged plant was measured. Plant height was measured from the base to the apex of the youngest leaf using a meter rule every 14 days interval till 12 WATP.

3.8.2 Number of leaves

The number of leaves per plant was counted and recorded for the tagged plants every two weeks till 18 WATP. The average was computed and recorded.

3.8.3 Leaf length and Leaf width

Leaf length and width of the randomly tagged plants were measured and recorded every 14 days from 2WATP for three months. The leaf length and width were measured using the meter rule to ± 0.1 cm (Asfaw, A., 2016). The leaf length was measured from the apex to the start of the petiole while the width was measured at the center of the leaf from side to side. Three leaves were measured from each tagged plant and the average was taken.

The leaf area was obtained through the measurement of lengths and widths of the middle leaves of the tagged plants in a plot. The mean of the lengths and widths of the leaves was computed and used to estimate the leaf area after (Adubasim & Obalum, 2017)

Equation 16: Leaf area = length × width × 0.45.

Thereafter, leaf area index (LAI) was estimated with the following equation:

Equation 17 Leaf area index (LAI) = $\frac{leaf\ area}{area\ occupied\ by\ plant}$

3.8.4 Number and Length of internodes

The number of internodes from the soil level to the plant apex of the randomly tagged plants were counted and the average was computed and recorded. Internode length was measured using a meter rule at three points; 50, 100 and 150 cm above the soil level on each plant for all the tagged plants (Asfaw, A., 2016).

3.8.5 Stem girth and Canopy size

At eight weeks after transplanting, the stem girth of the randomly tagged plants per plot was measured at 50,100 and 150 cm from the soil level with the use of a vernier caliper. Three measurements were taken per plant and the average computed was determined and recorded.

The canopy size was recorded on a scoring basis based on the individual plot performance on a three-score scale: 1-large, 2- medium, and 3- small.

3.8.6 Chlorophyll content

Chlorophyll content of the leaves was taken from 4 WATP from five leaves per plant from the tagged plants. Chlorophyll was measured with the use of a SPAD chlorophyll meter manufactured by KONICA MINOLTA INC in USA

3.8.7 Soil data and weed biomass

Soil moisture was measured before and after irrigation from six stops on each plot at three depths (0 -10, 10-20, 20-30 cm) at each stop directly under the emitter where the soil was a little firm to ensure good contact and correct soil moisture readings. Moisture was measured one hour before irrigation from all the plots that were to be irrigated using a time-domain refractometer (TDR) manufactured by spectrum technologies Inc in USA. At least one hour after irrigation, soil moisture was measured.

Soil temperature was taken from 0-10, 10-20, 20-30 cm from two stops from each plot in the morning (6:00- 10:00 am) and evening (4:00 – 7:00 pm) once every seven days using Hanna HI935005 K-type thermocouple thermometer manufactured Hanna Instrument USA.

Weed fresh and dry weight was measured by collecting all the weeds from each plot at 4, 8 and 12 WATP. The fresh weight of the weeds was recorded and then dried in the oven at 80^{o}C for 48 hours; the dried weight was measured using a sensitive electronic balance. The oven was a drying oven manufactured by Huanghua Faithful instrument Co., LTD, China.

3.8.8 Yield, above and below-ground biomass and Crop Water Productivity

At harvest, the number of plants stands per plot were counted and the survival rate was estimated from the ratio of plant stand at harvest to the number transplanted.

The number of mini tubers harvested per plot was counted and recorded.

Total weight of mini-tubers per plot, the total yield of yam mini-tubers was obtained by adding all the mini-tubers harvested per plot and weighed using a sensitive electronic balance manufactured by Joanlab in China.

The average weight of mini tuber per plot, the mean mini tuber weight per plot was computed from five randomly selected mini tubers at harvest. The ten mini tubers were weighed and the weight was divided by the number of mini-tubers weighed.

Mini tuber length, the lengths of five randomly selected mini tubers per plot were measured from the bottom to the comb using a measuring tape and the mean value was computed. Mini tuber width, the mean girth of mini tuber at harvest was computed by measuring the diameters at the middle of five randomly selected mini-tubers in each plot using a measuring tape. The harvested tubers were graded into classes from less than 10 g to greater than 100 g per plot.

Crop fresh weight was done by harvesting three crops per plot and weighing the fresh vine and tubers then drying and weighing again. Each sample was placed in a paper bag and oven-dried at 80°C until a constant weight was attained. Each sample was then immediately weighed and recorded as dry weight yield.

Water productivity was estimated as a ratio of mini-tuber yield (Yld) to the total ETc through the growing season and it was calculated using the following

Equation 18: crop water productivity CWP $= \frac{Yld}{ETc}$

where CWP is crop water productivity (kg/m³), Yld is crop yield (kg/ha) and ETc is the seasonal crop water consumption (m³/ha).

3.8.9 Soil physical and chemical properties after harvest

After harvest, soil physical and chemical properties were determined to characterize the effects of irrigation regimes and mulching on the soil of the experimental field. Disturbed and undisturbed soil samples were taken across the field to a depth of 0-20,20-40 cm and bulked for laboratory analysis. Two volumetric samples were taken from each research treatment plot after harvest in two replicates per plot. The soil samples were analyzed and the bulk density, pH, and infiltration rate determined.

3.9 Statistical Analysis

Count and scoring data were transformed using a log to the base ten transformations. Data collected on all parameters/ response variables were subjected to analysis of variance (ANOVA) using the GenStat statistical package12th Edition. Means separation was done by Duncan's multiple range test (DMRT) at 5% level of probability. Correlation analysis was done to examine the association between the parameters measured.

CHAPTER FOUR

4.0 RESULTS

4.1 Long Term Weather Data

Monthly averages of climate parameters: minimum temperature, maximum temperature, relative humidity, wind speed, sunshine hours, radiation, reference evapotranspiration, and rainfall from 1970 to 2019 were used to compute crop water requirements (**Table 2**).

Table 2: Monthly averages of weather parameters from CSIR-SARI for 1970 to 2019.

Month	MinT °C	MaxT °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day	Rain mm
January	20.5	35.6	26	112	7.3	18.3	4.89	1.8
February	22.8	37	33	112	7.2	19.2	5.24	11.4
March	24.4	36.8	44	112	7.3	20.6	5.48	35.2
April	24.4	35.6	62	121	6.9	20.2	5.2	76.7
May	23.9	33.5	71	112	7	19.9	4.76	108.4
June	22.2	31.1	78	104	6.3	18.5	4.09	138.3
July	22.2	29.7	79	121	5	16.7	3.71	175.2
August	21.7	29.5	80	112	3.9	15.2	3.42	182.7
September	21.7	30	80	78	4.7	16.4	3.5	216.3
October	21.7	32.1	74	78	6.9	19.1	4.04	90.4
November	21.7	35	58	69	8.1	19.5	4.28	6.5
December	20	35	38	86	7.4	17.9	4.29	2.9
Average	22.3	33.4	60	102	6.5	18.5	4.41	1045.8

4.2 Soil physical properties

The baseline results of soil physical properties showed that the experimental soil texture was sandy loam, high in gravel, slightly acidic, moderate in organic carbon content, and high in bulk density (**Table 3**).

Table 3: Baseline results of soil physical properties

Soil properties	0-20 cm	20-40 cm
Particle's size		
% Clay	5.84	7.76
% Sand	54.84	53.04
% Silt	39.32	39.2
Soil texture	Sandy loam	Sandy loam
% Gravel by Mass <2mm	43.3	53.4
Total organic matter (%)	2.88	1.34
Permanent wilting point %	4.9	7.4
Field capacity %	18.4	20.2
Saturations %	47.5	47
PH (1:2.5)	5.65	6.06
Bulk density (g cm^{-3})	1.69	1.27
Porosity %	36.24	52.15
Saturated hydraulic conductivity (k_s cm/min)	0.075	0.44

4.3 Soil and water Chemical properties

The soil and irrigation water chemical properties results showed that the experimental site was slightly acidic, low in total Nitrogen(N), and high in available Phosphorus(P), Potassium(K), and Electrical Conductivity (EC) (**Table 4**).

Table 4: Baseline Soil and water Chemical properties

Soil depth(cm)	**EC (µS/cm)**	**pH**	**% OC**	**% N**	**P (mg/kg)**	**K (mg/kg)**	**Ca (Cmol/kg)**	**Mg (Cmol/kg)**
0-20	0.92	5.44	0.741	0.068	4.65	64	3.4	5.2
20-40	0.83	5.25	0.527	0.049	3.35	42	2.8	1.2

Water	**pH**	**EC**	**Salinity**	**TDS**
		µS)	**µS)**	**(mg/l)**
	6.55	13.41	13.42	8.04

EC=Electrical conductivity, OC=Organic carbon, P=phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, TDS=Total dissolvable solids

4.4 Soil infiltration

Data collected at the field from a double ring infiltrometer on infiltrated depth and time taken was tabulated. This data was used to generate the cumulative infiltration and the infiltration rate curves (**Figure 2**). The infiltration rate which is the speed at which water enters the soil is measured by the depth of the water that can enter the soil in one hour. The average infiltration rate in this experiment was found to be 15.13 mm/hr. (Hillel, 2004). This means that a water layer of 15.13 mm on the soil surface takes one hour to infiltrate.

4.4.1 Infiltration rate Before planting

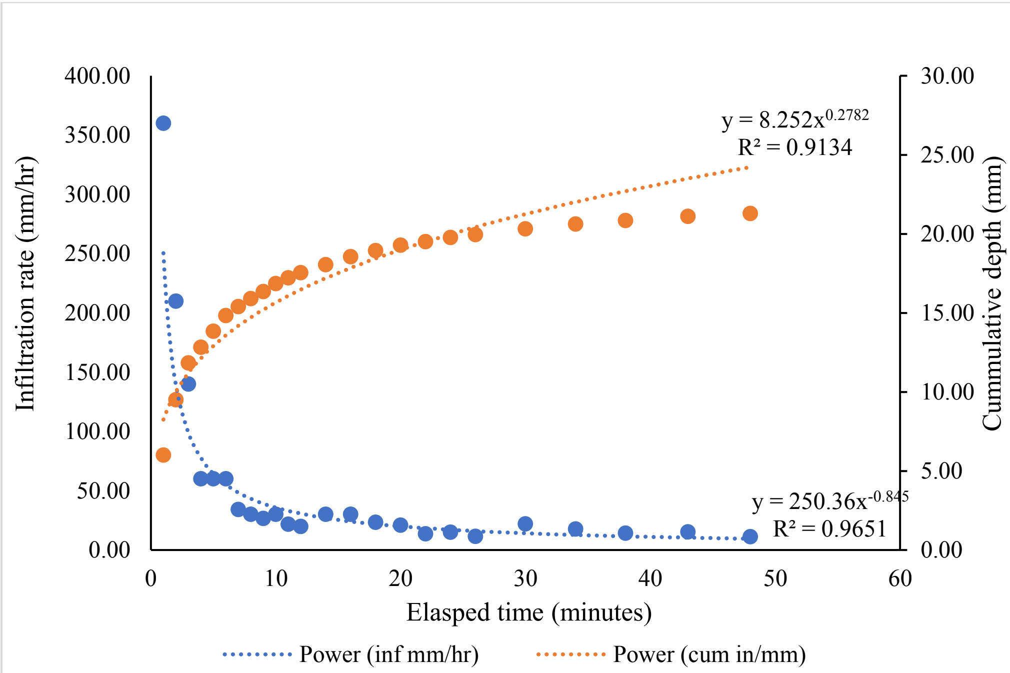

Figure 2: Infiltration rate and Cumulative infiltration depth before the experiment

4.4.2 Infiltration rate After harvest

The infiltrated depth with the time taken was used to generate the cumulative infiltration (**Figure 3**) and the infiltration rate curves (Figure 4). The average infiltration rate of the various treatments was found to be 187.92, 102.87, 86.61, 25.54, 79.12, 18.77, 50.81, 60.49, 59.76 mm/hr. for T1, T2, T3, T4, T5, T6, T7, T8 and T9 respectively.

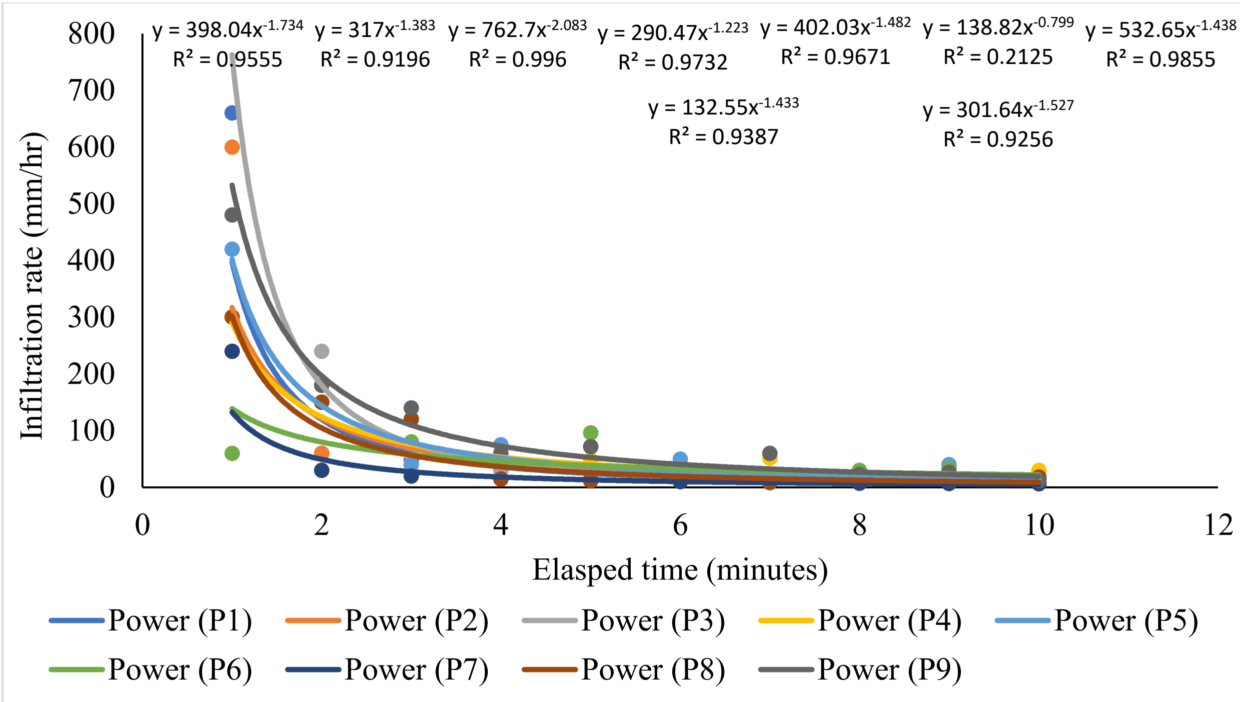

Figure 3: Infiltration rate of the soil of various treatment after harvest

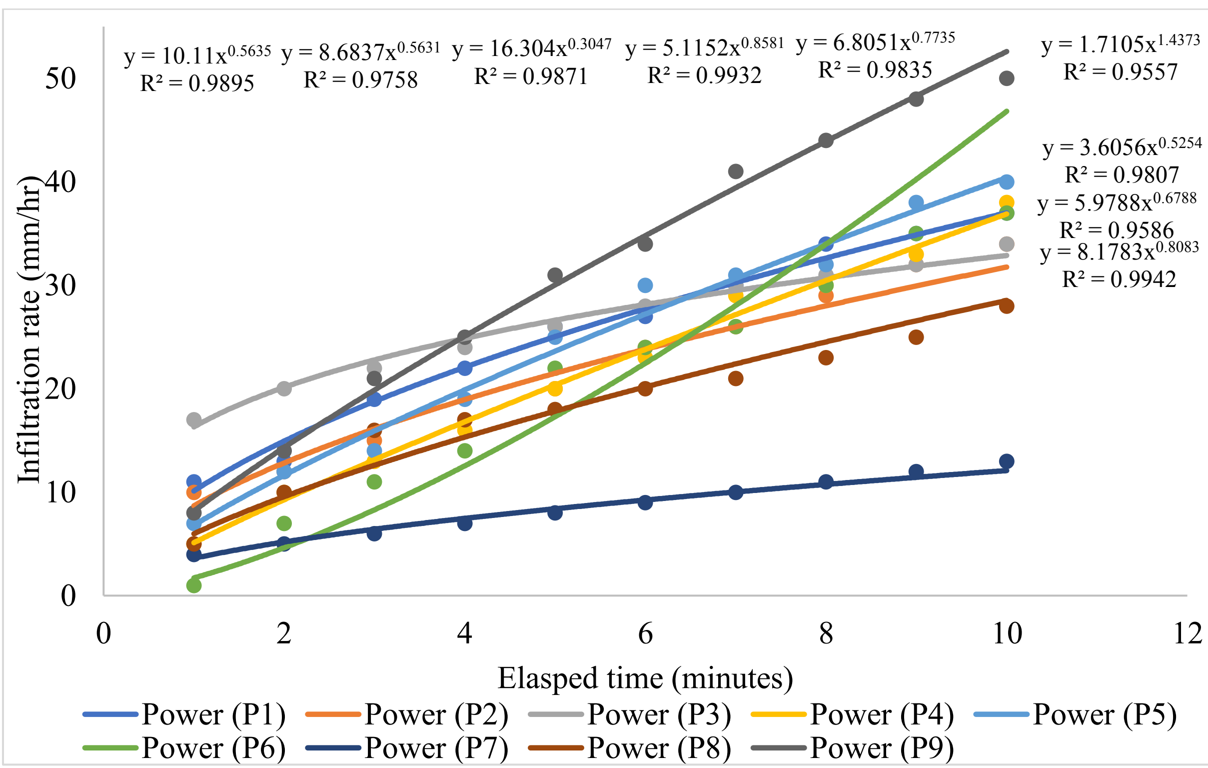

Figure 4: Cumulative infiltration depth of the soil of various treatment after harvest

4.5 Distribution uniformity of the Drip Irrigation System

This term describes how uniformly water is distributed during an irrigation event using drip irrigation systems **(Equation19**). Some parts of the irrigated area will receive different amounts of water if the irrigation application is not consistent.

Equation 19: distribution Uniformity (DU) DU = $\frac{Qlq}{Qa}$

in which: Qlq = average discharge rate of the lowest 1/4 of emitter discharge observations (l/hr) and Qa = average discharge rate of all observations (l/hr).

The emission uniformity of the experimental site was determined for the field as 89.5%, the highest DU was recorded by Replications 1 plus2 as93.6% and the lowest was for Replication 2 plus as 87.2% (**Table 5**).

Table 5:Variation of drip system emitter distribution uniformity.

	$R_1+R_2+R_3$	R_1+R_2	R_1+R_3	R_2+R_3	R_1	R_2	R_3
Qmin	155.0	156.3	158.0	151.7	158.8	166.3	171.3
Qmax	206.7	196.7	220.0	220.0	220.0	220.0	216.7
Qa	178.1	169.2	198.0	181.7	171.8	186.8	196.1
Qlq	159.5	158.3	174.4	158.4	159.4	166.9	177.2
DU%	89.5	93.6	88.1	87.2	92.8	89.3	90.3

4.6 Irrigation deficit of yam seedlings and crop water requirements

The crop water requirement (ETc) is estimated for yam single nodes generated from yam vines over the growing season (**Table 6**). Based on recognized procedures, it was calculated using average weather data (Allen *et al*., 1998). Seasonal crop water requirement was determined based on the monthly ETo and seasonal Kc from transplanting to harvest and it varied based on treatments. The highest net irrigation water application was 4.95 mm per day for April obtained from the 100% ETc treatment and the minimum was 1.52 mm per day for the month of May from the highly stressed treatment 50% ETc.

Table 6: Crop water requirement and deficit irrigation level of yam seedlings

Parameters	Jan	Feb	March	April	May
ETo (mm/day)	4.46	5.16	5.36	5.08	4.72
Kc	0.63	0.9	0.94	0.71	0.44
ETc (mm/day)	2.81	4.64	5.04	3.61	2.08
Localized ETc (mm/day)	2.74	4.53	4.91	3.52	2.02
100% ETc (mm/day)	2.74	4.53	4.91	3.52	2.02
75% ETc (mm/day)	2.05	3.39	3.68	2.64	1.52
50% ETc (mm/day)	1.37	2.26	2.46	1.76	1.01

4.7 Soil Moisture Variation

4.7.1 Soil Moisture before irrigation

The results of soil moisture measured before irrigation showed that rice straw and partially decomposed rice husk respectively conserved soil moisture better than no mulch at 100%, 75% and 50% ETc (**Figure 5**). The highest soil moisture recorded before irrigation for 50% ETc was observed for Rice straw mulch as16% and the lowest was noted for No mulch as 6%. Rice straw and partially decomposed rice husk respectively conserved soil moisture better than no mulch at 75% ETc (**Figure 6**). The highest soil moisture recorded before irrigation for 75% ETc was observed in Rice straw mulch as 16.8% and the lowest was noted in No mulch to be 8%. Rice straw recorded the highest soil moisture before irrigation followed by partially decomposed rice husk then-No mulch at 100% ETc (**Figure 7**). The average highest soil moisture recorded before irrigation for 100% ETc was observed in Rice straw mulch to be 18.9% and the lowest was noted in no mulch as10.9%.

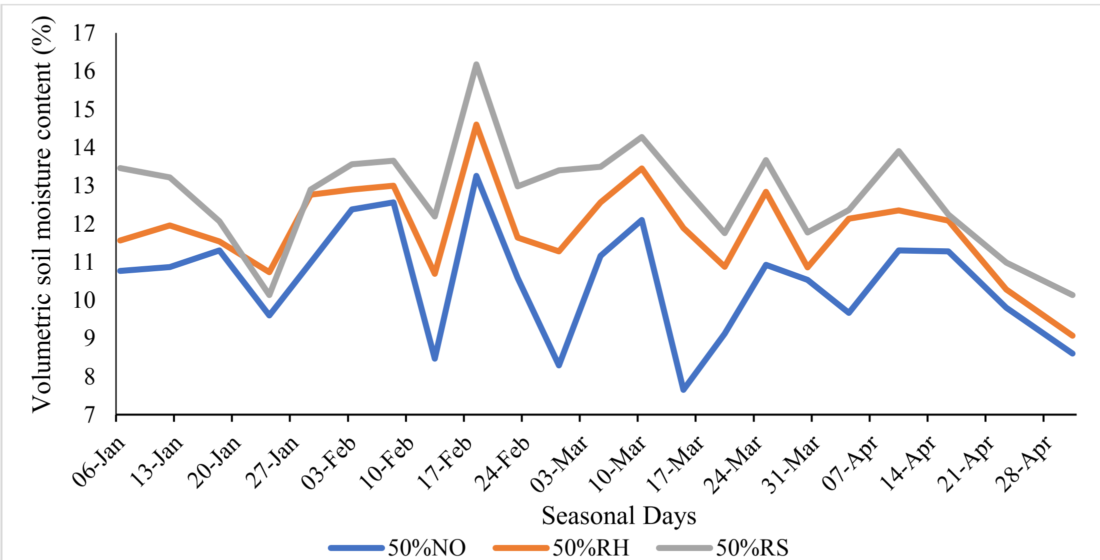

Figure 5: Soil Moisture before irrigation for 50% irrigation

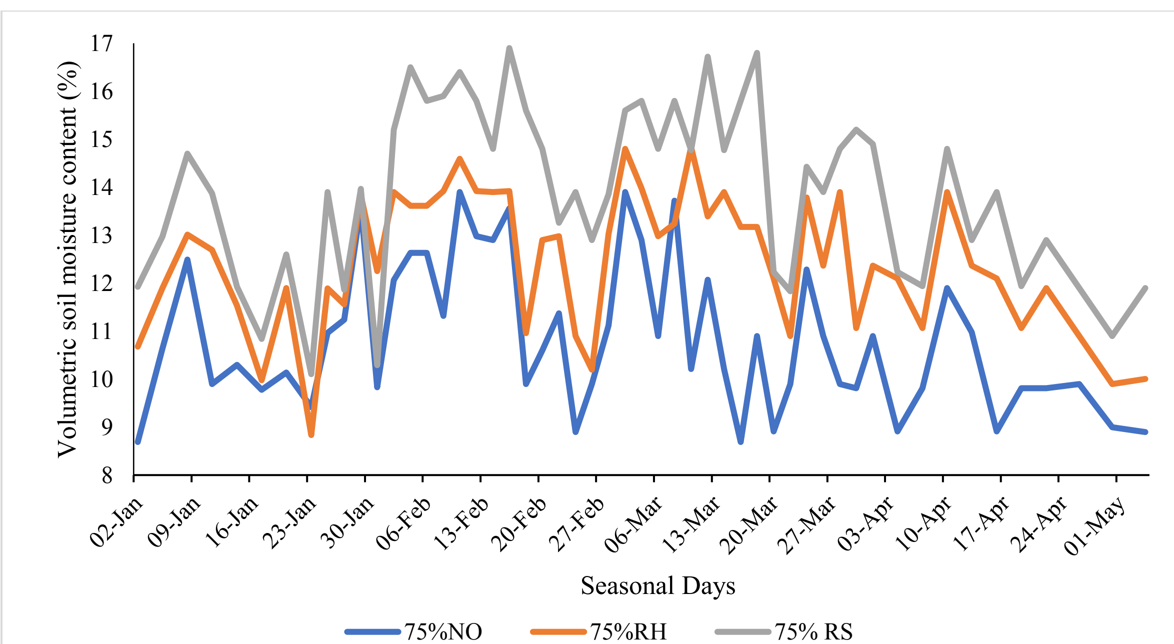

Figure 6: Soil Moisture before irrigation for 75% irrigation

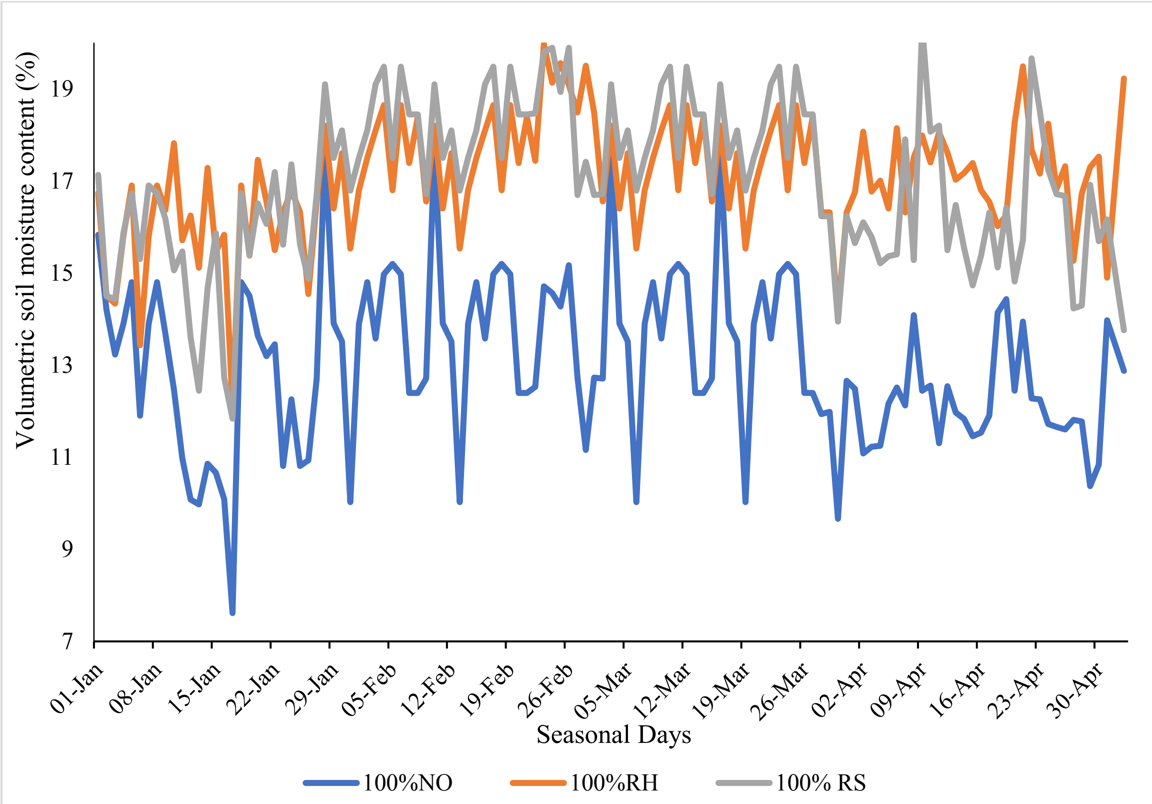

Figure 7: Soil Moisture before irrigation for 100% irrigation

4.7.2 After irrigation soil moisture

The moisture content of the soil after irrigation showed that 100% ETc replenishes soil moisture back to field capacity of 19.3 and above for mulching material, with rice straw, partially decomposed rice husk, with no mulch having values slightly lower than field capacity. For 50% ETc, rice straw had the highest average soil moisture content and no mulch recorded the lowest average soil moisture one hour after irrigation (**Figure 8**). For 75% ETc, rice straw had the highest moisture content, followed by aged rice husk and No mulch, a similar pattern was observed for 50% ETc (**Figure 9**). For 100% ETc, rice straw had the highest moisture content, followed by partially decomposed rice husk and No mulch (**Figure 10**).

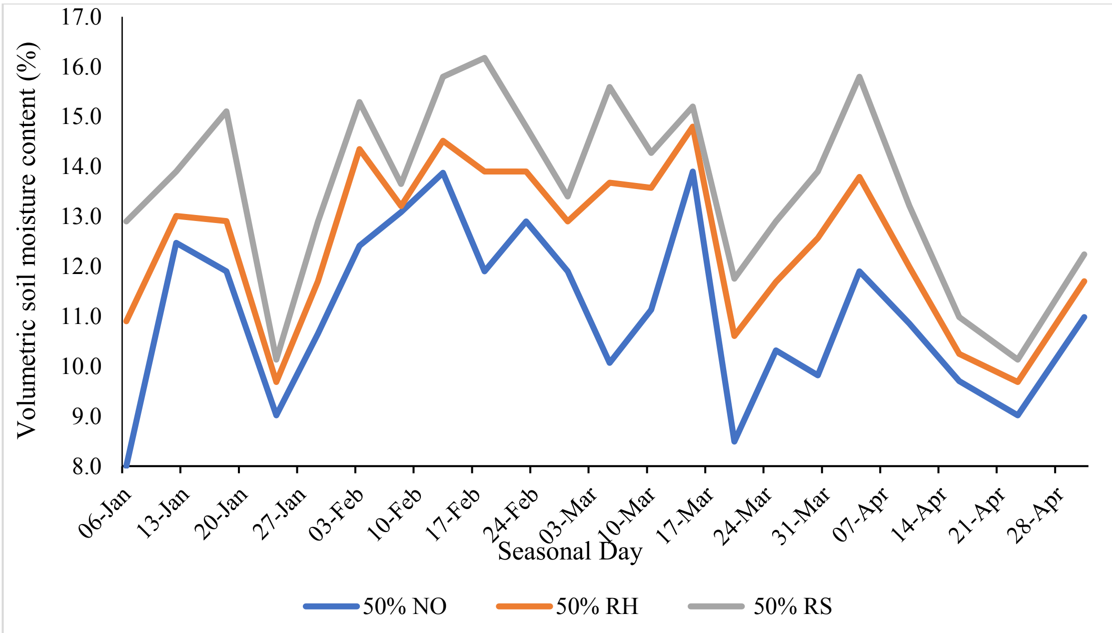

Figure 8: Average moisture content after irrigation for 50% irrigation

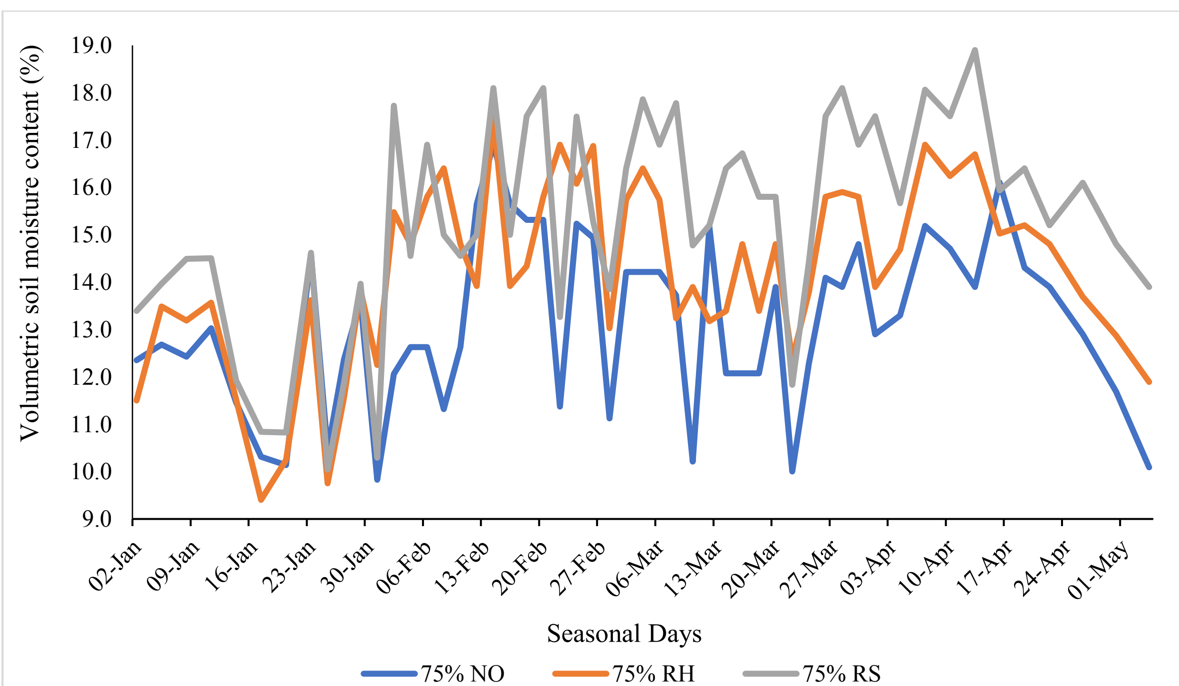

Figure 9: Average moisture content after irrigation for 75% irrigation

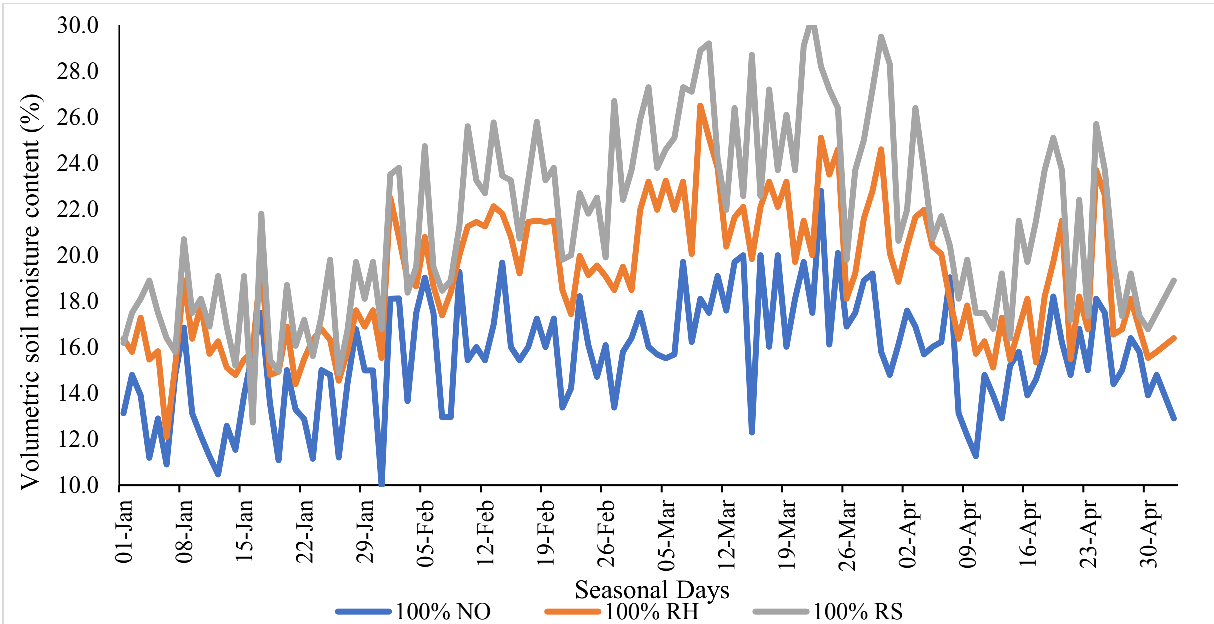

Figure 10: Average moisture content after irrigation for 100% irrigation

4.8 Soil Temperature

4.8.1 Soil temperature in the morning

All experimental treatments that were mulch together with irrigation levels increased soil temperature continuously in the morning across the months compared to the minimum atmospheric temperature (Tmin) (**Figure 11**). Irrigation at 50% no mulch and 75% No mulch had the highest morning temperature and 100% partially decomposed rice husk and 75% rice straw having the lowest temperatures between 6:00 am and 9:00 am respectively.

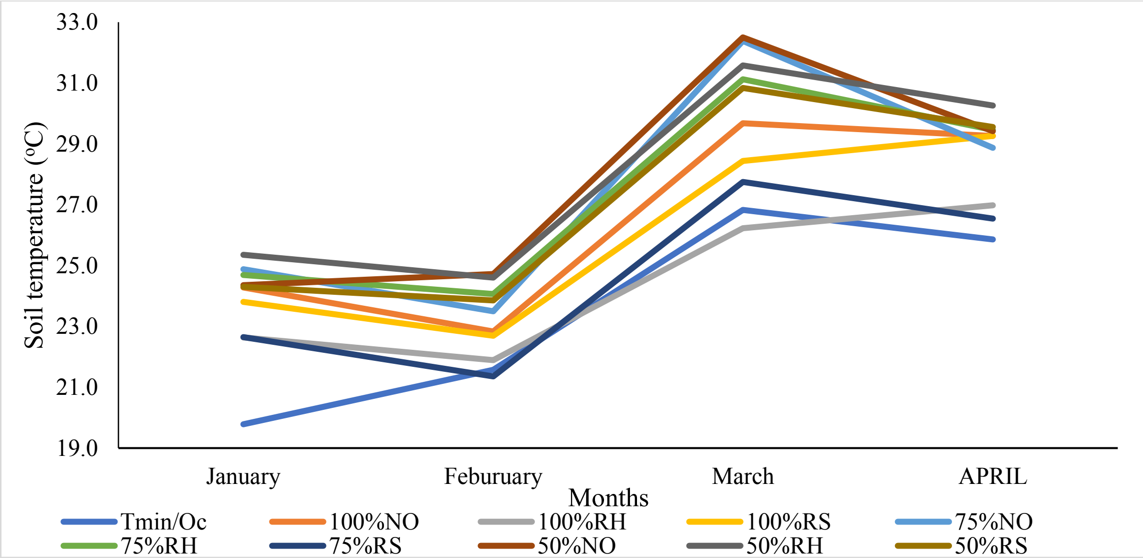

Figure 11:Variation of morning soil temperature with mulch and irrigation levels

4.8.2 Soil temperature in the evening

Mulch together with irrigation levels decreased soil temperature continuously in the evening across the months compared to the maximum atmospheric temperature (Tmax), with 50% No mulch and 75% ETc No mulch having the high evening temperature and 100% ETc rice straw and 50% ETc rice straw having the lowest temperatures between 3:00 pm and 6:00 pm respectively (**Figure 12**).

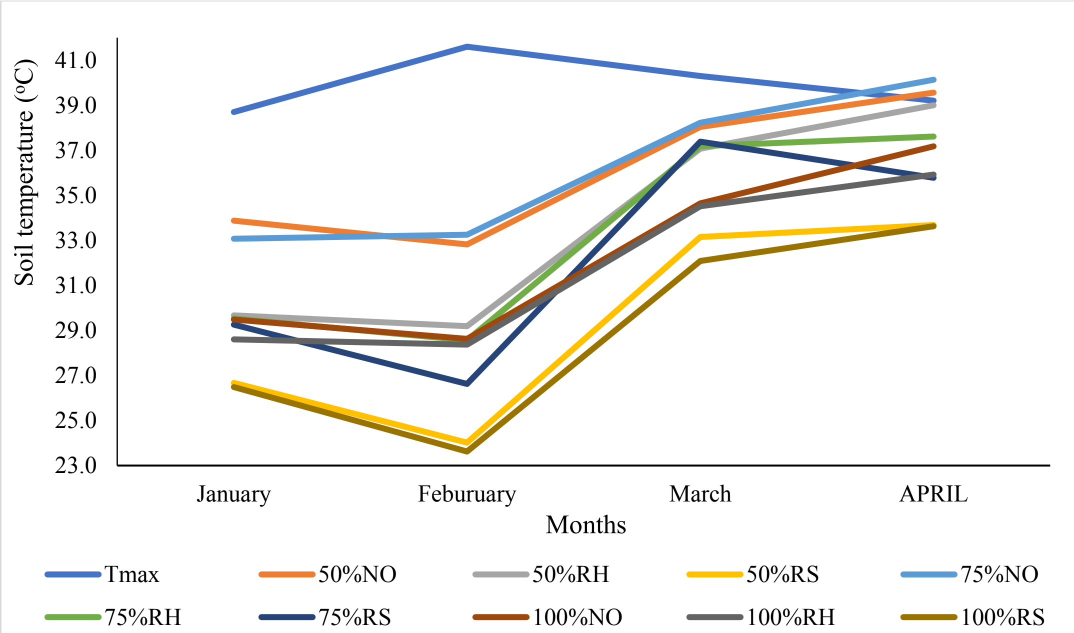

Figure 12:Variation of evening soil temperature with mulch and irrigation levels.

4.9 Growth parameters

4.9.1 Plant stands per plot

The interaction of irrigation levels and mulch significantly (*p<0.001*) affected plant stands at 16 and 18 WATP **Figure 10**. Irrigation at 100% ETc and partially decomposed rice husked recorded the highest number of plants as 29 plants per plot. This was followed by irrigation at 75 % ETc and partially decomposed rice husked with the number of plants as 26 at 18 WATP. Irrigation at 75% ETc with No mulch was the least with a record of 19 plants per plot at 18 WATP.

Table 7: Interaction of irrigation levels and mulching on plant stands per plot.

Irrigation (% ETc)	16 WATP			18 WATP		
	Mulching material					
	ZM	PDRH	RS	ZM	PDRH	RS
IRR 50 %	25c	25c	25.5bc	21.5c	23c	22c
IRR 75 %	21d	26bc	25c	19.5d	26.5b	25b
IRR 100%	29.5a	29.5a	27b	28.5a	29.5a	26.5b
LSD (0.05)			1.56			1.77
p-value			>0.001			>0.001

4.9.2 Plant height

The interaction of irrigation regime and mulch significantly (*p<0.05*) affected plant height at 12WATP. The main effects of irrigation and mulch significantly (*p<0.05*) affected plant height from 2 WATP to 12 WATP. Irrigation at 100% ETc and partially decomposed rice husk (PDRH) increased plant height to 160 cm (**Figure 13**). However, plants treated with irrigation at 75% ETc and PDRH were 140 cm tall, which was similar to the maximum. Irrigation at 75% ETc with No mulch gave the lowest plant height of 90 cm.

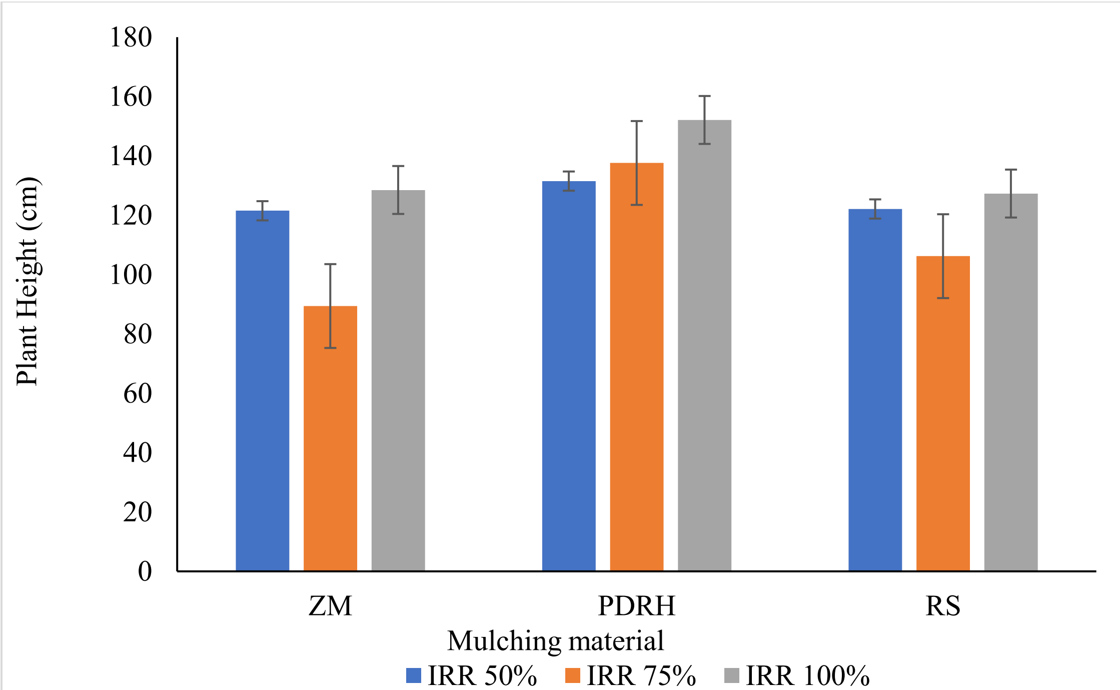

Figure 13: Interaction of irrigation regime and rice mulch material of plant height at 12WATP. Bar = SEM.

4.9.3 Number of leaves

There were statistically significant differences in the response of the number of leaves of yam to the main effects of irrigation and mulch at (*p<0.001*) at 18 WATP. However, the interaction of irrigation by mulch had no significant effects on the number of leaves. The number of leaves produced by 100% ETc at 16 and 18 WATP ranged from 200 to 250, and however, that of 75% ETc and 50% ETc, gave similar results (**Figure 14**). Partially decomposed rice husk mulch increased the number of leaves by 32% compared to No mulch and by 20% compared to rice straw (**Figure 15**). No mulch registered the smallest number of leaves as 80.

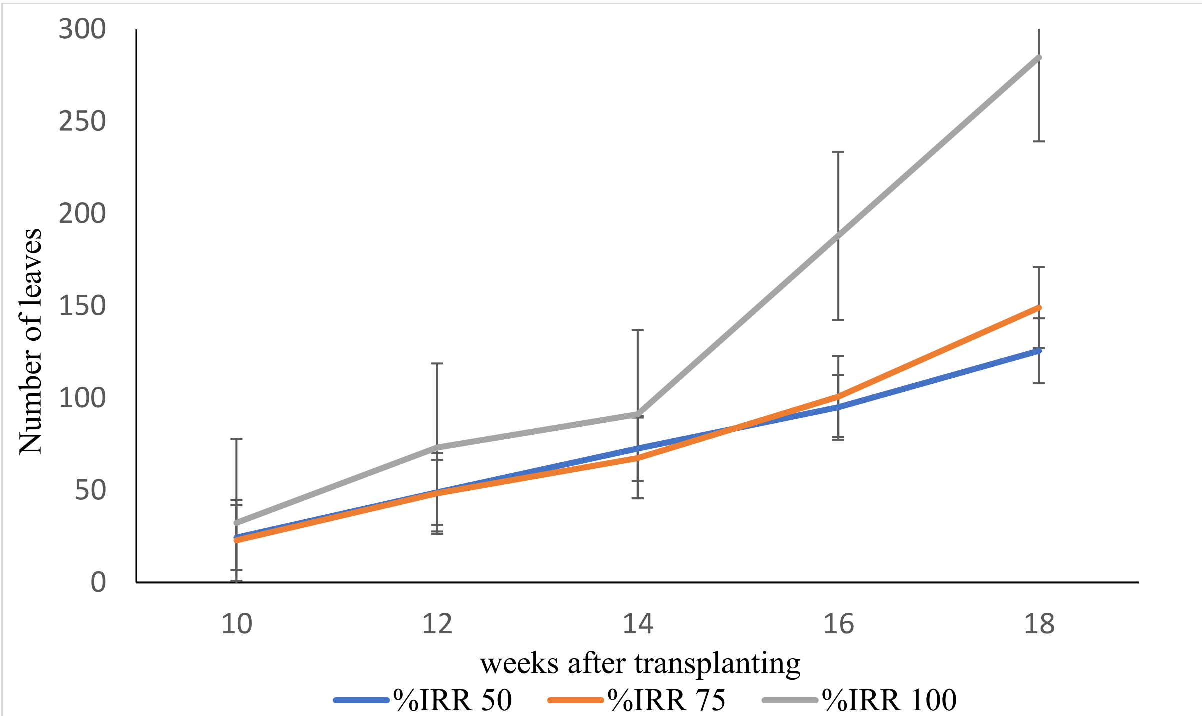

Figure 14: Effect of level of irrigation on the number of leaves of yam. Bar =SEM

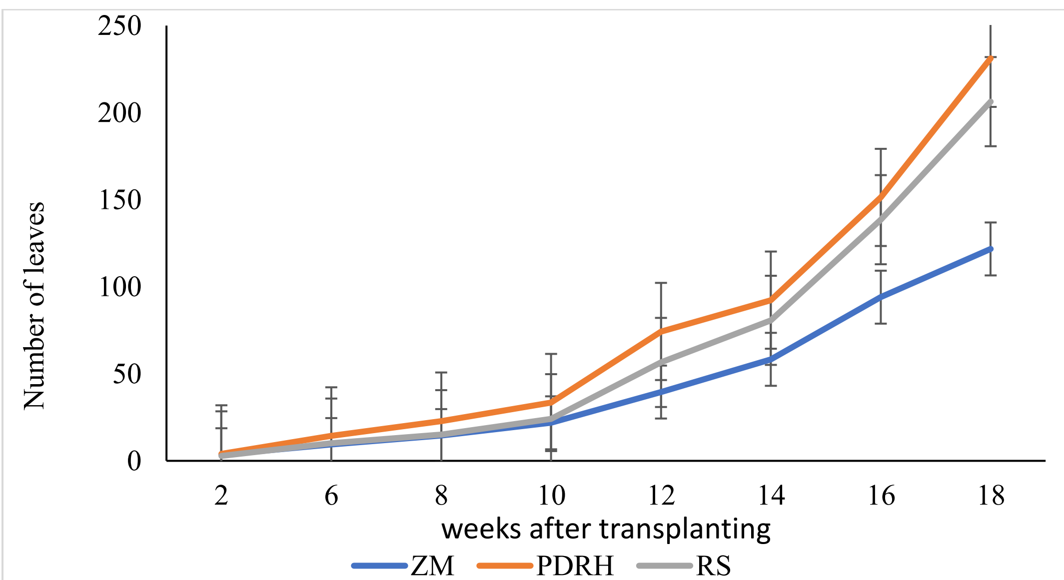

Figure 15: Effect of mulching material on the number of leaves of yam. Bar =SEM

4.9.4 Leaf area index

The interaction of irrigation levels and mulch significantly (*p< 0.05*) affected the leaf area index (LAI) of yam at 10 WATP. Irrigation at 100% ETc together with partially decomposed rice husk increased LAI this was followed by irrigation at 100% with rice straw mulch. Irrigation at 75% ETc with No mulch registered the lowest LAI (**Figure 16**).

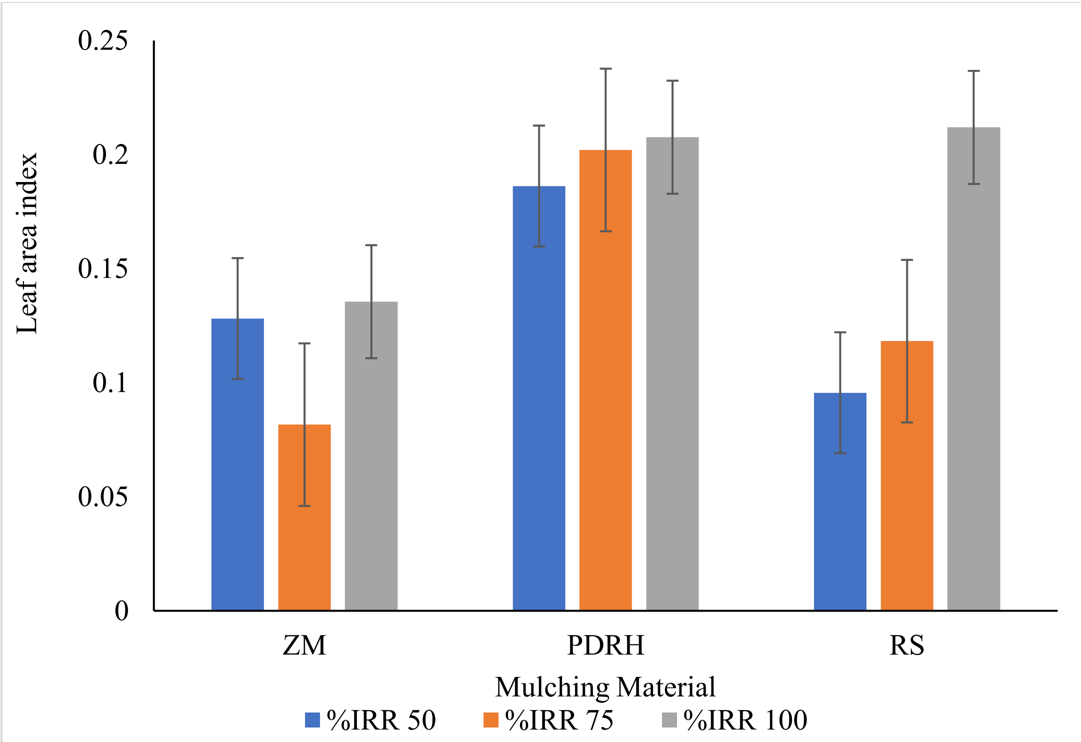

Figure 16: Interaction between levels of irrigation and mulching material LAI at 10WATP. Bar =SEM

4.9.5 Chlorophyll Content (Spad)

The interaction of irrigation levels and mulch application significantly (*p< 0.001*) affected the leaf chlorophyll content of yam at 8 and 16 WATP. The interaction effects of irrigation and mulch were not significant throughout the crop's growing season (**Table 8**). At the weekly levels, for 4 WATP, 75 % irrigation in combination with PDRH recorded the highest chlorophyll. For weeks 8and 16, irrigation at 100% together with PDRH over took 75% irrigation with PDRH in chlorophyll content. Irrigation level at 100% ETc together with partially decomposed rice husk, increased plant chlorophyll content to 53 spad. This was followed by an irrigation level at 50%

ETc with rice straw mulch with a value of 51 spad. Irrigation at 75% ETc with No mulch registered the lowest leaf chlorophyll content of 28 spad.

Table 8: Interaction between the level of irrigation and mulching material on chlorophyll content (spad) of yam.

Irrigation (% ETc)	4 WATP			8 WATP			16 WATP		
	Mulching material								
	ZM	PDRH	RS	ZM	PDRH	RS	ZM	PDRH	RS
IRR 50	28.9ab	29.6a	30.1a	37.1de	37.1de	38.3cd	48.4b	50.5ab	51.7ab
IRR 75	28.5ab	29.8a	26.8b	34.8f	40.2b	39.4bc	42.5c	49.0b	51.3ab
IRR 100	23.6c	26.4b	27b	36ef	42.4a	42.3a	51.1ab	53.2a	48.7b
LSD (0.05)	2.4			1.7			3.1		
	0.047			<.001			<.001		

WATP=Weeks After Transplanting, ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.9.6 Number of internodes

The interaction of irrigation levels and mulch significantly (*p<0.03*) affected the number of internodes per plant. The interaction effects of irrigation and mulch were significant at 14 WATP in the crop growing season. Irrigation application at 75% ETc together with partially decomposed rice husk increased the number of internodes to about 95 internodes per plant, this was followed by irrigation at 100% ETc with rice straw mulch with a value of 89. Irrigation at 75% ETc with No mulch registered the lowest number of plant internodes of 36 (**Table 9**).

Table 9: Interaction between the level of irrigation and mulching material on the number of internodes of yam.

Irrigation (% ETc)	10 WATP			12 WATP			14 WATP		
	Mulching material								
	ZM	PDRH	RS	ZM	PDRH	RS	ZM	PDRH	RS
IRR 50	26.5ab	25ab	20.5bc	42c	47bc	36c	69.5abc	59.5cd	68.5abc
IRR 75	18c	25ab	21bc	23c	66.5ab	33.5c	36d	95.5a	54cd
IRR 100	22.5bc	31a	30.5a	41c	81.5a	76.5a	64bc	88.5ab	89.5ab
LSD	5.972			21.91			25.45		
(0.05)	0.030			0.032			0.009		

WATP=Weeks After Transplanting, ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.9.7 Internode length

The interaction of irrigation levels and mulch had a significant ($p<0.001$) impact on length of internodes of the plants. The interaction effects of irrigation and mulch were significant at 2, 4, 10, and 14 WATP in the crop growing season (**Table 10**). Irrigation at 75% ETc together with rice straw mulch gave the longest internode length per plant, this was followed by irrigation at 100% ETc with no mulch with a value of about 5.8 cm. Irrigation at 50% ETc with No mulch registered the shortest plant internode length by the close of the experiment.

Table 10: Interaction between the level of irrigation and mulching material of Internode length of yam

Irrigation (% ETc)	4 WATP			10 WATP			14 WATP		
	Mulching material								
	ZM	PDRH	RS	ZM	PDRH	RS	ZM	PDRH	RS
IRR 50	5.2b	5.3b	5.1b	4.6bc	4.9ab	5.1ab	4.7e	5.4bc	5.5bc
IRR 75	5.3b	4.8b	7.1a	4.3c	4.9ab	4.3c	4.9de	5.3bc	6.3a
IRR 100	7.1a	4.7b	5.6b	5.3a	5.1ab	5.2a	5.9b	5.4bc	5.5bc
LSD (0.05)	1.38			0.47			0.439		
	0.010			0.033			<.001		

WATP=Weeks After Transplanting, ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.9.8 Weed fresh weight

Weed fresh weight was significantly (*$p<0.001$*) affected by the main effects of irrigation and mulch. Irrigation application at 100% ETc had the highest fresh weight of weed, followed by 75% ETc. **W**ater levels of 50% ETc had the smallest weed fresh weight (**Figure 17)**. No mulch had the highest fresh weed weight**,** followed by partially decomposed rice husk (**Figure 18:)**. Rice straw had the smallest weed fresh weight. A range of 50 g to 180 g was produced per treatment.

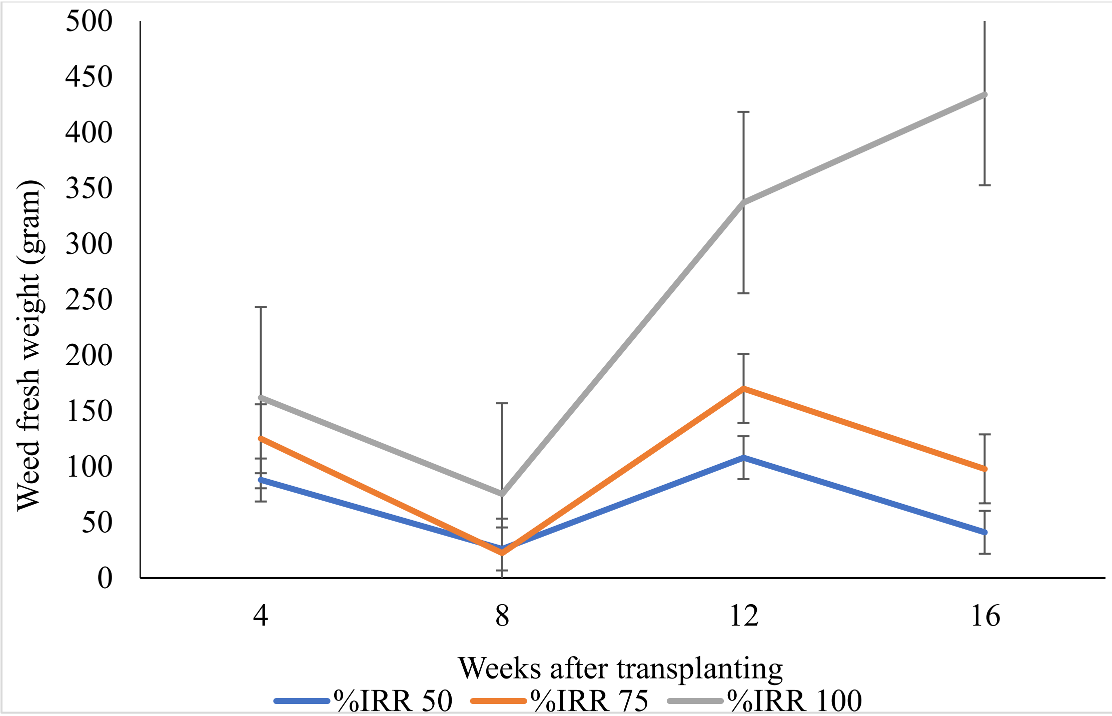

Figure 17: Effect of irrigation level weed fresh weight (g) of yam. Bar =SEM

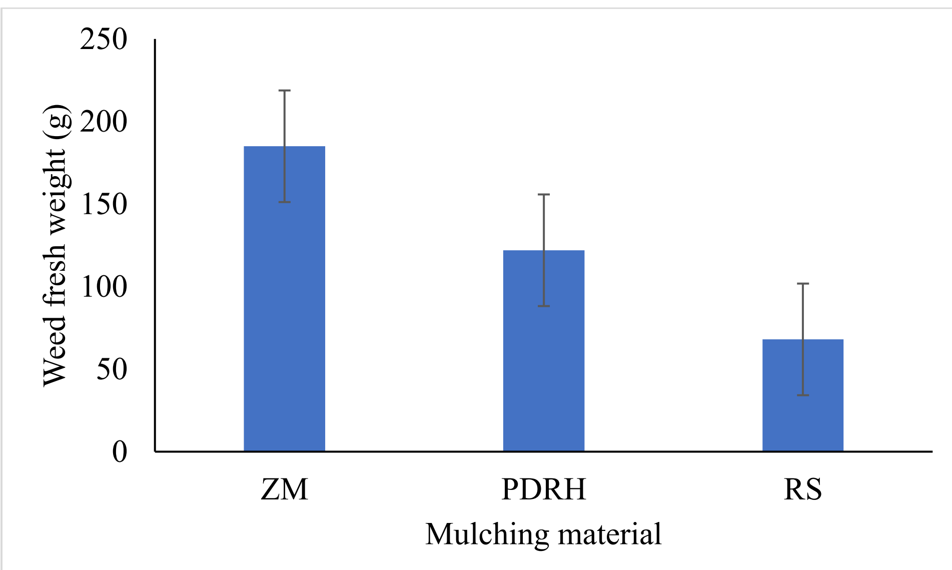

Figure 18: Effect of mulching material on weed fresh weight (g) of yam

4.9.9 Weed dry weight

Weed dry weight was significantly (*$p<0.01$*) affected by the main effects of mulch at 12 WATP. Rice straw had the highest dry weed weight of70 g, followed by No mulch with 40 g as dry weed weight. Partially decomposed rice husk had the smallest weed dry weight of 35 g (**Figure 19)**

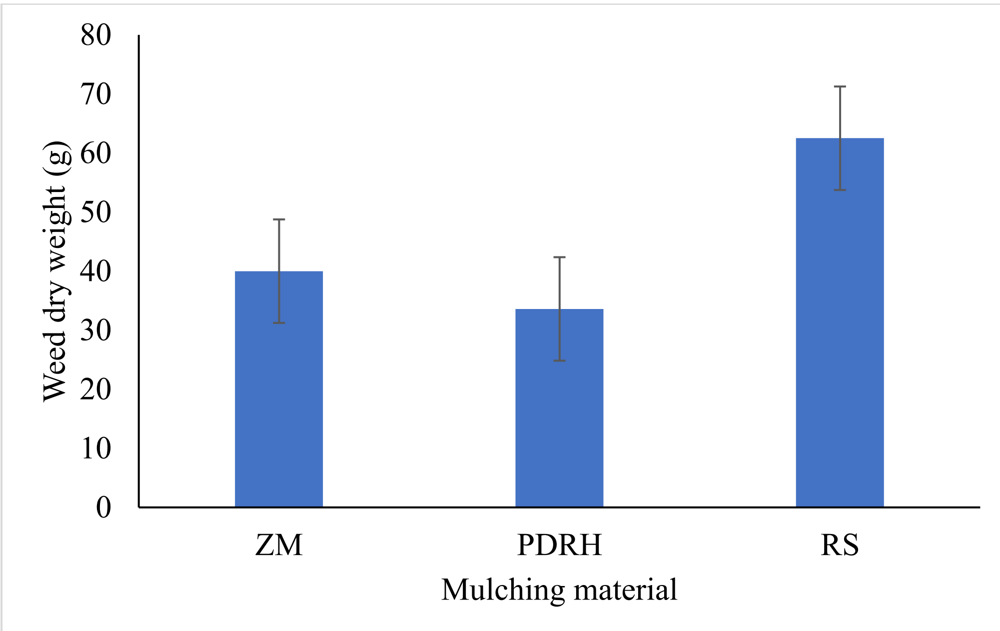

Figure 19: Effect of mulching material on weed dry weight (g) of yam. Bar =SEM

4.10 YIELD PARAMETERS

4.10.1 Total surviving plants

Irrigation and mulch interaction together with the main effects significantly (*P<0.001*) affected the number of surviving plants at the time of harvesting. Results obtained showed that irrigation levels of 100% ETc with partially decomposed rice husk had the highest number (22) of surviving plants. the lowest irrigation at 50% ETc with No mulch recorded the smallest number (6) of surviving plants at the time of harvest (**Table 11)**.

Table 11: Interaction between the level of irrigation and mulching material on total surviving plants.

Irrigation (% ETc)	Mulching material		
	ZM	PDRH	RS
IRR 50	6e	14cd	12d
IRR 75	1.5f	18abc	18.67ab
IRR 100	20ab	22a	17bc
LSD (0.05)			4.228
p-value			<.001

WATP=Weeks After Transplanting, ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.10.2 Total number of mini tubers harvested

The total number of harvested mini tubers was significantly (*p<0.001*) affected by the main effects of drip irrigation and mulch application. The interaction of drip irrigation regime and mulch did not significantly (*P<0.05*) affect the number of mini tubers harvested. Irrigation level of 100%

ETc recorded the highest number of mini tubers harvested as 27, this was followed by 50% ETc irrigation, and 75% ETc registered the smallest number of tubers harvested as 17 **(Figure 20)**.

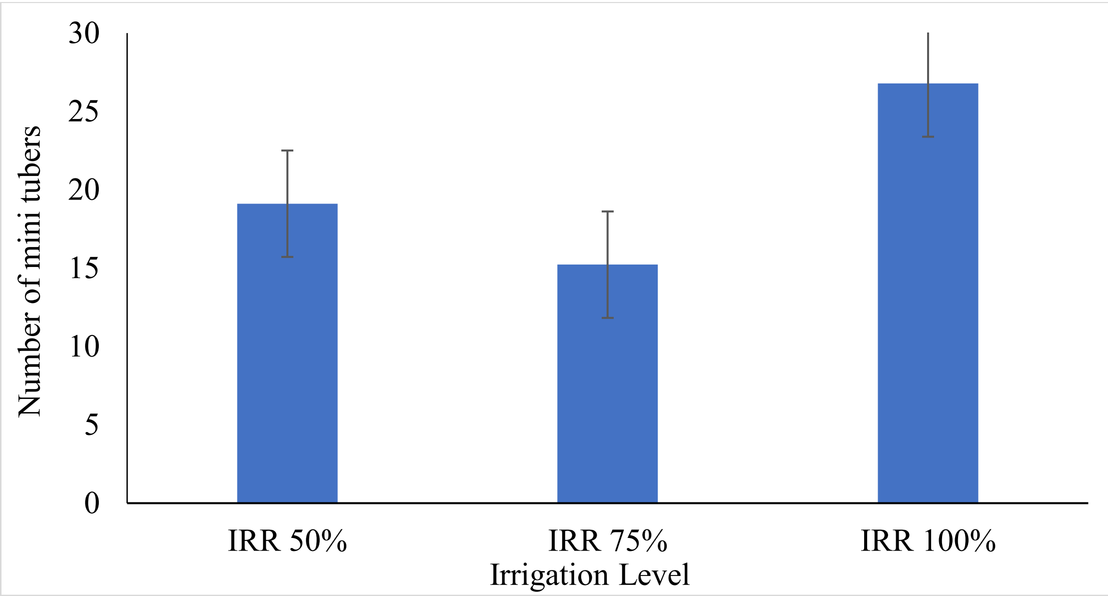

Figure 21: Effect of irrigation level on the Total number of mini tubers harvested. Bar =SEM

The total number of harvested mini tubers was significantly (*p<0.001*) influenced by the main effects of mulch application. Application of partially decomposed rice husk recorded 27 as the highest number of tubers harvested, this was followed by rice straw mulch, no mulch registered the smallest number of tubers harvest as 15 (**Figure 221:**1).

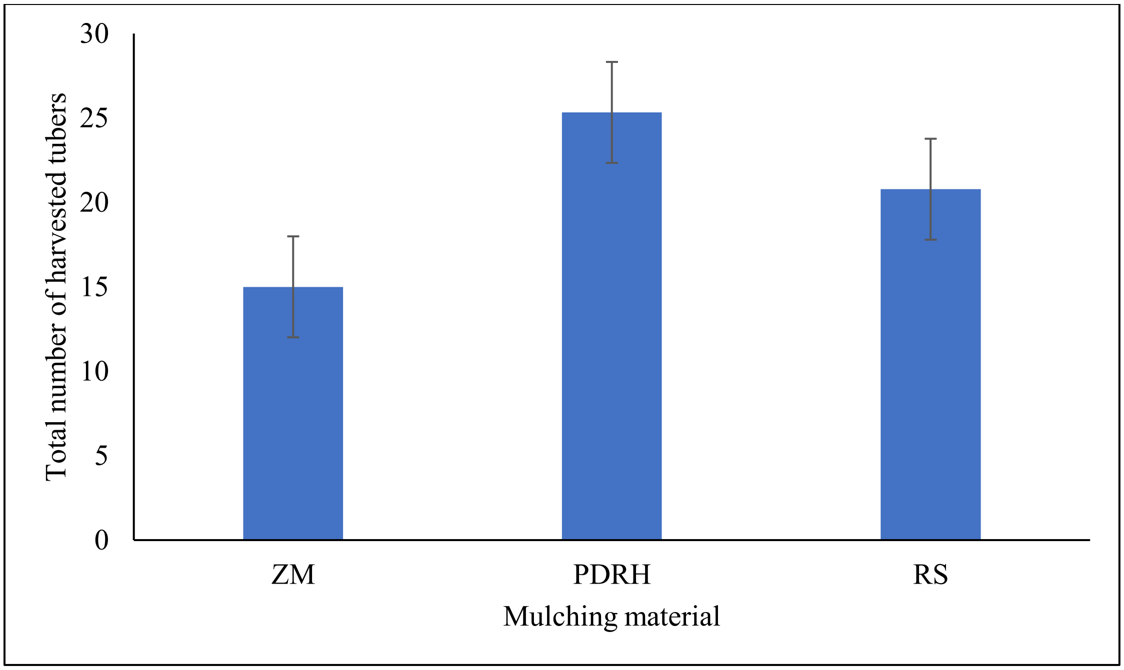

Figure 221: Effect of mulching material on the Total number of mini tubers harvested. Bar =SEM

4.10.3 Total mini tuber yield

Irrigation levels and mulch interaction together with the main effects of irrigation regimes and mulch application significantly (*P<0.001*) affected the total yield of mini tuber at the time of harvest. Results obtained showed that irrigation regime of 100% ETc with an application of partially decomposed rice husk had the highest yield of 1105 kg/ha and irrigation level at 75% ETc with rice straw mulch recorded the lowest yield of 112 kg/ha at the time of harvest (**Table 12)**.

Table 12: Interaction between the level of irrigation and mulching material on Total yield of mini tuber

Irrigation (% ETc)	Total mini tuber yield (kg/ha)		
	ZM	PDRH	RS
IRR 50	185d	232d	533c
IRR 75	129d	261d	112d
IRR 100	307d	1105a	747b
LSD (0.05)			203.7
p-value			<.001

ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.10.4 Average mini tuber yield (kg/ha)

The interaction of Irrigation levels and mulch together with the main effects significantly (P<0.007) affected the average yield of mini tuber at the time of harvest. Obtained results showed that irrigation at 100% ETc with aged rice husk had the highest average yield of the mini tuber of 613 kg/ha and irrigation at 75% ETc with No mulch recorded the lowest average yield of mini tubers of 77 kg/ha at the time of harvest (**Table 13)**.

Table 13: Interaction between the level of irrigation and mulching material on Average mini tuber yield in kg/ha

Irrigation (% ETc)	Average Mini tuber yield (kg/ha)		
	ZM	PDRH	RS
IRR 50	136cd	159cd	274c
IRR 75	77d	157cd	81d
IRR 100	227cd	613a	431b
LSD (0.05)			142.9
p-value			0.007

ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.10.5 Mini tuber circumference

Mini tuber circumference was significantly (*P<0.003, 0.001*) affected by the interaction of irrigation and mulch application together with the main effects of irrigation regime and mulch respectively. Results obtained showed that irrigation level at 100% ETc with partially decomposed rice husk had the highest record of mini tuber diameter of 259.7 mm, this was followed by irrigation at 100% ETc with rice straw with a value of 194.4 mm and irrigation at 75% ETc with No mulch recorded the lowest diameter of 43.2 mm (**Table 14).**

Table 14: Interaction between the level of irrigation and mulching material on mini tuber circumference

Irrigation (% ETc)	Mini tuber circumference(mm)		
	ZM	PDRH	RS
IRR 50	63.4d	77.9cd	127.5c
IRR 75	43.2d	89.4cd	58.3d
IRR 100	97cd	259.7a	194.4b
LSD (0.05)	51.88		
p-value	0.003		

ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.10.6 Mini tuber length

Irrigation and mulch interaction together with the main effects significantly (*$P<0.05$*) affected mini tuber length at the time of harvest. Results obtained showed that irrigation at 100% ETc had the highest mini tuber length of 200 mm which was longer compared to 75% ETc and 50% ETc irrigation levels. Irrigation at 50% ETc registered the shortest mini tubers length of 65 mm

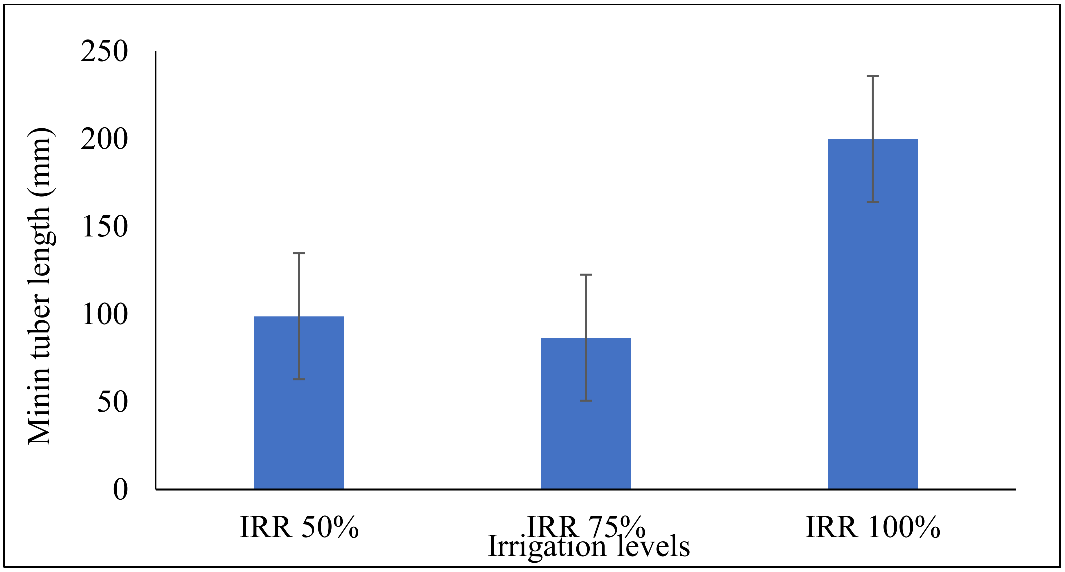

Figure 232: Effect of irrigation level on mini tuber length. Bar =SEM

The main effect of Mulch significantly (*$P<0.001$*) affected the average mini tuber length. Results show that partially decomposed rice husk had the longest mini tubers of 160 mm and No mulch recorded the shortest tuber length of 70 mm at the time of harvest.

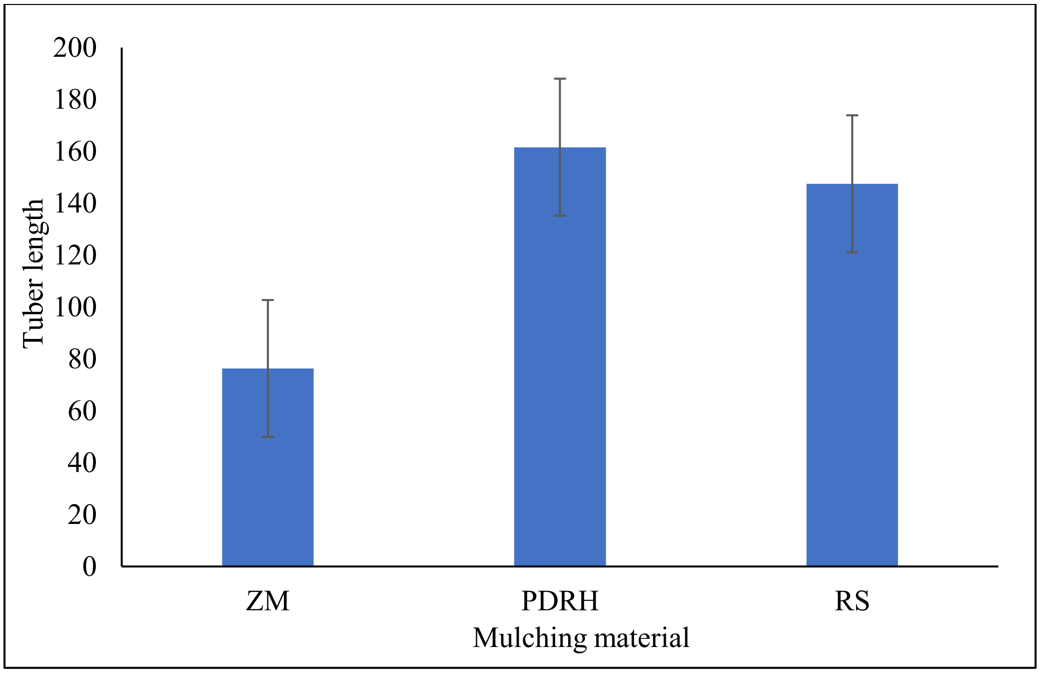

Figure 243: Effect of mulching material on mini tuber length. Bar =SEM

4.10.7 Mini tuber grading

Differences were observable ($p<0.001$) for grades of mini tubers as affected by the interaction of irrigation and mulching as compared to the control condition. In the case of large-size mini tubers (<50g) the maximum number of large tubers were found in partially decomposed rice husk and rice straw mulch (2) while the minimum number was in the control condition (1). Medium-sized tuber (30 -50 g) was found not statistically significant in all treatments. Small-sized tubers (<30 g) numbers per plant were found significantly higher in the control condition as compared to the mulch condition. The largest number of small-sized tubers was in the control condition (9) which was statistically at par with partially decomposed rice husk (4) and rice straw mulch (4.5). The minimum number of small-sized tubers was in partially decomposed rice husk (6.67) (**Table 15** and **Table 16**).

Table 15: Effect of different treatment on the grading of mini tuber (small, medium and large)

Treatments	<30 g	30 to 50 g	<50 g
T1	9	2	1
T2	11	2	2
T3	17	3	4
T4	17	3	4
T5	11	2	2
T6	12	1	1
T7	16	3	4
T8	12	1	1
T9	12	4	1

Table 16: Interaction effect of irrigation and mulching on mini tuber grading (<30 g)

Irrigation (% ETc)	Mini tuber grade <30g, small		
	ZM	PDRH	RS
IRR 50	9a	4e	4.67de
IRR 75	5bcde	4.67cde	4e
IRR 100	3.67e	6.67bcd	7abd
LSD	2.136		
p-value	<.001		

ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

Table 17: Interaction effect of irrigation and mulching on mini tuber grading (<50 g).

Irrigation (% ETc)	Mini tuber grade<50g, grade		
	ZM	PDRH	RS
IRR 50	2.67a	0.67cd	0d
IRR 75	1d	1bcd	0d
IRR 100	0d	2ac	2abc
LSD	0.992		
p-value	<.001		

ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.10.8 Vines fresh and dry Weight

Irrigation levels' main effects significantly (*$P<0.007$*) affected the fresh weight of the yam vine above the ground. Results obtained showed that irrigation at 100% ETc had the highest weight record of 500 g and irrigation at 75% ETc followed with a fresh weight record of 350 g and No mulch recorded the lowest fresh weight of above-ground crop part of 250 g.

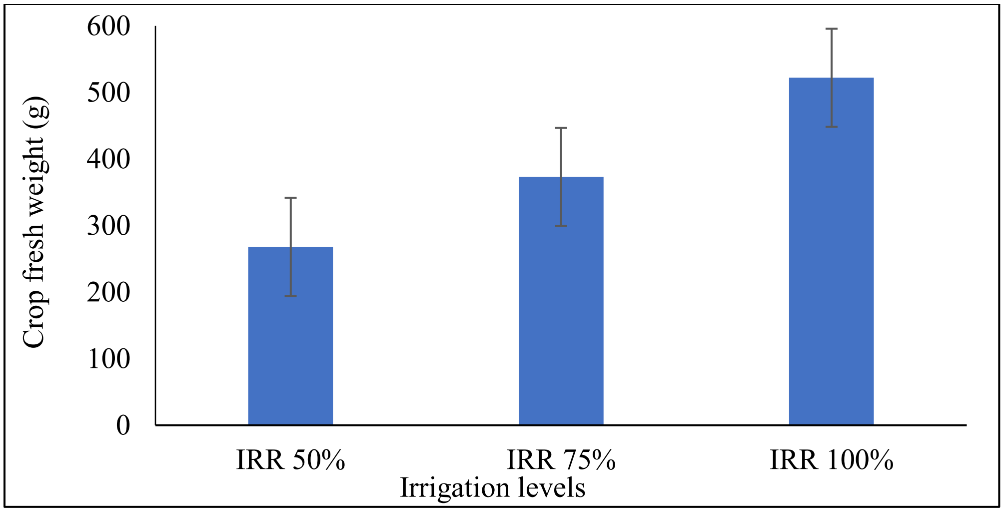

Figure 254*:* **Effect of irrigation level on Crop fresh shoot weight of yam. Bar =SEM**

The main effect of mulch significantly (*P<0.017*) affected the fresh weight of the yam crop above the ground. Results obtained showed that partially decomposed rice husk had the highest fresh weight record of 490 g and rice straw followed with a fresh weight record of 450 g and no mulch recorded the lowest fresh weight of above-ground crop part of 220 g.

The main effect of mulch significantly (P<0.007) affected the dry weight of the yam crop above the ground. Results obtained showed that partially decomposed rice husk had the highest dry weight record of about 90 g and rice straw followed with a fresh weight record of about 80 g and no mulch recorded the lowest fresh weight of above-ground crop part of about 40 g.

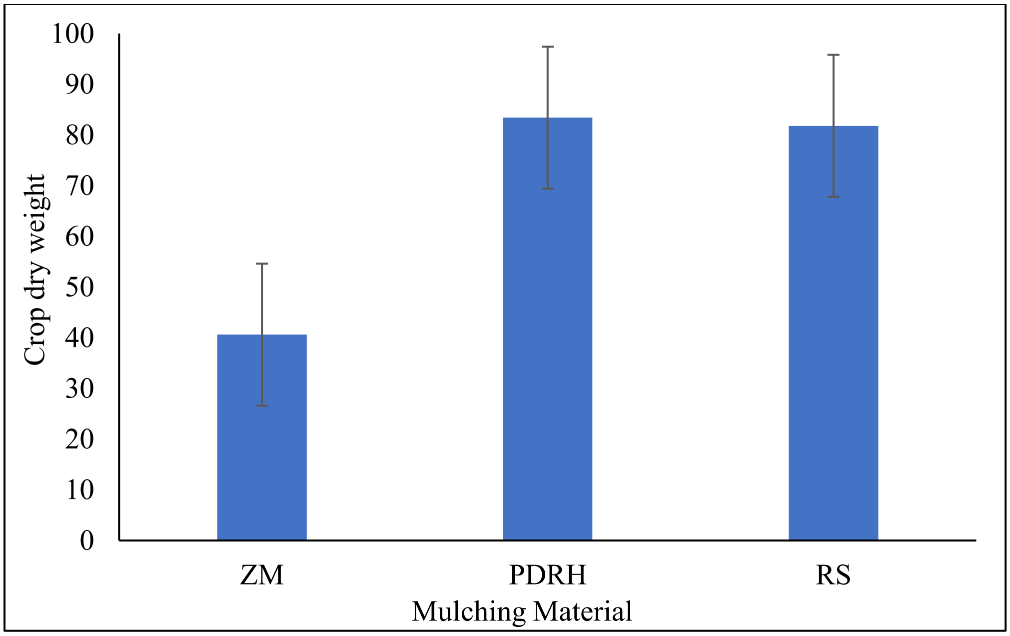

Figure 265: Effect of mulching material on Crop fresh shoot weight of yam. Bar =SEM

4.11 Crop water productivity

The average water used for all treatments at 50, 75 and 100% ETc irrigation levels were 144.38, 216.57 and 288.75 L, respectively. There was high significant difference(*$p<0.001$*) in crop water use efficiency among treatments. At the same 100% ETc irrigation level better CWP was recorded in partially decomposed rice husk mulch (3.83 kg/ha/L) followed by rice straw mulch and No mulch treatment with values of 2.59 kg/ha/L and 1.06 kg/ha/L respectively. No mulched treatment always lags behind mulched treatment in terms of crop water productivity (T4 100 percent ETc with partially decomposed rice husk mulch, 3.83 kg/ha/L). While rice straw and partially decomposed rice husk were significantly different at a low irrigation level of 50% ETc, the No mulched treatment was significantly different at a low irrigation level of 50% ETc.

Using varied irrigation levels on partially degraded rice husk mulch resulted in a change in crop water consumption efficiency (50 percent ETc, 75 percent ETc and 100 percent ETc). Other differences were mulch type (partially decomposed rice husk), irrigation level (50 percent ETc with 75 percent ETc and 100% ETc), and irrigation level (no mulch) (**Table 18**).

Table 18: Interaction effect of irrigation levels and mulching material on Crop water use efficiency

IRRIGATION	MULCH		
	ZM	PDRH	RS
%IRR 50	1.284cd	1.609c	3.693a
%IRR 75	0.597d	1.205cd	0.516d
%IRR 100	1.062cd	3.827a	2.586b
LSD		0.8425	
p-value		<.001	

ZM= Zero Mulch, PDRH=Partially Decomposed Rice Husk, RS=Rice Straw, IRR= Irrigation Regime.

4.12 Correlation Analysis

Total mini tuber yield correlated highly and positively with average yield, mini tuber length, min tuber circumference, number of mini tubers harvested, and water use efficiency. The coefficients of correlation were; r = 0.99, 0.95, 0.99, 0.82, and 0.89 respectively (**Table 19**).

Table 19: Pearson correlation coefficient(r) for some parameters measured for yam mini tuber.

	*TY	MY	TL	TC	NT	PH	NL	WUE
TY	1							
MY	0.99**	1						
TL	0.95**	0.94**	1					
TC	0.99**	0.99**	0.98**	1				

NT	0.82**	0.81**	0.86**	0.84**	1			
PH	0.58	0.56	0.64	0.61	0.82**	1		
NL	0.67	0.68	0.79	0.72	0.73	0.74	1	
WUE	0.89**	0.86**	0.78	0.85**	0.68	0.50	0.56	1

*TY =Total mini tuber yield, MY = Marketable mini tuber yield, TL = Mini tuber Length, TC = Mini Tuber Circumference, NT = Number of mini tubers, PH= Plant Height, NL= Number of leaves, WUE= water use efficiency, **=significance at $p<0.01$.

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Soil physical properties

Soil bulk density decreased with soil depth from 1.69 to 1.27 g/cm^3, being lower at 20 to 40 cm layer, which could be attributed to higher organic matter content in the lower soil layer as a result of long fallow period and the land refilled prior to the experiment. The bulk density of the soil layer of 0 to 20 cm was within the range for sandy loam soils as stated by Hunt and Gilkes, (1992). These results agree with Bhardwaj, (2013) who reported decreased bulk density under straw mulch (1.42 g cm-3) compared to bare soil (1.50 gcm-3).

The field capacity and permanent wilting point for both soil layers were similar to those derived when using the SPAW (soil-plant-air-water) module (Keith, n.d.). Applications of mulch decreased bulk density between mulched and no mulched plots at harvest. The reduction in soil bulk density observed by mulched plots compared with no mulched could be due to an increase in soil organic matter resulting from the degraded mulch materials. The organic matter stabilized the soil structure thereby reducing bulk density and increasing water content. Adekiya *et al*., (2015) ascertained that organic mulch had favorable effects on soil organic matter, water retention and stability of aggregates, leading toa suitable biological environment for root penetration and proper crop growth (Adekiya *et al*., 2015).

Organic mulch returns organic matter and plant nutrients to the soil and improves soil physical, chemical and biological properties after decomposition: which in turn increases crop yield. The soil under the mulch remains loose and friable leading to a suitable environment for root penetration and anchorage (Bhardwaj, 2013).

The results of the soil chemical analyses showed that there is slight acidity in the soils with a mean pH value of 5.35 as earlier observed by Inusah *et al*., (2013). The soil electrical conductivity was classified as non-saline according to the classifications of the Unite. As a result of soil chemical testing d State Soil Salinity Staff (FAO, 1999) states that soil with electrical conductivity (ECe) of 0- 2 dS/m are non-saline. The total organic carbon (TOC) varied from 0.53 to 0.74%, which was considered low according to (Tadese, 1991); being in the low range of 0.5 to 1.5%. Hence, the soil required continuous fertilizer application to the crops to rejuvenate the TOC. Total soil nitrogen (TN) was in the range of 0.049 and 0.068 and could be described as very low and low. Tadese, (1991) classified 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. This is in congruence with many studies reporting Nitrogen as one of the most restrictive soil nourishments for optimum crop growth in the zone, due to easy leaching of the nutrient. The analyses of applied irrigation water showed that pH value was within the normal range of pH 5.5 to 7.5. The electrical conductivity, salinity and TDS of the irrigation water were very slight (FAO, 1985).

5.3 Infiltration Rate

5.3.1 Soil infiltration Before Transplanting

The data collected from the field using the double-ring infiltrometer was used to generate the cumulative infiltration and the infiltration rate curves. The infiltration rate which is the velocity at which water enters the soil is measured by the depth of the water that can enter the soil in one hour. The basic infiltration rate in this experiment was found to be 15.2 mm/hr, which was in the range of 13 to 76 mm/hr for sandy loam soil stated by Peter and Yitayew, (2016). The present findings agree with the standard infiltration rates range for sandy soils. This also makes the soil fitting for used with the stated drip irrigation system since the drippers discharge was far lower compared to the soil infiltration rate.

5.3.2 Soil infiltration at harvest

Irrigation regime at 100% with partially decomposed rice husk mulch had an ideal infiltration rate of 25.54 mm/hr which was higher than the initial value. These results reveal that mulch probably enhanced soil structure, improved soil water storage capacity and reduced compaction of the soil. Bhardwaj, (2013) found that crop residue on soil surface had a direct influence on the infiltration of rainwater and evaporation. He further said mulch reduced runoff and held rainwater at the surface thereby giving it more time to infiltrate into the soil. Other works showed that covering soil surface reduced the amount of irrigation water required for pepper and onion crops by 14 to 29% 70 respectively ((Inusah *et al.*, 2013). Trials conducted in the higher potential areas of Zimbabwe indicated that mulching significantly reduced surface runoff and infiltration (Bhardwaj, 2013).

5.4 Distribution uniformity of Irrigation System

How evenly water is applied in a drip irrigation system is measured by its uniformity. In an unbalanced irrigation system, some parts of the irrigated area will receive too much water, whilst others will receive insufficient water, affecting plant growth. Ninety-two percent of the emissions were uniform in this study, which concurred to that stated in (FAO, 2002) by Rainbird International (1980) which recommended application efficiency of 85% for hot dry climate when the area wetted by one emitter did not exceed 60 cm diameter. The overall DU resulted in uneven water application, hence a replication by replication DU of 92% was used which in agreement with (FAO, 2002).

5.5 Yam seedlings' crop water requirements and irrigation deficit levels

Irrigation parameters for yam have not been developed in the literature. Hence, the crop coefficient for sweet potatoes grown in semiarid regions was used to compute crop and irrigation water requirements for yam seedlings since both are often referred to as drought-tolerant crops, and similar in morphology. The soil had a total of 52.6 mm of water available to it. To calculate the actual ETc, we used the CROPWAT 8 Computer model. To calculate the localized ETc, we used Excel and used a formula described in (FAO, 2002). The various deficit regimes determined were within FAO recommended limits of 65% allowable soil moisture depletion for sweet potatoes (FAO, 2002).

5.6 Moisture in the soil prior to and the following irrigation

When comparing the three soil depths of the sites before and after irrigation, the average moisture content in the three soil depths decreased down the profile. As a result of this, 40 percent of the TAW was be extracted from the root zone within the first 10cm and 10 percent was be extracted within the last 10cm of the root zone. (Waller and Yitayew, 2016). Before irrigation, the available soil moisture within the soil depth was in increasing order down the profile. The mulched treatments had a relatively more uniform water content along with the profile compared to no mulched. These results could be attributed to the fact that mulch helped to conserve soil moisture by reducing evaporation and deep percolation beyond the root zone. Mulched plots conserved more moisture than no mulched. These results were similar to those of (Adekiya *et al*., 2015) who used siam as mulch and recorded that mulch significantly conserved soil moisture as compared to bare soil.

Plots with mulch had relatively more soil moisture recorded before irrigation than no mulched treatments. This can be backed that crop residues or mulch on the soil surface acted as shade; serve as a vapor barrier against moisture losses from the soil, causing slow surface runoff and conserving sufficient water in the soil for better development of crops. Reduced irrigation water requirement and increased water use efficiency by reduced evaporation have been recorded by the use of mulch in irrigation experiments, this leads to reduced irrigation frequency. Using mulch to conserve soil moisture has been registered to reduce the incidence of soil moisture-related physiological disorders such as blossom end rot in tomatoes, fruit cracking in lime and pomegranate (Bhardwaj, 2013). Further, a 34-50 percent reduction in soil water evaporation was reported as a result of crop residue mulching, which improved the ecological environment of the soil and maintained soil water levels.

5.7 Soil Temperature

5.7.1 Soil temperature in the morning

Results of soil temperature within 30 cm indicated that type of mulch improved soil the parameter in the morning above minimum daily temperature following the order of Rice straw > Rice husk> Control. Applying rice straw increased soil temperature by 1.1 – 3.6 °C as compared to partially decomposed rice husk (0.9 –4.4°C) and bare soils (3.0 – 4.2°C). These findings are in agreement with many other field studies which recorded an increase in soil temperatures using mulch (Kumari, 2012; Singh, 2012; Xing, 2012; Yaghi, 2013; Moursy, 2015; Simsek, 2017; Li, 2018;). The warmer soil temperatures quicken seedling growth to achieve the desired structure at an earlier growth stage which maximizes the absorption of solar radiation and enhances yield. Furthermore, elevated soil temperature in the morning can be lethal for nematode and soil-borne pathogens as well as many weed seeds (Eruola *et al*., 2012; Singh, 2012; Bharati *et al*., 2020). Mulching reduces soil temperature in summer, raises it in winter and prevents the extremes of temperatures for temperate climates. The findings in this research collaborate with those of Bhardwaj in 2013 who noted that Wheat straw mulch raised soil temperature by 2–3^{o}C in the peak winter season. Further, at night condensation on the underside of the mulch absorbs the longwave radiation emitted by the soil thereby slowly cooling the soil.

5.7.2 Soil temperature in the evening

Results indicated that the type of mulch greatly decreased the evening soil temperature at 30 cm below maximum daily temperature following the order of Rice straw >Rice husk>Control. Applying rice straw mulch decreased the evening soil temperature by 7.7 – 11.0 °C, partially decomposed rice husk mulch (6.2 – 8.1 ^{o}C) and bare soils (3.8 – 7.5 ^{o}C). These findings are congruent with field studies on yam which registered lower evening temperatures under mulch treatments as compared to bare soil (Agbede *et al*., 2013; Adekiya *et al.*, 2015). This could be attributed to the reduction of evaporation losses of soil, whilst in bare no mulched plots, there was increased soil moisture evaporation due to high soil temperature status. In a field study to evaluate the effect of grass mulch on soil and yield of maize and millet, the maximum temperature of 38 - 43 ^{o}C at a soil depth of 5 cm in no mulched plots but the application of mulch at 5 t/ha reduced the maximum temperature at 5 cm by 7 ^{o}C and at 10 cm by 4^{o}C were reported (Agbede *et al*., 2013). Mulches insulated and protected the soil from direct sunlight and prevented it from hard setting and toughness by controlling rates of evaporation. Therefore, the soil that was covered by mulch remained cooler as compared to non-mulched soil because of minimal temperature change.

5.8 Growth parameters

The interaction between irrigation levels and mulch revealed the highest growth parameters were recorded for 100% ETc irrigation supported with PDRH mulching. The results supported remarkably previous studies that demonstrated the combined effects of mulching and irrigation in ameliorating the growth and yield of crops (Mohamed, 2016).

5.8.1 Plant population and survival rate of yam seedlings

Aged rice husk mulch with 100% irrigation recorded the highest plant population and survival rate of yam seedlings' probably because the treatment provided a conducive environment for crop growth and survival of the seedlings, in the form of required moisture amounts, adequate soil temperatures, and nutrients (Ahaiwe *et al*., 2016). Mulches could protect the soil from compaction caused by rain, foot traffic, drying winds, and heat which enhances plant growth. Soil cover helps to control weed proliferation (by excluding light from germinating seedlings) thereby reducing competition for light, water, and nutrients. Organic mulches also increase the water absorption rate of soils making it readily available to the plant. The reduced soil temperatures under organic mulches encourage root growth in the upper soil layer where there is more oxygen and fertilizer. Mulch also reduces the splattering of soil on vegetable leaves and fruit during rains, which could reduce losses due to soil-borne diseases (Okunade *et al*., 2010; Bhardwaj, 2013; Inusah *et al*., 2013).

5.8.2 Plant height

Plant height, one of the growth attributing parameters was found significantly highest in rice straw mulched under 100% irrigation. This could be possibly due to better availability of soil moisture and optimum soil temperature provided by the mulch and irrigation water. Availability of soil moisture enhanced plant uptake of soil nutrients, and decomposing organic mulching materials increased soil nutrient load available to plants. Various mulches have proven to increase plant height in various crops, as earlier reported with the application of black plastic on plant height (Ahmed, 2017; Bharati *et al*., 2020). Agbede *et al* (2013) reported that the significant response of vine length to siam weed mulch compared with no application could be due to reduced temperature and bulk density and increased availability of SOM, N, P, K Ca and Mg from the mulch (Agbede *et al*., 2013). The improved soil moisture and reduced temperature could have enhanced root development possibly through greater soil moisture and nutrient uptake, which favored vine length under mulched (Adekiya *et al.*, 2015; Khalid *et al*., 2017).

5.8.3 Number of leaves

Number of leaves per plant being one of the major growth attributing parameters, was highest in 100% irrigation and also aged riced husk mulch Irrigation at 100% increased number of leaves due to availability of adequate moisture for good root development which might have boosted plant nutrient uptake for increased growth indexed by number of leaves per plant. PDRH on the other hand registered highest leave number, because of the availability of nutrients from the decomposed rice husk. Mulching helped to reduce the evaporation and maintained adequate moisture content to support maximum number of leaves as found with mulching as compared to no-mulching; as earlier reported (Dong, 2014; Bharati *et al*., 2020).

Ahaiwe *et al*., (2016) noted the mineralization of organic mulches increased the soil nutrient pool available for ginger plants resulting in production of more leaves than in the control and black polythene mulched plots. Research have recorded a per unit decrease on applied irrigation water, decreased number of leaf vine length by 0.088 and 0.090 for two sweet potatoes varieties (Thompson *et al*., 1992; Gibberson *et al*., 2016).

5.8.4 Leaf area index

Deficit irrigation reduced leaf area of yam seedlings which was corroborated by findings of Gibberson *et al.,* 2016 who observed that stem length, diameter and length, leaf area and number decreased in response to drought stress and no mulch. This observation is further corroborated by findings that showed that leaf area in sweet potato plants decreases as water stress increases. The reduction in leaf area and number could be attributed to reduction in chlorophyll, net CO_2 uptake by leaves and photosynthetic ability of plant (Gibberson *et al*., 2016). The beneficial effects of grass mulch on yam growth could be attributed to the nutrients released by decomposing mulch and its physical effect on the possible reduction of nutrient losses by surface erosion and leaching. He reported that using polythene nylon mulch will considerably improve the production of yam and in particular the seed yam by checking the weed growth (Eruola *et al*., 2012). Improved leaf area development could be the consequent of increase in soil moisture content and modification of soil temperature under mulched plot and reduced evaporative loss and increase infiltration probably due to increased soil biological activities as a result of lower soil temperature were reported by (Adekiya *et al*., 2015; Kaur and Brar, 2016).

5.8.5 Chlorophyll Content (Spad)

Partially decomposed rice husk recorded the highest chlorophyll content, probably, this could be credited to the fact that the mulch might have gone through some degree of decomposition before application to the field; which increased nutrient availability needed for chlorophyll formation and photosynthesis. It was observed that since increase in plant nutrient improves chlorophyll and enhances photosynthesis, PDRH has a significant impact on leaf development (Zaman-Allah *et al.,* 2015).

5.8.6 Number of internodes and Internode length

The interaction effect of irrigation at 100% and PDRH mulch had the highest number of internodes and internode length due to availability of adequate moisture and plant nutrient from degradation of mulch material and release of plant nutrient in the soil for good root development. This moisture and nutrient which when taken up translate it into increased growth and number and length of internodes. Studies have indicated that water stress without mulch reduce vine length, number and length of internode by 3.2cm, 0.39, and 0.024 cm respectively in sweet potatoes Thompson et al., 1992; Zaman-Allah et al., 2015; (Gibberson et al., 2016) It was also mentioned that water deficit reduces stomatal conductivity, shoot elongation, leaf area and number of leaves and water loss by transpiration of sweet potato.

5.8.7 Weed fresh weight and Biomass

Irrigation at 100% had the highest fresh weed weight and biomass, which could be attributed to high continuous availability of water supplied by irrigation to support rapid weed growth. PDRH on the other hand, might have influenced high weed fresh weight and biomass due to uptake of nutrients released from the decomposing mulch material. In addition, the combination of irrigation and mulch provided the right and conducive environment for weed root growth and development.

By providing a physical barrier, PDRH mulching reduces the germination and nourishment of many weeds. Covering the soil surface prevent weed seed germination or physically suppress seedling emergence. Loose materials such as straw, bark and composted municipal green waste can provide effective weed control. Sawdust is a soil improver and weed suppressor as it conserves soil moisture, decreases run-off, increases infiltration and percolation, decreases evaporation and weed growth can be substantial under clear mulch(Hajšlová & Schulzová, 2012; Bhardwaj, 2013; Kaur & Brar, 2016).

5.9 Yield Parameters

5.9.1 Total number of mini tubers harvested

Irrigation at 100% and PDRH independently increased the number of tubers of seed yam harvested at the end of the experiment. This increase could be as a result of conducive root zone environment provided by maximum irrigation and PDRH which showed in high number of leaves, plant height, LAI, and chlorophyll content to impact on total number of mini tubers. High LAI and chlorophyll content might have enhanced food manufacture in the leaves through photosynthesis and storage of the food in the roots. Findings from Bharati *et al* in 2020 recorded that rice husk increased number of tubers produced over rice straw and no mulch in potatoes. It was further explained that mulch materials created favorable condition for the growth of plant, which leads to the production of maximum vegetative growth with maximum number of tubers per hill (Maduakor *et al*., 1984; Gibberson *et al*., 2016; Bharati *et al.*, 2020)

5.9.2 Total mini tuber yield

The interaction of irrigation at 100% and PDRH mulch significantly enhanced total tuber yield and this could be attributed to the release of SOM, N, P, K Ca and Mg by these treatments as a result of complete decomposition of the mulch materials. Hence, the provision of favorable growth conditions for the plants, which translated to the production of maximum yield per hectare. In addition, better soil and microclimatic conditions that brings about proper growth and development of yam were provided. These results corroborated with other studies which indicated that irrigation and mulch improved total tuber yield in sweet potatoes over reduced irrigation and no mulch (Thompson *et al.,* 1992; Adekiya *et al*., 2015; Farrag, 2016; Bharati *et al.*, 2020). The interaction between irrigation and mulch levels also increased rhizome yield of ginger (Kar & Kumar, 2007; Kaur and Brar, 2016; Mohamed, 2016; Khalid *et a*l., 2017).

This result however, contradicts the common perception that yam and sweet potatoes are drought tolerant crops. Daryanto *et al*., (2016) reviewed that whilst sweet potato might be resistant to drought in terms of its survival, it might be sensitive in terms of yield. Irrigation at 60% moisture depletion level, for example, could increase root yield by 24% over non-irrigated sweet potatoes.

The tradeoff between yield and survival is also related to the physiological and biochemical changes in the leaves. Under water deficit, stomatal resistance tends to increase to preserve leaf water content and prevent leaf senescence. Increasing stomatal resistance, however, also decrease CO_2 exchange, net photosynthetic rate and eventually yield. If droughts occur during tuber initiation and tuber bulking, these physiological processes could considerably reduce yield; explaining the yield sensitivity of sweet potato to drought (Ekanayake and Collins, 2015; Daryanto et al., 2016).

5.9.3 Mini tuber circumference

Largest mini tubers were recorded in 100% ETc irrigation regime with PDRH, this could be because irrigation made the micro environment favorable for bulking of mini tubers whilst PDRH mulch probably provided plant nutrients from degradation of the organic mulch. These results could be accredited to the reason that Irrigation and mulch materials created favorable condition for the growth of plant. Such response could be mainly due to the physiochemical and biological improvement which occurred in the soil including favorable temperature and moisture regimes, nutrient availability and microbial activity in mulch condition. The above results are in accordance with the findings of (Ahmed, 2017; Bharati *et al*., 2020).

5.9.4 Mini tuber length

Generally, yam seedlings planted under 100% irrigation recorded longer mini tubers than 75 and 50 respectively. Thompson found that there was a strong linear relationship (94%) between water stress level vs average tuber length and the decrease on tuber length was obtained as 0.088 cm for per unit decrease on applied irrigation water for sweet potatoes variety (Thompson et al., 1992). On the other hand, PDRH recorded the longest tuber lengths compared to rice straw and No mulch.

Also in agreement with a previous report, the length of yam was significantly longer in mulched plots than un-mulched ones (Eruola *et al*., 2012).

5.9.6 Mini tuber grading

Irrigation and mulching produce a significant difference in tuber weight per plant as compared to reduced irrigation and no mulch plots. In case of large size tubers(<50g) the maximum number of large tubers were found in 100% irrigation and ARH while the minimum number were found in 50% no mulch. Medium sized tuber (25 -50 gm) was found higher in the same interaction of 100% and PDRH mulch condition as compared to the control condition. Small sized tubers (<10 gm) numbers per plant were found higher in control condition as compared to the mulch condition**.** This results are similar to those recorded by (Bharati et al., 2020; Zhao, 2012) for potatoes under irrigation and mulch. The higher yield of large sized tubers and medium sized tubers with mulch was due to the less resistance by soil and more up take of water and nutrients which might have led to better development and growth of individual tuber and hence large sized potato. The results were more pronounced in case of PDRH mulch compared to other mulches and control condition because of more soil moisture and nutrient retention due to lesser weed competition (Zhao, 2012; Bharati *et al*., 2020;)

5.10 Water use efficiency

Moisture evaporation from soil surface was reduced by mulch. Interaction of 100% ETc and PDRH registered the highest WUE, which might be because irrigation provided sufficient moisture to plant root zones slowly, decreasing deep percolation whilst PDRH could have reduced soil moisture lost through evaporation (Kassahun, 2017). This current finding was in line with (Kebede, 2019) who reported that WUE was significantly greater for mulched than no mulched treatments at full irrigation. These results counteract yam as a drought tolerant crop. These results can be adducted to the point that yam is not normally cultivated under adequate conditions. Hence, when soil moisture increased tuber yield increased. This results are contradicted by the results of (Gibberson *et al*., 2016; Kaur and Brar, 2016; Mohamed, 2016; Behzadnejad *et al*., 2020) who found that water stress (40–60% water deficit) and organic mulch such as PDRH, rice straw improved crop water use efficiency of sesame, turmeric, maize, explaining that organic mulch increased soil water storage capacity, reducing direct soil water loss, or limiting early transpiration losses. Therefore, deficit irrigation and residue cover will probably preserve an adequate condition of stomata closure resulting in the enhancement of leaf relative water content and cell turgidity. This suggests that increasing the irrigated areas with the saved water could compensate for any yield loss due to deficit irrigation. Herein, crop water requirement under (100 ETc) was about 288.75 L; and that under 50% ETc was about 144.38 L, on an average. The water saved which was about 169 mm (288.75 – 144.38 = 144.37 mm) could be used to irrigate 0.5 ha yam seed*lings* cropped land with extra yield produced as a result of water saved. The result agreed with (Patel, N. *and* Rajput, 2013) who reported that by 40% DI throughout the growing season, a water saving of about 272 mm may be used to irrigate additional half a hectare cropped area (Kebede, 2019).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the outcome and statistical analyses, plant height, number of leaves, LAI and leaf chlorophyll content, were highest under 100% crop water requirement and partially decomposed rice husk. Plant height was measured until the plants attained a height of 160 cm. The highest number of leaves per plant of 260 and leaf area index of 0.2 was attained from 100% crop water requirement plus partially decomposed rice husk, with the lowest biomass coming from 50% irrigation and partially decomposed rice husk. The highest fresh weed weight and biomass were recorded for 100% irrigation water and no mulch.

The highest tuber yield of 1105 kg/ha was attained under 100% irrigation with partially decomposed rice husk, 50% irrigation plus rice straw mulch recorded 50% of maximum total tuber yield. The highest tuber number of 27 tubers per plot was recorded for 100% irrigation in combination with partially decomposed rice husk. Tuber circumference of 259.7 mm was recorded as maximum diameter for tuber under 100% irrigation by partially decomposed rice husk. This was directly followed by 194.4 mm in 100% ETc by rice straw mulch. irrigation at 100% ETc by partially decomposed rice husk gave varied grades of mini tubers according to weights, these grades were less than 10 g, 10 - 30 g, and 30 - 50 g.

Yam seedling cultivated under full irrigation in the dry season produced the best in terms of vegetative growth and yield implying the water enhanced yam seedling growth and yield under 100% irrigation water in combination with partially decomposed rice husk. This provided extra nutrient to soil which increased as the decomposition process advanced. This treatment retained soil moisture, regulated soil temperature, reduced evaporative water loss, enhanced infiltration, increased soil nutrients, soil organic matter and modified the soil microclimate within the root zone to improve yam seedlings growth and yield. This pattern was followed by rice straw mulch plus 100% ETc and lowest in No mulch with 100% ETc.

Combining drip irrigation and partially decompose rice husk for seed yam production in the dry season is an efficient and effective method to achieve increased yam seedling survival rate, enhance yam seedlings growth for improved tuber yield in Northern Ghana. In the absence of partially decomposed rice husk, rice straw which is often burned could be use as mulch for seed yam production from single node rooted vines. Drip irrigation is an efficient method of water application to crops. In semi-arid areas like Northern Ghana where water is a scare resource and rice husk are abundant, drip irrigation in combination with mulch should be employed to produce high value crops such as seed yam in the dry season. This by-product of rice processing can be used to enrich the soil with nutrient and produce yam seeds through mulching to conserve soil moisture during the harsh climatic conditions where agricultural activities are on hold.

The following conclusions can be drawn based on the research's goals, results, and discussions presented in earlier sections. Water use efficiency and agronomic parameters of yam seedlings were significantly affected by 100 percent ETc with mulch in the majority of the cases. When using 100 percent ETc with a partially decomposed rice husk mulch, the highest yield production and crop water use efficiency were achieved with yields of 1102 kg/ha and 3.83 kg per hectare per liter, respectively. However, 50% ETc by rice straw mulch produced 533 kg/ha and 3.69 kg/ha/L WUE, which was 50% of the maximum total yield attained. To minimize evapotranspiration, the use of 100 percent ETc with RS mulch played a greater role in this experiment. It's clear that PDRH and RS mulch have different moisture retention capacities, so the mulching material should be considered when applying water because irrigation at 100% in combination with PDRH recorded similar WUE as with 50% and RS. This will also save 50% of the water that would have been used otherwise. Unlike PDRH, RS can also be applied directly to the field without prior decomposition.

6.2 Recommendations

Based on the results, it is therefore recommended that:

- The findings of this research have shown that 100% ETc with PDRH mulch produced the best results, closely followed by 50% ETc with 1 t/ha RS mulch. However, the latter treatment of 50% ETc with Rice straw Mulch is highly recommended in areas like Northern Ghana where water is a scare agricultural input in the dry season and rice straw is readily available to reduce production cost and enhance yield.
- Compared to non-mulched practices, mulching and drip irrigation can save water and increase yield. Here, farmers must be equipped with the knowledge and skills to do so, especially in semi-arid regions where water scarcity is a major issue and conflict between upstream and downstream irrigators is a major concern.
- To put these findings into practice by farmers, the experiment must be repeated at different locations and seasons so that concrete conclusions can be drawn.
- Irrigation characteristics (crop coefficient, Kc, length of growth stages) for yam should be developed to enhance near accurate computation of yam crop water requirement.

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APPENDICES

Appendix 1. Variate: Leaf Area Index at 10 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.000378	0.000189	0.18	
REP.*Units* stratum					
Irrigation	2	0.01486	0.00743	6.93	0.007
Mulch	2	0.03274	0.01637	15.26	<.001
Irrigation.Mulch	4	0.013813	0.003453	3.22	0.041
Residual	16	0.017159	0.001072		
Total	26	0.07895			

Appendix 2. Variate: Number of leaves at 16 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	734.7	367.4	0.84	
REP.*Units* stratum					
Irrigation	2	48843.2	24421.6	55.57	<.001
Mulch	2	16296.2	8148.1	18.54	<.001
Irrigation. Mulch	4	3141.3	785.3	1.79	0.181
Residual	16	7031.8	439.5		
Total	26	76047.2			

Appendix 3. Variate: Number of leaves at 2 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2	1	2.29	
REP.*Units* stratum					
Irrigation	2	3.1667	1.5833	3.62	0.051
Mulch	2	6.1667	3.0833	7.05	0.006
Irrigation. Mulch	4	4.8333	1.2083	2.76	0.064
Residual	16	7	0.4375		

Total	26	23.1667			

Appendix 4. Variate: Number of leaves at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.5	2.25	0.32	
REP.*Units* stratum					
Irrigation	2	21.167	10.583	1.49	0.256
Mulch	2	129.167	64.583	9.06	0.002
Irrigation. Mulch	4	70.333	17.583	2.47	0.087
Residual	16	114	7.125		
Total	26	339.167			

Appendix 5. Variate: Number of leaves at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.89	0.44	0.04	
REP.*Units* stratum					
Irrigation	2	80.17	40.08	3.17	0.069
Mulch	2	393.17	196.58	15.56	<.001
Irrigation. Mulch	4	122.83	30.71	2.43	0.09
Residual	16	202.11	12.63		
Total	26	799.17			

Appendix 6. Variate: Number of leaves at 10 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	40.5	20.25	1.05	
REP.*Units* stratum					
Irrigation	2	469.5	234.75	12.16	<.001
Mulch	2	686	343	17.76	<.001
Irrigation. Mulch	4	214	53.5	2.77	0.063
Residual	16	309	19.31		

Total	26	1719

Appendix 7. Variate: Number of leaves at 12 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	272.2	136.1	1.13	
REP.*Units* stratum					
Irrigation	2	3627.2	1813.6	15.11	<.001
Mulch	2	5461.2	2730.6	22.76	<.001
Irrigation. Mulch	4	960.3	240.1	2	0.143
Residual	16	1919.8	120		
Total	26	12240.7			

Appendix 8. Variate: Number of leaves at 18 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	797	398	0.31	
REP.*Units* stratum					
Irrigation	2	132812	66406	50.86	<.001
Mulch	2	59360	29680	22.73	<.001
Irrigation. Mulch	4	12879	3220	2.47	0.087
Residual	16	20890	1306		
Total	26	226737			

Appendix 9. Variate: Plant Height at 10 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.9	1.9	0.01	
REP.*Units* stratum					
Irrigation	2	3417.8	1708.9	4.64	0.026
Mulch	2	1910.5	955.2	2.59	0.106
Irrigation.Mulch	4	2033.6	508.4	1.38	0.285
Residual	16	5894	368.4		

Total	26	13259.7			

Appendix 10. Variate: Plant Height at 12 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	109.81	54.9	0.6	
REP.*Units* stratum					
Irrigation	2	2804.37	1402.18	15.43	<.001
Mulch	2	3754.81	1877.41	20.66	<.001
Irrigation.Mulch	4	1201.87	300.47	3.31	0.037
Residual	16	1454.05	90.88		
Total	26	9324.91			

Appendix 11. Variate: Plant Height at 14 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.76	2.38	0.03	
REP.*Units* stratum					
Irrigation	2	1464.98	732.49	9.11	0.002
Mulch	2	1919.05	959.53	11.94	<.001
Irrigation.Mulch	4	793.8	198.45	2.47	0.087
Residual	16	1286.29	80.39		
Total	26	5468.89			

Appendix 12. Variate: Plant Height at 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	142.24	71.12	0.95	
REP.*Units* stratum					
Irrigation	2	604.22	302.11	4.03	0.038
Mulch	2	203.31	101.66	1.36	0.286
Irrigation. Mulch	4	143.36	35.84	0.48	0.751
Residual	16	1198.59	74.91		
Total	26	2291.72			

Appendix 13. Variate: Plant Height at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	45	22.5	0.09	
REP.*Units* stratum					
Irrigation	2	3379.7	1689.8	6.51	0.009
Mulch	2	1971.3	985.7	3.8	0.045
Irrigation. Mulch	4	2116.8	529.2	2.04	0.137
Residual	16	4153.9	259.6		
Total	26	11666.7			

Appendix 14. Variate: Wees Dry weight at 12 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4241.2	2120.6	6.32	
REP.*Units* stratum					
Irrigation	2	20291.5	10145.7	30.26	<.001
Mulch	2	4138.6	2069.3	6.17	0.01
Irrigation. Mulch	4	1464.2	366.1	1.09	0.394
Residual	16	5365.2	335.3		
Total	26	35500.7			

Appendix 15. Variate: Weed Fresh weight 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	81339	40669	9.43	
REP.*Units* stratum					
Irrigation	2	24200	12100	2.81	0.09
Mulch	2	61400	30700	7.12	0.006
Irrigation. Mulch	4	33050	8262	1.92	0.157
Residual	16	69011	4313		
Total	26	269000			

Appendix 16. Variate: Weed Fresh weight 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3620.7	1810.4	2.79	
REP.*Units* stratum					
Irrigation	2	15743.6	7871.8	12.12	<.001
Mulch	2	3064.5	1532.3	2.36	0.126
Irrigation. Mulch	4	1552.3	388.1	0.6	0.67
Residual	16	10388.1	649.3		
Total	26	34369.2			

Appendix 17. Variate: Weed Fresh weight 12 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	104272	52136	8.17	
REP.*Units* stratum					
Irrigation	2	251150	125575	19.68	<.001
Mulch	2	36600	18300	2.87	0.086
Irrigation. Mulch	4	24700	6175	0.97	0.452
Residual	16	102078	6380		
Total	26	518800			

Appendix 18. Variate: Weed Fresh weight 16 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	479057	239529	7.94	
REP.*Units* stratum					
Irrigation	2	811098	405549	13.45	<.001
Mulch	2	137458	68729	2.28	0.135
Irrigation. Mulch	4	46326	11581	0.38	0.817
Residual	16	482475	30155		
Total	26	1956414			

Appendix 19. Variate: Vine Dry weight (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	115.3	57.7	0.08	
REP.*Units* stratum					
Irrigation	2	9977	4988.5	6.56	0.008
Mulch	2	10583.2	5291.6	6.96	0.007
Irrigation. Mulch	4	3937.5	984.4	1.29	0.314
Residual	16	12173.1	760.8		
Total	26	36786.2			

Appendix 20. Variate: Vine Fresh weight (kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	9619	4809	0.18	
REP.*Units* stratum					
Irrigation	2	292646	146323	5.32	0.017
Mulch	2	384795	192398	7	0.007
Irrigation. Mulch	4	157627	39407	1.43	0.268
Residual	16	439666	27479		
Total	26	1284353			

Appendix 21. Variate: Number of mini tubers less than 10 g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	11.63	5.81	0.53	
REP.*Units* stratum					
Irrigation	2	89.19	44.59	4.03	0.038
Mulch	2	144.52	72.26	6.53	0.008
Irrigation. Mulch	4	95.04	23.76	2.15	0.122
Residual	16	177.04	11.06		
Total	26	517.41			

Appendix 22. Variate: Total Number of mini-Tuber

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	36.96	18.48	1.23	
REP.*Units* stratum					
Irrigation	2	622.3	311.15	20.71	<.001
Mulch	2	482.74	241.37	16.07	<.001
Irrigation. Mulch	4	105.93	26.48	1.76	0.186
Residual	16	240.37	15.02		
Total	26	1488.3			

Appendix 23. Variate: mini tuber Length (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2045	1023	0.75	
REP.*Units* stratum					
Irrigation	2	69776	34888	25.7	<.001
Mulch	2	37703	18851	13.88	<.001
irrigation. Mulch	4	14429	3607	2.66	0.071
Residual	16	21724	1358		
Total	26	145677			

Appendix 24. left harvested yam seeds grouped according to weight., Right field 30 DATP

Appendix 25. field 2 MATP prior to weeding.

Appendix 26. Left chlorophyll data collection using the chlorophyll spad meter, Right yam seedlings 1WATP under PDRH mulch.


Appendix 27. Left extracted single node vines, right single nodes vines in rooting media.


Appendix 28. left field 6 WATP, right field at harvesting.


Appendix 29. left fertilizer application 4 WATP, right field at 16 WATP

Appendix 30. Left collecting total mini tuber weight at harvest, right Vernier caliper for measurement stem girth, mini tuber length and circumference.

Appendix 31. Left Rooted single nodes 4 WAP, Right measurement of leaf area.

Appendix 32. left dominant weed type on field, right single nodes 1 WAP in media.

Appendix 33. left mini tuber after harvest with vine, right harvested mini tuber.

Appendix 34. left fertilizer applied, right field 4 WATP prior to weed control.

Appendix 35. left measurement of fresh weed weigh, right measurement of plant height.