DESIGN AND EVALUATION OF A SIMPLE PVC DRIP IRRIGATION SYSTEM USING *AKPOSOE* MAIZE VARIETY AS A TEST CROP

by

Evans Asenso

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DECLARATION

I hereby declare that this work is my own work towards the Master of Science degree (Soil and Water Engineering) and that, to the best of my knowledge, it contains no material previously published by another person nor materials which have been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

Evans Asenso (PG 3770109)	....	....
Student Name and ID	Signature	Date

Certified by:

Dr. Emmanuel Ofori	....	....
Supervisor	Signature	Date
Dr. W. A. Agyare	....	....
Co-Supervisor	Signature	Date
Prof. Ebenezer Mensah	....	....
Head of Department	Signature	Date

ABSTRACT

Maize *(Zea mays, L.)* is an important staple crop and has contributed significantly in ensuring food security and the growth of Ghana's economy. Its productivity over the years has been limited by unpredictable rainfall pattern. The experiment was conducted to design and evaluate a simple PVC drip irrigation system using *akposoe maize* variety as a test crop, during the 2011 major growing season in a semi-decidous environment in Kumasi, Ghana. Irrigation water applied at the surface (0 cm), 20 cm, and 40 cm below surface, with "No irrigation" as control forming the four treatments. The design was a Randomized Complete Block Design (RCBD) and was replicated four times. The depth at which irrigation water is applied significantly influenced maize growth and dry matter yield. Ten weeks after planting, water applied at 20 cm depth below the ground surface, produced the tallest plant (177.85 cm), biggest stem girth (8.95 cm) and highest dry matter yield (6085.06 kg/ha). The highest number of leaves (13.15) was recorded in the treatment where water was applied 20 cm below surface and at 0 cm depth. The treatment with water applied at 40 cm depth recorded the largest leaf diameter (9.73 cm) and the longest leaf length (73.59 cm).The "No Irrigation" treatment gave the shortest plant height (132.77 cm), smallest stem girth (6.77 cm), lowest number of leaves (10.40), smallest leaf diameter (7.06 cm), lowest leaf length (58.67 cm) and the lowest dry matter (2296.95 kg/ha). In general, plant height, stem girth, leaf diameter, number of leaves and leaf length under drip irrigation were statistically similar, but significantly different as compared to No Irrigation treatment and surface and subsurface (i.e. 40 cm, 20 cm and 0 cm) water treatments. Generally the depth at which water is applied had a statistically significant effect on maize growth and yield.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Agriculture accounts for about 70 – 80% use of available water in the world (Duhrkoop *et al.*, 2009). However, dwindling water availability has made it necessary to improve on the way water is used in Agriculture. In other to make water available to farmers throughout the season to ensure food security. The increased competition for water among agricultural, industrial and domestic consumers creates the need for continuous improvements in techniques for judicious use of water in crop production. Efficient water use is becoming increasingly important and alternative water application methods such as drip and sprinkler irrigation may contribute substantially in making the best use of the scarce available water for crop production.

Irrigation is the artificial application of water to the soil or plant, in the required quantity and at the time needed, is a risk management tool for agricultural production. The risk of yield reduction due to drought is minimized with irrigation. Irrigation is widely carried out through surface, sub-surface and pressurized systems, characterized by the mode of transport of the water onto the point of application (Keller and Bliesner, 1990). When water is applied on the surface, a considerable amount is lost through evaporation, run off and deep percolation making it less efficient.

Field application efficiency in most traditional irrigation methods is still very low, typically less than 50 % (sprinkler irrigation) and often as low as 30 % (surface irrigation) (Molden *et al*. 1998). Excessive application of water generally entails losses because of surface run-off from the field and deep percolation below the root zone within the field. Both run-off and deep percolation losses are difficult to control under furrow irrigation system, where a large volume of water is applied at a single instance. An alternative water application method such as the drip irrigation method allow for much more uniform distribution as well as more precise control of the amount of water applied and also decreases nutrient leaching (Phene *et al.* 1994).

Drip irrigation is defined as "the slow, frequent application of small volumes of irrigation water to the base or root zone of plants" (Smeal, 2007). More widespread adoption of this technology in recent years began in the late 1960s to early 1970s. Advantages of drip irrigation system include: less water loss, reduction in weed growth, less labour requirements, minimal evaporation compared to other watering methods, less usage of fertilizer, reduced soil erosion, equitable water distribution and higher crop production.

Disadvantages of this technology include: clogging of drip holes, high initial cost, algae growth and easy damage to drip lines.

Drip irrigation is an efficient method for minimizing the water used in agricultural and horticultural crop production. Frequency of water application is one of the most important factors in drip irrigation management because of its effect on soil water regime, root distribution around the drip holes, the amount of water uptake by roots and water percolating beyond the root zone (Coelho and Or 1999; Assouline, 2002; Wang *et al.* 2006).

Maize (*Zea mays* L.) is the third most important cereal crop after wheat and rice in terms of production in the world (IITA, 2009). In Ghana, it is the most important cereal in terms of production and consumption across all the agronomical zones (Breisinger *et al*., 2008). Not- withstanding this importance, productivity of maize in farmers' fields throughout the country under rain-fed is generally low due to poor rain fall, uneven distribution and prolong drought, averaging 1.5 t/ha, (PPMED, 1998), and it could even be as low as 0.5 t/ha compared to over 5.0 t/ha in parts of northern and southern Africa (PPMED, 1992), 8.0 t/ha in Indonesia (Krisdiana and Heriyanto, 1992), 6.3 t/ha in the Julin Province of China (Qiao *et al*., 1996), and 7.0-8.9 t/ha in Ethiopia (Onyango and Ngeny, 1997). This low productivity has been attributed mainly to low soil fertility (low soil N) and drought stress in farmers' field (Bänziger *et al*., 2000). Frequent drought stress in the largely rain-fed agricultural system is a major constraint that limits maize production in Ghana (Ohemeng-Dapaah, 1994; Kasei *et al.*, 1995; Obeng-Antwi *et al*., 1999). Maize production in Ghana is prone to drought stress because rainfall is unpredictable in terms of quantity and distribution during the growing season (Ohemeng-Dapaah, 1994; Kasei *et al*., 1995) resulting in significant yield losses. As a typical example, total maize production in Ghana declined by 30% in 1982 as a result of drought stress throughout the country (GGDP, 1983). Drought is common in tropical environments, and is an important factor limiting maize production in low-income countries (Edmeades *et al.* 1998). Furthermore, maize yields are most sensitive to water stress, especially at flowering, pollination and grain filling stages. For instance, NeSmith and Ritchie (1992) reported that the reductions in maize yield exceeded 90 % due to water deficit during flowering and pollination stages. The high water requirement of maize with their sensitivity to water stress indicates that limited or deficit irrigation is difficult to implement successfully without causing yield reductions, particularly in light-textured soils. Therefore, frequent and uniform supply of water is extremely important for maize yield to meet the water requirements of plants. Therefore, innovative ways to increase the water availability use efficiency are needed. Irrigation technology such as drip irrigation that will supply water at a uniform rate may be adopted for more effective and rational use of limited supplies of water.

1.2 Problem Statement

Rainfall is the single most important factor affecting crop production (Rukuni and Carl 2004). The smallholder farming sector has been experiencing decreasing maize yield due to;

- The erratic rainfall patterns
- Non uniform water requirement in all the growth stages
- Sensitivity of maize to water stress of the maize plant.
- Competing use of water among different sectors (e.g. Ghana Water Company, Ministry of Fisheries etc.) due to climate change

To address all these issues there is the need to develop an irrigation (surface and subsurface drip irrigation) system that meets the water use and uniform water requirement of maize, to improve yield and production.

1.3. Aim

The study aimed at designing and evaluating a simple PVC drip irrigation system using *Akposoe* maize variety as a test crop.

1.4 Objective

1. To assess maize growth parameters under;

a) Irrigation water place;

i. on the surface (0cm)

ii. at 20cm depth below ground surface

iii. at 40 cm depth below ground surface

b) No irrigation treatment

2. To compare dry matter yield of maize;

a) Irrigation water place;

i. on the surface (0cm)

ii. at 20cm depth below ground surface

iii. at 40 cm depth below ground surface

b) No irrigation treatment

1.5 Organization of Dissertation

The write up is made up of five distinct chapters. The contents are summarized and elaborated below:

Chapter one is the general introduction on the research topic with emphasis on irrigated maize farming. It comprises the background of the study, problem statement, aim and objectives, and finally the organization of the subsequent chapters.

The chapter two is the literature review. This is a review of relevant literature from primary, secondary and tertiary sources. These include articles, presentations, conference papers, published materials and scientific journals in the area of interest.

The materials and methods, experimental design used to conduct the field test are presented in Chapter three, which also describes the characteristics of the study area.

Chapter four presents data, calculations, interpretation discussion and analysis obtained from the study.

The final chapter, five, presents the summary of the major findings of the research, conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1. Irrigation and types of irrigation scheme

Irrigation is the artificial application of water to the land to provide adequate moisture for crop production (Solomon, 1990). Phocaides (2000) also defined irrigation as the application of water, supplementary to that supplied directly by precipitation, for the production of crops. Rain-fed agriculture is erratic in which man cannot depend sole on his activities without supplementary application of water hence the need of artificial application of water cannot be underestimated in achieving a sustainable agriculture. Agriculture is the greatest user of water resources in the world totaling 70% of total withdrawals and over 80% of the consumptive use of water (Baudequin and Molle, 2003; Stockle, 2001). Notably, there are large regional variations, from 88% in Africa to less than 50% in Europe. Ascough and Kiker (2002) stated that irrigated agriculture is the largest user of water resources in South Africa accounting for 53% of the total annual amount used.

Irrigation includes the development of the water supply, conveyance system, method of application, and the waste water disposal system, along with the necessary management to achieve the intended purpose. In dry areas, rainfall during the growing season falls short of most crop needs and thus irrigation makes up for the shortage. Even in areas of high seasonal rainfall, crops often suffer from lack of moisture for short periods during some part of the growing season (USDA, 1984). These therefore underline the importance of irrigation in attaining crop production targets. Notwithstanding the foregoing potentials, irrigation systems have inherent application limitations that make field calibration and irrigation scheduling critical for proper use of the applied water.

There are two basic types of irrigation systems namely open canal systems and pressurized piped systems (Phocaides, 2000). Irrigation is thus implemented through surface and pressurized systems, characterized by the mode of transport of the water to the point of application (Keller and Bliesner, 1990). Scherer (2005) expands it further that there are four basic methods, of water application, which are subsurface irrigation, surface/gravity irrigation, trickle/drip irrigation and sprinkler irrigation.

2.1.1 Surface irrigation

Surface irrigation is a technique where water is applied and distributed over the soil surface by gravity. It is by far the most common form of irrigation throughout the world and has been practiced in many areas virtually unchanged for thousands of years.

Surface irrigation is often referred to as flood irrigation, implying that the water distribution is uncontrolled and is, inherently inefficient. In reality, some of the irrigation practices grouped under this name involve a significant degree of management. Surface irrigation comes in three major types: level basin, furrow and border strip.

Basin irrigation has historically been used in small areas having level surfaces that are surrounded by earth banks. The water is applied rapidly to the entire basin and is allowed to infiltrate. Basins may be linked sequentially so that drainage from one basin is diverted into the next once the desired soil water deficit is satisfied. A “closed” type basin is one where no water is drained from the basin. Basin irrigation is favoured in soils with relatively low infiltration rates (Walker and Skogerboe, 1987).

Furrow irrigation is conducted by creating small parallel channels along the field length in the direction of predominant slope. Water is applied to the top end of each furrow and flows down the field under the influence of gravity. Water may be supplied using gated pipe, siphon and head ditch or bankless systems. The speed of water movement is determined by many factors such as slope, surface roughness and furrow shape but most importantly by the inflow rate and soil infiltration rate.

The process of surface irrigation can be described using four phases. As water is applied to the top end of the field it will flow or advance over the field length. The **advance phase** refers to that length of time as water is applied to the top end of the field and flows or advances over the field length. After the water reaches the end of the field it will either run-off or start to pond. The period of time between the end of the advance phase and the shut-off of the inflow is termed the wetting, ponding or **storage phase**. As the inflow ceases the water will continue to runoff and infiltrate until the entire field is drained. The **depletion phase** is that short period of time after cut-off when the length of the field is still submerged. The **recession phase** describes the time period while the water front is retreating towards the downstream end of the field. The depth of water applied to any point in the field is a function of the **opportunity time**, the length of time for which water is present on the soil surface.

2.1.2 Sprinkler irrigation

With sprinkler irrigation, artificial rainfall is created. The water is carried to the field through a pipe system in which the water is under pressure. The spraying is accompanied by using several rotating sprinkler heads or nozzles or a single gun type sprinkler (Benami *et al.*, 1984).

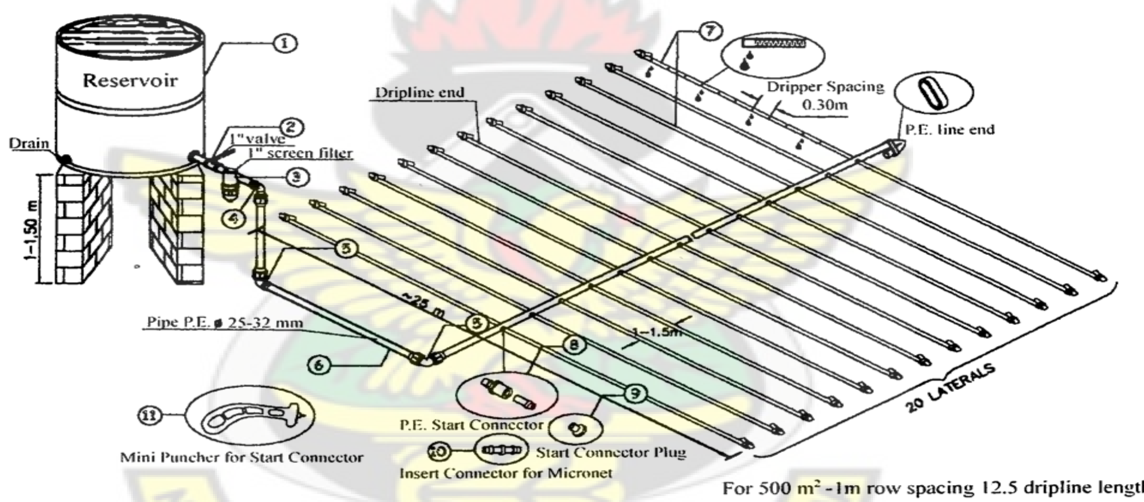
2.1. 3 Drip Irrigation

Africa's regions with extensive periods of drought and inadequate rainfall contribute to the continent's food shortage problem. While nature cannot be controlled, society does have the ability to develop and practice more efficient water usage techniques in order to improve water supply management.

One type of technology that may contribute to the improvement of water supply management and the associated food crisis is drip irrigation. Drip irrigation systems (DIS) have discharge points or sufficiently small holes in sections of hose such that filtration is a primary concern (Burt and Styles, 1994). These systems commonly use low flow rates and low pressures at the emitters and are typically designed to only wet the root zone and maintain this zone at or near an optimum moisture level (James, 1988). Hence, there is a potential to conserve water losses by not irrigating the whole field. Obvious advantages of drip irrigation include a smaller wetted surface area, minimal evaporation and weed growth, and potentially improved water application uniformity within the crop root zone by better control over the location and volume of water application (Hoffman and Martin, 1993). Drip systems are also commonly designed to include fertigation and automation capabilities.

In recent years, low-pressure drip irrigation (LPDI) systems have been developed for smaller farming areas. For many subsistence farmers, a standard pressurized system is too expensive and complicated, as pressurized systems are intended for large areas of land, and therefore do not match the needs of small subsistence farming (Bustan, 2008). Figure 1 shows the components of a typical LPDI system. These systems are economical and fairly simple to use, thus they are appropriate for subsistence farming in rural areas of developing countries.

LPDI systems work with gravity-power and are low water pressure; there is no longer a need for operation by an outside power source, thus reducing the initial cost. With the bottom of the water reservoir sitting at 1-2 m above the ground, these systems can generate a flow of about 1 m^3/h (Phocaides, 2007). Dov Pasternak, a drip irrigation specialist from Israel, has combined the LPDI system with an appropriate crop mix to create the African Market Garden (AMG), but for this design the bottom was set at a height of 0.80 m above ground. The AMG generates revenue for small farmers and has been implemented in West African countries such as Senegal, Ghana and Niger.



Source: Bustan (2008)

Figure 1: Diagram of the LPDI System

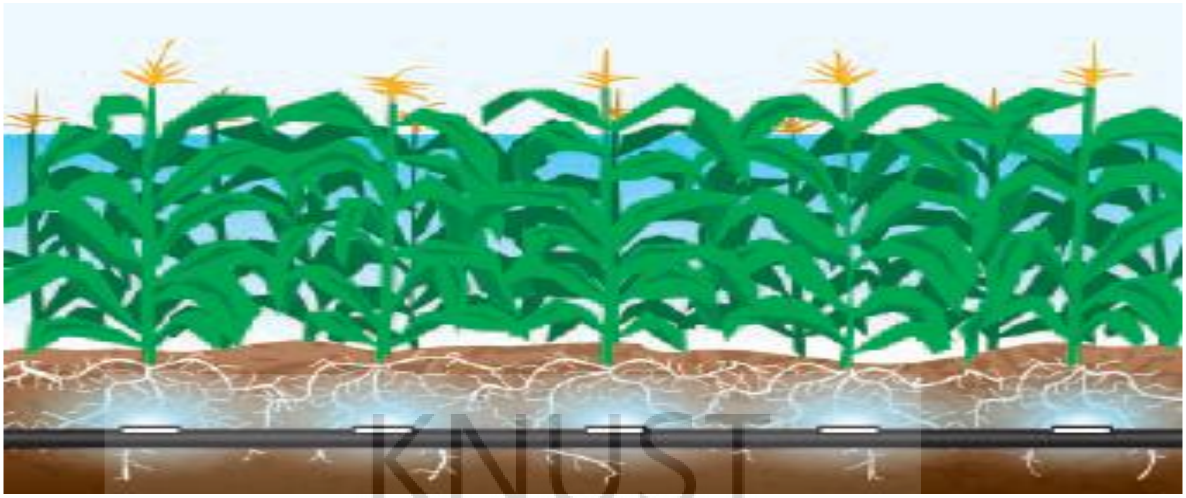


Figure 2,Subsurface drip irrigation works

Subsurface drip irrigation (SDI) consists of flexible polyethylene tubing with drippers permanently welded to the inside wall of the tubing as shown on Figure 2.The tubing system is buried within the soil in rows (typically 180 cm to 270 cm apart), at a depth (typically 54 cm to 81 cm deep) suitable for the grower’s purposes. Water is pumped under low pressure from the source through a filtering system to the tubing. The drippers slowly emit specific amounts of water directly to the root zone of the plant. The controlled, precise output of the dripper provides water at a rate that allows the plant to uptake most of the water supplied.

Drip systems are commonly categorized according to either their physical structure or their placement in the field (e.g. surface, subsurface or suspended). The physical structures may be either:

• Flexible thin-walled drip (or trickle) tape made of polyethylene where the emitter is formed in the join, or the emitter is joined to the inside of the tape or

• Drip (or trickle) tube where the structure is a thicker walled polyethylene pipe into which the separately formed emitter is inserted, welded, glued within, or attached externally to the hose.

A major benefit of drip is the ability to apply small amounts of water at high frequency intervals.

This provides the opportunity to maintain the soil moisture at a specified moisture content and changes the focus of irrigation scheduling away from "irrigating at a frequency which does not affect output quantity/quality" to "irrigating on a schedule which maximizes output quality/quantity". This change in emphasis may produce benefits depending on the specific crop response to moisture stress. However, where the crop is relatively insensitive to moisture stress and when the available moisture content is high the benefits of more frequent irrigation are likely to be minor if present at all. Hence, many researchers (Hanson and Patterson, 1974; Wendt *et al.*, 1977; Bucks *et al.*, 1981) have found that drip irrigation does not increase yield compared to other application systems where both the volume and timing of the water applied for evapotranspiration is non-limiting.

Drip systems provide not only the potential to irrigate more frequently but also the ability to more readily maintain specific moisture deficits at a level below field capacity either for part or all of the irrigation season. Irrigating to maintain a specified root zone soil moisture deficit provides the opportunity for increased soil moisture storage from rainfall during the irrigation season.

The potential water application efficiency of drip irrigation systems is often quoted as greater than 90% (Golberg *et al.*, 1976; Hoffman *et al.*, 1990; Keller and Karmeli, 1975;

Jensen, 1983). However, as with all irrigation systems, the ability to achieve high levels of efficiency is a function of the design, installation and management practices.

Losses of water in drip irrigation systems principally occur through evaporation from the soil surface, surface run-off and deep drainage. Evaporation losses are generally small in subsurface irrigated systems due to a limited wetted surface area. Run-off losses are also normally small due to the low application rates. However, excessive watering periods and the use of shallow subsurface drip on low infiltration soils (e.g. sodic soils) can result in appreciable tunneling of

flows to the surface creating surface ponding and the potential for localized run-off.

2.1. 4 Performance Evaluation

The performance of drip irrigation systems is heavily influenced by the uniformity of flow through each emitter along a drip line. However, unlike other systems, the uniformity of drip irrigation systems is not only a function of the design characteristics but is also significantly affected by installation, maintenance and management practices. Therefore, measuring application uniformity in drip irrigation systems is an important component of performance evaluation and the assessment of the likely system longevity (Sadler *et al*., 1995).

Discharge uniformity may be assessed by measuring discharge from a number of emitters using a catch can methodology. For subsurface systems, this involves excavating the soil around the emitter and collecting the water quantity discharged (Sadler *et al.*, 1995). Pressure may be measured at the flush point or end of the lateral using a standard pressure gauge or at specific points along the lateral using a needle point pressure gauge inserted directly through the tape or tube. Where an assumption of no plugging can be made, the models used for the design and evaluation of drip irrigation systems may also be used to evaluate the application uniformity of subsurface systems based on the measured pressures and the system design characteristics (Phene *et al*., 1992; Feng and Wu, 1990; Wu and Yue, 1991; Wu, 1992). Root zone recharge may be measured directly using soil moisture sensors, such as tensiometer, gypsum block and capacitance probe. In this case, sensors should be placed in vertical grid pattern along a radial axis from the emitter to measure both lateral and vertical soil water movement. Soil moisture sensing is also commonly used to identify deep drainage losses and variations in wetted pattern due to application rate and period of watering (Or, 1995).

A wide range of irrigation uniformity coefficient is commonly used in performance evaluation (Jensen 1983). Camp *et al*. (1997) evaluated the appropriateness of various uniformity coefficients for drip irrigation systems including the traditional Christiansen (1942) equation as used by a number of workers. Acceptable flow rate 10 – 20 % (Qvar), uniformity coefficient (UC) should be greater than 90% and coefficient of variation (CV) between 1-20%. (Bralts *et al*.1987).

2.1. 5 Advantages and Benefits of Drip Irrigation System

1. Drip irrigation system uses water efficiently: sprinklers waste a lot of water as a result of wind-scattered spray, sun-powered evaporation, runoff, the evaporation of accumulated puddles, or deep leaching.

2. Provides precise water control: every part of a drip irrigation system can be constructed with an exact flow rate. It is very easy to calculate what the total flow of the system amounts to and to match this with the plants' needs.

3. Increase yield: drip irrigation can be used for slow, gradual application of tiny amounts of water on a frequent or daily basis. This maintains an ideal soil moisture level, promoting more abundant foliage, greater bloom, and higher yields (by actual comparison) of produce, fruits, and nuts than those produced by any other irrigation approach.

4. Provides better control of saline water: Sprinklers apply water to the foliage; if your water is saline, this can cause leaf burn. Drip irrigation applies water only to the soil, and frequent applications with drip irrigation help to keep the salts in solution so they don't affect the roots adversely. (Any salt crust buildup at the margins of the moist area can be leached away with an occasional deep irrigation).

5. Improves fertilization: with a device called a fertilizer injector (or proportioner), are easily apply dissolved or liquid fertilizers with accuracy and without leaching the fertilizer beyond desired root zones. The liquid fertilizers can be applied with each irrigation or only when required.

6. Encourages fewer weeds growth: the small moist spot around each emitter, where the water slowly dribbles out, covers only a fraction of the soil's surface. The larger dry areas between emitters remain too dry for weed seeds to sprout.

7. Saves time and labor: drip irrigation systems eliminate tedious and inefficient hand watering. Automatic drip systems add the convenience of not even having to remember to turn valves on and off by hand. (The initial installation of such a system, however, will take more time and effort than all other forms of irrigation except permanent sprinkler systems).

8. Reduces disease problems: without the mist produced by a sprinkler, drip-irrigated plants are less likely to develop water-stimulated diseases such as powdery mildew, leaf

spot, anthracnose, shot-hole fungus, fire-blight, and scab. Furthermore, careful placement of emitters away from the trunks of trees, shrubs, perennials, vegetables and stalks of cereals will keep the crown of the root system dry and minimize such root problems as crown rot, root rot, collar rot, and armillaria root rot.

9. Provides better water distribution on slopes: sprinklers often create wasteful run-off when set to water the upper slopes of hills or berms. Drip emitters can apply the water slowly enough to allow all the moisture to soak into the soil. Some emitters, known as pressure-compensating emitters, are designed to regulate the water flow so that all emitters in the system put out the same gentle flow, regardless of slope.

10. Promotes better soil structure: heavy sprinkler irrigation can produce puddles, causing clay particles to stick together, and increase soil compaction. Drip-applied water gradually soaks into the ground and maintains a healthy aerobic soil which retains its loamy structure.

11. Conserves energy: because of the low-pressure requirements of a drip irrigation system, the pumping costs are lower.

12. Uses low flow rates: the low-volume application rate of drip emitters permits larger areas to be watered at the same time than is possible with sprinkler systems.

2.1.6. Limitations of Drip Irrigation

Some drawbacks of drip irrigation include the following:

1. Initial costs are high; a garden hose with a simple oscillating sprinkler will always be cheaper than drip irrigation, but it doesn’t offer the same measure of control and water conservation. A well-designed drip system will repay the cost of installation in reduced effort, fewer irrigation chores, and greater yields.

2. Weeding can be difficult; especially with surface drip irrigation and unmulched drip irrigation systems will stimulate some weeds around each emitter, and care must be taken not to damage the drip system while weeding. A protective and attractive layer of mulch will greatly reduce, if not eliminate.

2.2.1 Soil and plant water concepts

2.2.2. Soil water potential

Soil water potential is expressed in energy terms (bars or MPa). The difference in energy between pure water and that of soil water at standard pressure and temperature is called the soil water potential. The total water potential can be expressed as:

$$\psi_t = \psi_g + \psi_m + \psi_p + \psi_o \qquad [1]$$

where, ψ_t = the total soil water potential energy, ψ_g = the gravitational potential energy, ψ_m = the matric potential due to capillary pressure, ψ_p = the pressure potential, ψ_o = the osmotic potential due to salts (Don Scott, 2000). To determine the potential energy status of soil water, piezometers, tensiometers and psychrometers are commonly used (Goldhamer and Snyder, 1989).

2.2.3 Soil water content

Soil water content is expressed as the mass of water in unit mass of soil (gravimetric) or as volume of water in unit volume of soil (volumetric) (Jalota *et al., 1998).*

Gravimetric water content (θ_g) is measured by weighing the soil when wet (m_{wet}) and again after drying at 105°C (m_{dry}).

$$\theta_g = (m_{wet} - m_{dry}) / m_{dry} \qquad [2]$$

Volumetric water content (θ_v) is the volume of liquid water per volume of soil, and can be calculated from θ_g using bulk density (ρ):

$$\theta_v = volume_{water} / volume_{soil} \qquad [3]$$

$$= (m_{water} / \rho_{water}) / (m_{soil} / \rho_{soil})$$

$$= \theta_g \times \rho_{soil} / \rho_{water}$$ (where ρ_{water} is usually assumed =1.0 g/cm^3).

2.2.4 Moisture characteristic and concepts of available soil water

The energy of soil water and soil water content are related by the moisture characteristic (Prunty and Casey, 2002). In saturated soil, all pores are filled with water and the water potential is zero. As suction is increased, progressively smaller pores drain so the soil water content decreases and the water potential becomes more negative. At very high suctions, only the very small pores retain water. In light to medium textured soils (sands, sandy loams, loams and clay loams), soil structure affect the soil moisture characteristic, while in heavy textured soils the influence of structure is less distinct (Williams *et al., 1983).*

Field capacity is defined as the water content of the soil following drainage of a saturated soil profile underlain by dry soil for about 24 - 48 hours depending on soil types (Hardy, 2004). The soil water potential at field capacity is variously defined as around -0.1 bar to -0.3 bar (-0.01 to -0.03 MPa) depending on soil texture and whether the soils have been homogenised or they are structured (as in the field condition) (NEH, 1991). The permanent wilting point is the soil water content at which plants are unable to absorb soil water, and wilt permanently (Ley *et al.,* 2006). The soil water potential at this point is usually considered to be -15 bars (Sankara and Yellamanda, 1995), although the actual value will depend on plant type and the demand for water. The available water in a soil is the amount of water that can be utilized by plants for their growth and development. It is commonly taken to be the difference between the water contents at field capacity and the permanent wilting point.

2.2.5 Soil water movement and Hydraulic conductivity

The sum of the suction and gravitational potentials is defined as the hydraulic head (Hillel, 1972). The hydraulic head determines the direction and rate of water movement.

Water moves from soil with lower to higher potential.

In this research work, we are concerned about upward flux and downwards of water, soil matric potential and evaporative demand. The scientific principle underpinning evaluation of the modified SDI in this research is that the water required for crop establishment is met by upward flux from the subsurface drip. Hydraulic conductivity is a measure of the ability of the soil to conduct water and depends upon the permeability of the soil to water (Don Scott, 2000). Knowledge of the hydraulic conductivity of soil is important to the understanding of soil-water behaviour including the movement of water and solutes within the soil profile and studies of water uptake by plant roots.

Hydraulic conductivity depends greatly on soil water content (Miyazaki, 2006), so it is often determined in both the saturated and unsaturated condition (Lal and Shukla, 2004). Saturated hydraulic conductivity pertains to the conductivity of soil when all pores are filled with water, whereas conductivity is unsaturated when pores are partially filled. The soil factors affecting hydraulic conductivity include the pore geometry, soil structure and presence of entrapped air in the soil pores (Jalota *et al.*, 1998).

2.2.6 Yield threshold depletion

Yield threshold depletion (YTD) is the amount of water that can be depleted from the soil before there is an effect on yield or quality of crop. If the YTD is known, the soil water balance can also show the maximum time allowable between irrigation. Commonly, a crop should be irrigated before reaching the YTD level. YTD depends upon soil, plant and climatic factors. Crops differ in their sensitivity to water stress.

2.2.7 Soil water balance

The soil water balance can be variously expressed. For irrigation research:

$$ASW_1 - ASW_2 = P + I - (ET + Ro + D) \quad [4]$$

ASW is available soil water at times 1 and 2, (ASW_1 - ASW_2) is the change in soil water during the interval t_1 to t_2, and P = precipitation, I = irrigation, ET = evapotranspiration, R_o = surface runoff and D = deep percolation beyond the root zone, all for the interval t_1 to t_2 (Sankara and Yellamanda, 1995). If ASW_1 is the desired state and ASW_2 is the present state, then irrigation required to return the soil water to the desired state (the replenishment of water use in the period), (ASW_1 -ASW_2) can be estimated by assuming R_0 and D are zero.

$$\text{Irrigation requirement} = ET - (I+P) \quad [5]$$

In budgeting approaches to irrigation scheduling, ET is estimated from potential evaporation combined with the use of a crop coefficient (Hartz, 1999).

Sankara and Yellamanda (1995) suggested a simplified water balance equation, used by Burt (1999) to calculate the components of the water balance when water was applied to a bare soil surface:

E = I - D, where E = Evaporation, I = Irrigation and D = Drainage. This equation is used to calculate E later in this thesis.

2.2.8 Monitoring soil and plant water in irrigation scheduling

Successfully operating and managing an irrigation system requires a proactive monitoring approach to managing soil water. There are three approaches to monitoring and scheduling irrigation, as stated by Goldhamer and Snyder (1989).

i. Soil-based methods that estimates soil water status by its appearance, feel or, more objectively, by water content or suction.

ii. Plant-based methods which includes visible symptoms such as wilting, that reflect leaf turgor and thus indirectly leaf water potential, the Scholander or 'pressure bomb' that measures plant water potential, and non contact thermometry with an infrared thermometer (a water stressed plant transpires less and is cooled less by evaporation).

iii. The water budget approach, which estimates crop water use from weather data and, from this, the irrigation requirement.

Measurements of soil water can be used to indicate when to irrigate, thus avoiding over and under irrigation. Soil water sensors measure either soil water potential (SWP) or volumetric soil water content (VSWC). Devices for measuring soil water potential include the tensiometer, gypsum blocks and granular matrix sensor (Shock *et al.,* 2005). A variety of FDR (frequency domain reflectometry) (Stirzaker *et al.*, 2005), TDR (time domain reflectometer) (Charlesworth, 2005) and capacitance probes (Fares and Alva, 2000) are available for measuring volumetric soil water content.

2.2.9 Tensiometer

Tensiometers measure only soil water potential. They do not provide direct information on the amount of water held in the soil (Whalley *et al.*, 1994). The use of tensiometers for irrigation scheduling has been widely reported for over thirty years (Pogue and Pooley, 1985; Goyal and Rivera, 1985; Hartz, 2000). There has been much research on the appropriate depth of placement and water potential guidelines. Recommendations vary with soil type and crop. The main limitation with tensiometers is that they operate only in water potential up to - 75 kPa. Further drying leads to breaks in the water column thus requiring a high degree of maintenance (Giddings, 2000). Also farmers will often want to deplete soil water beyond the range of the tensiometer, meaning that some interpretation needs to be made, for example from soil water tension deeper than the zone of greatest root proliferation.

2.3.0. Granular matrix sensor/gypsumblock

The granular matrix sensor is similar to the gypsum block, although apparently more durable. It operates on the principle that resistivity of the block depends on its moisture content, which in turn depends on soil water potential. Like the gypsum block, the granular matrix sensor has been reported to have slow response times in some circumstances and each sensor needs calibration (Shock *et al.*, 1998). However, both sensors are inexpensive. Granular matrix sensors operate in the range 0-0.2 MPa, and therefore have a wider range of applications than the tensiometer. In comparison of instruments, Munoz-Capena *et al.* (2005) found that granular matrix sensors (and tensiometers) were the most suitable for automated drip irrigation,

2.3.1. Wetting front detector, capacitance probe/frequency domain reflectometer

The wetting front detector, which originated from Australia, is a soil moisture-monitoring device which can be used to detect wetting fronts. Stirzaker *et al. (2005)* suggested that the 'FullStop' wetting front detector might be the simplest one and it comprised of a specially shaped funnel, a filter and a float mechanism. The funnel of the detector is buried in the soil within the root zone of the crop. If sufficient water or rain falls on the soil to move to the funnel, it passes through a filter.

2.3.2. Time domain reflectometer

A TDR is an instrument which emits a pulse charge of electromagnetic energy, using sensors or 'wave guides' buried in the soil. The pulse signal reaches the end of the sensor and is reflected back to the TDR control unit. The time taken for the signal to return is related to the water content of the soil surrounding the probe (Whalley *et al.*, 1994; Charlesworth, 2005).

The use of multi-wire probes in the TDR provide rapid determination of soil profile water content and offers the capability of monitoring the dynamics of the soil water volume around a point source to differentiate soil water conditions at different vertical and horizontal soil volumes (Souza and Matsura, 2003).

2.3.3. Neutron probe

The neutron scattering method (neutron probe) measures volumetric water content of soil indirectly using high-energy neutrons emitted from the probe. Neutron probe method is suitable for coarse or medium textured soils but not suitable for measurements near the soil surface and in shallow soils without special calibration (Campbell and Mulla, 1990).

2.3.4. Water balance approaches in irrigation scheduling

The soil water balance represents the integrated amount of water in the soil at a particular time. The water balance method is an indirect way of monitoring water status, using simplifications of the soil water balance equation. It is used to estimate crop water use (Goldhamer and Snyder, 1989) from climatic data (Allen *et al.*, 1998). Climatic parameters including solar radiation, temperature, relative humidity and wind have either direct or indirect effects on crop water use through their influence on evaporation and transpiration (Howell *et al.*, 1986). Various methods of estimating crop water use from meteorological information are used (Bowel *et al.*, 1986). The combination of soil evaporation (E) and transpiration (T) make up the total water use, which is commonly referred to as evapotranspiration (ET). Estimation of evapotranspiration generally uses four factors: reference evapotranspiration (ET_r) based on a specific type of crop, a crop factor (K_{cb}) that describes both the dynamic seasonal and developmental change in the crop evapotranspiration in relation to ET_r, a soil factor (K_{cs}) which describes the effect of low soil water content on transpiration and has close relationship with crop growth parameters such as rooting depth and the soil factor (K_{so}), which describes the evapotranspiration amount from either rainfall or irrigation, The crop water use is represented by the following equation (AlIen *et al. 1998):*

$$ET_c = ET_r \, [(K_{cb} \, K_{cs}) + K_{so}] \qquad [6]$$

Reference evapotranspiration (ET_r), expressed in mm/day, can be estimated by different methods such as modified Blaney-Criddle method, the modified Jensen-Haise method, the Penrnan-Monteith combination equation, or directly by pan evaporation. Evaporation pans of various designs have been widely used throughout the world as an index of reference evapotranspiration (ET_r). To calculate the particular crop water use or crop evapotranspiration, crop coefficient values are used. The crop coefficient (K_c) value varies between crops and growth stages. Crop evapotranspiration (ET_c) is calculated by multiplying crop coefficient (K_c) and reference evapotranspiration (ET_r) (Qassim and Ashcroft, 2001).

The water balance approach was developed in irrigation to estimate ET from large areas. Its application is difficult under drip irrigation because of the multidimensional water application pattern (Lazarovitch *et al.*, 2007).

2.3.5. Water use efficiency

Generally, plant growth is directly related to transpiration (T), although under field conditions changes in soil moisture result from both T and soil evaporation (E) (Hillel, 2004). E and T are commonly summed to give evapotranspiration (ET), which can either be measured as a change in soil water or estimated as discussed above. Both farmers and scientists are concerned with water use efficiency. In irrigated crops, efficiency of water use can be affected by the method, amount, and timing of irrigation.

Water use efficiency has been defined in various ways and it is important to understand the differences. Loomis (1983) defined it as the ratio of dry matter produced (Y) per unit of water transpired by a crop (T), in equation 7 expressed as kg/mm or kg/ha/mm.

$$WUE = Y / T. \qquad [7]$$

This approach given the biomass production relative to the water actually used by the plant, and should more correctly be termed the 'transpiration efficiency' (TE). The TE of different crops may vary with differences in photosynthetic mechanism (C_3, C_4, and CAM) and vapour pressure deficit (van Keulen, 1975; Lof, 1976).

$$WUE = Y_e / ET. \qquad [8]$$

The term Ye / ET given the agronomic yield of the system relative to total water use, and is a more correct use of the term 'water use efficiency' or agronomic water use efficiency (Loomis, 1983). Soil surface modifications such as tillage and retaining surface residue may influence WUE by reducing soil evaporation (E) and increasing crop transpiration (T) (Hatfield *et al.*, 2001). One potential advantage of SDI is reduced soil evaporation (Solomon, 1993). Loch *et al.* (2005) described water use efficiency as the amount of water transpired relative to the amount of irrigation applied (t yield/ML water), which could be called irrigation efficiency. He noted that factors such as poor soil structure, profile salinity; and irrigation management that restrict the expansion and efficiency of the plant root system will all reduce water use efficiency.

Overall agronomic efficiency of water use (Fag) in irrigated systems is defined by FAO (1997) using an adaptation of the soil water balance:

$$Fag = P/U, \qquad [9a]$$

where P is crop production (total dry matter or the marketable yield) and U is the volume of water applied. The components of U are expressed by the following equation:

$$U = R + D + Ep + Ec + Tw + Tc, \qquad [9b]$$

where R is the volume of water lost by runoff from the field, D the volume drained below the root zone (deep percolation), E_p the volume lost by evaporation during the conveyance and application to the field, E_c the volume evaporated from the soil surface, T_w the volume transpired by weeds and T_c the volume transpired by the crop. Overall irrigation efficiency is calculated by multiplying the efficiencies of the components. For a system, which includes reservoir storage, water conveyance, and water application, the overall irrigation efficiency is defined as

$$E_o = (E_s) \text{ X } (E_c) \text{ X } (E_a). \qquad [9c]$$

where E_s = reservoir storage efficiency, E_c = water conveyance efficiency, E_a = irrigation application efficiency.

In all agricultural systems, low water use efficiency can occur when soil evaporation is high in relation to crop transpiration. Early growth rate is slow (eg. crop establishment stage), water application does not correspond to crop demand, and also shallow roots are unable to utilize deep water in the profile. This was demonstrated by Patel and Rajput (2007) during the early growth phase of potato. These problems are especially pronounced in intensive vegetable production (Gallardo *et al.*, 1996).

Irrigation control may increase water use efficiency (yield / water used) (Upchurch *et al.*, 1990), water 'use' here meaning the sum of ET and deep percolation. The role of irrigation scheduling in improving water use efficiency is considered below.

2.3.6. Irrigation scheduling to improve water use efficiency

Irrigation scheduling means applying water at intervals based on the needs of the crop, with the primary objective of managing soil water within defined limits. It is the process by which an irrigator determines the timing, amount and quality of water to be applied to the crop (Qassim and Ashcroft, 2001; Bierman, 2005). Vazquez *et al.* (2005) illustrate the difficulty in trying to precisely apply irrigation water with drip irrigation. They compared scheduling using crop evapotranspiration (ET_c) with volumetric soil water content measured by TDR, maize in a silty clay loam. The surface drip had drainage during crop establishment when water was applied at a higher rate than crop evapotranspiration. Sensors must be placed in the active root zone in proximity to the emitter. Sensor placement in SDI systems varies, but is mostly located midway between emitters (Howell and Meron, 2007).

2.3.7. Drip irrigation and its adaptation in surface and sub-surface drip irrigation management

Drip irrigation systems allow water to be applied uniformly and slowly at the plant location so that essentially all the water is placed in the root zone (Johnson *et al., 1991).*

Drip systems are categorised according to their placement in the field:

- Surface drip irrigation: Water is applied directly to the soil surface.
- Subsurface drip irrigation: Water is applied below the soil surface through perforated pipes.

Subsurface drip irrigation has been used in Africa and elsewhere for crops including citrus, cotton, sugarcane, some vegetables, sweet corn, ornamentals, lucerne and potato (Raine *et al.,* 2000; Alejandro and Eduardo, 2001; Thorburn *et al.,* 2003; Bhattari *et al.,* 2004; Shock *et al.,* 2004; Lamm and Trooien, 2005).

2.3.8. Lateral drip line

Tapes and tubes are available for use as laterals. Tape products are thinner than tubes (Neufeld *et al.,* 1993). Commonly, tube wall thickness ranges from 0.04 mm to 1.5 mm (Hanson *et al.,* 2000). Camp *et al.* (2000) identified two classes of tape wall thickness. Flexible thin-walled (0.15 mm to 0.30 mm) tapes are typically used for shallow installation, whilst thicker-walled (0.38 mm to 0.50 mm) tapes are installed deeper or where the soil does not provide sufficient support to prevent collapse by equipment or soil weight.

2.3.9. Tape installation depth

The use of surface and subsurface drip irrigation varies by region and by crop, and is often based on perceived constraints on the vertical placement of the drip tape/tube or laterals (Clark and Smajstrla, 1996). With SDI, the choice of drip tape depth is influenced by crop, soil, climate characteristics and anticipated cultural practices, but it generally ranges from 0.02 to 0.7 m (Camp, 1998). Although installation depth is generally decided for other reasons, another consideration for determining depth is that deeper placement (0.45m) will be required if the primary aim is to reduce soil evaporation and capture the potential benefit of improved water use efficiency (yield and quality) that is possible with SDI (Bryla *et al.*, 2003).

With the shallow systems, relatively deeper installation should reduce soil evaporation and also allow for a wider range of cultural practices. However, as noted above, deeper installation may limit the effectiveness of the SDI system for seed germination/crop establishment. Deeply placed drip lines may require an excessive amount of irrigation for germination/crop establishment. This practice can result in off-site environmental effects (Camp, 1998), and it reduces water-use efficiency. Deeper placement may restrict the availability of surface applied nutrients and other chemicals (Camp and Lamm, 2003).

Relatively shallow tape placement has been tried for many years to assist germination (Burt and Styles, 1994) for corn on a silt loam (Lamm and Trooien, 2005). It can be assumed that shallow placement is especially important for establishment if there is no supplementary source of surface irrigation.

2.4.0. Lateral spacing and installation

A wider lateral spacing is practiced in heavy textured soil (Camp, 1998). Closer spacing is recommended for sandy soil (Phene and Beale, 1976) and Lateral spacing is generally one drip line per row/bed or an alternative row/ bed with one drip line per bed or between two rows (Lamm and Camp, 2007). Lateral spacing of 1.5 m in sub-surface drip-irrigated corn was successful use in a silt loam soil (Darusman *et al.*, 1997).

Lateral lines should be laid following the contour of the land as closely as practicable to avoid pressure variations within the line due to elevation change (Haman and Smajstrla, 2003). The first step in successful SDI system installation is maintaining proper hydraulic design. This allows the system to deal with constraints related to soil characteristics, field size, shape, topography, and water supply. Lateral diameter and length influence water application uniformity (Kang *et al.*, 1999).

2.4.1. Emitters / Drip holes spacing

Emitters are plastic devices which precisely deliver small amounts of water. Hla and Scherer (2003) described two types of emitter. Point-source emitters discharge water from individual or multiple outlets. Line-source emitters have perforations, holes, porous walls, or emitters extruded into the plastic lateral lines (Ayars *et al.*, 2007). Line-source emitters are generally used for widely spaced crops such as vines, ornamentals, shrubs and trees. The emitters used for SDI are much the same as those used for surface drip, but the emitter is fixed internally in the drip line (Harris, 2005c).

Soil characteristics and plant spacing determine emitter spacing. Similarly, an emitter spacing of 0.3 m was suitable for corn production for deep silt loam soils under subsurface drip (Lamm and Aiken, 2005). In a semi-arid environment, 0.45 m emitter spacing was used in clay loam soils for drip-irrigated corn (Howell *et al.,* 1995). In general, emitter spacing should normally be less than the drip lateral spacing and closely related to crop spacing (Lamm and Camp, 2007).

2.4. 2. Water application uniformity

Water application uniformity in micro-irrigation depends on system uniformity and spatial uniformity in the field (Wu *et al.,* 2007).

The system uniformity is affected by system design factors such as lateral diameter and emitter spacing (Wu *et al.,* 1986), and manufacturing variation (Bralts *et al.,* 1981a). It is also affected by emitter clogging (Bralts *et al.,* 1981b). The parameters used to evaluate microirrigation system application uniformity are: the Uniformity Coefficient (UC); emitter flow variation (q_{var}); and Coefficient of Variation (CV) of emitter flow (Bralts and Kensar, 1983; Wu *et al.,* 1986). Using these parameters, Ayars *et al.* (1999) discussed various drip tape products and determined the values of these uniformity parameters. System uniformity values predicted by design or evaluation models are similar for both surface and subsurface drip (Camp *et al.*, 1997).

The spatial uniformity in the field refers to variation in soil water. In addition to system design factors noted above (Wu *et al.,* 2007), it is also affected by field topography and soil hydraulic properties (Burt and Styles, 1994; Burt *et al.,* 1997).

2.4.3. Causes and consequences of non-uniformity

The causes of non-uniformity include unequal drainage and application rates (Burt, 2004). Even where system uniformity is high, variation in soil properties, such as hydraulic conductivity, can affect drainage and lead to variation in water content. Application uniformity can be directly related to yield (Solomon, 1984b; Letey, 1985).

Burt (2004) considered the typical manufacturing coefficient of variation in tube is only 0.02 to 0.06, which will be negligible. Soil ‘excavating’ was shown to increase flow rate by 2.8% to 4%, but not sufficiently to affect uniformity calculations (Sadler *et al.,* 1995). One consequence of non-uniform application is increased demand for drainage (Ben-Asher and Phene, 1993; Phene and Phene, 1987), assuming irrigation for uniformly good crop growth. Drainage may also if the application is uniform but the soil water holding capacity or hydraulic properties are not uniform. Obtaining sufficiently moist soil for germination and crop establishment by applying uniform irrigation to soils which are inherently variable is a challenging issue for SDI (Patel and Rajput, 2007). They found that to provide adequate irrigation water for potato plants in the early growth period, they had to be over-irrigated, leading to more downward movement of water on sandy loam soil than upward capillary movement of water.

2.4.4. Minimising non-uniformity

Minimising non-uniformity of the drip system requires a design which considers the topography of the field (Wu *et al.,* 2007), periodic checking of the system (Clark and Phene, 1992), and irrigation scheduling (volume and frequency) (Burt *et al.*1997). Greater irrigation uniformity can be achieved by using pressure-compensating emitters in surface and subsurface drip (Schwankl and Hanson, 2007).

Flow meters are widely recommended to check the system performance in sub surface drip irrigation (Alam *et al.*, 2002). They are used to determine the rate and volume of water applied in an automated irrigation control system (Ayars and Phene, 2007).

2.4.5 Comparison of uniformity in surface and subsurface drip

In SDI, emitter clogging and accumulation of salt caused by evaporation is less than in surface drip (Hills *et al.,* 1989a). More uniform water content was observed in the root zone with SDI than surface drip (Ghali and Svehlik, 1988), and thus drainage would be less with SDI (Ben-Asher and Phene, 1993; Phene and Phene, 1987).

2.5.0 Management of SDI

2.5.1. Discharge rate and irrigation frequency in relation to crop and soil type

Subsurface drip irrigation systems generally consist of emitters that have discharge rates less than 8 L/hr (ASAE, 2001). A discharge rate of 0.25 l / hr gave high yield of corn in sandy loam soils of Israel (Assouline, 2002), although the difference in yields between discharge rates was not statistically significant. In a drip system, frequency and emitter discharge rate determine the soil water availability and plant water uptake pattern (Coelho and Or, 1996; 1999) and consequently yield (Bucks *et al.,* 1981; EI-Gindy and El-Araby, 1996).

Illustrating the importance of matching irrigation frequency to soil type, Ruskin (2005) reported that a coarse textured sandy soil required drip lines with higher flow rates and shorter irrigation cycles than clay soil. High frequency water application under drip enables maintenance of salts at reasonable levels within the rooting zone (Mmolawa and Or, 2000b).

The main reported benefit of increased irrigation frequency with SDI is the increase yield. A less commonly reported benefit of increased irrigation frequency is improved crop establishment (Phene and Beale, 1976). As crop establishment is a common problem in SDI, it is surprising that there seem to be relatively few studies of irrigation frequency in relation to establishment. More frequent or pulsing irrigation, which involves applying small increments of water multiple times per day rather than applying large amount for long duration, has been advocated to improve surface and near surface soil moisture wetting for crop establishment (Lamm and Camp, 2007). However, there is a lack of operational guidelines for SDI (Lamm and Camp, 2007). In Australia, a comparison of pulsed and continuous irrigation on a Hanwood loam soil in NSW revealed very little difference between treatments, leading the author to conclude that responses depended on tape depth and soil type (Miller *et al.*, 2000). Other potential benefits of high frequency SDI are reduced deep drainage of water (Ayars *et al.*, 1999), although for this it will be important to have both uniform application and uniform soil and crop growth. High frequency SDI may have lower water requirement, as shown by Wendt *et al.* (1977).

The flow rate of the drip line has to match the particular soil type. When soil hydraulic conductivity decreases, the pressure head of the soil next to the emitter will increase, which reduces the flow rate of emitters (Warrick and Shani, 1996). On the other hand, emitter discharge decreases due to backpressure, which depends on the soil type, possible cavities near the dripper outlet, and the drip system hydraulic properties (Shani *et al.*, 1996). When the pressure in the emitter increases this may significantly reduce the source discharge rate (Lazarovitch *et al.*, 2005).

In most cases, supplementary irrigation has been used in crop establishment (e.g. Schwankl *et al.*, 1993; Howell *et al.*, 1997). Of the many papers dealing with irrigation management with SDI, few appear to have independently varied management for the establishment and growth periods other than adjust the crop factor. It appears that crops are often over-watered in the establishment period (Enciso *et al.*, 2007; Patel and Rajput, 2007) to ensure establishment. This has been reported to increase drainage (Howell *et al.*, 1997)

One topic which appears to have received little notion is the need to vary irrigation frequency through the life of a crop to meet different requirements. Frequent irrigation may be needed for good establishment, but irrigation frequency subsequently should reduce deep drainage, and increase water use efficiency. This approach is analogous to securing establishment by increasing irrigation rate above the crop requirement determined by K_c and ET_r (Howell and Meron, 2007), but with less risk of increased drainage.

2.5.2. Fertigation via drip irrigation

Through this thesis is not concerned directly with 'fertigation', the application of nutrients together with the irrigation water, there are some considerations directly relevant to SDI, so the topic will be briefly reviewed. Fertigation is an efficient method of applying fertilizers with irrigation water (Magen, 1995). It contributes to the achievement of higher yields and better quality by increasing fertilizer efficiency (Haynes, 1985; Imas, 1999), regardless of whether DI or SDI is being used. In addition, minimization of leaching below the root zone may be achieved through fertigation (Hagin and Lowengart, 1996; Hanson, 1996). Although fertigation can be used with any drip irrigation system, a major potential advantage of subsurface drip is that water and nutrients are potentially used more efficiently when compared to surface installation (Phene *et al.*, 1987). Subsurface drip irrigation and fertilizer management together has been found to increase yield of sweet corn (Bar- Yosef, 1989), cabbage and zucchini (Rubeiz *et al., 1989).*

SDI may also manage the placement and availability of immobile nutrients (e.g. P). The restricted mobility of the phosphate ion implies that pre-irrigation mixing of P in both clay and sandy soils is necessary, supplemented by addition to the irrigation water, to obtain a uniform P concentration in the soil volume (Bar- Yosef and Sheikholslami, 1976). Immobile nutrients are delivered at the centre of the soil root volume rather than on top of the soil in subsurface drip (Martinez *et al.*, 1991). Fertigation with P in SDI improves yield, root growth and environmental performance in sweet corn (Phene *et al.,* 1991).

Potassium is also easily soluble in water and applied through drip irrigation. Phene and Beale (1976) have shown that daily low rate application of nitrogen and potassium with a high frequency drip irrigation system improved nutrient uptake efficiency of sweet corn in sandy soils and reduced leaching loss.

2.5.3. Growth and yield of maize in surface and sub surface drip irrigation

According, Lamm and Camp, (2007) crops which are suitable for surface drip irrigation are also suited to SDI. Information on root distribution is useful to understanding crop responses to irrigation and fertigation, especially with the limited wetted soil volume that develops under subsurface drip (Phene *et al.*, 1991). Phene and Beale (1976) showed that root length and rooted soil volume of sweet corn could be improved by frequent irrigation with shallow SDI. They revealed that frequent irrigation maintained a portion of the root zone within the optimal matric potential range. In high-frequency irrigated corn, root length density and water uptake patterns are determined primarily by the soil water distribution under the drippers, whether the drippers are placed on, or beneath the crop row (Coelho and Or, 1999).

Unfavourable results obtained with drip irrigation have often resulted from inadequate root growth and distribution (Brown and Don Scott, 1984), especially in heavy textured soil (Meek *et al.,* 1983). Subsurface drip irrigation can minimise the period between crops, especially with reduced tillage, and facilitate more intensive cropping. Multiple cropping with SDI has several practical advantages.

2.5.4. Problems encountered with SDI

There are potential disadvantages with SDI, including high initial investment cost, clogging of emitters, 'tunnelling' of soil, and difficulties with uneven wetting and poor plant establishment (Mizyed and Kruse, 1989; Lamont *et al., 2002;* Charles worth, 2005). Qassim (2003) and Harris (2005b) discussed the specific benefits and disadvantages of SDI:

1. *Crop establishment:* In the absence of supplementary irrigation, germination and crop establishment with subsurface drip irrigation depends on unsaturated water movement (i.e. upwards or laterally from the buried emitter). Therefore, important determinants of uniform germination/establishment include the distance from the emitter to the seed/transplant, soil properties (structure, texture, hydraulic conductivity) and initial soil moisture content (Charlesworth and Muirhead, 2003).

2. *Soil and water interaction:* According to Lamm (2002), emitter discharge rate can exceed the ability of some soils to distribute the water in the soil. The water pressure in the region around the emitter may exceed atmospheric pressure thus altering emitter flow. This leads to the "tunnelling" of emitter flow to the soil surface causing undesirable wetting spots in the field. Small soil particles may be carried with the water, causing a 'chimney effect' that leads a preferential flow path. The 'chimney' may be difficult to permanently remove.

The rest of this section deals with the establishment issue, especially in relation to wetting pattern, which varies with soil type (Brouwer *et al.,* 1990). It was shown earlier in this review that subsurface drip is commonly placed relatively deep in the soil, even for shallow-rooted horticultural crops, to reduce soil evaporation or to facilitate tillage operations. Consequently, the variable wetting pattern and inadequate surface wetting of subsurface drip irrigation often provides insufficient surface soil moisture to meet the demands of seeds (eg Zimmer *et al.,* 1988) or seedlings. Several reviews have concluded that crop establishment can be difficult with SDI (Camp *et al.,* 2000; Lamm, 2002; Raine and Foley, 2001), at least for germination of shallow-planted seeds. Harris (2005b) went further to say that, in most situations, a crop cannot be established using subsurface drip irrigation alone. If so, then requiring a parallel surface system represents an added cost to SDI, whilst it would also reduce water use efficiency during the period of surface irrigation, and increase the risk of deep drainage.

As discussed previously, wetting patterns can be managed by varying dripper discharge rate and spacing (Lubana and Narda, 2001), influencing the dripper inter-face (Meshkat *et al.,* 2000), increasing irrigation frequency (Phene and Beale, 1976) or amount (Howell and Meron, 2007), and reducing the depth of installation (Patel and Rajput, 2007). It may also be approached through modifying the SDI tape design (Welsh *et al., 1995)*. Accordingly, research has been undertaken to improve crop establishment under SDI following a range of approaches. However, from the literature discussed previously, none of the solutions involving shallow tape installation or higher discharge rates will be satisfactory under all circumstances.

This leaves modification to the drip tape as the most likely approach to achieve satisfactory performance under a wide range of soil and climatic conditions. Even with this, to achieve adequate surface wetting and remove the risk of poor establishment (Zimmer *et al.* 1988) under all circumstances, it is likely that situation-specific guidelines will be needed for irrigation rate and frequency.

The modification in SDI design by adding an impermeable membrane has the potential advantage of changing the wetting pattern (Miller *et al.*, 2000) and inhibiting the downward percolation of water (Welsh *et al.,* 1995). To counter problems of poor germination, a new technique was suggested for manipulating the wetting pattern of SDI using an impermeable membrane to transform the point source of water in drip lines to a broad band source from which a capillary force operates to draw water upward and outward (Welsh *et al.*, 1995). Although the impervious layer is intended to reduce downward 'percolation (Welsh *et al.*, 1995), it is hypothesised here that any benefit may arise because the layer creates a temporary water table, from which the upward flux of water is increased.

Modifying the drip tape to include the impermeable layer was commercialised in the Capillary Root Zone Irrigation (CRZI) product. It was evaluated in loam and sandy loam soils

(Charles worth and Muirhead, 2003). In this case, however, establishment was considered to be good (-50%) with standard subsurface drip because of the particular soil properties that gave rise to adequate surface water. So, despite the improved wetting pattern, germination was no better. The results did show that an impermeable barrier can be beneficial for surface wetting. Similar results have been obtained with lettuce germination (Deery, 2003). It appears that further research is needed to define the conditions under which the establishment problems arise and to reduce the technical barriers to SDI. Barriers to the adoption of SDI include the need to adapt system design and management to local soil and climatic conditions and constraints.

CRZI has undergone extensive development and is now sold under the trade name Kapillary Irrigation Subsurface System (KISSS^{TM}). The advantage of this product over conventional SDI for maize establishment is yet to be evaluated.

2.6. Soil properties and SDI performance in the corn industry

2.6.1. Role of soil texture and structure

Study in heavy a textured soil in a region where secondary salinity is a problem, subsurface drip irrigation increased the rate of salinization compared with furrow irrigation because of improved structure and reduced slaking and dispersion in subsoil which led to increased solute movement through the soil profile (Hulugalle *et al.*, 2002). Slaking and dispersion are used to measure the structural stability of soil (Daniells *et al.*, 2002). Gypsum improves soil structural stability and economic use of gypsum depends on soil properties and seasonal condition (Greene and Ford, 1980; Ford *et al.*, 1980). Soil conditioners applied by drip irrigation have also increased water stable aggregation in the wetting zone around the drippers (Shaviv *et al.*, 1987).

Drip irrigation can improve plant water availability in medium and low permeability fine-textured soil, and in highly permeable coarse-textured soil in which water and nutrients move quickly downward from the emitter (Cote *et al.*, 2003). Continuous irrigation at a rate equal to evapotranspiration was optimal for medium textured soils whilst greater application rate was required for coarse textured soils to minimise deep percolation losses (Ghali and Svehilk, 1988).

2.6.2. Role of soil hydraulic properties

Knowledge of soil hydraulic properties assists design of irrigation systems (Mehta and Wang, 2004). Non-uniformities in hydraulic properties and infiltration rates are considered to be major reasons for inefficiencies in drip irrigation and may cause non-uniformities in soil water content and could potentially affect plant growth. Soil hydraulic conductivity is a limiting factor for water uptake by plants under drip irrigation, particularly in sandy soils (Li *et al.*, 2002). However, in clay loam soils, subsurface drip irrigation resulted in very non-uniform soil water contents above the depth of emitters (Amali *et al.*, 1997), which may be corrected by using a membrane under the drip tube.

2.6.3. Soil chemical responses to drip and sub-surface drip irrigation

In a study, soil electrical conductivity, pH and soluble cations were lower under subsurface drip compare surface drip (Nightingale, 1985), suggesting increased leaching. Haynes (1990) observed that the conversion of fertigated ammonium sulphate and urea into nitrate-N caused acidification in the wetted soil volume to the surface (0-20 cm) of silt loam soils, also suggesting an increase in leaching. Similarly, acidification throughout the soil profile was observed in vegetable beds planted with tomato (Stork *et al.*, 2003), again suggesting leaching of $N0_3$.

2.6.4. Soil wetting pattern

A basic need for better drip irrigation systems is information about the moisture distribution pattern, shape and volume of soil wetted by emitter (Levin *et al.*, 1979). The volume of wetted soil represents the amount of water stored in the root zone. Its depth should coincide with rooting depth while its width should be related to the spacing between emitters. One possibility for controlling the wetted volume of a soil is to regulate the emitter discharge rate according to the soil hydraulic properties (Bresler, 1978; Lubana and Narda, 2001). The wetting front is an important factor in drip infiltration, indicating the boundaries of the wetted soil volume (Bresler, 1978). A simple technique known as the pit method was developed by Battam *et al.* (2003) for design and management of drip systems.

Soil texture is an unreliable predictor of wetting and for adopting different spacing of emitters. For different soil texture, site-specific information on soil wetting is required (Thorburn *et al.*, 2003). Under given climatic conditions, the effect of soil type on the depth-width-discharge combination is influenced by water holding capacity and hydraulic conductivity of the soil (Zur, 1996).

The wetting pattern with SDI can be affected not only by irrigation management, but also SDI design aspects such as emitter spacing and drip line depth. Dripper function can also be modified after installation. In one study, heterogeneity of the soil in the neighbourhood of a subsurface emitter that had been disturbed by farm equipment resulted in low emitter flow, leading the authors to suggest using soil conditioners to improve and stabilize soil structure around the dripper (Shaviv and Sinai, 2004). The wetting pattern has also been enhanced by the addition of plastic barriers beneath the drip line (Brown *et al.,* 1996; Charlesworth and Muirehead, 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.1. INTRODUCTION

This Chapter describes the materials utilized for the field trials necessary for obtaining the requisite data presented in this study. The methods adopted for the field trials, have also been described. The study area characteristics, relevant equations and statistical tools and measures of performance of drip irrigation systems have also been presented.

3.1.1 Location of the study area

The field experiment was conducted at the Department of Agricultural Engineering at Kwame Nkrumah University of Science and Technology, from 5th March to 18th May 2011at latitude 06˚ 41′ N, longitude 01˚ 33′ W and altitude of 295.7m. The site has an area of 320m^2. The site has been under serious cultivation, source of water for the experiment was a tap water from the department.

3.1.2. Soils

The predominant soil in the area is the Bomso-Ofin soil compound association (Ghana Soil Classification) or Ferric Acrisol-Dystic Fluvisol (FAO/UNESCO soil Classification), with predominant soils of the Bomso, Kotei, Akroso, Nta, Ofin and Densu series. Bomso series are deep well-drained, clay loam with abundant frequent quartz gravel and iron stone nodules in the subsoil found on the upper slopes and summits. The top soil is dark brown sandy loam, humus-stained to a depth of 10-15cm.

The subsoil is sandy clay loam which grades to red with depth and the preponderance of the mica flakes at a depth of about 2m before entering into the partially decomposed rock at several meters below. (Dwomoh and Kyei, 1998).

The soil of the study area is sandy-loam with the following characteristics;

• The field capacity (FC) of the soil is = 27.08% (*volumetric*)

• Permanent wilting point (PWP) is = 8.38% (*volumetric*)

• Dry bulk density = 1.22 g/cm^3

• Available moisture content = 18.7%

Textural analyses of the study site up to 60cm as given below;

Horizon (cm)	**Texture**
0 – 20	Sandy loam
20 – 40	Sandy clay loam
40 – 60	Sandy clay loam

3.1.3. Climate

Mean annual rainfall is about 1300mm. Average maximum and minimum temperature is about 31˚C and 23˚C respectively. The rainfall distribution has binomial nature with the first and second rainfall during April to July and August to October respectively. The Peak evapotranspiration rates occurred in February (5.444mm).The month of March was characterized by high rainfall during the study period. The highest relative humidity prevalent in the area occurs in the morning with values of 90% in July-September and

78% in January-February. The relative humidity is usually around 50% at mid-day (Dwomoh and Kyei, 1998).

3.1.4. Vegetation

The natural vegetation of the study area is the semi-deciduous forest, inferring from Figure 3, however, repeated farming has reduced the vegetation to mosaics of secondary forest.

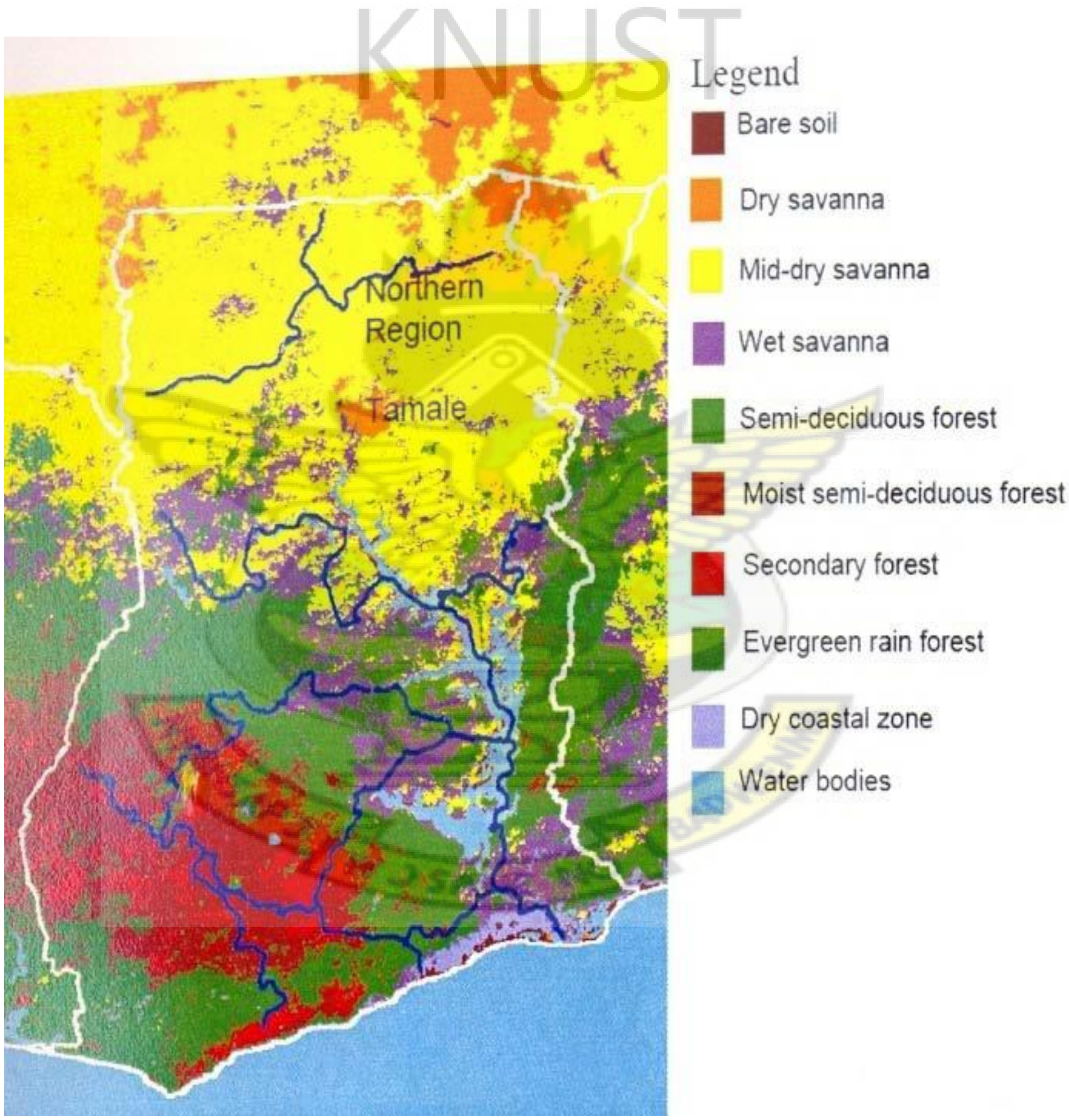


Figure 3.Vegetation map of Ghana,Source: (Menz and Bethke, 2000) as in (Nyarko, 2007)

3.1.5. Materials

The materials used for the experiment were as follows;

- ½ inch (0.0127m) PVC pipe 6m in length
- ½ inch (0.0127m) end caps
- ½ inch (0.0127m) elbow
- ½ inch (0.0127m) tap
- 2 mm drill bit
- 2 mm drill machine
- Geotextile layer
- Flexible copper wire (core)
- 8 Storage tank (25 liters capacity)
- Wooden stand raise height of water flow from the storage tank
- 50 m water hose
- Funnel
- Recordable rain gauge (Truchek – 200, commercial name)
- Measuring tape
- Leveling instrument (spirit level)
- Electronic digital caliper
- Measuring cylinder ($100cm^3$)
- Collection cans

3.1.6. Field Methods

3.7.1 Field preparation

Field preparation was done by digging trenches of depth 0.6 m at aspacing of 75cm in the East to West direction. PVC pipes at a drip hole spacing of 35 cm were layed manually in each trench at a nominal depth of 40cm, 20cm and 0cm. (Figure 4).

0.6 m of trench below ground surface   Trench spacing of 0.75 m row spacing bewteen crop

Figure 4.Dug-out trenches for lateral placement

3.1.7. Field layout and general crop culture

The experiment was laid Randomized Complete Block Design (RCBD) with 4 replication.The laterals were 6m long and 1.5m wide placement representing three different laterals for each treatment,as in dicated on Figure 5.

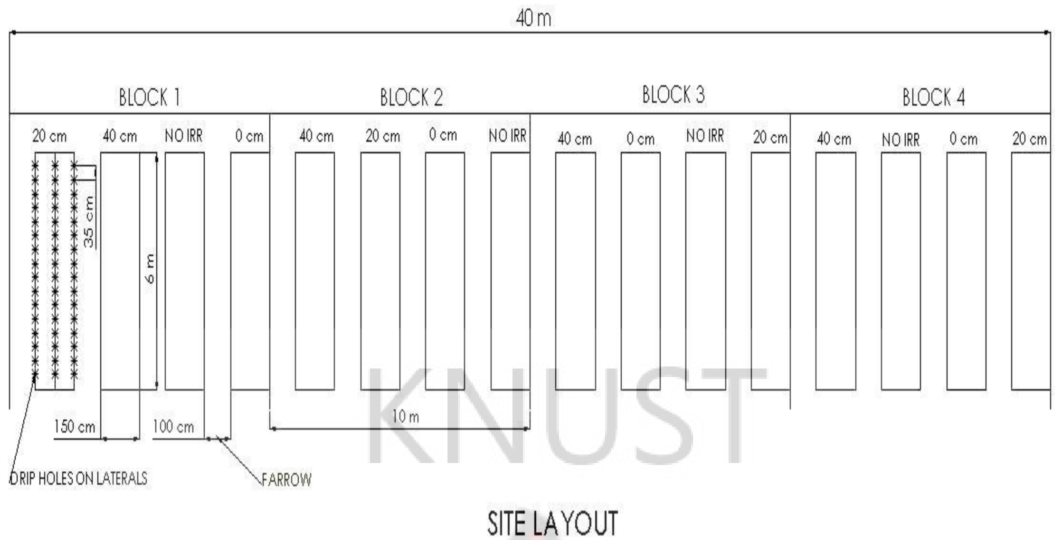


Figure 5.Layout of the experimental field

Maize *(Zea may L.)* was planted at a spacing of 35cm within rows and 75cm between rows based on the recommended planting structure of *Akposoe* maize varaiety. The were three rows of lateral per each treatment. A compound fertilizer NPK 15-15-15 at a rate of 7.5g and Sulphate of Ammonia at a rate of 3.75g was applied to the maize plant two (2) per hill at 14 days and 28 days after planting respectively. Weeding was done two weeks after planting by hand-weeding and hoeing.

3.1.8. Laying of pipe

The laterals were laid with caution to ensure that there will be a uniform flow and distribution of water from each drip hole. Levelling instruments were used to get a good level of pipe placement on the field in the trenches. As indicated in Figure 6 and 7.

Figure 6.Pipe laying on the field in the various trenches

0.75m recommended between row spacing for maize; 0.35m; recommended between row spacing for maize.

Figure 7.Laying of laterals (example 0cm depth)

3.2. The Experimental set up

3.2.1. Design and Installation

Thirty-six (36) PVC pipes of length 6m and diameter 22.5 mm were used. Drip holes of diameter 2mm were made at a spacing of 0.35m on each PVC pipe based on maize planting distance as shown in Figure 8. The drip holes were drilled with a hand drill with a drill machine with a drill size of 2mm. End caps were used to cover one end of the pipe line to prevent water flowing out. Elbows were used to connect the extension pipes to the main lateral. The geotextile material (of 0.06m × 0.39m dimension) and a copper wire (of length 0.25m) were used to restrict the flow of water from the drip holes of the laterals, which served as a soaking medium and control drip flow. The PVC pipes were laid at three different depths; 0cm, 20cm and 40cm. The maize variety (*Akposoe*) was planted as a test crop at a planting spacing of 0.75m between rows and 0.35m within rows with a furrow of 1m between treatments.

Figure 8.Geotextile material and flexible copper wire affixed on the drip hole to give an interval of 0.35m.

3.8.2. Calibration of flow in PVC pipes (tied and untied)

To obtain a uniform flow of water from the laterals with a length of 6m, for surface and subsurface laid pipes, the pipes were calibrated to determine;

- Quantity of water from each drip hole.
- Flow variation in each drip hole under the 25L, 0.8m head setup.

To calibrate the pipe for uniformity of flow from 16 drip holes of 2mm diameter each per lateral of 6m, end cap fixed at one end, elbow fixed at the other and jointed to a pipe of height 0.6m. This was connected to the main pipe through the elbows to supply water from the storage tank to the main laterals through the drip holes. Collector cans were used to collect water from the drip holes. The collector cans were placed on a leveled surface which was checked with a leveling device (spirit level), to ensure even distribution of water in the drip holes as illustrated in Figure 9

A 25 liter container was used as the storage tank and placed at a height of 0.8m to provide the flow head. A funnel was put at the 0.6m pipe end to direct the water into the lateral. The tap connected to the tank was opened fully to allow the water flow through the lateral.

The collected water over 30min was measured using a measuring cylinder to check uniformity of water flow from each drip hole.

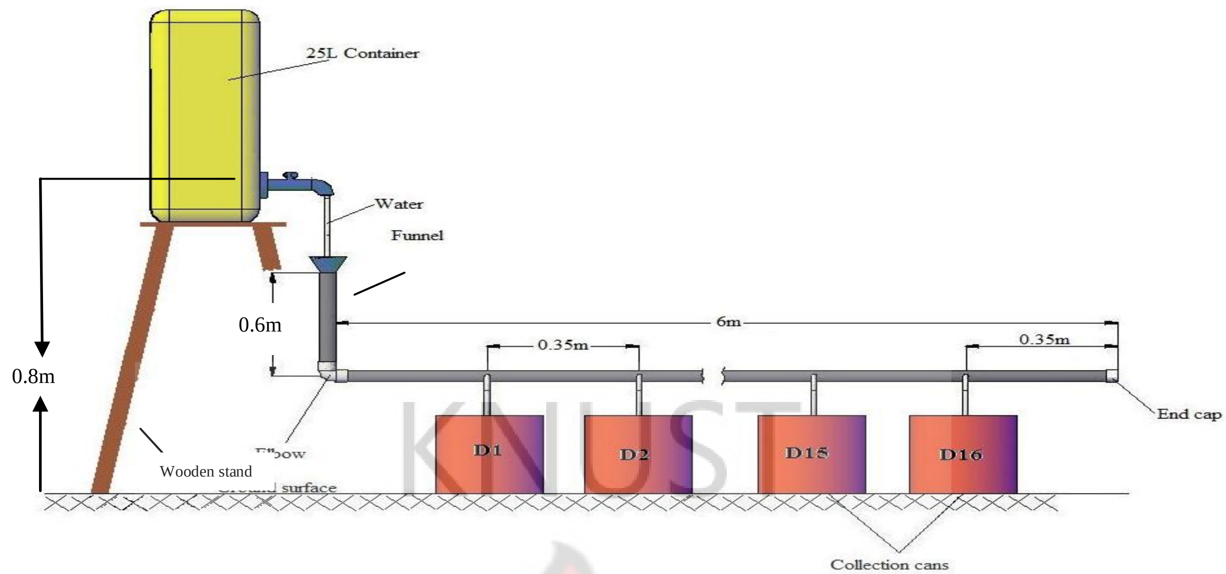


Figure 9.Layout of set-up for flow Calibration

3.2.2. Experimental design

The experimental design consisted of a randomized arrangement of three water application depths and one "No irrigation" control treatment. The layout consisted of four blocks, with 4 plots in each block, in a randomized complete block design (RCBD). The treatments were water application depth at 0 cm, 20cm, 40 cm and No irrigation. Each plot measured 6m x 10m. There was a buffer zone of 1.0 m between plots. The time ranges of individual growth as observed and adopted for the experiment based on the variety grown for the experiment are shown on Table 1.

Table 1.Duration and period within the various growth stages

Growth stages	Duration	Period
Initial stage	14	March 5 to March 18
Crop development stage	24	March 19 to April 11
Mid stage	27	April 12 to May 8
Late stage	20	May 9 to May 28

3.3. Data collection

3.3.1. Plant growth parameters

The plant growth parameters were observed weekly throughout the study. For this purpose, five plants in each replicate were randomly selected and tagged for growth monitoring the treatment. The parameters considered were: plant height, leaf length, number of leaves, leaf diameter and stem girth. Were weekly collected on these selected plants and average value were calculated for each replicated.

Plant heights were measured from the soil surface to the highest point of the arch of the uppermost of the maize plant with a ruler and a wooden rule was then made for the measurement when the plant was taller than the normal 30cm rule. The stem girth of the maize plant was measured with an Electronic digital caliper weekly. The number of leaves unfurled was recorded every week for all the treatments till the last stage of plant development. The leaf length and width was taken on each plant sample at the various growth stages of the plant.

The results for all the treatments were analyzed statistically using analysis of variance (ANOVA). A 5% level of significance were used for all the analyses and mean separation based on least significance difference (LSD) was calculated where significance difference was found between the treatments.

3.3.2. Dry matter, below and above ground-biomass

Grain yield analysis was made after harvesting of crop. The grains were weighed to determine the wet mass and then dried to a moisture content of 13.5% to obtaining the moisture content of the maize grain. Below and above ground biomass was also determined and analyzed (i.e. stalk and root determination).

3.3.3. Amount of water to apply

Amount of water to apply was calculated based on the various growth stages of the maize variety. Rooting depth (Dr), depletion factor (Df), field capacity (FC) and permanent wilting point (PWP) were considered, resulting in the following equation;

$$\text{Amount of water to irrigate} = Df \times (FC - PWP) \times Dr \times \text{Wetted diameter}$$

Df was considered to be 50% and Dr based on the maize, the rooting depth at each growth stage of the plant. Wetted diameter of the calibrated pipe was 17 cm as indicate in Figure 11.

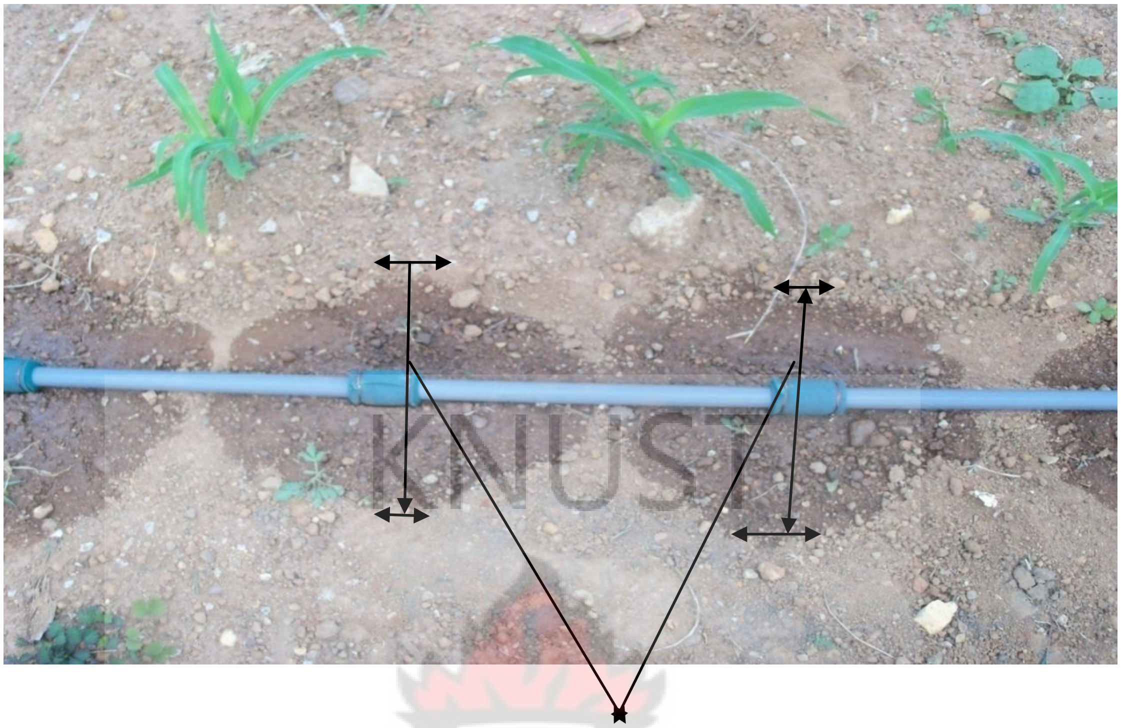
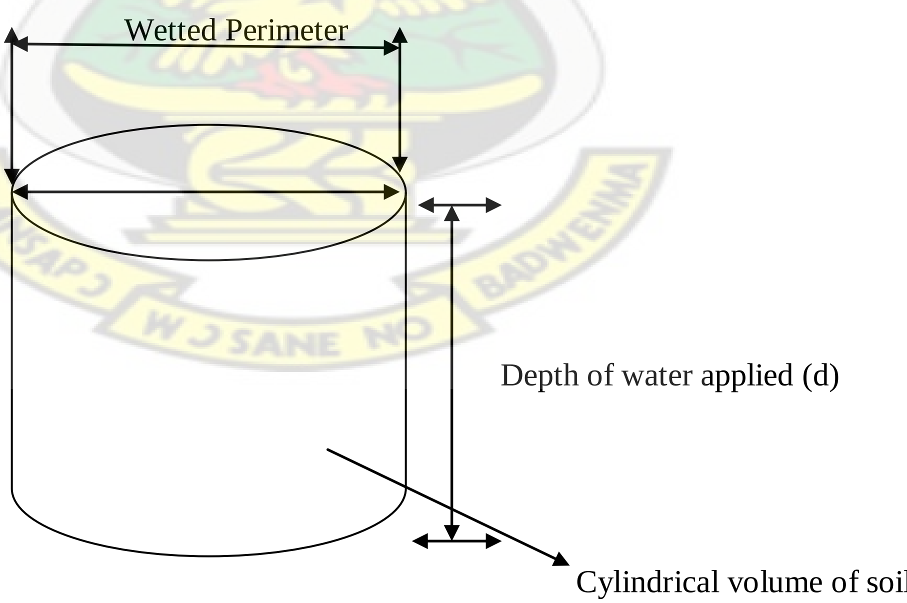


Figure 10.Wetting pattern of pipe calibrated

3.3.4. Calculation of Irrigation Requirements (Theoritical / Ideal Flow)



Volume of water applied (V) = Wetted area (A) × Depth of water (d)

$$V = A \times d$$

Wetted area was given as $A = \pi d^2/4$

$$A = 3.1428 \times (34^2 / 4)$$

$$A = 908.038 \text{ cm}^2 = (9080.38\text{mm}^2)$$

Volume of water applied considering the capacity of the storage tank which is 25 liters. Taking the number of drip holes on the lateral (16 drip holes); each drip hole is expected to release an amount of 1.56 liters, assuming a perfectly uniform application.

3.3.5. Depth of irrigation water applying for 20.466 litres

(25 litre container was used for the calibration but because the tap was fixed closed to the bottom of the container some of the water was left at the bottom by letting 20.466 litres be collected through the catching cans and this applies to all liters used for the calibrations throughout the calibration of the pipe for 30L, 35L, 45L and 50L respectively).

Volume of water applied (V) = 20.466 liters / 16 drip holes

$$V = 1.28 \text{ liters} \times 1000\text{cm}^3$$

$$V = 1280\text{cm}^3 \text{ (per drip hole)}$$

Therefore depth (d) of water applied = V / A

$$d = 1280 \text{ cm}^3 / 908.038 \text{ cm}^2 \quad d = 1.4\text{cm} = (14\text{mm})$$

3.3.6. Depth of irrigation water applying for 24.614 litres

Volume of water applied (V) = 24.614 liters / 16 drip holes

$$V = 1.54\text{liters} \times 1000\text{cm}^3$$

$$V = 1540\text{cm}^3 \text{ (per drip hole)}$$

Therefore depth (d) of water applied = V / A

$$d = 1540 \text{ cm}^3 / 908.038 \text{ cm}^2$$

d= 1.7cm = (17mm)

3.3.7. Depth of irrigation water applying for 28.650 litres

Volume of water applied (V) = 28.650 liters / 16 drip holes

V = 1.8 liters × 1000cm^3

V = 1800cm^3 (per drip hole)

Therefore depth (d) of water applied = V / A

d= 1800 cm^3 / 908.038 cm^2

d= 2.00cm = (20mm)

3.3.8. Depth of irrigation water applying for 36.851 litres

Volume of water applied (V) = 36.851 liters / 16 drip holes

V = 2.3 liters × 1000cm^3

V = 2300cm^3 (per drip hole)

Therefore depth (d) of water applied = V / A

d = 2300 cm^3 / 908.038 cm^2

d = 2.3cm = (23mm)

3.3.9. Depth of irrigation water applying for 40.982 litres

Volume of water applied (V) = 40.982 liters / 16 drip holes

V = 2.56 liters × 1000cm^3

V = 2560cm^3 (per drip hole)

Therefore depth (d) of water applied = V / A

d= 2560 cm^3 / 908.038 cm^2

d = 2.9cm = (29mm)

3.4. Performance criteria for system flow

Three widely-used parameters for measuring emitter discharge uniformity are: Flow variation, (Q_{var}), Uniformity coefficient (*UC)* and Uniformity coefficient *(CV)*.

3.4.1. Flow variation

Emitter flow variation q_{var} was calculated using the equation:

$$\text{Flow variation, } Q_{var} = \frac{100 \times (Q_{max} - Q_{min})}{Q_{max}}$$

Where: Q_{max} = maximum emitter (drip hole) flow rate

Q_{min} = minimum emitter (drip hole) flow rate

Example: for 20.466 liters

$$\text{Flow variation, } Q_{var} = \frac{1.89 - 0.93}{1.89} \times 100$$

$$= 50.79\%$$

3.4.2. Uniformity coefficient

Uniformity coefficient, *UC*, as defined by Christiansen (1942) and modified to reflect a percentage, was calculated using the equation:

$$\text{Uniformity coefficient, } UC = 100 \times \left[1 - \left(\frac{\frac{1}{n}\sum_{i=1}^{n}|q_i - \bar{q}|}{\bar{q}}\right)\right]$$

Where: q = discharge

$\bar{q}$ = Mean of discharge (q)

n = number of (drip holes) emitters evaluated.

Example: for 20.466 liters

$$\text{Uniformity coefficient, } UC = 100[1 - \frac{1}{16}(1.46875)]$$

$$= 100[1 - (0.0625 \times 1.46875]$$

$$=100[1 - 0.09179687]$$

= 90.8%

3.4.3. Coefficient of variation

$$\text{Uniformity coefficient, } CV = \frac{s}{\bar{q}}$$

Where: s = standard deviation of (drip flow) emitter flow rate

$\bar{q}$ = Mean of discharge (q)

Example: for 20.466 liters

$$\text{Coefficient of variation, } CV = \frac{0.298987}{1.28}$$

= 0.233

= 23.3

3.4.4 Data analysis

1. Graph and statistical methods will be used to analysis the data.

2. Data will be analysed using MINITAB and LDS at 5% level.

3. Comparism and analysis of variance will be performed on the effects of supplementary irrigation and "No Irrigation" on maize growth parameters and dry matter yield.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

In this Chapter, the summarized results are presented in tables or figures and the relevant interpretations given. The parameters studied have also been explained vis-à-vis standard values and reasons given for any deviations.

4.1.1 Amount of Water Applied

Amount of water required during the growing season and amount of irrigated water applied per each treatment plots are presented in Table 2.

Table 2.Amount of water supplied during the growing season (i.e. irrigation water plus rainfall) for all treatments.

Treatment	**Irrigation water supplied (mm)**	**Rainfall during crop growth stages (mm)**				**Total water supplied: Irrigation water + Rainfall (mm)**
		I	**II**	**III**	**IV**	
40 cm Depth	**250.5**	119.2	181.6	135.9	0	**687.245**
20 cm Depth	**250.5**	119.2	181.6	135.9	0	**687.245**
0 cm Depth	**250.5**	119.2	181.6	135.9	0	**687.245**
No Irrigation	**0**	119.2	181.6	135.9	0	**436.745**

Total water supplied is the summation of rainfall and irrigation water applied during the growth stages of the crop development (i.e. I-Initial stage, II- Crop development stage, III- Mid stage, and IV- late season stage). Treatment 40 cm, 20 cm and 0 cm depth respectively were irrigated within three (3) days interval. Treatment which was not irrigated (No Irrigation) showed very often symptoms of wilting indicating critical water stress during the crop growing season whiles treatments that were irrigated did not show any sign of wilting as shown in the Figure 11 below respectively.

Figure 11 A – "No irrigation" showing signs of wilting and B - irrigated treatments showing no signs of wilting.

4.1.2. Drip hole calibration base on flow variation for 25L, 30L, 35L, 45L and 50L

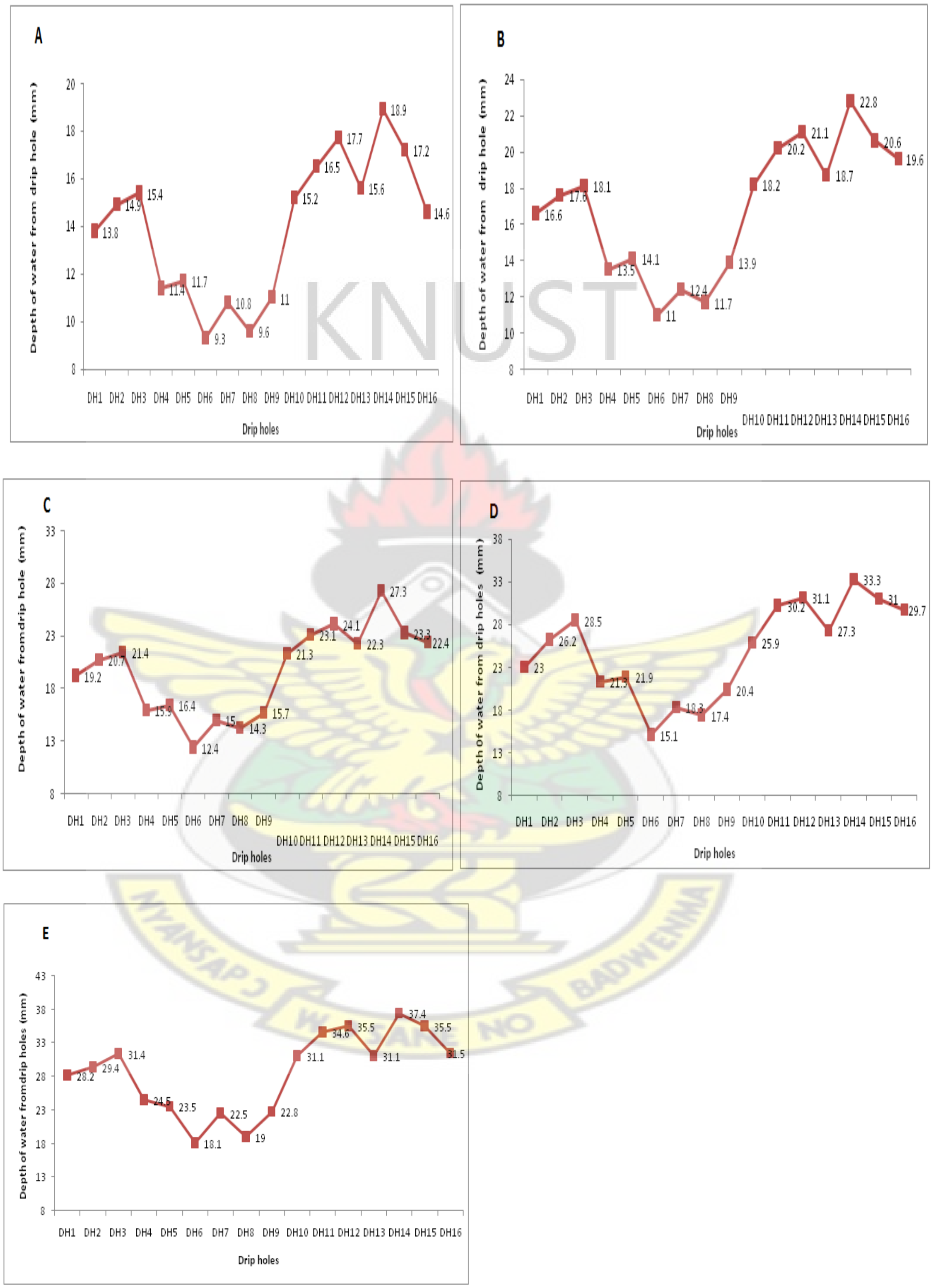


Figure 12.Depth of water from drip holes for A: 25L; B: 30 L; C: 35 L; D: 45 L and E: 50L

Calibration of a 25L capacity gave a 17 cm wetted diameter and was used for the wetted diameter for 30, 35, 45 and 50 l applications. Figure 12 shows the differences in theoretical flow through the drip holes as shown in Appendix.

4.1.3. Average theoretical depth of flow of water per each litre of application into the soil

The various average theoretical depth of water with a 17 cm wetted diameter into the soil from the drip holes per liter of application is presented in Table 3. This indicate that a litre of 25 applied from a drip hole of size 2 mm may go as far as 1.28 cm into the soil, 1.69 cm for 30 litres, 1.97 cm for 35 litres, 2.50 cm and 2.85 cm or for 50 litres. The calibration was repeated several times for a uniform flow of water.

Table 3.Average theoretical depth of flow of water into the soil per drip hole for each irrigated treatment

Litres per application	Volume of water from each drip hole (cm^3)	Depth of irrigation water (cm)
25	1,279.00	1.28
30	1,535.40	1.69
35	1,786.20	1.97
45	2,271.26	2.50
50	2,590.84	2.85

Table 4.Performance criteria determination of flow through the pipe

Quantity of Water Applied *(L)*	**Total Time of Flow (Sec)**	**Flow Variation *(Qvar) %***	**Uniformity Coefficient*(UC)* %**	**Coefficient of Variation *(CV)* %**
25	1457	50.79	90.8	23.30
30	1489	51.75	99.9	21.72
35	1547	54.58	99.0	21.50
45	1589	54.24	99.9	22.00
50	1668	51.60	99.9	21.40

The uniformity coefficient (UC) agrees with Bralts et al., (1987) i.e. is being greater than 95%, except for 25L water application. Flow variation (Qvar) and coefficient of variation (CV) does not agree with Bralts et al., (1987), since their report states that Qvar and CV should be between 10 – 20% and between 1- 20% respectively. The design could not achieve this because either the head or capacity of the container was too small for the Qvar and CV with the 2 mm drip hole. Also the water from the tank/container was exposed to the atmosphere, the design was automated, the tap was turned off whenever the lateral became full and this could affect the uniformity of flow in the lateral/pipe.

4.1.4. Growth Parameters of maize

This section presents data on growth parameters such as plant height, stem girth, number of leaves, leaf length, and width, as influenced by depth of water application at different growth stages.

4.1.5. Plant height

Figure 13 presents the mean the plant height observed for all treatments during the plant growth. There was a steady increase in the height of the plant over the weeks. The height of plants of treatments under water application (i.e. 40 cm, 20 cm and 0 cm) obtained the maximum average height after 6-7th week. From week four (4) to week six(6) of the growth period, all treatments under irrigation (i.e. 40 cm,20 cm and 0 cm) performed better as compared to treatments under No Irrigation. At the tenth week, treatments under 20 cm performed better as compared to all treatments. In all, "No Irrigation" treatment performed worse throughout the growth period as compared to irrigated treatments.The plant height was influenced by water application depth (at 0 cm, 20 cm and 40 cm) at crop development and mid growth stages. From the 8th – 10th week, water application depth at 20cm recorded a significantly ($P<0.05$) higher plant height (177.9) than 0 cm (171.6), 40 cm (166) and No Irrigation (132.765). In turn 0 cm depth was significantly ($P<0.05$) higher than 40 cm and "No irrigation" all at an LSD of 43.91. Appendix C, Table 1.

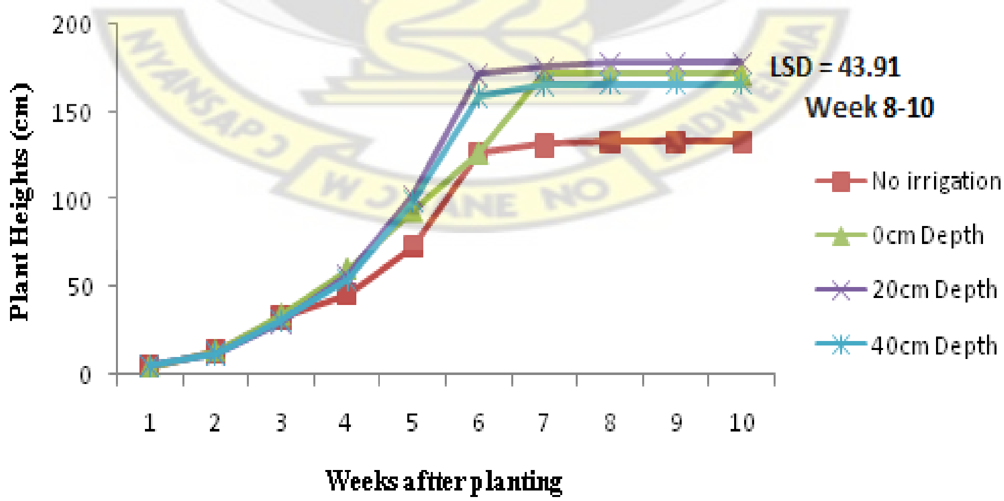


Figure 13.Plant height (cm) of maize under water application treatments

4.1.6. Stem Girth

Figure 14 shows the mean stem girth for all treatments. There was a general increase in the mean stem girth for all treatments from the start of the experiment to the end of the tenth week. The mean stem girth marginally reduced after the end of the seventh week in No Irrigation treatment through to the tenth week. At the end of the tenth week, treatment 20 cm had the highest stem girth followed by 40 cm and 0 cm in that order. No Irrigation treatment had the lowest stem girth at the end of the tenth week. From this, it can be inferred that, all treatments under irrigation performed better than the No Irrigation treatment.

The stem girth was influenced significantly ($P<0.05$) at crop development and mid growth stages of the crop by irrigation water applied. Between the 8^{th} to 10^{th} week, the stem girth 8.95 cm for 20 cm placement depth, 8.805cm for 40cm, 8.675cm for 0 cm placement depth and 6.765cm for the "no irrigation "treatment. Comparing the values, 0cm, 20cm and 40 cm with the "no irrigation", the differences were significant at $P<0.05$ level at an LDS of 1.6. Appendix C, Table 1.

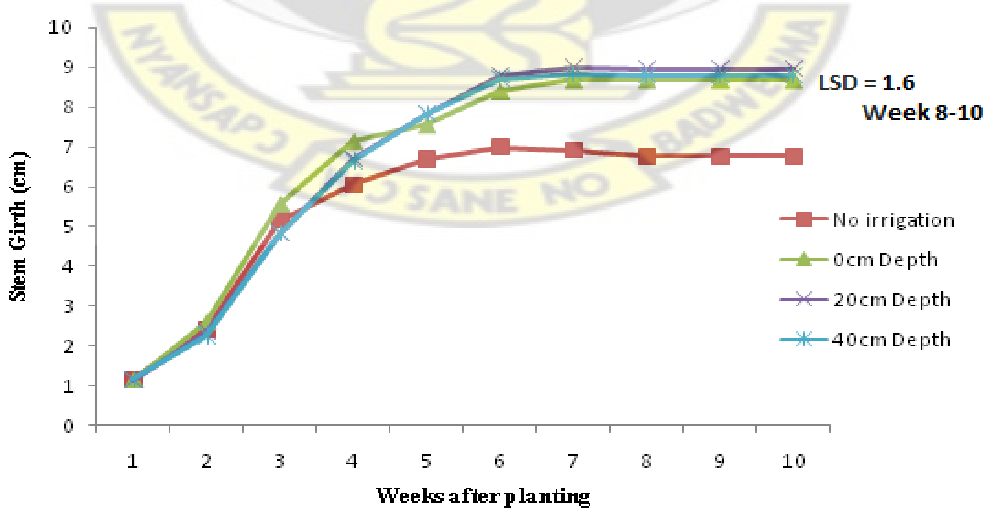


Figure 14.Stem girth (cm) of maize under water application treatments

4.1.7. Number of Plant Leaves

Figure 15 presents the average number of leaves obtained for all treatments. There was a general increase in the average number of plant leaves for all treatments from the start of the experiment to the end of the tenth week. The mean number of plant leaves however reduced after the sixth week for the "No Irrigation" treatment and 7- 8th for the other treatments through to the tenth week, this been that the cobs were developed and the plant need to conserve more water for the cobs development there by shedding of more leaves.. At the end of the tenth week, treatment 20 cm had the highest number of plant leaves (13). "No Irrigation" treatment had the lowest number of plant leaves (10). Based on this, it can be inferred that, all treatments under irrigation performed better than the No Irrigation treatment. The number of plant leaves was not significantly (P<0.05) different among treatments from week 1 - 4. At 8th to 10th week, treatments 40 cm, 20 and 0 cm had significantly (P<0.05) higher number of leaves than "No irrigation" at an LDS of 1.6. Appendix C, Table 1.

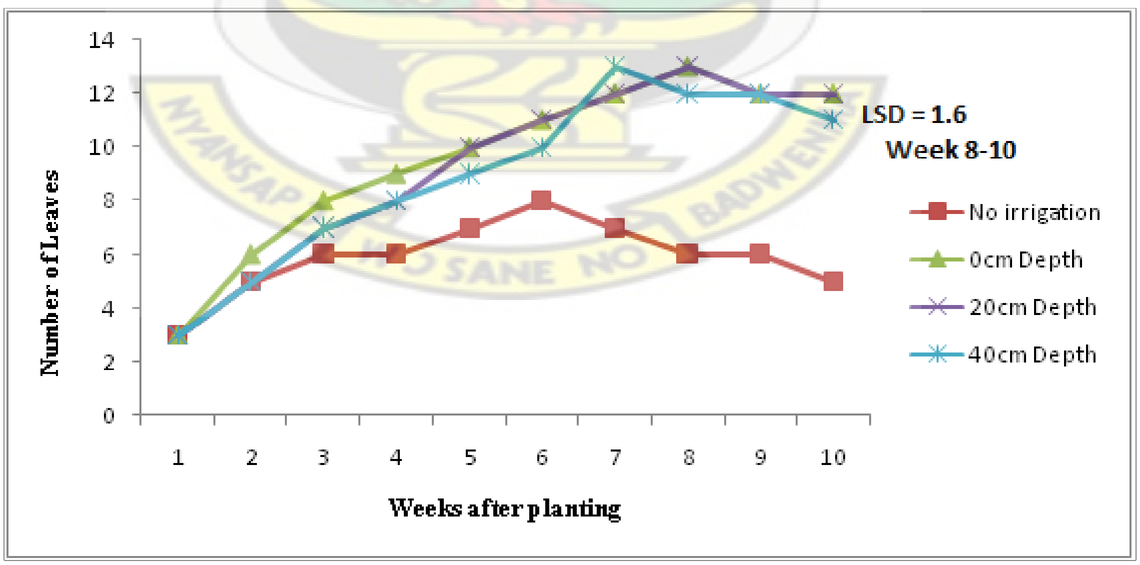


Figure 15.Number of plant leaves under different water application treatments

4.1.8. Leaf diameter

Figure 16 presents the mean leaf width as obtained for all the treatments. There was an increase in the mean leaf width for all treatments from the first week to the fifth week of the experiment and started reducing from the six week to the tenth week. At the end of the tenth week, treatment 40 cm had the highest leaf width followed by 20 cm and 0 cm in that order. No Irrigation treatment recorded the least leaf width. From this, it can be inferred that, all treatments under irrigation performed better than the "No Irrigation" treatment. The leaf width was not significantly different at the early growth stages of the crop by depth of water application but significantly different from week 7 to 10. At 7th to 10th week, treatment 40 cm, 20 cm and 0 cm were significantly ($P<0.05$) higher than "No irrigation treatment at an LSD of 1.5. Appendix C, Table 1.

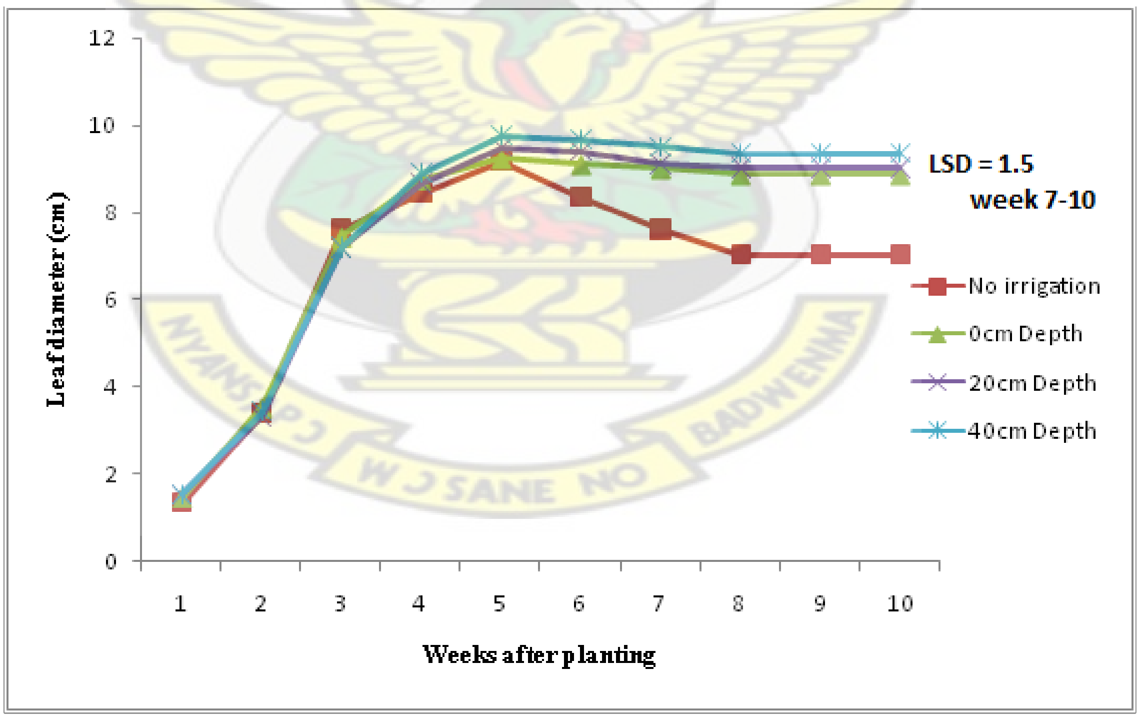


Figure 16.Leaf width in (cm) under different water application treatments

4.1.9. Leaf length

Figure 17 presents the average leaf length as obtained for all treatments. The leaf length was not significantly (P<0.05) different among the treatments from week 1 to 7. But significant (P<0.05) differences were observed from 8th to 10th week. At 8th to 10th Week, there was a high significant (P<0.05) difference among treatments 40 cm, 20 cm, 0 cm and "No Irrigation" but no significant difference recorded among 40 cm, 20 cm and 0 c at an LSD of 12.29. Appendix C, Table 1.

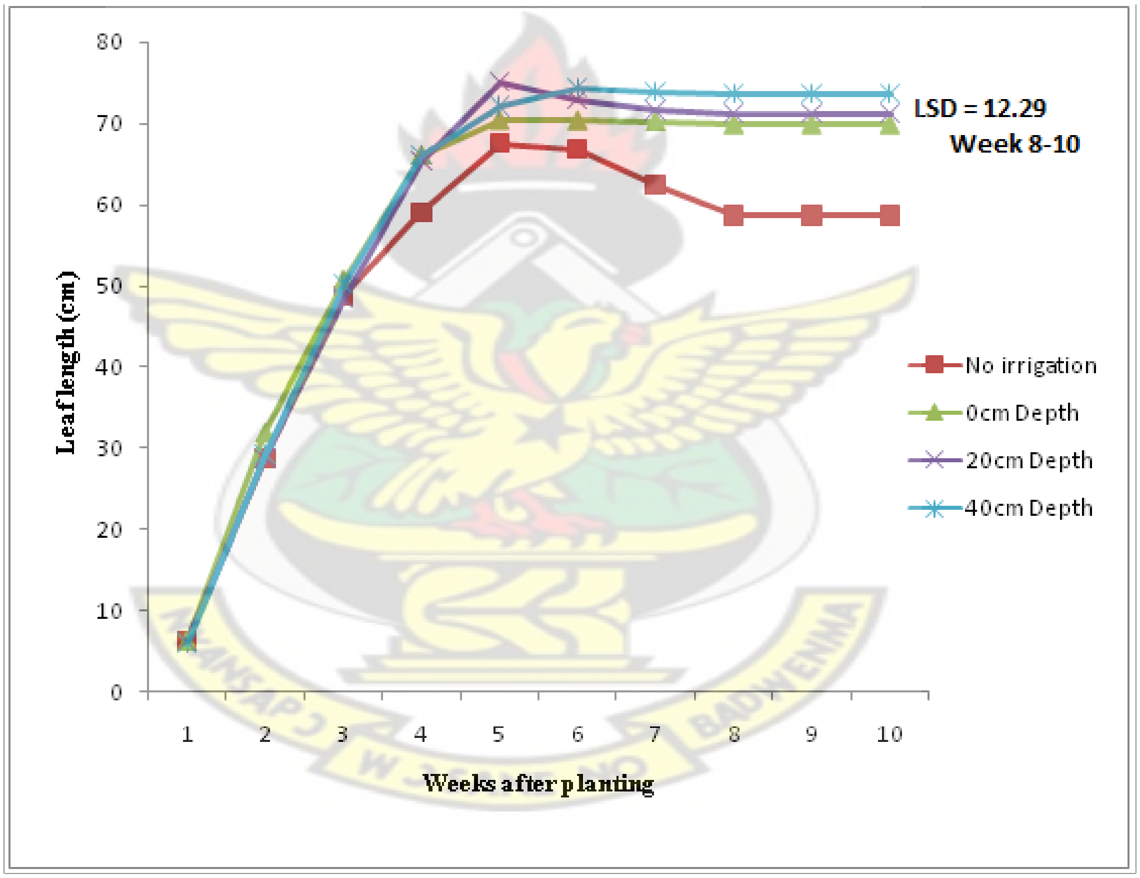


Figure 17.Leaf length in (cm) under different water application treatments

4.2.0. Mass of dry grain (yield) at 13.5% moisture (kg/ha)

The mass of dry grain at 13.5% moisture is presented in Figure 18. ANOVA showed a significance differences (P<0.05) between treatments 40 cm, 20 cm and 0 cm and "No irrigation" treatment. However, there was no significance difference (P<0.05) between treatment 40 cm, 20 cm and 0 cm. (LSD 1985). The highest yield was obtained by applying water at 20 cm depth. Considering the curve or trend the 20 cm was first in terms of yield (6085.08.kg/ha) among the other treatments. This may be due to the fact that the water released at 20 cm was readily available within the root zone of the maize plant. There was also no interference of evaporation and deepercolation. The 40 cm was second in terms of yield (5320.05 kg/ha), the water released at 40 cm might have been percolated beyond the root zone of the plant. The 0cm (5050.57kg/ha) was third in terms of yield which might have been the effects of evaporation and run-off. The "No irrigation" was last in terms of yield (2296.95kg/ha) since it was not supplemented with irrigation. From the curve or trend, the pipe could be placed at 23 cm or 25cm and a higher yield compared to the 20cm depth could be achieved but the pipe cannot be placed around 30cm or even higher between the 40cm and 0 cm since the yield difference between is not much. Appendix E, Table 1.

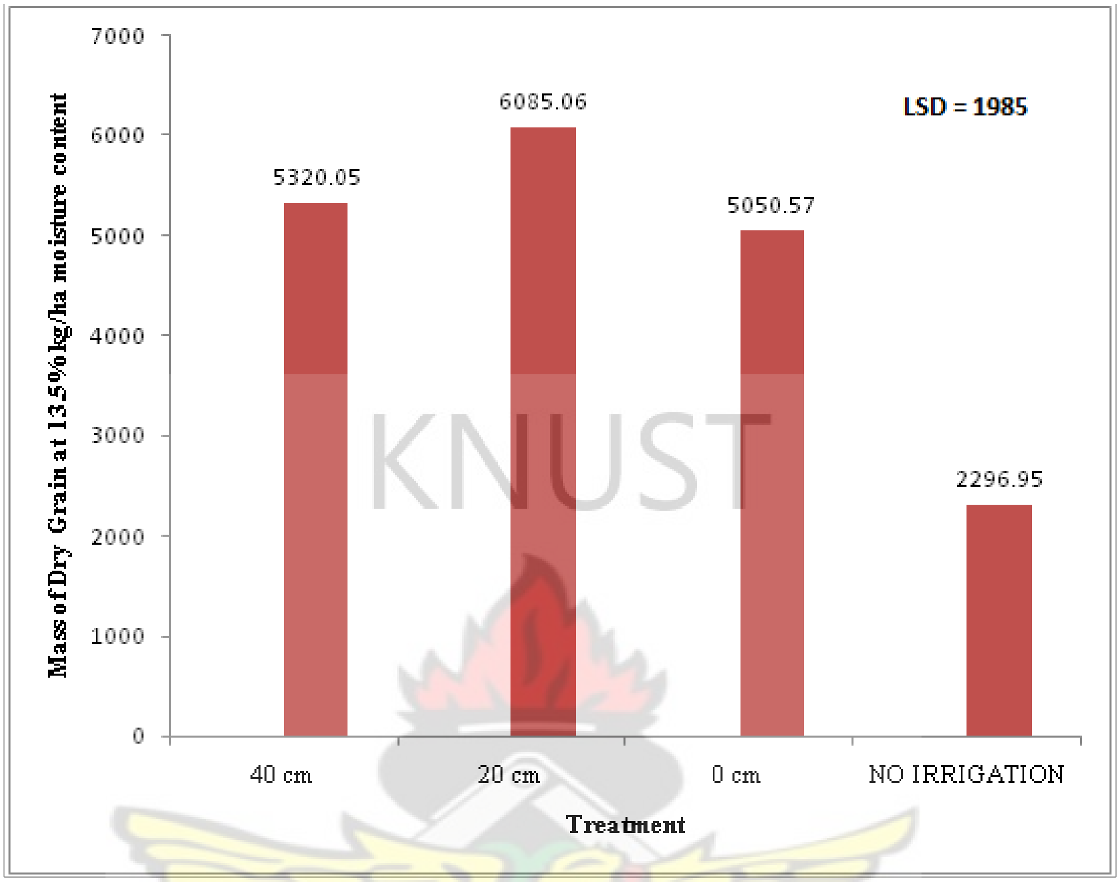


Figure 18.Dry grain at 13.5% moisture (kg/ha) of the various treatments

4.2.1. Dry mass of above ground biomass (kg/ha)

The mass of above ground biomass is presented on Figure 19. ANOVA showed that there was a significant difference (P<0.05) between 40 cm, 20 cm and 0 cm as compared to "No Irrigation" at an LSD of 6144. Appendix G, Table 1.

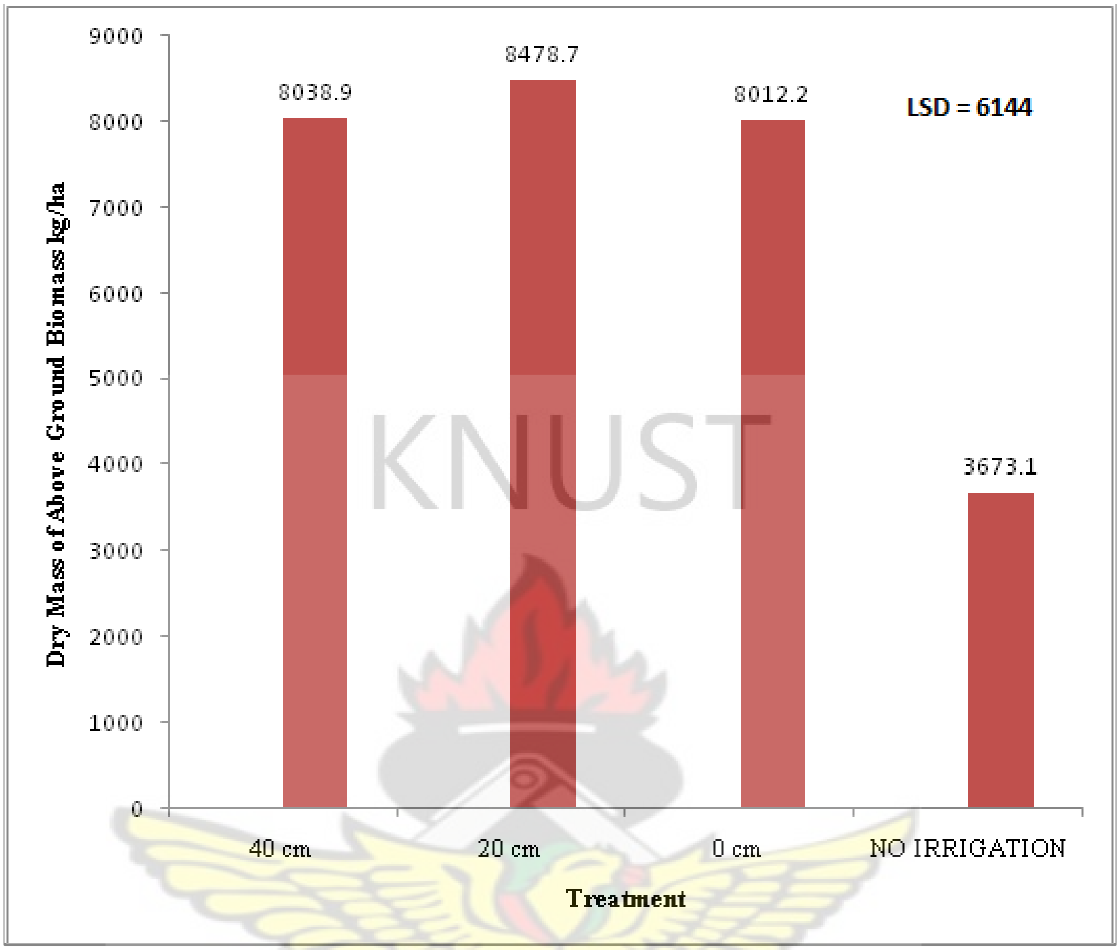


Figure 19.Dry mass of above ground biomass in kg/ha of the various treatments

4.2.3. Dry mass of below ground biomass (kg/ha)

The mass below ground biomass is presented on Figure 20. ANOVA showed that there was no significant difference ($P<0.05$) between treatments. Appendix G, Table 1.

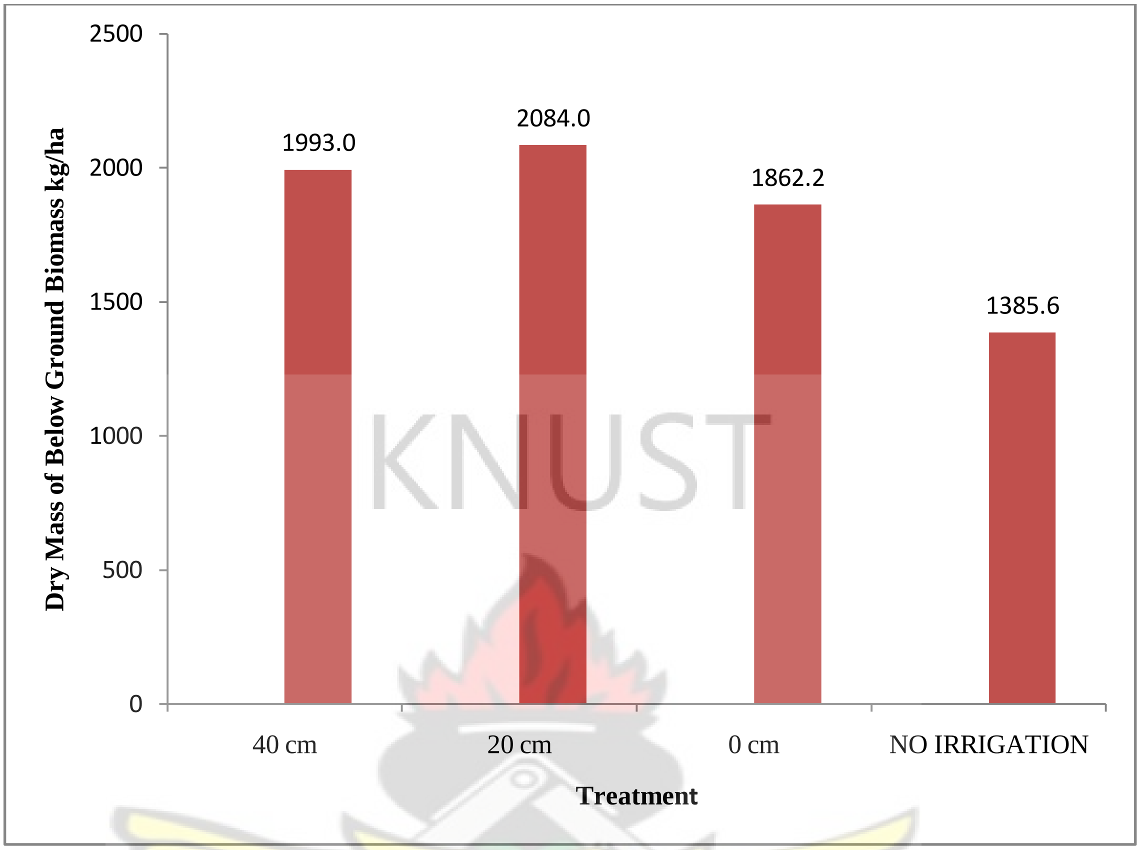


Figure 20.Dry mass of below ground biomass in kg/ha of the various treatments

4.2.4. Average Root Length (cm)

The average root length is presented in Figure 21. ANOVA showed a significant longer root length ($P<0.05$) between treatment 40 cm and 20 cm, compared to 0cm and "No Irrigation" at an LSD of 1.5. Appendix G, Table 1.

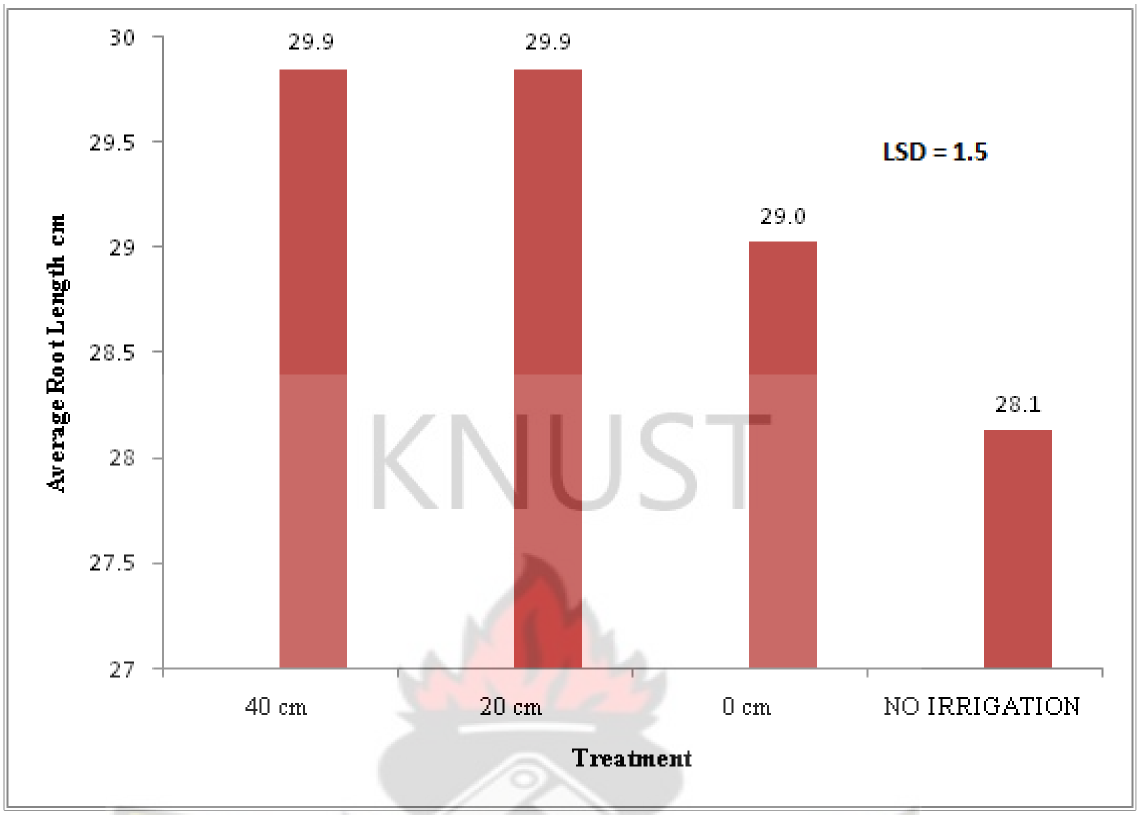


Figure 21.Average root length in cm of the various treatments.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1. Design and evaluation of PVC drip irrigation system

A PVC drip irrigation system was design and calibrated. The design was evaluated by planting *akposoe* maize variety, of which PVC pipe placed at 20 cm depth gave a better yield as compared to 40cm, 0cm and "No irrigation".

5.1.2. Assessing maize growth under rain-fed and supplementary drip irrigation system

Maize growth under drip irrigation gave better results in terms of growth parameters as compared to rain-fed ("No irrigation"). In general, plant height, stem girth, leaf width, number of leaves and leaf length under drip irrigation was statistically similar, but significantly higher as compared to "No Irrigation" treatment.

5.1.3. Comprism of dry matter yield of maize under rain-fed and supplementary drip irrigation system

Maize grain dry matter yield under supplementary drip irrigation gave significantly better results in terms of grain dry matter, above and below ground biomass as compared to rain-fed. Generally, the depth of water application had a statistically no significant effects on maize performance under drip irrigation, but significantly different as compared to "No irrigation" treatment. From the trend or curve on the grain yield analysis at 13.5 % moisture, the depth of pipe placement could be 23 cm or 25 cm below the ground surface and a comparable yield of 6085.08 kg/ha to the 20cm depth could be achieved. It would not be recommendable to place the pipe beyond 25 cm or closed to 30 cm, since the yield differences between 40cm (5320.05 kg/ha) and 0 cm (5050.57 kg/ha) are not much.

In this case supplementary irrigation, where the depth of pipe is placed at 20 cm (i.e. 6085.08 kg/ha), compared to rain-fed agriculture or "no irrigation" (i.e. 2296.95 kg/ha) could help boost maize production by 265%.

5.1.4. Possible Users

Considering the specifications for the design possible users are:

1. Small scale farmers.
2. Agric Extension Agents (AES)
3. Non Governmental Organizations (NGOs) in Agriculture.

5.1.5. Limitation

Even though the 20 cm depth of water application gave the highest yield, there are other limiting factors to this design:

1. Clogging of the drip holes
2. Problems of weeding around the pipe lines.
3. Initial capital for the establishment of the design
4. Difficulty in adopting it for mechanized farming, but that does not totally rule it out.

5.2. RECOMMENDATIONS

- The study should be repeated in the dry season when soil moisture content can be effectively monitored.
- Further studies should focus on the design performance criteria.
- There is the need to determine the long-term effects of the depth of pipe placement and depth of water application on maize growth and yield.
- The experiment should be repeated to ascertain the optimum depth of water application for *akposoe* maize varieties and others such as *obaatanpa*, *dobidi*, *abrotia*, *okomasa* as well as other crops such as, tomato, pepper and garden egg.
- The experiment should be repeated to determine fertilizer (fertigation) application through the design system.
- Economic analysis should be under taken to determine cost and benefits of the effects of depth of pipe placement and depth of water application on maize performance.

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APPENDICES

APPENDICES A - DRIP HOLE CALIBRATION

Table 1.Depth of irrigation water for 25 litres per application

DRIP HOLE	**VOLUME of water from each drip hole (cm^3)**	**DEPTH of irrigation water (cm)**
DH_1	1250	1.38
DH_2	1350	1.49
DH_3	1400	1.54
DH_4	1033	1.14
DH_5	1066	1.17
DH_6	840	0.93
DH_7	983	1.08
DH_8	873	0.96
DH_9	1000	1.10
DH_{10}	1383	1.52
DH_{11}	1500	1.65
DH_{12}	1610	1.77
DH_{13}	1416	1.56
DH_{14}	1716	1.89
DH_{15}	1560	1.72
DH_{16}	1486	1.46
AVERAGE	**1,279.00**	**1.28**

Table 2. Depth of irrigation water for 30 litres per application

DRIP HOLE	VOLUME of water from each drip hole (cm^3)	DEPTH of irrigation water(cm)
DH_1	1506.7	1.66
DH_2	1623.3	1.79
DH_3	1646.7	1.81
DH_4	1226.7	1.35
DH_5	1283.3	1.41
DH_6	1000	1.10
DH_7	1126.7	1.24
DH_8	1066.7	1.17
DH_9	1266.7	1.39
DH_{10}	1650	1.82
DH_{11}	1833.3	2.02
DH_{12}	1920	2.11
DH_{13}	1700	1.87
DH_{14}	2066.7	2.28
DH_{15}	1873.3	2.06
DH_{16}	1776.7	1.96
AVERAGE	**1,535.40**	**1.69**

Table 3. Depth of irrigation water for 35 litres per application

DRIP HOLE	VOLUME of water from each drip hole (cm^3)	DEPTH of irrigation water (cm)
DH_1	1740	1.92
DH_2	1883.3	2.07
DH_3	1940	2.14
DH_4	1440	1.59
DH_5	1493.3	1.64
DH_6	1126.6	1.24
DH_7	1360	1.50
DH_8	1300	1.43
DH_9	1426.7	1.57
DH_{10}	1933.3	2.13
DH_{11}	2093.3	2.31
DH_{12}	2186.7	2.41
DH_{13}	2026.6	2.23
DH_{14}	2476.7	2.73
DH_{15}	2120	2.33
DH_{16}	2033.3	2.24
AVERAGE	**1,786.20**	**1.97**

Table 4. Depth of irrigation water for 45 litres per application

DRIP HOLE	VOLUME of water from each drip hole (cm^3)	DEPTH of irrigation water(cm)
DH_1	2086.6	2.30
DH_2	2376.7	2.62
DH_3	2586.7	2.85
DH_4	1936.7	2.13
DH_5	1986.7	2.19
DH_6	1366.7	1.51
DH_7	1660	1.83
DH_8	1576.7	1.74
DH_9	1850	2.04
DH_{10}	2350	2.59
DH_{11}	2743.3	3.02
DH_{12}	2826.7	3.11
DH_{13}	2480	2.73
DH_{14}	3000	3.30
DH_{15}	2813.3	3.10
DH_{16}	2700	2.97
AVERAGE	**2271.26**	**2.50**

Table 5. Depth of irrigation water for 50 litres per application

DRIP HOLE	VOLUME of water from each drip hole (cm^3)	DEPTH of irrigation water (cm)
DH_1	2560	2.82
DH_2	2666.7	2.94
DH_3	2853.3	3.14
DH_4	2223.3	2.45
DH_5	2133.3	2.35
DH_6	1640	1.81
DH_7	2046.7	2.25
DH_8	1726.7	1.90
DH_9	2073.3	2.28
DH_{10}	2826.7	3.11
DH_{11}	3140	3.46
DH_{12}	3220	3.55
DH_{13}	2826.7	3.11
DH_{14}	3400	3.74
DH_{15}	3230	3.55
DH_{16}	2886.7	3.18
AVERAGE	**2,590.84**	**2.85**

Table 6.Average Volume of water collected from catch can from each drip holes

Litres per application	Volume of water from each drip hole (cm^3)	Depth of irrigation water (cm)
25	1,279.00	1.28
30	1,535.40	1.69
35	1,786.20	1.97
45	2,271.26	2.50
50	2,590.84	2.85

Table 7.Water application amount (Rainfall and Irrigation)

Months / Days	Weeks	Rainfall amounts (mm)	Irrigation water applied (Litters = Millimeter)	Depth of water applied per application per hill (mm)
March 5	1	38.721		
March 6				
March 7		9.672		
March 8				
March 9				
March 10		12.178		
March 11				
March 12	2	44.45		
March 13				
March 14				
March 15		14.224		
March 16				
March 17				
March 18				
March 19	3	49.53		
March 20		33.02		
March 21		44.704		
March 22		9.906		
March 23		8.636		
March 24				
March 25				
March 26				

March 27		**2.794**		
March 28			**25**	**9.3 – 18.9(14.1)**
March 29	**4**			
March 30				
March 31			**25**	**9.3 – 18.9(14.1)**
April 1				
April 2				
April 3			**30**	**11.0 – 22.8 (16.9)**
April 4		**33.02**		
April 5				
April 6	**5**			
April 7			**30**	**11.0 – 22.8 (16.9)**
April 8				
April 9				
April 10			**30**	**11.0 – 22.8 (16.9)**
April 11	**6**			
April 12		**34.29**		
April 13				
April 14				
April 15				
April 16				
April 17			**35**	**12.4 – 27.3 (19.9)**
April 18		**64.77**		
April 19	**7**			
April 20				
April 21				
April 22				
April 23			**35**	**12.4 – 27.3 (19.9)**
April 24				
April 25				
April 26				
April 27	**8**			
April 28		**36.83**	**45**	**15.5 – 33.0 (24.05)**
April 29				
April 30				
May 1				
May 2			**45**	**15.5 – 33.0 (24.05)**
May 3	**9**			
May 4				
May 5			**50**	**18.1– 37.4 (27.75)**
May 6				
May 7				
May 8				
May 9			**50**	**18.1 – 37.4 (27.75)**
May 10				
May 11	**10**			
May 12			**50**	**18.1 – 37.4 (27.75)**
May 13				

May 14	**11**			
May 15				
May 16				
May 17				
May 18			***MATURITY STAGE***	
May 19				
May 20	**12**			
May 21				
May 22				
May 23				
May 24				
May 25				
May 26				
May 27				
May 28			***HARVESTING DATE***	
TOTALS		**436.745 mm**	**425 L = 425000mm^3**	**162.1 – 338.9 (250.5) mm**

APPENDICES B - GROWTH PARAMETERS OF MAIZE (AKPOSOE) VARIETY

Table 1.Average Plant height as influenced by depth of water application for all treatments.

Treatment	Average Plant Height (cm)								
	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	WK 9
40 cm	5.305	12.15	31.25	54.25	99.00	159.10	165.75	166	166
20 cm	5.215	12.25	30.25	56.95	101.6	170.98	174.85	177.85	177.85
0 cm	5.035	13.95	34.5	60.8	93.7	126.9	171.3	171.6	171.6
No IRR	4.91	13.25	32.65	46.15	72.95	126.9	131.02	132.77	132.76

Table 2.Average stem girth as influenced by depth of water application for all treatments.

Treatment	Average Stem girth (cm)								
	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	WK 9
40 cm	1.65	2.265	4.82	6.64	7.825	8.71	8.83	8.805	8.805
20 cm	1.14	2.34	4.805	6.705	7.83	8.775	8.985	8.95	8.95
0 cm	1.14	2.959	5.56	7.13	7.545	8.395	8.675	8.675	8.675
No IRR	1.17	2.425	5.17	6.055	6.699	6.6995	6.93	6.765	6.765

Table 3.Average number of plant leaves as influenced by depth of water application for all treatments.

Treatment	Average Number of Plant Leaves (cm)								
	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	WK 9
40 cm	3	5	7	8	9	10	13	12	12
20 cm	3	5	7	8	10	11	12	13	12
0 cm	3	6	8	9	10	11	12	13	12
No IRR	3	5	6	6	7	8	7	6	6

Table 4.Average leaf diameter as influenced by depth of water application for all treatments.

Treatment	Average Leaf diameter (cm)								
	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	WK 9
40 cm	1.56	3.45	7.21	8.92	9.765	9.69	9.515	9.73	9.73
20 cm	1.55	3.325	7.215	8.665	9.505	9.41	9.12	9.03	9.03
0 cm	1.47	3.54	7.45	8.765	9.245	9.105	9.02	8.88	8.88
No IRR	1.35	3.41	7.61	8.46	9.18	8.36	7.61	7.055	7.055

Table 5.Average leaf length as influenced by depth of water application for all treatments.

Treatment	Average Leaf length (cm)								
	W1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	WK 9
40 cm	5.97	29.075	50.15	66.05	72.05	74.28	73.85	73.585	73.585
20 cm	6.54	28.785	48.55	65.3	75.1	72.925	71.6	71.165	71.165
0 cm	6.35	31.95	50.75	66.21	70.5	70.42	70.36	69.45	69.95
No IRR	6.32	28.725	48.8	59.1	67.55	66.825	62.425	58.67	58.67

APPENDICES C - ANOVA OF GROWTH PARAMETERS

ANOVA showing Growth Parameters of Maize (Akposoe) variety

WEEK 1

One-way ANOVA: Plant Height versus TREATMENT

```
Source      DF      SS      MS      F      P
TREATMENT    3   0.378   0.126   0.54  0.663
Error       12   2.793   0.233
Total       15   3.171

S = 0.4825   R-Sq = 11.92%   R-Sq(adj) = 0.00%

Level          N  Mean    StDev
0 cm depth     4  5.0350  0.6446
20 cm depth    4  5.2150  0.3855
40 cm depth    4  5.3050  0.3052
No Irrigation  4  4.9100  0.5232

               Individual 95% CIs for Mean Based on Pooled StDev
Level            +---------+---------+---------+---------
0 cm depth          (------------*------------)
20 cm depth             (-------------*-------------)
40 cm depth               (-------------*------------)
No Irrigation    (------------*------------)
                 +---------+---------+---------+---------
               4.40      4.80      5.20      5.60

Pooled StDev = 0.4825
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source     DF  SS       MS       F     P
TREATMENT   3  0.00307  0.00102  0.11  0.953
Error      12  0.11190  0.00932
Total      15  0.11497

S = 0.09657   R-Sq = 2.67%   R-Sq(adj) = 0.00%

                         Individual 95% CIs for Mean Based on Pooled StDev
Level          N  Mean   StDev  --+---------+---------+---------+-------
0 cm depth     4  1.1400  0.0938  (--------------*--------------)
20 cm depth    4  1.1400  0.0966  (--------------*--------------)
40 cm depth    4  1.1650  0.0597     (--------------*--------------)
No Irrigation  4  1.1700  0.1249      (--------------*--------------)
                                  --+---------+---------+---------+-------
                                  1.050     1.120     1.190     1.260
Pooled StDev = 0.0966
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source     DF      SS      MS      F     P
TREATMENT   3      0.0600  0.0200  0.41  0.746
Error      12      0.5800  0.0483
Total      15      0.6400

S = 0.2198   R-Sq = 9.37%   R-Sq(adj) = 0.00%

                              Individual 95% CIs for Mean Based on Pooled StDev
Level          N  Mean    StDev  ------+---------+---------+---------+---
0 cm depth     4  2.8500  0.3000          (--------------*--------------)
20 cm depth    4  2.8000  0.1633       (--------------*--------------)
40 cm depth    4  2.8500  0.1915          (--------------*--------------)
No Irrigation  4  2.7000  0.2000  (--------------*--------------)
                                  ------+---------+---------+---------+---
                                      2.56      2.72      2.88      3.04
Pooled StDev = 0.2198
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source     DF      SS      MS      F     P
TREATMENT   3      0.1163  0.0388  1.53  0.257
Error      12      0.3039  0.0253
Total      15      0.4202

S = 0.1591   R-Sq = 27.67%   R-Sq(adj) = 9.59%

                        Individual 95% CIs for Mean Based on Pooled StDev
Level          N  Mean    StDev  --+---------+---------+---------+-------
0 cm depth     4  1.4700  0.2335          (-----------*-----------)
20 cm depth    4  1.5500  0.1571                (-----------*-----------)
40 cm depth    4  1.5650  0.1408                 (-----------*-----------)
No Irrigation  4  1.3500  0.0476  (-----------*-----------)
                                  --+---------+---------+---------+-------
                                  1.20      1.35      1.50      1.65
Pooled StDev = 0.1591
```

One-way ANOVA: Leaf Length versus TREATMENT

```
Source     DF     SS     MS     F      P
TREATMENT   3     0.401  0.134  0.68  0.580
Error      12     2.352  0.196
Total      15     2.753

S = 0.4427   R-Sq = 14.57%   R-Sq(adj) = 0.00%

                            Individual 95% CIs for Mean Based on Pooled StDev
Level          N    Mean   StDev  ---+---------+---------+---------+------
0 cm depth     4  6.3450  0.5157            (------------*-------------)
20 cm depth    4  6.3400  0.1736           (-------------*-------------)
40 cm depth    4  5.9700  0.2793  (-------------*------------)
No Irrigation  4  6.3200  0.6402           (-------------*------------)
                                  ---+---------+---------+---------+------
                                   5.60      5.95      6.30      6.65

Pooled StDev = 0.4427
```


WEEK 2

One-way ANOVA: Plant Height versus TREATMENT

```
Source     DF     SS     MS     F      P
TREATMENT   3     8.99   3.00   0.51  0.684
Error      12     70.76  5.90
Total      15     79.75

S = 2.428   R-Sq = 11.28%   R-Sq(adj) = 0.00%

                    Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev  ---+---------+---------+---------+------
0 cm depth     4  13.950  2.620            (-------------*------------)
20 cm depth    4  12.250  2.739   (------------*------------)
40 cm depth    4  12.125  2.510  (-------------*------------)
No Irrigation  4  13.250  1.708        (------------*------------)
                                 ---+---------+---------+---------+------
                                 10.0      12.0      14.0      16.0
Pooled StDev = 2.428
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source     DF     SS     MS     F      P
TREATMENT   3     0.241  0.080  0.64  0.603
Error      12     1.506  0.125
Total      15     1.747

S = 0.3542   R-Sq = 13.81%   R-Sq(adj) = 0.00%

                                 Individual  95%  CIs  For  Mean  Based  on  Pooled
StDev
Level          N    Mean   StDev  -------+---------+---------+---------+--
0 cm depth     4  2.5950  0.4334             (------------*-----------)
20 cm depth    4  2.3400  0.4121    (------------*------------)
40 cm depth    4  2.2650  0.3126  (------------*-----------)
No Irrigation  4  2.4250  0.2156       (------------*------------)
                                  -------+---------+---------+---------+--
                                       2.10      2.40      2.70      3.00
Pooled StDev = 0.3542
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source      DF      SS      MS      F       P
TREATMENT    3      0.647   0.216   0.75   0.543
Error       12      3.450   0.288
Total       15      4.098

S = 0.5362   R-Sq = 15.80%   R-Sq(adj) = 0.00%

                                  Individual  95%  CIs  For  Mean  Based  on  Pooled
StDev
Level           N   Mean   StDev   -+---------+---------+---------+--------
0 cm depth      4  7.0500  0.3416            (-----------*-----------)
20 cm depth     4  6.5500  0.8062   (-----------*-----------)
40 cm depth     4  6.6000  0.2309    (-----------*-----------)
No Irrigation   4  6.8500  0.5745        (-----------*-----------)
                                   -+---------+---------+---------+--------
                                  6.00      6.50      7.00      7.50

Pooled StDev = 0.5362
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source      DF     SS      MS      F       P
TREATMENT    3    0.096   0.032   0.15   0.926
Error       12    2.497   0.208
Total       15    2.593

S = 0.4562   R-Sq = 3.69%   R-Sq(adj) = 0.00%

                     Individual 95% CIs For Mean Based on Pooled StDev
Level           N   Mean   StDev  ---------+---------+---------+---------+
0 cm depth      4  3.5400  0.4918        (--------------*--------------)
20 cm depth     4  3.3250  0.5688  (--------------*--------------)
40 cm depth     4  3.4500  0.2735     (---------------*--------------)
No Irrigation   4  3.4100  0.4383    (--------------*---------------)
                                   ---------+---------+---------+---------+
                                          3.15      3.50      3.85      4.20
Pooled StDev = 0.4562
```

One-way ANOVA: Leaf Diameter 2 versus TREATMENT

```
Source      DF      SS      MS      F       P
TREATMENT    3      0.096   0.032   0.15   0.926
Error       12      2.497   0.208
Total       15      2.593

S = 0.4562   R-Sq = 3.69%   R-Sq(adj) = 0.00%

                               Individual  95%  CIs  For  Mean  Based  on  Pooled
StDev
Level           N    Mean    StDev   ---------+---------+---------+---------+
0 cm depth      4  3.5400  0.4918        (--------------*--------------)
20 cm depth     4  3.3250  0.5688  (--------------*--------------)
40 cm depth     4  3.4500  0.2735     (---------------*--------------)
No Irrigation   4  3.4100  0.4383    (--------------*---------------)
                                   ---------+---------+---------+---------+
                                          3.15      3.50      3.85      4.20
Pooled StDev = 0.4562
```

WEEK 3

One-way ANOVA: Plant Height versus TREATMENT

```
Source      DF      SS    MS      F      P
TREATMENT    3    39.8  13.3   0.74  0.550
Error       12   216.2  18.0
Total       15   256.0

S = 4.245   R-Sq = 15.56%   R-Sq(adj) = 0.00%

                           Individual 95% CIs For Mean Based on Pooled StDev
Level           N  Mean    StDev  -------+---------+---------+---------+--
0 cm depth      4  34.450  4.829              (------------*-------------)
20 cm depth     4  30.250  5.160  (------------*-------------)
40 cm depth     4  31.250  3.609     (------------*-------------)
No Irrigation   4  32.650  3.017         (-------------*------------)
                                  -------+---------+---------+---------+--
                                      28.0      31.5      35.0      38.5

Pooled StDev = 4.245
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source      DF    SS      MS      F      P
TREATMENT    3   1.526   0.509   0.77  0.535
Error       12   7.977   0.665
Total       15   9.502

S = 0.8153   R-Sq = 16.06%   R-Sq(adj) = 0.00%

                        Individual 95% CIs For Mean Based on Pooled StDev
Level           N   Mean   StDev   ----+---------+---------+---------+-----
0 cm depth      4  5.5600  0.8357            (------------*------------)
20 cm depth     4  4.8050  1.0921  (------------*-----------)
40 cm depth     4  4.8200  0.8124  (------------*-------------)
No Irrigation   4  5.1700  0.3284       (------------*------------)
                                   ----+---------+---------+---------+-----
                                     4.20      4.90      5.60      6.30
Pooled StDev = 0.8153
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source      DF    SS     MS      F      P
TREATMENT    3   0.890  0.297   0.56  0.653
Error       12   6.380  0.532
Total       15   7.270

S = 0.7292   R-Sq = 12.24%   R-Sq(adj) = 0.00%

                       Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev  --+---------+---------+---------+-------
0 cm depth      4  10.300  0.577          (-------------*------------)
20 cm depth     4   9.650  0.929  (------------*------------)
40 cm depth     4   9.900  0.872      (------------*------------)
No Irrigation   4  10.050  0.412        (-------------*------------)
                                  --+---------+---------+---------+-------
                                  9.00      9.60     10.20     10.80
Pooled StDev = 0.729
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source      DF    SS      MS     F      P
TREATMENT    3    0.454  0.151  0.19  0.903
Error       12    9.743  0.812
Total       15   10.198

S = 0.9011   R-Sq = 4.46%   R-Sq(adj) = 0.00%

                             Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean   StDev  ------+---------+---------+---------+---
0 cm depth      4  7.4500  0.8108      (----------------*----------------)
20 cm depth     4  7.2150  1.1801  (----------------*----------------)
40 cm depth     4  7.2100  1.0142  (----------------*----------------)
No Irrigation   4  7.6100  0.4110        (----------------*----------------)
                                   ------+---------+---------+---------+---
                                       6.60      7.20      7.80      8.40

Pooled StDev = 0.9011
```

One-way ANOVA: Leaf Length versus TREATMENT

```
Source      DF   SS     MS     F      P
TREATMENT    3   13.8   4.6   0.36  0.784
Error       12  154.5  12.9
Total       15  168.3

S = 3.588   R-Sq = 8.21%   R-Sq(adj) = 0.00%

Level           N    Mean  StDev
0 cm depth      4  50.750  4.705
20 cm depth     4  48.525  3.637
40 cm depth     4  50.185  3.284
No Irrigation   4  48.800  2.311

                  Individual 95% CIs For Mean Based on Pooled StDev
Level             -+---------+---------+---------+--------
0 cm depth               (-------------*------------)
20 cm depth       (------------*------------)
40 cm depth            (------------*------------)
No Irrigation      (------------*------------)
                  -+---------+---------+---------+--------
                 45.0      48.0      51.0      54.0

Pooled StDev = 3.588
```

WEEK 4

One-way ANOVA: Plant Height versus TREATMENT

```
Source      DF     SS     MS     F      P
TREATMENT    3  459.4  153.1  5.31  0.015
Error       12  346.0   28.8
Total       15  805.3

S = 5.369   R-Sq = 57.04%   R-Sq(adj) = 46.30%

                           Individual 95% CIs For Mean Based on Pooled StDev
Level          N   Mean  StDev  --+---------+---------+---------+-------
0 cm depth     4  60.750  5.244                      (--------*-------)
20 cm depth    4  56.950  5.328                 (-------*--------)
40 cm depth    4  54.250  3.778             (--------*-------)
No Irrigation  4  46.150  6.720   (-------*-------)
                                  --+---------+---------+---------+-------
                                  42.0      49.0      56.0      63.0
Pooled StDev = 5.369
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source      DF     SS     MS     F      P
TREATMENT    3  2.345  0.782  1.19  0.355
Error       12  7.881  0.657
Total       15  10.226

S = 0.8104   R-Sq = 22.93%   R-Sq(adj) = 3.67%

                        Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean   StDev  -----+---------+---------+---------+----
0 cm depth     4  7.1300  0.5219              (----------*----------)
20 cm depth    4  6.7050  0.9913         (----------*----------)
40 cm depth    4  6.6400  1.0779        (----------*----------)
No Irrigation  4  6.0550  0.4582  (----------*----------)
                                  -----+---------+---------+---------+----
                                     5.60      6.40      7.20      8.00
Pooled StDev = 0.8104
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source      DF      SS     MS     F      P
TREATMENT    3   7.970  2.657  6.84  0.006
Error       12   4.660  0.388
Total       15  12.630

S = 0.6232   R-Sq = 63.10%   R-Sq(adj) = 53.88%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev  --+---------+---------+---------+-------
0 cm depth     4  12.650  0.526                      (--------*--------)
20 cm depth    4  12.600  0.327                     (--------*--------)
40 cm depth    4  12.150  0.500               (--------*-------)
No Irrigation  4  10.900  0.959  (-------*--------)
                                 --+---------+---------+---------+-------
                                 10.40     11.20     12.00     12.80
Pooled StDev = 0.623
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source      DF   SS     MS     F      P
TREATMENT    3   0.45   0.15   0.12  0.947
Error       12   14.90  1.24
Total       15   15.34

S = 1.114   R-Sq = 2.90%   R-Sq(adj) = 0.00%

                          Individual 95% CIs For Mean Based on Pooled StDev
Level          N  Mean   StDev  ---------+---------+---------+---------+
0 cm depth     4  8.765  1.123      (---------------*--------------)
20 cm depth    4  8.665  1.335     (--------------*--------------)
40 cm depth    4  8.920  1.248        (--------------*---------------)
No Irrigation  4  8.460  0.603  (--------------*--------------)
                                ---------+---------+---------+---------+
                                       8.00      8.80      9.60     10.40
Pooled StDev = 1.114
```

One-way ANOVA: Leaf Length versus TREATMENT

```
Source      DF  SS     MS     F      P
TREATMENT    3  138.6  46.2  2.62  0.099
Error       12  211.3  17.6
Total       15  350.0

S = 4.197   R-Sq = 39.61%   R-Sq(adj) = 24.51%
Level          N   Mean   StDev
0 cm depth     4  66.205  2.859
20 cm depth    4  65.300  5.385
40 cm depth    4  66.050  4.761
No Irrigation  4  59.100  3.257
                Individual 95% CIs For Mean Based on Pooled StDev
Level            -+---------+---------+---------+--------
0 cm depth                     (--------*---------)
20 cm depth                  (---------*--------)
40 cm depth                    (--------*--------)
No Irrigation     (--------*--------)
                 -+---------+---------+---------+--------
               55.0      60.0      65.0      70.0
Pooled StDev = 4.197
```

WEEK 5

One-way ANOVA: Plant Height versus TREATMENT

```
Source     DF  SS    MS     F      P
TREATMENT   3  2023  674   4.36  0.027
Error      12  1856  155
Total      15  3879

S = 12.44   R-Sq = 52.16%   R-Sq(adj) = 40.20%

                              Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev   +---------+---------+---------+---------
0 cm depth      4   93.70  9.72                (--------*--------)
20 cm depth     4   101.55 12.53                      (--------*--------)
40 cm depth     4   99.00  15.27                    (--------*--------)
No Irrigation   4   72.95  11.59   (--------*--------)
                                   +---------+---------+---------+---------
                                  60        75        90       105

Pooled StDev = 12.44
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source     DF   SS     MS     F     P
TREATMENT   3   3.447  1.149  2.26  0.134
Error      12   6.100  0.508
Total      15   9.547

S = 0.7130   R-Sq = 36.11%   R-Sq(adj) = 20.14%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N   Mean   StDev  -----+---------+---------+---------+----
0 cm depth      4  7.5450  0.5360              (----------*----------)
20 cm depth     4  7.8300  0.8731                  (----------*----------)
40 cm depth     4  7.8250  0.6720                  (----------*----------)
No Irrigation   4  6.6950  0.7295  (----------*----------)
                                   -----+---------+---------+---------+----
                                      6.30      7.00      7.70      8.40

Pooled StDev = 0.7130
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source     DF    SS      MS     F     P
TREATMENT   3    5.460  1.820  4.32  0.028
Error      12    5.060  0.422
Total      15   10.520

S = 0.6494   R-Sq = 51.90%   R-Sq(adj) = 39.88%

                             Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev  ---+---------+---------+---------+------
0 cm depth      4  13.650  0.719                (--------*-------)
20 cm depth     4  13.900  0.503                   (--------*--------)
40 cm depth     4  13.800  0.589                  (-------*--------)
No Irrigation   4  12.450  0.755  (--------*-------)
                                  ---+---------+---------+---------+------
                                  12.00     12.80     13.60     14.40

Pooled StDev = 0.649
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source      DF  SS     MS     F     P
TREATMENT    3  0.858  0.286  0.54  0.662
Error       12  6.323  0.527
Total       15  7.180

S = 0.7259   R-Sq = 11.95%   R-Sq(adj) = 0.00%

Level          N   Mean  StDev
0 cm depth     4  9.245  0.540
20 cm depth    4  9.505  0.845
40 cm depth    4  9.765  0.695
No Irrigation  4  9.180  0.787

               Individual 95% CIs For Mean Based on Pooled StDev
Level            +---------+---------+---------+---------
0 cm depth        (------------*-------------)
20 cm depth           (-------------*-------------)
40 cm depth                (------------*------------)
No Irrigation    (------------*------------)
                 +---------+---------+---------+---------
               8.40      9.00      9.60     10.20

Pooled StDev = 0.726
```

One-way ANOVA: Leaf Length versus TREATMENT

```
Source      DF   SS     MS     F      P
TREATMENT    3   119.4  39.8  1.97  0.172
Error       12   242.3  20.2
Total       15   361.8

S = 4.494   R-Sq = 33.01%   R-Sq(adj) = 16.26%

                       Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev  -----+---------+---------+---------+----
0 cm depth     4  70.500  1.309        (---------*---------)
20 cm depth    4  75.100  5.115                 (---------*---------)
40 cm depth    4  72.025  5.949           (---------*---------)
No Irrigation  4  67.525  4.184  (---------*---------)
                                 -----+---------+---------+---------+----
                                    65.0      70.0      75.0      80.0
Pooled StDev = 4.494
```

WEEK 6

One-way ANOVA: Plant Height versus TREATMENT

```
Source      DF   SS    MS     F      P
TREATMENT    3  4681  1560  3.78  0.040
Error       12  4954   413
Total       15  9635

S = 20.32   R-Sq = 48.59%   R-Sq(adj) = 35.73%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N   Mean  StDev  --------+---------+---------+---------+-
0 cm depth      4  165.50  22.67                (--------*--------)
20 cm depth     4  170.98  14.65                   (-------*--------)
40 cm depth     4  159.10  15.57              (--------*-------)
No Irrigation   4  126.90  26.08  (--------*--------)
                                  --------+---------+---------+---------+-
                                        125       150       175       200
Pooled StDev = 20.32
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source      DF    SS      MS     F      P
TREATMENT    3   8.317   2.772  3.71  0.043
Error       12   8.965   0.747
Total       15  17.283

S = 0.8644   R-Sq = 48.13%   R-Sq(adj) = 35.16%

                          Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean   StDev  ---------+---------+---------+---------+
0 cm depth      4  8.3950  0.7169                (--------*--------)
20 cm depth     4  8.7750  1.1950                   (---------*--------)
40 cm depth     4  8.7100  0.7571                   (--------*---------)
No Irrigation   4  6.9950  0.6879  (--------*--------)
                                   ---------+---------+---------+---------+
                                          7.0       8.0       9.0      10.0
Pooled StDev = 0.8644
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source      DF   SS     MS      F      P
TREATMENT    3  1.028  0.343  0.65  0.597
Error       12  6.310  0.526
Total       15  7.338

S = 0.7251   R-Sq = 14.00%   R-Sq(adj) = 0.00%

Level           N    Mean  StDev
0 cm depth      4  13.800  1.095
20 cm depth     4  14.000  0.632
40 cm depth     4  13.350  0.574
No Irrigation   4  13.500  0.416
```

```
                 Individual 95% CIs For Mean Based on Pooled StDev
Level              -+---------+---------+---------+--------
0 cm depth                 (------------*------------)
20 cm depth                   (------------*------------)
40 cm depth        (------------*-------------)
No Irrigation         (------------*------------)
                   -+---------+---------+---------+--------
                 12.60     13.20     13.80     14.40

Pooled StDev = 0.725
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source      DF   SS      MS     F     P
TREATMENT    3   3.940   1.313  1.96  0.173
Error       12   8.030   0.669
Total       15   11.970

S = 0.8180   R-Sq = 32.92%   R-Sq(adj) = 16.15%

                          Individual 95% CIs For Mean Based on Pooled StDev
Level          N   Mean  StDev  -------+---------+---------+---------+--
0 cm depth     4  9.105  0.459            (----------*----------)
20 cm depth    4  9.410  1.050               (-----------*----------)
40 cm depth    4  9.690  0.689                   (----------*----------)
No Irrigation  4  8.360  0.942  (-----------*----------)
                                -------+---------+---------+---------+--
                                     8.00      8.80      9.60     10.40
Pooled StDev = 0.818
```

One-way ANOVA: Leaf Length versus TREATMENT

```
Source      DF  SS     MS    F     P
TREATMENT    3  128.7  42.9  3.26  0.059
Error       12  157.8  13.2
Total       15  286.6

S = 3.627   R-Sq = 44.93%   R-Sq(adj) = 31.16%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev  ---+---------+---------+---------+------
0 cm depth     4  70.415  4.873           (---------*---------)
20 cm depth    4  72.925  3.134                 (---------*---------)
40 cm depth    4  74.280  0.782                     (---------*---------)
No Irrigation  4  66.825  4.293  (---------*---------)
                                 ---+---------+---------+---------+------
                                 64.0      68.0      72.0      76.0
Pooled StDev = 3.627
```

WEEK 7

One-way ANOVA: Plant Height versus TREATMENT

```
Source      DF  SS     MS     F      P
TREATMENT    3  4681   1560  3.78  0.040
Error       12  4954   413
Total       15  9635

S = 20.32   R-Sq = 48.59%   R-Sq(adj) = 3

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev  --------+---------+---------+---------+-
0 cm depth      4  165.50  22.67                 (--------*--------)
20 cm depth     4  170.98  14.65                    (-------*--------)
40 cm depth     4  159.10  15.57               (---------*-------)
No Irrigation   4  126.90  26.08  (--------*---------)
                                  --------+---------+---------+---------+-
                                        125       150       175       200
Pooled StDev = 20.32
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source      DF   SS     MS     F     P
TREATMENT    3   8.317  2.772  3.71  0.043
Error       12   8.965  0.747
Total       15  17.283

S = 0.8644   R-Sq = 48.13%   R-Sq(adj) = 35.16%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean   StDev  ---------+---------+---------+---------+
0 cm depth      4  8.3950  0.7169                (--------*--------)
20 cm depth     4  8.7750  1.1950                   (---------*--------)
40 cm depth     4  8.7100  0.7571                   (--------*---------)
No Irrigation   4  6.9950  0.6879  (--------*--------)
                                   ---------+---------+---------+---------+
                                          7.0       8.0       9.0      10.0
Pooled StDev = 0.8644
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source      DF  SS     MS     F     P
TREATMENT    3  1.028  0.343  0.65  0.597
Error       12  6.310  0.526
Total       15  7.338

S = 0.7251   R-Sq = 14.00%   R-Sq(adj) = 0.00%

Level           N    Mean  StDev
0 cm depth      4  13.800  1.095
20 cm depth     4  14.000  0.632
40 cm depth     4  13.350  0.574
No Irrigation   4  13.500  0.416
```

```
             Individual 95% CIs For Mean Based on Pooled StDev
Level            -+---------+---------+---------+--------
0 cm depth               (------------*------------)
20 cm depth                 (------------*------------)
40 cm depth      (------------*-------------)
No Irrigation       (------------*------------)
                 -+---------+---------+---------+--------
               12.60     13.20     13.80     14.40

Pooled StDev = 0.725
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source      DF   SS      MS      F      P
TREATMENT    3   8.308  2.769  7.38  0.005
Error       12   4.504  0.375
Total       15   12.812

S = 0.6126   R-Sq = 64.85%   R-Sq(adj) = 56.06%

                    Individual 95% CIs For Mean Based on Pooled StDev
Level          N  Mean  StDev   -+---------+---------+---------+--------
0 cm depth     4  9.020  0.370                 (-----*------)
20 cm depth    4  9.120  0.560                  (-----*------)
40 cm depth    4  9.515  0.601                     (------*------)
No Irrigation  4  7.610  0.830   (------*------)
                                 -+---------+---------+---------+--------
                                7.0       8.0       9.0      10.0
Pooled StDev = 0.613
```

One-way ANOVA: Leaf Length versus TREATMENT

```
Source      DF  SS      MS     F      P
TREATMENT    3  296.5  98.8  3.53  0.048
Error       12  335.6  28.0
Total       15  632.0

S = 5.288   R-Sq = 46.91%   R-Sq(adj) = 33.63%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev  ------+---------+---------+---------+---
0 cm depth     4  70.360  5.630              (---------*---------)
20 cm depth    4  71.600  4.570                (---------*---------)
40 cm depth    4  73.850  2.225                   (---------*---------)
No Irrigation  4  62.425  7.370  (---------*---------)
                                 ------+---------+---------+---------+---
                                     60.0      66.0      72.0      78.0
Pooled StDev = 5.288
```

WEEK 8

One-way ANOVA: Plant Height versus TREATMENT

```
Source     DF  SS     MS     F      P
TREATMENT   3  4856   1619  5.11  0.017
Error      12  3804   317
Total      15  9635

S = 17.80   R-Sq = 56.08%   R-Sq(adj) = 45.10

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N  Mean   StDev  --------+---------+---------+---------+-
0 cm depth      4  166.00  12.56                   (--------*--------)
20 cm depth     4  177.85  11.09                        (-------*--------)
40 cm depth     4  171.60  20.98                      (--------*-------)
No Irrigation   4  132.76  23.39   (--------*--------)
                                   --------+---------+---------+---------+-
                                         125       150       175       200
Pooled StDev = 17.80
```

One-way ANOVA: Stem Girth versus TREATMENT

```
Source     DF   SS     MS     F     P
TREATMENT   3   12.697 4232   6.10  0.009
Error      12   8.329  0.694
Total      15   21.027

S = 0.8331   R-Sq = 60.39%   R-Sq(adj) = 50.48%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean    StDev --+----------+----------+---------+----------
0 cm depth      4  8.8050  0.6678                      (--------*--------)
20 cm depth     4  8.9500  1.1347                        (---------*--------)
40 cm depth     4  8.6750  0.7762                    (--------*---------)
No Irrigation   4  6.7650  0.6636   (--------*-------)
                                    -+----------+-----------+---------+---------
                                     6.0       7.2        8.4      9.6
Pooled StDev = 0.8331
```

One-way ANOVA: Number of Leaves versus TREATMENT

```
Source     DF  SS      MS     F      P
TREATMENT   3  19.007  6.336  14.82  0.000
Error      12  5.130   0.428
Total      15  24.137

S = 0.6538   R-Sq = 78.75%   R-Sq(adj) = 73.43%

Level           N   Mean   StDev
0 cm depth      4  12.650  0.500
20 cm depth     4  13.150  0.526
40 cm depth     4  12.850  0.998
No Irrigation   4  10.400  0.432
```

```
                Individual 95% CIs For Mean Based on Pooled StDev
Level            -------+---------+---------+---------+--------
0 cm depth                      (------*-------)
20 cm depth                            (------*------)
40 cm depth                         (-------*------)
No Irrigation     (------*-----)
                 ---------+---------+---------+---------+--------
                        10.8      12.0      13.2      14.4
Pooled StDev = 0.654
```

One-way ANOVA: Leaf Diameter versus TREATMENT

```
Source     DF   SS     MS     F      P
TREATMENT   3   12.969 4.323  11.06  0.001
Error      12   4.692  0.391
Total      15   17.660

S = 0.6253   R-Sq = 73.43%   R-Sq(adj) = 66.79%

                    Individual 95% CIs For Mean Based on Pooled StDev
Level           N  Mean  StDev  --------+---------+---------+---------+--------
0 cm depth      4  9.370  0.605                         (-----*------)
20 cm depth     4  9.030  0.554                      (-----*------)
40 cm depth     4  8.880  0.374                    (------*------)
No Irrigation   4  7.055  0.867   (------*------)
                                  -------+---------+---------+---------+--------
                                        7.0       8.0       9.0      10.0
Pooled StDev = 0.625
```

One-way ANOVA: Leaf Length versus TREATMENT

```
Source     DF  SS     MS     F     P
TREATMENT   3  526.3  175.4  7.07  0.005
Error      12  297.9  24.8
Total      15  824.2

S = 4.982   R-Sq = 63.86%   R-Sq(adj) = 54.82%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev  ------+---------+---------+---------+---
0 cm depth      4  73.585  1.994                        (---------*---------)
20 cm depth     4  71.165  4.698                      (---------*---------)
40 cm depth     4  69.945  2.614                    (----------*---------)
No Irrigation   4  58.670  6.459  (---------*---------)
                                  ------+---------+---------+---------+---
                                      56.0      63.0      70.0      77.0
Pooled StDev = 4.982
```

Table1. LSD of Growth Parameters

Treatment	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8
Plant height								
0 cm	5.0350	13.950	34.450	60.750a	93.70 c	165.50	165.50	166.00 c
20 cm	5.2150	12.250	30.250	56.950b	101.55a	170.98	170.98	177.85 a
40 cm	5.3050	12.125	31.250	54.250c	99.00 b	159.10	159.10	171.60 b
No Irr.	4.9100	13.250	32.650	46.150d	72.95 d	126.90	126.90	132.76 d
LSD(0.05)	**NS**	**NS**	**NS**	**13.24**	**1.60**	**NS**	**NS**	**43.91**
Stem girth								
0 cm	1.1400	2.5950	5.5600	7.1300	7.5450	8.3950	8.3950	8.8050 b
20 cm	1.1400	2.3400	4.8050	6.7050	7.8300	8.7750	8.7750	8.9500 a
40 cm	1.1650	2.2650	4.8200	6.6400	7.8250	8.7100	8.7100	8.6750 a
No Irr.	1.1700	2.2450	5.1700	6.0550	6.6950	6.9950	6.9950	8.7650 c
LSD(0.050)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**1.6**
Number of leaves								
0 cm	2.8500	7.0500	10.300	12.650a	13.650	13.800	13.800	12.650 b
20 cm	2.8000	6.5500	9.650	12.600a	13.900	14.000	14.000	13.150 a
40 cm	2.8500	6.6000	9.900	12.150b	13.800	13.350	13.350	12.850 b
No Irr.	2.7000	6.8500	10.050	10.900c	12.450	13.500	13.500	10.400 c
LSD(0.05)	**NS**	**NS**	**NS**	**1.54**	**NS**	**NS**	**NS**	**1.6**

Leaf diameter								
0 cm	1.4700	3.5400	7.4500	8.765	9.245	9.105	9.020 b	9.370 a
20 cm	1.15500	3.3250	7.2150	8.665	9.505	9.410	9.120 b	9.030 a
40 cm	1.15650	3.4500	7.2100	8.920	9.765	9.690	9.515 a	8.880 b
No Irr.	1.13500	3.1400	7.6100	8.460	9.180	8.360	7.610 c	7.055 c
LSD(0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**1.5**	**1.5**
Leaf length								
0 cm	6.3450	28.7250	50.750	66.205	70.500	70.415	70.360	73.585 a
20 cm	6.3400	25.2500	48.525	65.300	75.100	72.925	71.600	71.165 ab
40 cm	5.9700	26.2000	50.185	66.050	72.025	74.280	73.850	69.945 b
No Irr.	6.3200	25.4250	48.800	59.100	67.525	66.825	62.425	58.670 c
LSD(0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**12.29**

Treatment means having the same letters along the column are not significantly different from each other at 5% level.

APPENDICES D – GRAIN YIELD DETERMINATION

***Table1.**Wet cob of an area of 324m^2 as compared to a hectare (10,000m^2) of land*

Treatment	Mass of Wet cob (g) for an area of 324m^2	kg/ha
40 cm Depth	822.215	12533.77
20 cm Depth	921.7475	14051.03
0 cm Depth	836.82	12756.4
No Irrigation	447.465	6821.113

***Table 2.**Dry cob of an area of 324m^2 as compared to a hectare (10,000m^2) of land*

Treatment	Mass of Dry cob (g) for an area of 324m^2	kg/ha
40 cm Depth	632.4075	9640.358232
20 cm Depth	708.1825	10795.46494
0 cm Depth	626.9575	9557.278963
No Irrigation	302.03	4604.115854

***Table 3.**Wet grain and corn-cob of an area of 324m^2 as compared to a hectare (10,000m^2) of land*

Treatment	Mass of Wet grain and Corn-cob (g) for an area of 324m^2	kg/ha
40 cm Depth	541.8625	8260.099
20 cm Depth	602.9625	9191.502
0 cm Depth	537.1975	8188.986
No Irrigation	247.8625	3778.392

Table 4. Dry grain and corn-cob of an area of 324m^2 as compared to a hectare (10,000m^2) of land

Treatment	Mass of dry grain and Corn- cob (g) for an area of 324m^2	kg/ha
40 cm Depth	403.67	7336.014
20 cm Depth	432.1175	8203.582
0 cm Depth	387.43	7265.473
No Irrigation	180.96	3254.535

Table 5. Dry grain and corn-cob of an area of 324m^2 as compared to a hectare (10,000m^2) of land

Treatment	Mass of Corn-cob (g) for an area of 324m^2	kg/ha
40 cm Depth	97.405	1484.832
20 cm Depth	90.8475	1384.870
0 cm Depth	90.0225	1372.294
No Irrigation	42.48	647.561

Table 6. Wet Grain of an area of 324m^2 as compared to a hectare (10,000m^2) of land

Treatment	Mass of Wet grain (g) for an area of 324m^2	kg/ha
40 cm Depth	420.8225	5851.181
20 cm Depth	446.8325	6818.712
0 cm Depth	435.9225	5893.178
No Irrigation	176.5325	2610.785

Table 7.Mass of dry grain at 13.5% moisture content of an area of 342mas compared to a hectare (10,000m²) of land kg/ha of the various treatments

Treatment	**Mass of dry grain (g) at 13.5 % moisture content for an area of 324m²**	**kg/ha**
40 cm Depth	348.995	5320.046
20 cm Depth	399.18	6085.061
0 cm Depth	331.32	5050.572
No Irrigation	150.68	2296.951

Table 8.Average means of yield (kg/ha) of various treatments

Treatments	**Average Means of yield of all Treatment (kg/ha)**
40 cm	5320
20 cm	6085
0 cm	5050.6
No Irrigation	2297

APPENDICES E – ANOVA OF GRAIN YIELD DETERMINATION

ANOVA showing Grain Yield of Maize *(Akposoe)* variety in kg /ha

One-way ANOVA: Mass of Fresh Cob (kg/ha) versus TREATMENT

```
Source     DF  SS         MS         F      P
TREATMENT   3  124161463  41387154   10.96  0.001
Error      12  45333530   3777794
Total      15  169494993

S = 1944   R-Sq = 73.25%   R-Sq(adj) = 66.57%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev   ------+----------+----------+---------+------
--
0 cm depth      4    12534  1643                              (-------*------)
20 cm depth     4    14051  2105                                   (-------*---------
)
40 cm depth     4    12756  1923                              (--------*-------)
No Irrigation   4    6821   2069   (--------*-------)
                                   ------+----------+-----------+---------+-----
---
                                       6000      9000       12000    15000
Pooled StDev = 1944
```

One-way ANOVA: Mass of Dry Cob (kg/ha) versus TREATMENT

```
Source     DF  SS         MS         F      P
TREATMENT   3  91104644  30368215   16.29  0.000
Error      12  22363884   1863657
Total      15  113468528

S = 1365   R-Sq = 80.29%   R-Sq(adj) = 75.36%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev   -------+-----------+----------+----------+---
-----
0 cm depth      4    9640  1522                                (-----*------)
20 cm depth     4    10795 1448                                    (--------*--------)
40 cm depth     4    9557  1100                               (-------*------)
No Irrigation   4    4604  1353   (-----*------)
                                   -------+-----------+-----------+---------+--
------
                                         5000        7500         10000      12500
Pooled StDev = 1365
```

One-way ANOVA: Mass Wet Grain and Corn- cob (kg/ha) versus TREATMENT

```
Source     DF  SS          MS         F      P
TREATMENT   3  70718406  23572802   16.85 0.000
Error      12  16790992   139949
Total      15  87509398

S = 1183   R-Sq = 80.81%   R-Sq(adj) = 76.02%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev   ------+---------+---------+---------+--------
0 cm depth     4    8260  1427                                 (------*------)
20 cm depth    4    9192  1205                                      (-----*------
-)
40 cm depth    4    8189  950                                  (------*-----)
No Irrigation  4    3778  1099   (-------*-----)
                                  --------+-----------+-------------+---------+
                                          4000        6000                 8000

10000
Pooled StDev = 1183
```

One-way ANOVA: Mass of Dry Grain and Corn- cob (kg/ha) versus TREATMENT

```
Source     DF  SS          MS         F       P
TREATMENT   3  58876858  19625619   15.49  0.000
Error      12  15206277   1267190
Total      15  74083135

S = 1126   R-Sq = 79.47%   R-Sq(adj) = 74.34%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev   ------+---------+---------+---------+--------
0 cm depth     4    7336  1494                                  (-----*-------)
20 cm depth    4    8204  1103                                      (------*-----
-)
40 cm depth    4    7265  746                                  (------*------)
No Irrigation  4    3255  1031         (------*-----)
                                  ------+---------+-----------+---------+------
                                       2000      4000        6000      8000
Pooled StDev = 1126
```

One-way ANOVA: Mass of Corn-cob (kg/ha) versus TREATMENT

```
Source     DF  SS         MS         F      P
TREATMENT   3  1792702  597567    7.36   0.005
Error      12  973803   81150
Total      15  2766505

S = 284.9   R-Sq = 64.80%   R-Sq(adj) = 56.00%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level          N    Mean  StDev   ------+---------+---------+---------+--------
0 cm depth     4    1484.8  352.1                           (-------*-------)
20 cm depth    4    1384.9  318.9                         (--------*-------)
40 cm depth    4    1372.3  215.6                         (--------*-------)
No Irrigation  4     647.6  229.0 (--------*-------)
                                  ------+---------+-----------+---------+------
                                       400       800         1200      1600
Pooled StDev = 284.9
```

One-way ANOVA: Mass of Wet Grain (kg/ha) versus TREATMENT

```
Source      DF  SS         MS         F      P
TREATMENT    3  40775414  13591805   14.95  0.000
Error       12  10906383    908865
Total       15  51681797

S = 953.3   R-Sq = 78.90%   R-Sq(adj) = 73.62%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev    ------+---------+---------+---------+-------
-
0 cm depth      4    5851.2  1393.2                          (------*-----)
20 cm depth     4    6818.7   822.3                                (------*-
------)
40 cm depth     4    5893.2   581.4                          (------*-----)
No Irrigation   4    2610.8   824.7       (----*------)
                                    ------+-----------+-----------+---------+---
-----
                                         1600      3200       4800      6400
Pooled StDev = 953.3
```

One-way ANOVA: Mass of Dry Grain at 13.5 % Moisture content (kg/ha) versus TREATMENT

```
Source      DF  SS         MS         F      P
TREATMENT    3  32799334  10933111   16.90  0.000
Error       12   7761241    646770
Total       15  40560575

S = 804.2   R-Sq = 80.87%   R-Sq(adj) = 76.08%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean   StDev   ------+---------+---------+---------+-------
-
0 cm depth      4    5320.0 1124.0                           (-------*------)
20 cm depth     4    6085.1  768.8                                  (------*----
---)
40 cm depth     4    5050.6  475.9                          (------*-----)
No Irrigation   4    2297.0  711.5     (------*-----)
                                    ------+---------+-----------+---------+-----
---
                                       1500      3000          4500       6000
Pooled StDev = 804.2
```

Table 1.LSD of Means of various grain Yield determination

Treatment	Mass of fresh cob kg/ha	Mass of Dry cob kg/ha	Mass of Wet grain + corn-cob kg/ha	Mass of Dry grain + corn-cob kg/ha	Mass of Corn-cob kg/ha	Mass of Wet grain kg/ha	Mass of Dry grain at13.5% moisture kg/ha
0 cm	12534 a	9640 a	8260 a	7336 b	1484.8 a	5851.2 a	5320.0 a
20 cm	14051 a	10795 a	9192 a	8204 a	1384.9 a	6818.7 a	6085.1 a
40 cm	12756 a	9557 a	8189 a	7265 b	1372.3 a	5893.2 a	5050.6 a
No Irrigation	6821 b	4604 b	3778 b	3255 c	647.6 b	2610.8 b	2297.0 b
LSD(0.05)	**4796.55**	**3368.94**	**923.19**	**2777.99**	**702.99**	**2352.66**	**1984.65**

Treatment means having the same letters along the column are not significantly different from each other at 5% level.

APPENDICES F – ABOVE AND BELOW GROUND BIOMASS DETERMINATION

Table 1.Dry mass of above ground biomass in kg/ha of the various treatments

Treatment	Dry mass of above ground biomass (g) for an area of 324m^2	kg/ha
40 cm Depth	527.35	8038.872
20 cm Depth	556.2	8478.679
0 cm Depth	525.6	8012.195
No Irrigation	240.95	3673.056

Table 2.Dry mass of below ground biomass in kg/ha of the various treatments

Treatment	Dry mass of below ground biomass (g) for an area of 324m^2	kg/ha
40 cm Depth	130.74	1992.95
20 cm Depth	136.71	2083.956
0 cm Depth	122.16	1862.195
No Irrigation	90.89	1385.595

Table 3.Average root length in cm of the various treatments

Treatment	Average Root Length (cm)
40 cm Depth	29.85
20 cm Depth	29.85
0 cm Depth	29.03
No Irrigation	28.13

APPENDICES G - ANOVA OF ABOVE AND BELOW GROUND BIOMASS DETERMINATION

ANOVA showing Dry Weight of Above Ground Biomass in kg/ha

One-way ANOVA: Dry weight above ground biomass (kg/ha) versus TREATMENT

```
Source     DF  SS          MS          F      P
TREATMENT   3  124114297   41371432   6.67  0.007
Error      12   74380792    6198399
Total      15  198495089

S = 2490   R-Sq = 62.53%   R-Sq(adj) = 53.16%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev   ------+---------+---------+---------+--------
0 cm depth      4    12670  2208                              (-------*-------)
20 cm depth     4    12057  3197                             (-------*--------)
40 cm depth     4    12345  3103                              (--------*-------)
No Irrigation   4     5945  259        (--------*-------)
                                   ------+---------+-----------+---------+------
--
                                        3500      7000        10500     14000
Pooled StDev = 2490
```

ANOVA showing Dry Weight of Below Ground Biomass in kg/ha

One-way ANOVA: Dry weight below ground biomass (kg/ha) versus TREATMENT

```
Source     DF  SS         MS          F      P
TREATMENT   3  1158294   386098   2.64  0.097
Error      12  1754571   146214
Total      15  2912865

S = 382.4   R-Sq = 39.76%   R-Sq(adj) = 24.71%

                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev   ------+---------+---------+---------+--------
0 cm depth      4    1992.9 358.2                (-----------*----------)
20 cm depth     4    2084.0 307.7                   (----------*----------)
40 cm depth     4    1862.2 543.3              (-----------*----------)
No Irrigation   4    1385.6 258.2  (----------*---------)
                                   ------+---------+-----------+---------+------
--
                                        1200      1600        2000      2400
Pooled StDev = 382.4
```

One-way ANOVA: Root Length (cm) versus TREATMENT

```
Source      DF    SS      MS      F      P
TREATMENT    3   8.123   2.708  7.33  0.005
Error       12   4.435   0.370
Total       15  12.558

S = 0.6079   R-Sq = 64.68%   R-Sq(adj) = 55.85%
                         Individual 95% CIs For Mean Based on Pooled StDev
Level           N    Mean  StDev   ------+---------+---------+---------+--------
0 cm depth      4    29.850 0.173                      (--------*--------)
20 cm depth     4    29.850 0.058                      (--------*--------)
40 cm depth     4    29.025 0.050            (-------*---------)
No Irrigation   4    28.125 1.201 (--------*-------)
                                   ------+---------+-----------+---------+------
--
                                        28.00    28.80       29.60      30.40
Pooled StDev = 0.608
```


Table 1.LSD of Means of above and below ground biomass determination

Treatment	Above ground biomass (kg/ha)	Below ground biomass (kg/ha)	Root length(cm)
0 cm	12670 a	1992.9	29.850 a
20 cm	12057 a	2084	29.850 a
40 cm	12345 a	1862.2	29.025 b
No Irrigation	5945 b	1385.6	28.125 b
LSD (0.05)	**6143.98**	**NS**	**1.5**

Treatment means having the same letters along the column are not significantly different from each other at 5% level

APPENDICES H - COST AND BENEFIT ANALYSIS

Table 1.Comparison and profitability of maize under irrigation of means of yield (kg/ha) of Irrigated treatments against No Irrigation

Treatment	No Irrigation	Percentage (%) increase in yield	Total cost of Maize GH ¢
40 cm	$\frac{5320-2297}{2297}\times 100$	131.61	**3,000**
20 cm	$\frac{6085-2297}{2297}\times 100$	164.9	**3,750**
0 cm	$\frac{5050.6-2297}{2297}\times 100$	119.88	**2,750**

Table 2.Showing Comparison among means of yield (kg/ha) of Irrigated treatments

Treatm-ent	Surface	%	20 cm	%	40 cm	%
Surface	-		$\frac{6085-5050.6}{5050.6}\times 100$	**20.48**	$\frac{5320-5050.6}{5050.6}\times 100$	**5.3**
20 cm	$\frac{6085-5050.6}{5050.6}\times 100$	**20.48**	-		$\frac{6085-5320}{5320}\times 100$	**14.48**
40 cm	$\frac{5320-5050.6}{50506.}\times 100$	**5.3**	$\frac{6085-5320}{5320}\times 100$	**4.48**	-	

Table 3.Materials List for PVC Drip Irrigation System covering around 324 m as compared to 10,000m²

ITEM	Quantity per 324m²	UNIT Cost (Ȼh c) per 324 m²	**Total Cost (GHȻ) per 324 m²**	Quantity for 10,000m²	**Total Cost (GH Ȼ) For per hectare (10,000m²)**
½ inch PVC	40	3.00	**120.00**	1235	**3,705.00**
½ inch End cap	36	0.50	**18.00**	1,112	**556.00**
½ inch Elbow	36	0.70	**25.20**	1,112	**778.40**
½ inch Tap	12	5.00	**60.00**	371	**1,855.00**
Storage Tank (25 L)	12	3.00	**36.00**	371	**1,855.00**
½ inch Water holes	1(50 m)	50.00	**50.00**	30(50 m)	**1,500.00**
Wooden Stand	12	5.00	**30.00**	371	**1,855.00**
Funnel	12	1.00	**12.00**	371	**371.00**
Flexible wire (core)	5 kilos	12.00	**60.00**	155	**1,860.00**
Impermeable material	4 yards	15.00	**60.00**	124	**1860.00**
Trench Digging	36	5.00	**180.00**	1,112	**5,560**
Drilling of pipes	1	20	**20**	4	**80**
TOTALS			**GH Ȼ 611.2**		**GH Ȼ 21,835.40**

Table 4.Number of bags of maize yield obtained per treatment (1 bag =100kg)

Treatments	Kg / ha	Number of bags of maize yield per treatment	Total cost of yield GH cedi (1 bag =100kg = GH cedi 80.00)
40 cm	5320.05	53	4,256.00
20 cm	6085.06	60.5	4,868.00
0 cm	5050.57	50	4,040.00
No Irrigation	2297.95	22.5	1,837.00

APPENDICES I – PICTURES FROM THE EXPERIMENTAL SITE