بسم الله الرحمن الرحيم

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Comparison of Surface and Drip Irrigation Regimes for Banana (*Musa AAA*) cv. Grand Nain in Gezira, Sudan

By

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بسم الله الرحمن الرحيم

(الذى جعل لكم الأرض فراشاً والسماء

بناءً وأنزل من السماء ماءً

فأخرج به من الثمرات رزقاً لكم فلا تجعلوا

لله أنداداً و أنتم تعلمون).

صدق الله العظيم

(الأية 22 من سورة البقرة)

DEDICATION

To soul of my grand father

To my dear father

To my dear mother

To my dear fiancée

To my brothers & sisters

To my teachers, friends & colleagues

With everlasting love

For their diligence & encouragement

During all my life

Ahmed Alkalifa

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Ahmed Alkalifa

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Comparison of surface and drip irrigation regimes for banana (*Musa AAA*) cv. Grand Nain in Gezira

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Abstract

The experiment was established in the Horticultural Research Centre Farm, Agricultural Research Corporation, Wad Medani, Sudan during16th November 2009 and 16th October 2011. The soil used on the experimental site is silty clay loam soils with high silt content (68%). A drip irrigation system was designed and installed on an area of 2145 m^2. The system was evaluated for its performance relative to the conventional surface irrigation method. Three months old planting material propagated by tissue culture was transplanted in the field on 16th of November, 2009 at spacing of 3×3 meter (1111 mother plants/ha). Three months after planting two sucker were left (2222 plants/ha) and population was maintained thereafter. Five irrigation treatments were applied under drip irrigation system. These were 40%, 60%, 80%, 100% and 120% of crop evapotranspiration (ET_c). The traditional surface irrigation was used as a control. Irrigation interval in drip irrigation system was applied every other day. In surface irrigation method, irrigation scheduling was every 3 days at the beginning, then the interval was increased gradually to every 5-10 days depending on the prevailing weather conditions. The treatments were replicated four times in a randomized complete block design (RCBD) and four plants represented experimental plot. The parameters measured included plant height, plant girth, number of green leaves, leaf area, number of days from planting to shooting and harvesting, yield and yield components and total water applied. Irrigation water productivity, nutrients use efficiency and economic analyses were determined. The results on the hydraulic characteristic of drip irrigation system gave 7.92 l/h for average emitters discharge, 90.9% field emission uniformity, 91% absolute emission uniformity, 91.9% design emission uniformity and 81.9% irrigation efficiency. Growth parameters varied depending on the quantity of water applied under drip irrigation system. Applying water at 100% and 120% of ET_c under drip irrigation resulted in either higher or equal performance on all growth parameters tested relative to the surface irrigation. However, bunch weight for the mother plant and the first ratoon crops of banana were significantly variable by drip irrigation. The highest bunch weight was obtained with 120% and 100% of ET_c compared to surface irrigation. The drip irrigation treatments 100% of ET_c increased yield by 23% and at the same time saved irrigation water by 74% compared to surface irrigation. The highest irrigation water productivity (1.43 and 1.40 kg/m^3) was obtained with 120% and 100% of ET_c under drip irrigation and the lowest was (0.30 kg/m^3) with surface irrigation. The highest marginal rate of return was obtained from the 100% of ET_c treatment under drip irrigation system.

بسم الله الرحمن الرحيم

مقارنة الري السطحي والري بالتنقيط علي النمو والانتاجية في الموز

احمد بابكر احمد خليفة

خلاصة البحث

اجريت الدراسة بمزرعة مركز بحوث البساتين هيئة البحوث الزراعية, في الفترة من 16 نوفمبر 2009 وحتي 16 اكتوبر 2011 . وقد تم استعمال تربة قرينية خفيفة في هذه التجربة نسبة القرين بها حوالي 68%. ايضا تم تصميم وتركيب نظام الري بالتنقيط في مساحة 2145 $م^2$ تقريبا وتم تقويم اداء النظام مقارنة مع الري السطحي التقليدي المستعمل لدي المزارعين. الشتول التي تمت زراعتها اكثرت عن طريق زراعة الانسجة في ظروف محكمة. وزرعت في الحقل علي مسافات 3×3 متر اي 1111 نبات في الهكتار وبعد ثلاث اشهر من الزراعة تم تخفيف الخلف الي اثنين مع النبات الام وتلك هي الكثافة النباتية التي استمرت حتي نهاية التجربة اي 2222 نبات في الهكتار. ست معاملات استخدمت في هذه التجربة خمس منها تحت نظام الري بالتنقيط وهي 40%, 60%, 80%, 100% و120% من البخر النتح المحصولي والمعاملة السادسة هي الري السطحي التقليدي الذي يستخدمه المزراعين. فترات الري كانت كل يومين تحت نظام الري بالتنقيط وكل ثلاثة ايام عند بداية التجربة ثم زادت الي خمسة الي عشرة ايام في الري السطحي التقليدي اعتمادا علي حالة الطقس وسلوك المزراع, وضعت هذه المعاملات علي نظام المربعات العشوائية الكاملة. درست

مؤشرات النمو (طول الساق, سمك الساق, عدد الاوراق ومساحة الورقة) وعدد الايام من الزراعة الي الازهار ومن الازهار الي الحصاد والانتاجية ومؤشرات الانتاجية وكمية الماء المضافة لكل معاملة وكفاءة استخدام مياه الري وكفاءة استخدام الاسمدة وتم التحليل الاقتصادي لهذه التجربة. اظهرت الخواص الهيدرولكية لنظام الري بالتنقيط ان متوسط معدل تصريف النقاطات كان 7.9 لترفي الساعة, الكفاءة الحقلية كانت 90.9%, الكفاءة المطلقة 86.8%, كفاءة التصميم كانت 91.9% وكفاءة الري كانت 81.9%. اظهرت النتائج ان هناك فروق معنوية اعتمادا علي كمية الماء المضافة تحت نظام الري بالتنقيط مقارنة مع الري التقليدي, ايضا هناك فروق معنوية في الانتاجية ومؤشرات الانتاجية بين المعاملات, ايضا اظهرت النتائج ان نظام الري بالتنقيط عند 120% و 100% من البخر النتح المحصولي ادي الي زيادة الانتاجية بنسبة 23% و 34% وكذلك وفر حوالي من 74% الي 72% من مياه الري مقارنة مع الري التقليدي. وعند حساب كفاءة استخدام مياه الري كانت اعلي عند 120% و 100% من البخر النتح المحصولي تحت نظام الري بالتنقيط مقارنة مع الري التقليدي, وعند حساب كفاءة استخدام الاسمدة كانت اعلي عند 120% و 100% من البخر النتح المحصولي تحت نظام الري بالتنقيط مقارنة مع الري التقليدي. مع ان التكلفة الانشائية للري بالتنقيط عالية مقارنة مع الري السطحي الا ان معدل العائد الهامشي للري بالتنقيط عند المعاملة 100% من البخر نتح المحصولي كان الاعلي والاحسن.

CHAPTER ONE

INTRODUCTION

Banana belongs to the genus *Musa* of the family *Musaceae*. Its cultivation is distributed throughout the warmer countries and is confined to regions between 30°N and 30°S of equator. Together, bananas and plantains, are the fourth most important food crop in the world after rice, wheat and maize (Salvador *et al*., 2007). Banana is a popular fruit in Sudan and represents one of the most important cash crops (Elhassan *et al*., 2005). In Sudan the areas under banana cultivation are now about 23000 hectares mainly used for local consumption (Bakhiet *et al*., 2011). The crop is well adapted to the warm dry climate and productivity exceeded 50 ton/ha under light fertile soils of the Gash river basin and the Nile river banks of Sudan. The common feature of banana production in the Sudan is a mixed farming system and small holdings of pure stand depending on irrigation from wells and rivers. Banana ranks first in terms of volume and second, after citrus, in terms of value (Bakhiet, 2006). The major hurdle in quality banana production is the lack of professional outlook towards its production and the mismanagement of the available natural resources. Water is one of the most important constraints which significantly influence quality and productivity. Banana is a tropical plant that requires an ample and frequent supply of water. Many earlier workers have reported that water deficit adversely affects the crop growth and yield (Mahmoud, 2006).

Generally, the banana in Sudan is irrigated by surface irrigation. There are several problems in surface irrigation caused by accumulation of salts, increased level of tail water loss through evaporation and leaching, difficulties in moving of farm equipment, added expenses and time to make extra tillage practice (furrow construction), an increase in the erosive potential of the flow, requires a lot of water, does not work well on sandy soils, and irrigated area needs to be relatively flat. Also, it may add too much water near the inlet and not enough water at the edges. Generally, furrow systems are more difficult to automate particularly with regard to regulating an equal discharge in each furrow and losing too much water to deep drainage or runoff (Walker, 1989).

Water is increasingly becoming a scarce resource and the areas requiring irrigation are very extensive and encompass portions of every continent of the world (Israelsen and Hansen, 1972). An earlier estimate made by (FAO, 1993) for average irrigation water utilization showed that farm distribution losses constitute 15% of irrigation water; while field application system losses constitute 25%, irrigation system losses 15% and the water effectively used by crops constitutes only about 45%. This is of particular importance if we know that the amount of water present in the universe is about 1520 million cubic kilometers, 97% is ocean water and sea salt, 2% is frozen arctic waters and only 1% is water lakes, rivers and underground water, which is potable water for direct use to humans (Shaker, 2004).

Drip irrigation (trickle or micro irrigation) is a promising system for economizing the available irrigation water. It is also necessary to manage the available water efficiently for maximum crop production. Drip irrigation can apply water both precisely and uniformly at a high irrigation frequency compared with furrow and sprinkler irrigation (Hanson and May, 2007).

Banana has wide adaptability to soil conditions but its performance varies with soil types, lime concentration, nutrient status and drainage. In heavy soils, time taken for harvesting is longer as compared to light soils. The information on the soil factor is vital for the banana production which needs attention for maximizing the production with available resources. Drip irrigation systems are well suited to fertigation because of their frequency of operation and because water application can be easily controlled by the manager (Brad Lewis, 2001). In today's perspectives, it is essential to study the crops like banana, which is a heavy feeder of the nutrients with respect to most efficient method of fertilizer application to get maximum fertilizer use efficiency and net profit.

Banana cv. Grand Nain is identified to be the major export variety worldwide and released in Sudan in 2001. Plant characters resemble Cavendish for most parameters except for its robust stature, and well-spaced hands with straight fingers of bigger size. It bears a heavy bunch weighing 25-30 kg that usually requires propping. There is a need to compare different irrigation systems to allow for the identification of most efficient and profitable irrigation system. Accordingly, the objectives of the study were:

1. To compare between drip irrigation system and the conventional surface irrigation methods for banana production under Gezira condition in terms of yield and yield components, quantities of water applied, irrigation water productivity and economic analysis.
2. To estimate the crop coefficients (K_c) values for the different growth stages of banana under Gezira conditions.

CHAPTER TWO

LITERATURE REVIEW

2.1. Banana crop

2.1.1. Introduction

Banana is one of the most important tropical fruits. Banana, 2 to 9 m tall, bears leaves on a pseudostem consisting of leaf stalks. The flowering stalk emerges from the pseudostem and produces a handing bunch of flowers (Fig.2.1). Fruits are formed on hands with about 12 fingers, each bunch contains up to 150 fingers. After harvest the pseudostem is cut. The underground stem (corm or rhizome) bears several buds which, after sprouting, from new pseudostem, or so called suckers. They are removed except for one or two which provide the ratoon crop. The development of the plant can be divided into three periods; vegetative, flowering and yield formation. The time from planting to shooting (vegetative) is about 7 to 9 months and the time from shooting to harvest (flowering and yield formation) is about 90 days. The average life of a commercial plantation can be from 3 to 20 years, with mechanical cultivation the economic life is often 4 to 6 years. Some varieties are replanted after each harvest (Doorenbos *et al*., 1986).

2.1.2. Origin and distribution

Modern bananas and plantains originated in the South East Asian and west pacific regions where their inedible, diploid ancestors can be found in the natural forest vegetation (Robinson, 1996). Later *Musa* was introduced in the western hemisphere and into other parts of the world (Samson. 1980).

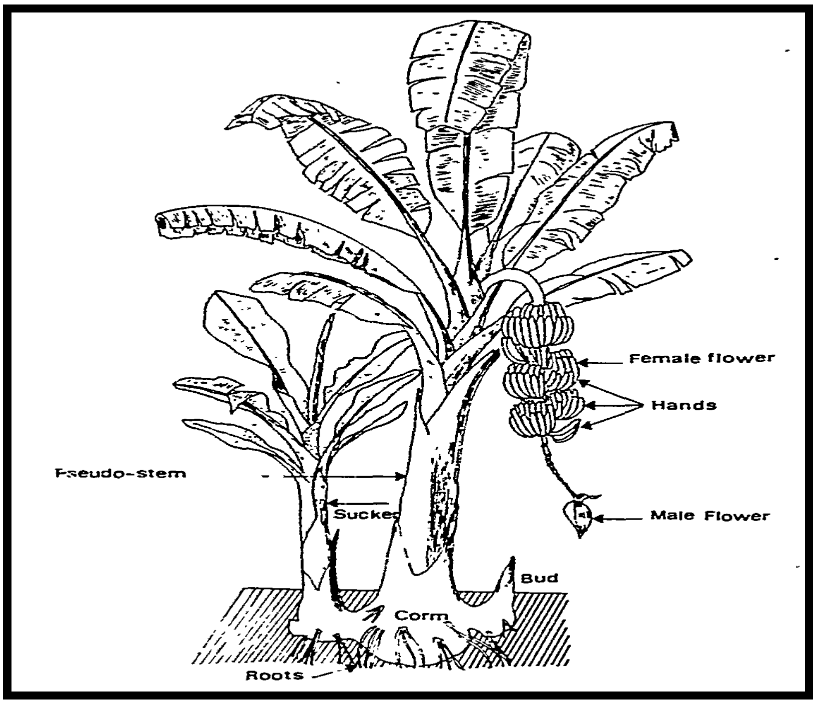

Figure 2.1 Banana crop

Source: Doorenbos, *et al*. (1986)

2.1.3. Importance of the bananas

Bananas are consumed both as dessert fruit and as a food crop, providing cheap sources of energy and vitamins, and can be harvested all year round. They are good source of vitamins A, B6 and C, and they have a high content of carbohydrates and fibers, but are low in protein and fat (Chandler, 1995). Bananas are a major stable food crop for millions of people in Central, East and West Africa, Latin America and the Caribbean. The plant as a whole provides a range of useful products in addition to the fruit. The fibers from the pseudostems and leaves are used to make ropes, baskets, mats and a wide range of handicrafts. In the tropics, banana is an important crop for many rural communities, providing a significant source of revenue as well as being an integral component of cultural ceremonies such as marriage, birth, death and harvest (INIBAP, 2003). Nearly 90% of the total banana and plantain produced worldwide are consumed locally in the producing countries leaving only 10% for export (Dadzie and Orchard, 1997). Banana cultivation continues to be one of the principal agricultural activities for many developing countries of Latin America, Caribbean and Africa. The banana industry has been designed and oriented almost exclusively towards the export markets. Export of fresh banana fruit demands high standard of quality (Bakhiet, 2006).

2.1.4. Banana in the Sudan

Banana fruits are popular in Sudan because they are cheap compared to other fruits. Banana plant is mainly grown along the banks of the Nile and its tributaries, and in Kassala area (Gash Delta). The major constraints facing the production of banana in Sudan are cultivars, hazards in flooding of banana growing areas, poor crop management and postharvest handling procedures and marketing. Banana production in Sudan is mainly based on the cultivar Dwarf Cavendish. This cultivar has a wide adaptation and resistant to Panama disease, but sensitive to cool temperature and less suitable for export (Bakhiet, 2006). Banana cultural practices are very poor in Sudan. Moreover, the postharvest handling of banana fruits is very poor in Sudan. Harvesting, packing, transport and ripening are applied without any standards resulting in low quality of fruits in the local market. Marketing of banana in Sudan is a major constraint for production of banana. The market channels, institutions and facilities are less developed compared to those in developed world. Prices of banana go high in rainy season due to the lack of paved roads in banana production areas. Sudan is near to the export markets and the potential of exporting banana is high if these constraints are solved (Bakhiet, 2006).

2.1.5. Grand Nain cultivar

In the 1990 the superior yields of Grand Nain compared with various imported and local Cavendish selections were confirmed in several trials. The cycle time of Grand Nain is slightly shorter, bunches are slightly heavier and fingers slightly longer than Williams. These advantages all add up to a higher annual yield of extra large fruit with Grand Nain. Worldwide Grand Nain is regarded as the most popular Cavendish dessert banana in both tropical and subtropical localities. In 1990 an Israel a selection of Grand Nain was imported. Plant vigour and yield potential of different cultivars can vary according to soil type, climatic conditions and management level (Robinson and Villiers, 2007). Recently, banana cv. Grand Nain was released to farmers (Bakheit and Ali, 2001). The plant of this cultivar is taller, higher in yield potential and lees sensitive to cool temperature than the local cultivar (Dawarf Cavendish). There is a high demand for export of this cultivar which will replace the widely grown banana cv. Dawarf Cavendish. Presently, Grand Nain is becoming a popular banana cultivar in Sudan, but the yields are low due to lack of proper water management and fertilization practices.

2.1.6. Environmental requirements

2.1.6.1. Temperature

The rate of banana growth and development is determined by temperature where water is not limiting (Robinson, 1996). Optimum temperature for growth and flower initiation is 22°C, and the optimum temperature for high rate of leaf emergence is about 31 °C (Turner and Lahav, 1983; Robinson and Anderson, 1991). The overall mean temperature for an optimum balance between growth and development is about 27 °C (Robinson, 1996). Samson (1980) reported that banana cannot withstand frost, and chilling injury occurs at temperature below 12°C. Growth begins at about 18 °C, reached an optimum at 27 °C, then declined and came to a stop at l2 °C and 38°C. Samson (1980) reported that banana fruits increase in girth up to 29 °C.

2.1.6.2. Wind

Wind can cause different types of damage in banana plantation. Gale force wind or hurricanes of more than 15 ms^{-1} frequently cause blow down in tropical banana plantation (Robinson, 1995). Wind velocity of 25-30 km/h gives rise to crown distortion, breakage or uprooting of pseudostem and root damage (Simmonds, 1966). A wind speed of 65 km/h will cause considerable loss and banana fields are completely destroyed at 100 km/h (Simmonds, 1966). To decrease wind effect on banana plants, they must be planted in a sheltered positions or provided with wind breaks such as bamboos (Acland, 1980).

2.1.6.3. Altitude and Latitude

The major banana growing area of the world is situated between the Equator and latitudes 20° N and 20° S. Banana is primarily a crop of the humid tropical low lands which are areas characterized by less than 10° latitude, less than 100 m altitude (Robinson, 1996). Samson (1980) reported that Musa is a crop of the tropical low lands and any extension of its culture in to the mountains or subtropics will prolong the growth cycle considerably. The optimum areas in the world for banana cultivation are located in a belt of land between 15° N and S of the equator (Litzenberger, 1974). The high altitude cause slower development in banana plant and at high as 1800 m it is unproductive (Acland, 1980). Bananas are a predominantly tropical fruit except the Dwarf Cavendish which also grows well in some subtropical areas

(Samson, 1980).

2.1.6.4. Drought

Banana plants have to be irrigated since periodical drought can cause plant damage. Yield reduction occurs long before visible symptoms of drought are evident. Visible signs of drought stress are prolonged wilting and folding of the leaves, followed by yellowing, marginal necrosis and leaf burn. Prolonged drought produces small stunted plants, slower leaf emergence, choked bunches, short fingers and in the worst case small bunches with shrivelled blackened fingers (Robinson and Villiers, 2007).

2.1.6.5. Floods

Flooding is normally a tropical phenomenon but is occurs occasionally in the subtropics after exceptionally high rainfall. Bananas will tolerate up to 72 hours of flooding with flowing water provided the water table falls rapidly along with the flooding waters. Under static and stagnant flood water only about 24 to 48 hours of flooding can be tolerated before oxygen starvation causes root dieback leading to leaf yellowing (Robinson and Villiers, 2007).

2.1.6.6. Soil requirements

The best banana soil is deep, well drained loams with high inherent fertility and organic matter content, and an absence of compaction, excessive clay, acidity or salinity (Samson, 1980). The clay content should be below 40% and the water table below one m (Stover, 1972). According to Delvaux (1995) the soil physical characters that are important for vigorous root growth of banana and plantain are porosity, mechanical impedance, aeration, natural drainage, water holding capacity and soil temperature. Bananas can not tolerate water logging (Donald and Low, 1990). They can tolerate acidic sulphate soil (Moormann, 1963). Most of the world bananas for export to temperate climates are produced on alluvial loams in central and South America (Samson, 1980). Deep well drained loams and light clay loams have been shown to give consistently high yield in Central America (Lahav and Turner, 1983).

2.2. Irrigation definition

Irrigation is the artificial application of water for the purpose of crop production. Irrigation water is supplied to supplement the water available from rainfall and the contribution to soil moisture from ground water. In many areas of the world the amount and timing of rainfall is note adequate to meet the moisture requirement of crops and irrigation is essential to raise crops necessary to meet the needs of man for food and fiber (Michael, 1978).

2.3. Water resources of the Sudan

The main resources are: Rainfall, River Nile, non-nilotic streams and groundwater. Rainfall ranges from zero in further North to about 800 mm in extreme South-west. River Nile, the main resource of water for Sudan is shared by other nine countries. The Nile river with an estimated length of over 6800 km, is the longest river flowing from South to North over 35 degrees of latitude (Appelgren *et al.*, 2000). It is fed by two main river systems, the White Nile and the Blue Nile which has two main tributaries, Dinder and Rahad. The confluence of the White Nile and the Blue Nile is at Khartoum. Further downstream is the Atbara tributary, the last important tributary of the Nile system. The mean annual natural discharge of the Main Nile on leaving Sudan is about 84 km^3. Egypt's share was agreed in 1959 at 55.5 km^3 and Sudan's share, as measured at Aswan, was raised from the four milliards formerly allowed under the 1929 treaty to 18.5 km^3. Non-nilotic rivers comprise four streams (Gash, Baraka, Azum and Hawar). Concerning groundwater, there is no accurate estimation of total groundwater in Sudan but, some of the studies estimate it as 500 milliards. The main aquifers of the Sudan include (Um rawaba formation, Nubian sandstone formation and Gezira formation) within the range of 40 to 400 meters depth. It is an important source of water supply as 80% of the population depends on groundwater for water supply. On the other hand, 90% of groundwater abstraction is used for irrigation (Elhadi Eltoum, 2006). The domestic sector and industry accounted for withdrawals of 0.99 km^3 and 0.26 km^3 respectively. Water used in Sudan derives almost exclusively from surface water resources. Groundwater is used only in very limited areas, and mainly for domestic water supply (AQUASTAT Survey, 2005).

2.4. Irrigation in the Sudan

The cultivable area is estimated to be 105 million ha or 42% of the total area. The cultivated land is 7.6 million ha, which is 7% of the cultivable area. Only about 3% consists of permanent crops. The remaining area consists of annual crops (FAO, 1997). The irrigated agriculture constitutes about 10% of the cultivated area and produces more than half (50%) of the agricultural output of Sudan. The irrigated sector is important for Sudan economy where most of the cash, food and fodder crops are usually grown. Productivity under irrigation is relatively high compared with that under rainfall. Water for crops grown under irrigation is applied through different forms of surface irrigation. In pump irrigated schemes water is lifted to the ground surface by pumping and then conveyed to the field by gravity or flooding (Elbadwi, 2001).

2.5. Crop water requirements

The crop water requirements (CWR) is defined as the depth of water needed to meet the loss of water through evapotranspiration of a disease free crop, growing in large fields under non-restricting soil condition, including soil water, fertility and achieving full production potential under a given growing environment (Doorenbos and Pruitt, 1977). The crop evapotranspiration (ET_c) is defined as the evapotranspiration from disease free, well fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. Crop evapotranspiration (ET_c) also refers to the amount of water that is lost through evapotranspiration (Allen *et al*. 1998).

The following equation is used to calculate crop water requirements:

$$ET_c = ET_0 \times Kc \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

In which:-

ET_c = crop evapotranspiration [mm d^{-1}],

K_c = crop coefficient [dimensionless],

ET_o = reference crop evapotranspiration [mm d^{-1}].

2.5.1. Reference crop evapotranspiration

Reference crop evapotranspiration (ET_o) is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass that covers the ground uniformly, is actively growing and shades the entire ground and not short of water. The FAO Penman-Monteith method is recommended as sole method for determining (ET_o).

Reference crop evapotranspiration can be calculated according to the equation as follows:

Penman-Monteith formula recommended by FAO 56 to estimate ET_o as stated by Allen *et al*. (1998).

$$ET_o = \frac{0.408\,\Delta(Rn - G) + \gamma \frac{900}{T + 273} u_2\,(e_s - e_a)}{\Delta + \gamma(1 + 034u_2)} \quad \ldots\ldots (2.2)$$

In which:-

ET_o =reference evapotranspiration [mm day^{-1}],

Rn =net radiation at the crop surface [MJ m^{-2} day^{-1}],

G= soil heat flux density [MJ m-2 day^{-1}],

T= mean daily air temperature at 2 m height [°C],

u_2= wind speed at 2 m height [m s^{-1}],

e_s= saturation vapour pressure [kPa],

e_a= actual vapour pressure [kPa],

e_s-e_a= saturation vapour pressure deficit [kPa],

Δ= slope of saturation vapour pressure curve [kPa °C^{-1}],

γ=psychrometric constant [kPa °C^{-1}].

The method has been selected because it closely approximates grass (ET_o) at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for estimating missing climatic parameters (Allen *et al.* 1998).

2.5.2. Crop coefficient

Crop coefficients (K_c) used for estimating ET_c for specific crops by measuring potential or reference (ET_o) must be derived empirically for local crop based on local climatic conditions (Doorenbos and Pruitt, 1977). Allen *et al.* (1998) stated that the K_c for any period of the season can be derived by assuming that, during the initial and mid- season stage, K_c is constant and equal to the K_c value of the growth stage under consideration. During the crop development and late season stage, K_c varies linearly between the K_c at the end of the previous stage and the K_c at the beginning of the next stage, which is K_c end in the case of the late season stage (Allen *et al.*, 1998). The following equation was used to compute the K_c value on each day of the entire season:

$$K_{ci} = K_{c\ prev} + \left[\frac{i - \Sigma(L_{prev}}{L_{stage}}\right](K_{c\ next} - K_{c\ prev}) \text{ .... } (2.3)$$

In which:-

i =day number within the growing season [1. length of the growing season].

$K_{c\ i}$ =crop coefficient on day i.

L_{stage} =length of the stage under consideration [days].

$\sum(L_{prev})$ =sum of the lengths of all previous stages [days].

2.5.2.1. Crop growth stages

As the crop develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the K_c for a given crop will vary over the growing period (Fig 2.2). The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late season (Allen *et al*., 1998).

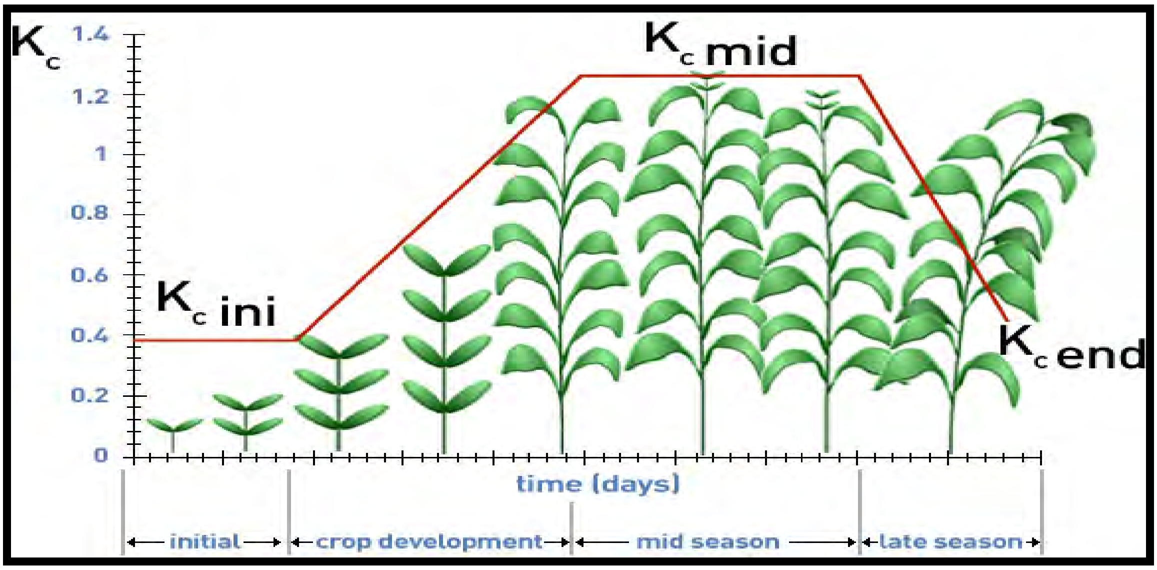

Figure 2.2 Crop coefficients and growing period of banana

Source: Allen *et al*. (1998)

2.5.2.1.1. Initial stage

The initial stage runs from planting date to approximately 10% ground cover. The length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate. The end of the initial period is determined as the time when approximately 10% of the ground surface is covered by green vegetation. For perennial crops, the planting date is replaced by the 'greenup' date, i.e., the time when the initiation of new leaves occurs. During the initial period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. Therefore, the K_c during the initial period ($K_{c\ ini}$) is large when the soil is wet from irrigation and rainfall and is low when the soil surface is dry. The time for the soil surface to dry is determined by the time interval between wetting events, the evaporation power of the atmosphere (ET_o) and the importance of the wetting event (Allen *et al*., 1998).

2.5.2.1.2. Crop development stage

The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. For row crops where rows commonly interlock leaves such as beans, sugar beets, potatoes and corn, effective cover can be defined as the time when some leaves of plants in adjacent rows begin to intermingle so that soil shading becomes nearly complete, or when plants reach nearly full size if no intermingling occurs. As the crop develops and shades more and more of the ground, evaporation becomes more restricted and transpiration gradually becomes the major process. During the crop development stage, the K_c value corresponds to amounts of ground cover and plant development. Typically, if the soil surface is dry, $K_c = 0.5$ corresponds to about 25-40% of the ground surface covered by vegetation due to the effects of shading and due to microscale transport of sensible heat from the soil into the vegetation (Allen *et al*., 1998).

2.5.2.1.3. Mid-season stage

The mid-season stage runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced relative to the reference ET_o. The mid-season stage is the longest stage for perennials and for many annuals, but it may be relatively short for vegetable crops that are harvested fresh for their green vegetation. At the mid-season stage the K_c reaches its maximum value. The value for K_c ($K_{c\ mid}$) is relatively constant for most growing and cultural conditions. Deviation of the K_c mid from the reference value '1' is primarily due to differences in crop height and resistance between the grass reference surface and the agricultural crop and weather conditions (Allen *et al*., 1998).

2.5.2.1.4. Late season stage

The late season stage runs from the start of maturity to harvest or full senescence. The calculation for K_c and ET_c is presumed to end when the crop is harvested, dries out naturally, reaches full senescence, or experiences leaf drop. For some perennial vegetation in frost free climates, crops may grow year round so that the date of termination may be taken as the same as the date of ‘planting’. The K_c value at the end of the late season stage ($K_{c\ end}$) reflects crop and water management practices. The $K_{c\ end}$ value is high if the crop is frequently irrigated until harvested fresh. If the crop is allowed to senesce and to dry out in the field before harvest, the K_c end value will be small (Allen *et al*., 1998).

2.5.2.2. Adjustment of FAO crop coefficient

The standard K_c of every growth stage (initial, mid, and end) for banana was taken from the FAO 56 table 12, and adjusted to local information. The K_c for the mid growing stage of crop was adjusted to the local climatic conditions by using the metrological data (wind speed at 2 m and minimum relative humidity) from Wad Medani Meteorological Station located almost inside the command area Allen *et al*. (1998). The adjusted K_c value of the mid growing stage for the banana crop was computed as follows:

$$K_{c\ mid} = K_{c\ mid\ (Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad \ldots(2.4)$$

In which:-

$K_{c\ mid\ (Tab)}$ =value for Kc mid taken from Table 12.

u_2 = mean value for daily wind speed at 2 m height over grass during the midseason growth stage [m s-1], for 1 m s-1 δ u2 δ 6 m s-1.

RH_{min} = mean value for daily minimum relative humidity during the mid-season growth stage [%], for 20% δ RH_{min} δ 80%.

h = mean plant height during the mid-season stage [m] for 0.1 m < h < 10 m.

2.6. Irrigation systems

There are many types of irrigation systems. These can be stated as follows:

2.6.1. Surface irrigation

As the oldest and most common method of applying water to croplands. Surface irrigation is the introduction and distribution of water in a field by the gravity flow of water over the soil surface (Thomas, 2003).

2.6.1.1. Types of surface irrigation

Each surface system has its own unique advantages and disadvantages depending on such factors as: initial development costs, size and shape of individual fields, soil characteristics, nature and availability of the water supply, climate, cropping pattern, social preferences and structures, and historical experience. For the most part, the most often used characteristics to distinguish surface irrigation systems are physical features of the irrigated fields. Efforts to classify surface systems differ substantially, but generally include the following:

2.6.1.1.1. Basin irrigation

Historically, basin irrigation has been the irrigation of small irregular or square areas having completely level surfaces and enclosed by dikes to prevent runoff. Water is added to the basin through a gap in the perimeter dike or adjacent ditch. It is important for the water to cover the basin quickly and be shut off when the correct volume has been supplied. If the basins are small or if the discharge rate available is relatively large, there are few soils not amenable to basin irrigation (Walker, 2003). Generally, basin irrigation is favored by moderate to slow intake soils and deep-rooted, closely spaced crops. Crops which do not tolerate flooding and soils subject to crusting: can be basin irrigated by furrowing or using raised bed planting. Basin irrigation is an effective method of leaching salts from the soil profile. Basin irrigation systems can be automated with relatively simple and inexpensive flow controls at the basin inlet (Walker, 2003). Basin irrigation has a number of limitations that are recognized primarily in association with agriculture in the less developed countries. Accurate land leveling is a prerequisite to high uniformities and efficiencies, but this is difficult to accomplish in small areas. The perimeter dikes must be well maintained to eliminate breaching and waste. It is difficult and often infeasible to incorporate the use of modem farm machinery in small basins, thereby limiting small-scale basin irrigation to hand and animal powered cultivation (Walker, 2003).

2.6.1.1.2. Border irrigation

In many circumstances, border irrigation can be viewed as an expansion of basin irrigation to include long rectangular or contoured field shapes, longitudinal but no lateral slope, and free draining or blocked conditions at the lower end (Walker, 2003).

2.6.1.1.3. Furrow irrigation

An alternative to flooding the entire field surface is to construct small channels along the primary direction of water movement. Water introduced in these "furrows," "creases," or "corrugations" infiltrates through the wetted perimeter and moves vertically and laterally thereafter to refill the soil. Furrows provide better on-farm water management capabilities under most surface irrigation conditions. Flow rates per unit width can be substantially reduced and topographical conditions can be more severe and variable. A smaller wetted area can reduce evaporative losses on widely spaced crops. Furrows provide operational flexibility important for achieving high efficiencies for each irrigation throughout a season. It is a simple (although labor intensive) matter to adjust the furrow stream size to changing intake characteristics by simply changing the number of simultaneously supplied furrows (Walker, 2003).

The disadvantage of furrows include: potential salinity hazards between furrows, greater likelihood of tail water losses unless end dikes are used, limited machinery mobility across the lateral field direction, the need for one extra tillage practice (furrow construction), and an increased erosion potential.

Furrow systems require more labor than border and basin systems and are occasionally more difficult to automate (Walker, 2003).

2.6.1.1.4. Spate irrigation

Spate irrigation as an ancient irrigation practice that involves the diversion of flashy spate floods running off from mountainous catchments where flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channelled through short steep canals to bunded basins, which are flooded to a certain depth". Subsistence crops, often sorghum, are typically planted only after irrigation has occurred. Crops are grown from one or more irrigations using residual moisture stored in the deep alluvial soils formed from the sediments deposited in previous irrigations (Steenbergen *et al*. 2010).

2.6.1.2. Advantages and disadvantages of surface irrigation

The practice of surface irrigation is thousands of years old and collectively represents by far the most common irrigation activity today. The easiest water supplies to develop have been stream or river flows which required only a simple river dike and canal to provide water to adjacent lands. These low-lying soils were typically high in clay and silt content and had relatively small slopes. A comparison of irrigation methods at various historical junctures would lead to differing conclusions, but some general advantages and disadvantages of surface irrigation can be outlined (Walker, 2003).

Surface irrigation systems can be developed with minimal capital investment, although these investments can be very large if the water supply and irrigated fields bare some distance apart. At the farm level and even at the conveyance and distribution levels, surface irrigation systems need not require complicated and expensive equipment. Labor requirements for surface irrigation tend to be higher than for the pressurized types, but the labor still need not be high unless maximum efficiencies are sought. However, when water supplies are short, irrigators have developed highly skilled practices which achieve high efficiencies. With the variety of irrigation systems in use today, it is difficult to conclude whether operation and maintenance costs are necessarily lower with surface methods. Generally, energy costs are substantially lower, but inefficiency may very well reverse this factor (Walker, 2003).

On the negative side, surface irrigation systems are typically less efficient in applying water than either sprinkle or trickle systems. Since many are situated on lower lands with tighter soils, surface systems tend to be more affected by water logging and salinity problems. The need to use the field surface as a conveyance and distribution facility requires that fields be well graded. Land leveling costs are high, so the surface irrigation practice tends to be limited to land already having small, even slopes (Walker, 2003).

2.6.2. Sprinkler irrigation

Sprinkler irrigation is a method of applying irrigation water, which is similar to natural rainfall. Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers (nozzles) so that it breaks up into small water drops, which fall to the ground. The operation conditions must be designed to enable a uniform application of water (Rolland, 1982).

2.6.3. Drip irrigation

2.6.3.1. Historical background

Drip irrigation is sometimes called trickle irrigation, a name suggested by the American society of Agricultural Engineers (Abdalla, 2003), or localized irrigation, a name recommended by Food and Agriculture Organization at the United Nations. Originally, drip irrigation was developed as a sub-surface irrigation system applying water beneath the soil (Abdalla, 2003). The first such experiments began in Germany in 1869 where clay pipes were used in combination with drainage systems. The first reported work in the USA was made by House in Colorado in 1913 who indicated that the concept was too expensive for practical uses. Subsequent to 1920, perforated pipes were used in Germany, which made this concept feasible around the development of drip system using perforated pipes made of various materials (Howell *et al.*, 1980).

Drip irrigation has not yet been used on a large scale for crop production in the Sudan. However it is used in green houses and privately owned small farms and gardens. (Abdalla, 2003) surveyed some areas in the Sudan, which are adapted to drip irrigation to produce valuable crops. For their soil characteristics and lack of water these include Northern state, north of Kordofan and Darfour.

2.6.3.2. Types of drip irrigation system

2.6.3.2.1. Drip irrigation

Delivering slow frequent application of water in discharge points or line source with discharge of 2 to 100 liters per hour. Drip irrigation can be on the surface or sub-surface. The latter is preferred in high soils.

2.6.3.2.2. Bubbler irrigation

Application of water as a small fountain. It is a combination of surface and drip irrigation that needs a small basin, because the discharge is too high to infiltrate, about 20 to 225 liters per hour. It is usually used for orchard and big trees (Ismail, 2002).

2.6.3.2.3. Micro sprayers

Small applications are used to spray irrigation water to cover an area of 1 to 10 square meters. They are also called aerosol emitters, foggers, micro sprayers or miniatures sprinklers (Michael, 1978).

2.6.3.3. Advantages of drip irrigation

Drip irrigation system offers special agronomical, agro technical and economic advantages for efficient use of water and labour, these include:-

- A major advantage of drip irrigation systems is the close balance between applied water and crop evapotranspiration that reduces surface runoff and deep percolation to a minimum (Ceunca, 1989).
- For perfect drip irrigation system design, about 40% of the irrigation water is saved with an application efficiency of 85%-95% as compared-with other irrigation systems.
- Trickle systems produce higher ratio of yield per unit area and yield per unit volume of water than typical surface or sprinkler irrigation systems (Ceunca, 1989).
- Lower pressures mean reduced energy for pumping.
- High levels of water management are achieved because plants can be supplied with precise amounts of water (Marr and Rogers, 1993).
- Providing better salinity control and better disease management since only the soil is wetted whereas the leaf surface stays dry (Hanson and May, 2007).
- Utilization of saline water resources. With drip irrigation, low soil moisture tensions in the root zone can be maintained continuously with frequent applications. The dissolved salts accumulate at the periphery of the wetted soil mass, and the plants can easily obtain the moisture

needed. This enables the use of saline water containing more than 3000 mg/liter TDS, which would be unsuitable for use with other methods (Phocaides, 2000).

- Labor and operating costs are generally less, and extensive automation is possible.
- Water applications are precisely targeted. No applications are made between rows or other non-productive areas.
- Field operations can continue during irrigation because the areas between rows remain dry, resulting in better weed control and lower production costs.
- Fertilizers can be applied efficiently to roots through the drip system.
- Watering can be done on varied terrains and in varied soil conditions.
- Soil erosion and nutrient leaching can be reduced (Marr and Rogers, 1993).
- Frequent or daily application of water keeps the salts in the soil water more dilute and leached to the out limits of the wet zone to make the use of saline water more practical (Jensen, 1993).
- Use of trickle irrigation is practical even in fields that have 5%-6% slope without erosion (Elobeid, 2006).
- Trickle irrigation needs no leveling, no drainage and no other field operations like ridging.

2.6.3.4. Disadvantages of drip irrigation

- The major disadvantage of the system is its high capital or initial cost.
- Clogging of emitters by biological, chemical and physical matters.
- Frequent application of water leach the salts out to the limit of the wetted zone, if system stops supplying water, the salts may enter to the

root of the plant causing wilting or poisoning of the plant (Elobeid, 2006).

- Shallow roots due to the limited wet zone. The field needs frequent irrigation and in case of trees they are liable to tilt in the windward direction and may be uprooted.
- Management requirements are high. A critical delay in operation decisions may cause irreversible damage to crops.
- Frost protection that can be achieved by sprinkler systems is not possible with drip systems.
- Rodent, insect, or human damage to drip tubes may cause leaks.
- Filtration of water for trickle irrigation is necessary to prevent clogging of the small openings in the trickle line (Marr and Rogers, 1993).

2.6.3.5. The components of drip irrigation system

Components that are usually required for a drip irrigation system include the pumping station; control head, main and sub-main lines, lateral lines, emitters, valves, fitting, and other important appurtenances (Fig.2.3) (Vermeiren and Gobling 1980).

2.6.3.5.1. Control head

The system of control head consists of the pump, filters, valves, control valves, pressure regulator, flow regulating valves, backflow preventer, flow meters, pressure gauges, automatic controllers, or time clocks and chemical injection equipment (Jensen, 1993).

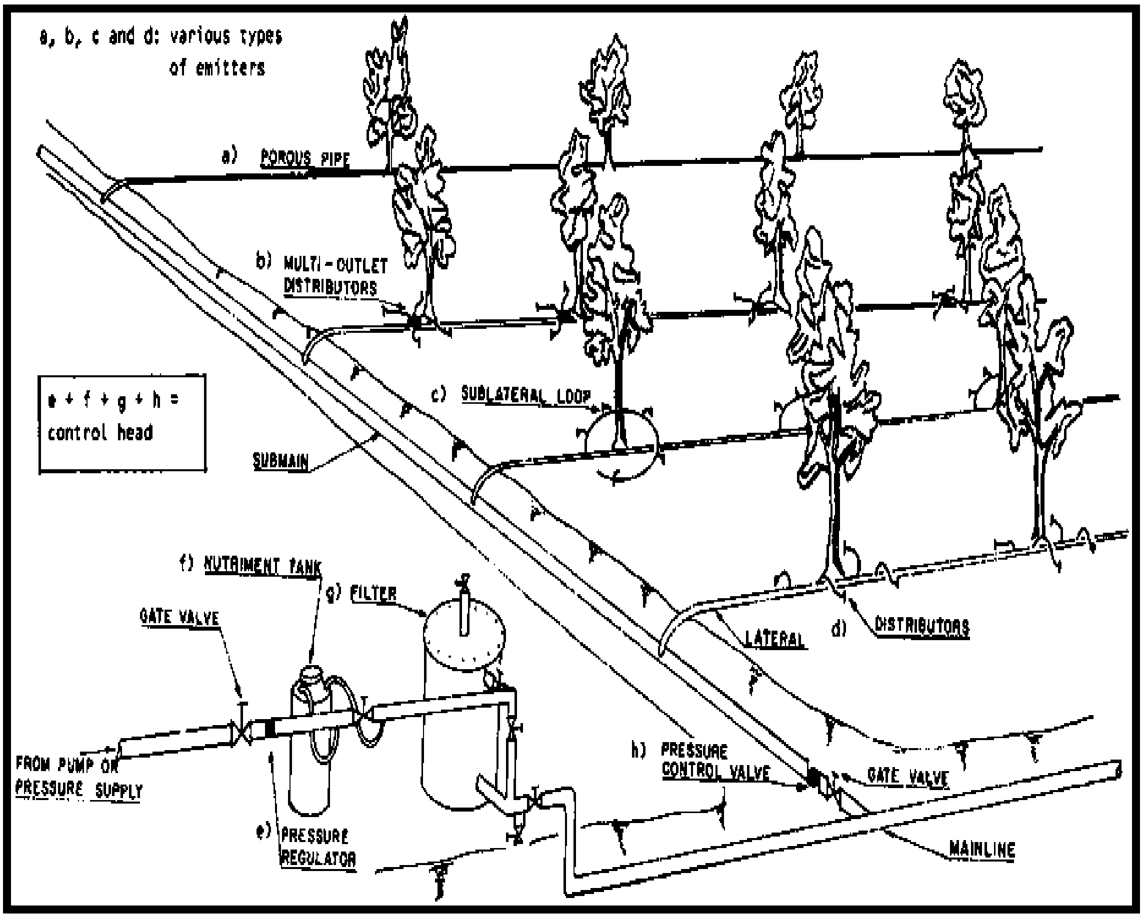

Figure 2.3 Basic components of drip irrigation system

Source: Vermeiren and Gobling, (1980)

2.6.3.5.2. Pumping station

The pumping station consists of the power unit (internal combustion engine or electric motor) and a centrifugal deep-well, or submersible pump and appurtenances. In the design and selection of pumping equipment for trickle irrigation system high efficiency is the principal requirement.

2.6.3.5.3. Filters

The filter is an essential component of the drip system. Its aim is to minimize or prevent emitter clogging; the type of filtration needed depends on water quality and on emitter type (Shaker, 2009).

Type of filters:

- Screen filters

The most common filter. It is excellent for removing hard particulates, but is not so good at removing organic materials (Shaker, 2009).

- Cartridge filters

It contains a paper filter, which works like a screen filter. It removes organic materials well. Most of them are replaceable when dirty (Shaker, 2009).

- Media filters

Media filter cleans water by forcing it through a container filled with a small sharp edged media, in most cases the media is uniform sized crushed sand (Shaker, 2009).

- Disk filters

Disk filters are a cross between screen and media filters with many of the advantage of both. A disk filter is good at removing particulates like sand and organic materials (Shaker, 2009).

- Centrifugal filters

They are primarily for removing particulates such as sand from water where a lot of sand is present in the water (Shaker, 2009).

2.6.3.5.4. Valves

Valves are required to control water flows inside the system, and to allow flushing of irrigation pipes (Smajstrla, 1997). It's made of brass, P.V.C or plastic. Valves are divided into:

- None return valve, which should be used before the pump or after water resource.

- Control valves.

The commonly used are gate valves, ball valves, disc valves. Valves can be operated manually, electrically, hydraulically and automatically (Jensen, 1993).

2.6.3.5.5. Pressure and flow regulators

Install it in the main line at over ground surface to regulate pressure and flow (Jensen, 1993).

2.6.3.5.6. Backflow preventer

The backflow preventer is located before the pump to prevent the flow back of irrigation water in order not to contaminate the source with chemical and fertilizers (Jensen, 1993).

2.6.3.5.7. Pressure gauge

Pressure gauges are required to properly monitor the operation of pressurized irrigation systems. Once on the pump discharge and with filters. Pressure gauge allows quick check to ensure that the system works at the correct pressure.

2.6.3.5.8. Fertilizers applicators

Fertilizers system is used to apply chemicals (fertilizers, pesticides, and anti-clogging agents) with irrigation water. This process is called (fertigation) and there are various ways of performing fertigation.

2.6.3.5.9. Main line

It is the largest diameter pipeline of the network that is capable of conveying the flow of the system under favorable hydraulic conditions of flow velocity and friction losses so as to deliver water to sub main line. The pipes used are generally buried and permanent made of PVC, black high density polyethylene (HDPE) or galvanized light steel. The sizes of these pipes range from 63 to 160 mm (2 - 6 inches). This depends on the area of the farm and the design of the system (Phocaides, 2000).

2.6.3.5.10. Sub main line

These are smaller diameter pipelines which extend from the main line, to which the system flow is diverted for distribution to the various plots. The pipes are of the same kind as the mains (Phocaides, 2000).

2.6.3.5.11. Lateral line

This delivers water to the emission devices from the sub main or direct from main line (Joseph, 1981). The diameters used are 13, 16, and 22 mm, in or online drippers usually made of black liner low density polyethylene tubes (LLDPE) which is called P.E tubes. They can be surface or subsurface lines.

2.6.3.5.12. Water applicators

The water applicators (emitters) specify the kind of system and in most cases the type of installation. They are fitted on the laterals at frequent spaces. They deliver water to the plants in the form of a rain jet, spray, mist, small stream, fountain or continuous drops. All kinds and types of emitters in use now are of the small orifice-nozzle, vortex or long-path labyrinth types (Phocaides, 2000). The types of water applicators, includes:

- **Drippers**

The drippers are small-sized emitters made of high quality Plastics.
The water enters the dripper emitters at approximately 1.0 kg/cm^2 (bar) and is delivered at zero pressure in the form of continuous droplets at low rates of 1.0-24 l/h. Drippers are divided into two main groups according to the way they dissipate energy (pressure) and these are:

- Orifice type, with flow areas of 0.2- 0.35 mm^2.
- Long-pass type, with relatively larger flow areas of 1.0 - 4.5 mm^2.

Both types are manufactured with various mechanisms and principles of operation. All the drippers now available on the market are turbulent flow. Drippers are also characterized by the type of connection to the lateral. On-line drippers are inserted in the pipe wall by the aid of a punch, where in-line drippers the pipe is cut to insert the dripper manually or with a machine. On-line multi-exit drippers are also available with four to six spaghetti type tube outlets (Phocaides, 2000).

- **Micro-sprayers**

Small applicators which spray water and they cover an area of 1-10 m^2. They are also called mini sprinklers, misters, foggers (Michael, 1978).

- **Bubblers**

Low pressure bubblers are small-sized water emitters. They are designed for localized flood irrigation of small areas. They deliver water in bubbler or in a low stream on the same spot. The flow rate is adjusted by twisting the top and ranges from 110 to 250 l/h at operating pressures of 1-3 bars. The bubbler discharge usually exceeds the soil infiltration rate (Phocaides, 2000).

- **Drip tape**

This type of lateral line uses thin-walled 0.1-1.25 mm, and the emitters with spacing of 10, 20, 30, 45 cm are built in. It delivers very low quantities of water than usual (0.4-1.0 l/h) at very low pressures (0.6-1.0 kg/cm^2). It is made of LDPE with diameter of 12 to 20 mm, and it has a filtration system inside with a very low liability to mechanical and biological blockages (Phocaides, 2000).

2.6.3.5.13. Fittings

These include an array of coupling and closure devices that are used to construct a drip system including connectors, tees, elbows, goof plugs and end caps. Fittings may be of several types, including compression, barbed and locking (Wilson and Bauer, 1998).

2.6.3.6. Drip irrigation design and hydraulics

The selection of components of the drip irrigation system to suit the water requirements of the crops and the local field conditions is called the design of the System. The main information required for drip irrigation design is as follows (Michael, 1978):

- Climate data

  According to the climate data, it can be known when and how much water to apply.

- Soil

  The soil characteristics must be known for selecting emitters type and setting up the schedule of the irrigation.

- Topographic condition

  It is necessary to know the slope of the land so as to determine the size and the location of main and sub main lines.

- Crop type

  The design of the irrigation system depends on the type of crop.

- Water source

  The water source is important for the system design so as to calculate the pump power and lines discharge.

2.6.3.7. Emission uniformity

The emission uniformity (EU) on the system is the most important parameter to know the system performance. Emission uniformity can be evaluated by direct measurement of emitter flow rate. Choudhary and Kadam (2006) showed that if the root zone is irrigated by emitter discharge, the emission uniformity of drip system can be defined using the following equations:

2.6.3.7.1. Field emission uniformity

$$EU_f = \frac{Q\,\mathrm{min}}{Q\,\mathrm{avg}} \times 100 \quad \text{.....................} \; (2.5)$$

In which:

EU_f = field emission uniformity (%).

Qmin = minimum emitter discharge (lph).

Qavg = average emitter discharge (lph).

2.6.3.7.2. Absolute emission uniformity

$$EU_a = \frac{1}{2}\left[\frac{Q\,min}{Q\,avg} + \frac{Q\,avg}{Q\,x}\right] \times 100 \quad \text{...............} \; (2.6)$$

In which:

EU_a = absolute emission uniformity, %.

Qmin = minimum emitter discharge, lph.

Qavg = average emitter discharge, lph.

Qx = average of highest 1/8th of emitter discharge, lph.

2.6.3.7.3. Design emission uniformity

$$EU_d = \left[1 - \frac{1.27\,(V)}{e^{0.5}}\right] + \frac{Q\,min}{Q\,avg} \times 100 \quad \text{............} \; (2.7)$$

In which:

EU_d = design emission uniformity, %.

V = coefficient of variation.

e = number of emitter per plant.

Qmin = minimum emitter discharged rate in the system, lph.

Qavg = average emitter discharged rate, lph.

2.7. Water use efficiency

Water use efficiency (WUE) has been defined as the ratio of dry matter produced per unit area (t ha^{-1}) per unit of ET (mm), or as the ratio of total dry matter per unit of ET, or as the harvested yield per unit of ET and as the ratio of photosynthesis per unit of water transpired. Consequently, care should be taken when comparing different WUE values (Al-Jamal *et al*. 2001). With drip irrigation system, water use efficiency is maximized because there is even less evaporation or runoff. Raina *et al*. (1998) reported the water use efficiency was higher under drip irrigation as compared with surface irrigation. Dawood and Hamod (1985) found water use efficiency for trickle irrigated lima beans to be twice as high as that for furrow and sprinkler irrigated lima beans. Sammis (1980) reported higher water use efficiency for trickle and subsurface irrigation as compared to sprinkler and furrow irrigated for potatoes. Simsek *et al*. (2004) observed the water use efficiency from 9.6 to 11.7kg/m^3 in 2002 and 10.8 kg/m^3 in 2003. El-Hendawy *et al*. (2008) reported water use efficiency increased with increasing irrigation frequency and nitrogen levels, and reached the maximum values at once every 2 and 3 days and at 380 kg N ha^{-1}. Aujla *et al*. (2007) reported the water use efficiency at 75% which produced the highest fruit yield, was 109.9 kg ha^{-1} mm^{-1} as compared with the 89.9 kg ha^{-1} mm^{-1} in alternate furrow to 73.3 kg ha^{-1} mm^{-1} in each furrow irrigation. Yohannes and Tadesse (1998) found the water use efficiency and irrigation application efficiency values were higher in drip system compared to furrow. Sharmasarkar *et al*. (2001) reported the water use efficiency and fertilizer use efficiency for drip irrigation were higher than the flood irrigation. Salvin *et al*. (2000) observed the water use efficiency was considerably higher in drip than basin irrigation. Narayanamoorthy (2003) reported water use efficiency up to 90% in drip irrigation against the efficiency of 30-40% under furrow method. Dean, (1992) found the water use efficiency values were 43 and 21 kg/m^3 for drip and sprinkler methods, respectively. Al-Omran *et al.* (2005) reported the water use efficiency values increased linearly with applied irrigation water and decreased at the highest irrigation level. Shaker (2004) reported water use efficiency of 4.5kg/m^3 for the drip irrigation with 400m^3/fed /month, 2kg/m^3 for the surface method and 0.6kg/m^3 for the drip with the 800m^3/fed/month. Kode (2000) found field water use efficiency was more than double in drip (578.1 kg/ha^{-cm}) than in surface irrigation (233.4 kg/ha^{-cm}). Muralikrishnasamy *et al.* (2006) reported the high water use efficiency was associated with drip irrigation compared with surface irrigation. Bosu *et al.* (1995) reported the maximum water use efficiency through drip irrigation on banana. Hegde and Srinivas (1991) observed the field water use efficiency was higher under drip (99.9 kg/ha/mm) than the (42.7 kg/ha/mm) in basin irrigation. Cevik *et al.* (1988) reported the water use efficiency was also higher in drip irrigation and 50% water saving was observed under drip as compared to basin irrigation. El-Boraie *et al.* (2009) found the highest value of water use efficiency was obtained by applying the drip irrigation with 100% of ET_c distributed every day. Cetin and Bilgel (2002) reported the water use efficiency values were proved to be 4.87, 3.87 and 2.36 kg / ha / mm for drip, furrow and sprinkler respectively. Mateos *et al.* (1991) reported that water use efficiency was 30% larger in the drip irrigation treatments, indicating a definitive advantage of this method under limited water supply. Malakouti (2004) reported the water use efficiency increased from 5.5 kg/m^3 in surface irrigation to 8.5 kg/m^3 for drip irrigation which is an important improvement for irrigated agriculture. Manickasundaram *et al.* (2002) found the water use efficiency was 20 to 60 per cent higher in drip irrigation treatments compared to that of surface irrigation method. Papodopoulos (1998 and 1999) explained that water use efficiency of vegetables could improve by controlling the growth limiting factors. Fertigation would play the most important role among different approaches to this effect, so that water use efficiency would increase 2 or 3 fold.

2.8. Irrigation water use efficiency

Irrigation water use efficiency, IWUE (irrigation water productivity), defined as the ratio of the crop yield (t ha^{-1}) to seasonal irrigation water (mm) applied, including rain. Both irrigation efficiency and irrigation water use efficiency can be increased by practicing deficit irrigation in parts of the field receiving the minimum water application depth. The most economical deficit irrigation level depends on the uniformity of application of the irrigation water and the associated cost of the irrigation water, any cost of remediation treatment on the drainage water, and the value of a unit of the crop (Al-Jamal *et al*. 2001). Mateos *et al*. (1991) reported the irrigation water use efficiency varied from 0.75 to 0.94 kg/m^3, respectively in cotton irrigated by a drip system. Dagdelen *et al.* (2009) reported the largest irrigation water use efficiency was observed in the 25% of the soil water depletion under drip (1.46 kg/m^3), and the smallest irrigation water use efficiency was in the 100% treatment (0.81 kg/m^3) the results also demonstrated that irrigation of cotton with drip irrigation method at 75% level had significant benefits in terms of saved irrigation water and large water use efficiency indicating a definitive advantage of deficit irrigation under limited water supply conditions. Zeng *et al*. (2009) found that the lower the amount of irrigation water applied, the higher the irrigation water use efficiency obtained.

2.9. Irrigation efficiency

Irrigation efficiency (Ea) defined as the ratio of the volume of water that is taken up by the crop to the volume of irrigation water applied. Drip irrigation has the potential to increase irrigation efficiency, because the farmer can apply light and frequent amounts of water to meet crops needs (Al-Jamal *et al*., 2001). (Battikhi and Abu-hammad, 1994; Chimonides, 1995; Zalidis *et al*., 1997; Oster *et al*., 1986) reported the irrigation efficiency ranged from 54 to 80% with a sprinkler irrigation system and 50 to 73% under furrow irrigation system. Al-Jamal *et al*. (2001) reported the Irrigation efficiency ranged from 80 to 91% when the crop was grown in fields using a surface drip system. Moller and Weatherhead (2007) calculated irrigation efficiency ranged between 82.7% and 93.9%.

2.10. Water saving

The important advantages of drip irrigation system are the save water, time and energy. Kode (2000) found the total seasonal requirement in drip was 210 cm as compared to 402 cm in surface irrigation treatment indicating 50.5% water saving in drip irrigation. Singh *et al*. (2006) reported the maximum water saving in case of drip irrigation at 60 kPa soil moisture level was calculated as 54.63 percent over surface irrigated treatments. Bashour and Nimah (2004) reported the trickle irrigation saves about 50% of the water used in surface irrigation. Fulton *et al*. (1991) reported more water was applied with the furrow systems compared to the drip system. Styles *et al*. (1997) found the furrow system applied 98mm more water compared to the drip system. Manickasundaram *et al*. (2002) reported the saving in irrigation water under drip scheduled at 50% of surface irrigation was 48.4% compared with that of surface method of irrigation. Hassanli *et al*. (2009) reported the maximum water saving was obtained using drip irrigation with 5907 m^3 ha^{-1} water applied and the minimum water saving was obtained using furrow with 6822 m^3 ha^{-1}. Aujla *et al.* (2007) reported a saving of 25% water on drip irrigation as compared with furrow irrigation. Francisco *et al.* (1995) reported the consumptive use of furrow irrigated vines was 12.5% greater than drip irrigated vines.

2.11. Comparison between drip irrigation and surface irrigation system

Some studies were done to compare drip irrigation with surface irrigation. Mohammad *et al.* (2010) compared different types of irrigation techniques revealed that the drip and sprinkler irrigations methods were more effective and efficient than that of surface irrigation for improved land productivity. Bogle and Hartz (1986) found that furrow and drip irrigation produced similar muskmelon yield and quality; however, rain prior to and during harvest may have masked treatment effects on soluble solids content. Dengiz (2006) concluded that the drip irrigation method increased the land suitability by 38% compared to the surface irrigation method. Also some researchers as cited by Dastane (1980) claimed that more frequent irrigations give higher yield than lesser number of water applications. It was asserted that there is better nutrient uptake and lesser leaching losses at higher every cycle. Liu *et al.* (2006) reported the drip irrigation was everywhere more suitable than surface irrigation due to the minor environmental impact that it caused. Kuruppuarachchi (1981) has compared banana cultivation under drip irrigation and surface irrigation. It was reported that yield and irrigation efficiency under drip irrigation was 18% and 30%, respectively higher than that of surface irrigation. Thadchayini and Thiruchelvam (2005) reported the highest banana yield 41 t/ha in the drip which was 31% higher than from surface irrigation. Srinivas and Hegde (1990) reported that on drip irrigation studies in banana grown on a well drained sandy loam clay loam resulted in a better plant growth, earlier flowering, higher fruit yields and increased water use efficiency compared with basin irrigation. Hegde and Srinivas (1991) reported that there was increase in the banana yield under drip (83.8 t/ha) than the basin irrigation (73.5 t/ha). Hand bunch and finger weight was also higher in drip. Plants were taller 3% and flowered 15 days earlier under the drip than the basin irrigation. Hegde and Srinivas (1990) reported that there was significant increase in banana yield with drip irrigation (84 t/ha) compared to basin system (79 t/ha) owing to significant differences in bunch weight mainly due to significant increase in finer weight. Banana plant under drip irrigation flowered 13 days earlier than those under basin irrigation. The TSS was higher in basin irrigation (24.3%) as compared with drip irrigation also pulp: peel ratio did not show any significant increase in drip as compared with basin irrigation. Cevik *et al*. (1988) compared drip and basin irrigation system in banana orchards on the South coast of Turkey. The results revealed that yield was higher in drip irrigation compared to basin method. Bisen *et al*. (1996) conducted a trial to study the effect of scheduling irrigation on the growth and yield of banana. The results revealed that highest values for plant growth (height, girth of pseudostem, number of functional leaves, and moisture content of top leaf at shooting), bunch character at harvest and fruit yield were recorded under the wettest regime. Kode (2000) conducted an experiment to the effect of water soluble fertilizers applied through drip on growth, yield and quality of banana. The result indicated that the fruit yield was increasing by 16.3% under drip irrigation (84.43 kg/ha) compared to surface irrigation (72.61 kg/ha). Mahmoud (2006) using three levels of irrigation through drip viz, 40%, 60% and 80% of pan evaporation compared with surface irrigation for yield and quality parameters. Irrigation level 40% (674 mm per year) in main crop substantially improved growth, bunch, fingers and fruit quality characters with reduction in crop duration and higher available soil nitrogen, phosphorus and potassium. But in ratoon crop, irrigation level of 60% (1187 mm per year) was observed to be most economical and effective in getting the best bunch and fingers characters, fruit quality and decreased days to shooting that subsequently reduced the total crop duration, and maintained higher available soil nitrogen, phosphorus and potassium. Robinson and Reynolds (1992) studied banana irrigation in Natal for cv Williams using drip Irrigation and micro sprinkler Irrigation system. Treatment (1) was applied daily so as to replace the previous day's evaporation x Crop factor. Treatment (2) was based on allowing 30 percent depletion of the total available moisture in the root zone. The annual yield for the two treatments amounted to 42, 40 and 32 t/ha, respectively: in the first ratoon cycle the annual yields amounted to 60, 61 and 40t/ha respectively and those in the second ratoon cycle to 47, 57 and 34 t/ha, respectively. Narayanamoorthy (2003) conducted a study on averting water crisis by drip method of irrigation for the water intensive crop and reported the productivity difference between drip and non-drip irrigated crops comes to about 27.3 t/ha for sugarcane and about 15.3 t/ha for banana. That is productivity gain due to the drip method of irrigation is about 25% in sugarcane and 29% in banana. Salvin *et al*. (2000) reported the highest bunch weight (14.26 kg) and yield 44 t/ha were observed under trickle irrigation at 75% evaporation compared to basin irrigation on Cavendish banana cv. Also improved growth, early shooting and higher productivity under drip irrigation. Lahav and Kalmar (1989) conducted field studies in northern coastal plain of

Israel to study the response of drip irrigated banana to various irrigation regimes based on class A evaporation factors. A higher yield (67.9 t/ha) resulted when plants received irrigation corresponding to a constant evaporation factor of 1.0 throughout the growing season and equivalent to 11.630 cubic meter per hectare. Raina *et al*. (1998) found the effect of drip irrigation and plastic mulch as compared to surface irrigation on green pod yield and water use efficiency of pea. They used different irrigation level based on pan evaporation, pan and crop factors. The drip irrigation gave higher yield (9 t/ha) as compared to surface irrigation (6 t/ha). Clark (1979) compared the relative efficiencies of drip, sprinkler and furrow irrigation for corn production in Texas. He found water use efficiency of 014, 11.9 and 11.5 kg ha^{-1} mm^{-1} with the three respective systems. Khalid (1999) compared drip and furrow irrigation system under the same conditions on two varieties of okra. The highest yield was obtained using drip irrigation as compared to furrow irrigation. Shaker (2004) conducted a study on the effect of drip irrigation system on two varieties of Phaseolus Bean production under the open field condition of Sudan. He used three levels of irrigation water $800m^3$/fed /month by surface irrigation. 800 m^3/fed /month by drip irrigation and $400m^3$/fed /month by drip irrigation. The highest yield was 492 kg/fed, 136kg/fed and 522kg/fed, respectively. Smajstrla and Koo (1984) studied the response of trickle irrigation on citrus yield in 5 years trial of mature Valencia orange trees irrigated by spray or drip systems. The scheduling was based on 100, 50 or 25% of potential evapotranspiration calculated from pan evaporation. Yield was not affected by the amount of water applied but strongly related to the application methods. The spray irrigation systems covered 28 to 51% of the area under the tree canopy increased yield by 65% compared with non irrigated controls, whereas drip system which irrigated 5 to 10% of the canopy area increased yield by 41 to 44%. The rainfall distribution also affected the yield. Yield was high when rainfall from April to October was above average. Manickasundaram *et al*. (2002) evaluated the efficiency of the drip irrigation system in tapioca. The results revealed that scheduling irrigation through drip once in two days at 100 per cent of surface method of irrigation registered the highest mean tuber yield of 58.7 t/ha which was significantly superior over surface irrigation scheduled at 0.60 IW/CPE ratio. Howell *et al*. (1989) compared drip and furrow methods for cotton yield. They found that there were no yield differences between drip and furrow irrigation. They also reported that 650mm of irrigation water was needed in order to get a maximum yield. On the other hand, Mateos *et al*., (1991) obtained 5 and 3t/ha of cotton yield for the drip and furrow irrigation methods, respectively. Yohannes and Tadesse (1998) conducted study to investigate the effect of drip and furrow irrigation on yield of tomato. The higher yield was obtained with drip compared to furrow irrigation. Cetin and Bilgel (2002) reported the effect of three irrigation methods (furrow, sprinkler and drip) on cotton yield. The maximum yield was 4380, 3630 and 3380kg/ha for drip, furrow and sprinkler, respectively. Styles *et al*. (1997) reported the cotton yield of the drip system was 16% higher than that of the furrow system. Fulton *et al*. (1991) found the cotton yield was 163 kg/ha more for the drip system than for the furrow systems. Tekinel *et al*. (1989) found that the highest yield was achieved in drip irrigation treatments. However, other methods did achieve similar yield under certain conditions, but with the lower water use efficiency. Deek *et al*. (1997) conducted a study on the effect of irrigation scheduling on Tomato and they used three irrigation treatments, namely irrigating three times a week (11), twice a week (12), and once a week (13). Total yield of tomato produced under the three irrigation treatment was

51.4, 40.8 and 35.3 ton ha^{-1}, respectively. Higher values of ETc were obtained under the treatment (11) due to lower soil moisture tension. El-Hendawy *et al*. (2008) investigated the effects of irrigation frequency and their interaction with nitrogen fertilization on water distribution, grain yield, yield components and water use efficiency (WUE) of two white grain maize hybrids with four irrigation frequencies (once every 2, 3, 4 and 5 days), two nitrogen levels (190 and 380 kg N ha^{-1}). The application of 190 kg N ha^{-1} resulted in a significant yield reduction of 25 %, 18 % and 9 % in 2005 and 20 %, 13 % and 6 % in 2006 compared with 380 kg N ha^{-1} at the four irrigation frequencies, respectively. Araujo *et al*. (1995) observed the response of 3-year-old grapevines (*Vitis vinifera* L. cultivar 'Thompson Seedless') to furrow and drip irrigation was quantified in terms of water status, growth, and water use efficiency (WUE). Drip irrigation was applied daily according to best estimates of vineyard evapotranspiration while furrow irrigations were applied when 50% of the plant available soil water content had been depleted. The data indicate that drip irrigation may increase the potential for control of vine growth by making vines more dependent on irrigation and N fertilization than furrow irrigation. Hassanli *et al*. (2009) conducted a study to evaluate the effect of three irrigation methods [subsurface drip (SSD), surface drip (SD) and furrow irrigation (FI)] on yields, water saving and irrigation water use efficiency (IWUE) on corn. The highest yield was obtained with SSD and the lowest was obtained with the FI method. Dean (1992) compared sprinkler and drip irrigation methods for sweet corn production. The soil water tension was maintained at 20 to 30 kPa. Yield with both irrigation methods was comparable but the amount of water used was greater for the sprinkler irrigation method. Over 50% more water was applied with sprinkler than drip irrigation to produce comparable yields of sweet corn. Hanson and May (2004) compared yield and quality of tomato of the drip with sprinkler irrigation. Yield increases from 12.9 to 22.6 t/ha for the drip systems compared to the sprinkler systems with similar amounts of applied water and soluble solids. Sharmasarkar *et al.* (2001) conducted study to compare NO_3 movement through soil under flood and drip irrigation for sugar beet production. They used three irrigation regimes corresponding to 20, 35 and 50% water depletion of field capacity compared against flood irrigation. The yield and sugar content under drip irrigation were higher (3-28%) than flood irrigation. Soil NO_3 in all three drip regimes was 1.6- 2.4 times the flood irrigation. Tiwari and Ajai Singh (2003) used three levels of drip irrigation which applied at 100%, 80% and 60% of the estimated irrigation requirement. The study revealed 62% higher yield in drip as compared to furrow irrigation. The highest yield per unit quantity of water used was 427 kg/ha^{-1} mm^{-1} for the 60% treatment. Cabello (2009) conducted a study to investigate the effects of different nitrogen (N) and irrigation (I) levels on fruit yield, fruit quality, irrigation water use efficiency (IWUE) and nitrogen applied efficiency (NAE) on melon. Both the irrigation and N treatments applied were: 60, 100 and 140% ET_c and 93, 243 and 393 kg N ha^{-1}. The best yield (41.3 Mg ha^{-1}) was obtained with 100% ET_c at N93. The highest NAE was obtained with quantities of water close to 100% ET_c and increased as the N level was reduced. These results suggested that it is possible to apply moderate deficit irrigation, around 90% ET_c, and reduce nitrogen input to 90 kg ha^{-1} without lessening quality and yields. Mustafa and Mohamed (2008) conducted a trial to study the effect of drip irrigation at intervals of one, two and three days compared to surface irrigation every six days on Strawberry. They reported yield 80, 69, 37 and 30 gram per plant, respectively. The irrigation every one and two days gave greater vegetative and productive growth. The total amount of water applied under drip irrigation during the two growing seasons was 428mm and 337 mm respectively, while it was 1600 mm and 1360 mm for the surface irrigation for the first and second seasons, respectively. Candido *et al.* (2000) carried out the experiment with the aim of evaluating the influence of different irrigation regimes on yield and quality characteristics of tomatoes to be used for processing purposes. In this research, four irrigation levels (i.e., unirrigated control and 100%, 66, 50 and 33% of ET_c) were applied. The highest marketable yields were obtained under conditions of 100% of ET_c application, while the highest dry matter content (6.1%) was determined under conditions of rain-fed treatment. Zeng *et al.* (2009) conducted a study to determine the optimum irrigation water amounts for muskmelon in plastic greenhouse. The irrigation water amounts were determined based on the percentage of field water capacity. The four irrigation water levels used were 100%, 90%, 80% and 70%. Fruit quality was the best at 90% depletion field capacity. Hence, based on the quality and quantity of muskmelon yield, the regime at 90% can save irrigation water and improve the quality of fruit. Tiwari and Ajai Singh (2003) investigated the effects of different levels of drip irrigation and planting methods on yield and yield components of green pepper Three irrigation levels (50, 75 and 100% of ET_c) and two planting methods (normal and paired-row planting) were applied. The maximum and minimum values of the yield and yield components were recorded from treatment plots 100% of ET_c (full irrigation level with paired-row planting method) and 50% of ET_c with paired-row planting method, respectively. The results revealed that full irrigation water supply (100% of ET_c) under paired-row planting method could be used for the production of green pepper in an area with no water shortage. Simsek *et al.* (2004) investigated the effect of drip irrigation on yield and yield components of watermelon. They used four irrigation regimes were applied as ratios of irrigation water/cumulative pan evaporation (IW/CPE): 125, 100, 57 and 50. Maximum yield was obtained from 125 with 84.1 t/ha in 2002 and 88.6 t/ha in 2003. The unstressed 125 produced 10.1kg marketable yield/m^3 applied irrigation in 2002, and 11.3kg/m^3 in 2003. By comparison the last irrigation 50 produced 12.4 kg/m^3 in 2002 and 14.9 kg/m^3 in 2003. Aujla *et al.* (2007) reported the effects of different levels of nitrogen (N) and water applied through drip and furrow irrigation on fruit yield of eggplant in the present field investigation, ridge planting with each furrow and alternate furrow irrigation were compared with drip irrigation at three levels of water: 100%, 75% and 50% of each furrow irrigation. The highest yield under drip was obtained under 75% treatment which was 23% higher compared with maximum yield obtained at each furrow irrigation. Capra *et al.* (2008) conducted a trial on the effect of four irrigation levels on yield and yield components of lettuce crop under drip irrigation. The highest marketable yield of lettuce was recorded for plots receiving 100% ET_o-PM. Crop water use efficiency was maximum at a 100% ET_o-PM level of water applied, corresponding to a value of 0.3 t ha^{-1} mm^{-1}. Irrigation water use efficiency reached its maximum at a 40% ET_o-PM level, with values of 0.54 and 0.44 t ha^{-1} mm^{-1} during 2005 and 2006, respectively. Al-Omran *et al.* (2005) conducted a study on squash and used four irrigation levels (T1 = 60, T2 = 80, T3 = 100 and T4 = 120% of ET_o) using surface and subsurface drip irrigation. Results indicated that squash fruit yield was significantly increased with the increase in irrigation water level for each season. Salokhea *et al.* (2005) tested the effect of four levels of drip fertigated irrigation equivalent to 100, 75, 50 and 25% of crop evapotranspiration (ET_c) on crop growth, crop yield, and water productivity of tomato. The maximum crop yield (0.44kg/m^{-2}) and high irrigation water productivity (0.92kg/m^{-3}) provided at 75% of ETc. Goenaga *et al*. (2004) reported the optimum water requirement of papaya grown under semiarid conditions with drip irrigation based on class A pan factors evaporation ranged from 0.25 to 1.25. The highest marketable fruit weight (75.9 kg/ha) was obtained from plant irrigation according to a pan factors of 1.25. They concluded that papaya under semiarid conditions should be irrigated according to a pan factor of not less than 1.25. El-Boraie *et al*. (2009) studied the effects of irrigation quantity and irrigation intervals under drip irrigation system on water consumptive use, water use efficiency (WUE), peanut yield and yield components. They used three applied irrigation viz, 80%, 100% and 120% of ET_c and three treatments for irrigation intervals were chosen i.e., daily, every two days and every three days. The superior effect on pod yield (1824 kg/fed.) was obtained as a result of applying 984 mm irrigation water (100% ET_c) distributed every day. They stated that applying irrigation with (100%) and distributed every day can produce the highest groundnut yield and save 763 m^3 water/feddan. Locascio *et al*. (1989) reported the early fruits yield of tomato were similar with application of water quantities of 0.5 and 1.0 Pan ET. The total marketable yield was significantly greater with 1.0 Pan ET water quantity (69.4 t/ha^{-1}) than with 0.5 Pan ET (62.5 t/ha^{-1}). Since the use of 0,5 Pan ET resulted in higher fruit production than use of 1.0 Pan ET at Gainesville, studies were conducted to evaluate further reductions in water. Locascio and Smajstrla (1989) observed the tomatoes were grown with water quantities of 0, 0.17, 0.34 and 0.50 Pan ET. Marketable fruit of extra large and total yield were increased significantly by irrigation. Irrigation increased marketable yield about 40% over the yield obtained with the non-irrigated treatment. Although the yield of extra large and large fit tended to increase with an increase in water quantity applied from 0.17 to 0.50 Pan ET, only the total marketable yield was increased significantly by water quantity. Total yield increased linearly from 64.4 to 70.4 t ha^{-1} with an increase in applied water quantity. (Kafkafi and Bar-Yosef, 1980; Locascio *et al.*, 1981 and 1989) reported that tomato irrigation requirements are between 0.5 and 1.0 Pan ET on fine sandy soils but are between 0.75 and 1.0 Pan ET on the fine sandy loam soils used in the present studies. (Navarro, 1987; Navarro, 1989) found the summer and fall planted tomato yield was influenced by drip irrigation rates of 0.4, 0.6, 0.8, and 1.0 Pan ET. In the summer, yield was significantly higher with 0.6 Pan ET as compared to treatments, while in the fall, 0.8 Pan ET was the superior treatment. (Navarro, 1987; Navarro, 1989) evaluated the effect of irrigation scheduling at various soil water content. The responses of ‘Royal Chico’ and ‘Tropic’ tomato to soil water tensions of 20, 40, and 60 kPa plus no irrigation treatment were also evaluated. The highest yield of Royal Chico’ was with the 40 and 60 kpa treatments, while the 20 kpa provided the highest ‘Tropic’ yields. Thus, cultivars varied in their response to soil water tension. A study to compare subsurface irrigation and drip irrigation for the production of tomato on a sandy soil was performed in Immokalee, Fla. Clark *et al*. (1987) observed irrigation amounts were scheduled in the drip irrigated plots to maintain soil water tensions at 15 kpa or below using tensiometers placed at 15 and 30-cm depths. Seepage irrigations were managed to maintain a 0.38 to 0.45 m deep water table. Yield and fruit size were higher with drip irrigation than with seepage irrigation. Two soil water contents and two emitter placements were utilized in another study. Navarro and Newman (1989) reported soils were maintained at 20 to 30 kpa (high) and at 40 to 50 kpa (low). Emitter placement on the soil surface or subsurface had no effect on yield. Yield was significantly higher with the high irrigation quantity than with the low quantity and the mean yield was 54.6 t. ha^{-1} and 45.4 t. h^{-1}, respectively. Basal *et al.* (2009) conducted a trial to observe the effects of various drip irrigation ratios (0%, 25%, 50%, 75% and 100% of soil water depletion) on water use efficiency (WUE), the irrigation water use efficiency (IWUE), lint yield, yield components and fiber quality on cotton. WUE was found to increase from 0.62 to 0.71 kg/m^3) as the irrigation water applied was reduced from 100 % to 75 %. The results revealed that irrigation of cotton with a drip irrigation method at 75 % level had significant benefits in terms of saved irrigation water without reducing yield, and high WUE indicated a definitive advantage of employing deficit irrigation under limited water supply conditions. Dagdelen *et al.* (2009) conducted a trial to observe the effect of different drip irrigation regimes on water use efficiency (WUE) and fiber quality parameters. Treatments were designated as full irrigation (100% of the soil water depletion) and those that received 75, 50 and 25% of the amount received respectively on the same day. Largest average cotton yield was obtained from the full irrigation treatment 100%. The largest fiber length and strength values were obtained in the fully irrigated treatment 100%. Singh *et al.* (2006) conducted trails on young mango. An automated drip irrigation system was used to schedule the irrigation at 20, 30 and 60 kPa soil moisture tension compared with surface irrigation based on 50% depletion of the available soil moisture. The average number of fruits set per tree was recorded for different irrigation treatments. The maximum number of fruits per plant during 2001-02, 2002-03, 2003-04 and 2004-05 was recorded as 446, 385, 550 and 728 respectively, in case of treatment under drip irrigation at 20 kPa soil metric tension. Against this, the lowest number of fruit set per plant was recorded as 144,124, 250, and 545 in case of surface irrigation. Collingwood *et al.* (1989) reported Cucumber response to drip irrigation and black polyethylene mulch was evaluated with soil moisture maintained at 30 kpa. Mulched cucumber produced significantly superior yield, used less water, and had a better water use efficiency as compared to unmulched cucumber.

2.12. Fertigaton

Fertigation is the injection of fertilizers through the irrigation system. Micro irrigation systems are well suited to fertigation because of their frequency of operation and because water application can be easily controlled by the manager.

2.12.1. Advantages of fertigation

- Fertigation ensures the fertilizer will be carried directly to the root zone. Amounts and timing of fertilizer application can be precise.
- Moving fertilizer into the root zone can be a problem in low rainfall areas. Fertigation with drip over comes this difficulty.
- Studies on local soils by PARC scientists have shown that compared to broadcast applications, dramatically less fertilizer needs to be used to achieve similar growth and yield due to direct application to root zones when using fertigation.
- When using fertigation combined with scheduling of irrigation there may be savings of up to 50 percent of the amount of water is used, compared to a fixed irrigation schedule. Dependent on soil type, leaching of nutrients into the ground water can be reduced.
- Compared to some forms of sprinkler irrigation or fertigation with a fixed irrigation schedule, scheduling of water use with fertigation still results in the same amount of fertilizer uptake by the tree.

However efficiency of fertilizer use improved from 10 to 38 percent, in some studies.

- There is often enhanced growth and yield from years 2 to 4 but not later compared to broadcast.
- Fertigation allows for increased flexibility at reduced rates of fertilizer timed more closely to tree demand.
- Compared to broadcast application of fertilizer, fertigation of phosphorus and potassium allows rapid movement into the root zone.

Uniformity of application mentioned below is much less of a concern when daily applications are made using automated systems and even less so when low amounts of fertilizer are applied for the entire irrigation cycle. This approach also assists in reduced leaching of nutrients providing water is not over applied (Peter, 2001).

2.12.2. Disadvantages of fertigation

- Uniformity of application depends on uniform water distribution. Poor system design, plugged lines and emitters means poor distribution.
- Soil acidification is a significant problem with the use of any acid fertilizers regardless of application method particularly in poorly buffered soils, and low pH soils. This problem is intensified with drip irrigation. An acidification index (ARI) has been established and can be requested when soil samples are analyzed, to determine how sensitive soils are to rapid acidification.

Some of these problems such as acidification can be overcome with the use of pH neutral fertilizers Attention to soil pH and nutrient levels in soil and leaves plus the use of various mulches may help identify and offset some of these difficulties (Peter, 2001).

2.13. Economic studies

In banana, 0.8 ha additional land could be brought under irrigation with drip irrigation when compared to surface method. Net extra income obtained due to drip was 262600 Rs over surface irrigation treatments. Net profit per mm of water use was 226 Rs in drip and 75 Rs in surface. The net seasonal income obtained was 219500 Rs in drip, while 132500 Rs in surface treatments (Anonymous, 1994).

Economic evaluations (Prevatt *et al.*, 1981; Prevatt *et al.*, 1984) were performed comparing drip irrigation with open ditch subirrigation, subsurface tile subirrigation, traveling gun, and center pivot systems for annual fixed and operating costs in Florida for vegetables. The most common irrigation system for vegetables in Florida, open ditch seepage, had the lowest annual fixed costs. The annual operating costs with drip were significantly lower than with all other systems evaluated (about 50% of the operating costs of open ditch seepage) due to 1ower water requirements and pumping costs. However, the annual total costs (the sum of annual fixed costs and operating costs) showed that open ditch seepage subirrigation had a distinct economic advantage over the other systems. The net profit per mm of water used was obtained to be highest (US $ 16.5) in case of drip 60%. Phocaides (2000) reported the cost of the pipes (all tubing, laterals included) is about 45 percent of the total cost and the head control unit accounts for 30 percent of the total cost.

Narayanamoorthy (2003) reported the farm business income (FBI), of drip adopters is (26.3 Rs/ha) higher than that of furrow method adopters in sugarcane and the same comes to about (32.4 Rs/ ha) for banana. The net preset worth (NPW) at 15% discount rate for banana of drip investment is about (257.6 Rs/ha) with the subsidy and (247.7 Rs/ha) without subsidy. For sugarcane the (NPW), of drip investment is about (166.6 Rs/ha) with subsidy and the same was about (149.8 Rs/ha) without subsidy. That indicates the adopters of drip irrigation technology from both crops would be able to recover the entire capital cost from their income in the every first year itself. The benefit cost ratio estimated for banana varies from 2.34 to 2.36 with sub and from 2.23 to 2.25 without subsidy and from 2.02 to 2.05 with subsidy and from 1.83 to 1.87 without subsidy for sugarcane. Drip irrigation was economically viable in these two crops even if adopted without subsidy. Thadchayini and Thiruchelvam (2005) reported an economic evaluation of a drip irrigation project for banana the yield and net revenue with drip irrigation are 31% and 42% higher than the surface irrigation, respectively. This is due to higher yield and better quality fruits in drip irrigation. In economic analysis, the net present value, benefit cost ratio and internal rate of return at 6% interest were found to be 50 Rs million, 3.93 and 24.58%, respectively. Traditional surface irrigation showed considerable short term benefit with less cost but the analysis highlighted a risk of 13% to 30% decrease in production after 3 years. Compared to surface irrigation, the investment cost was 43% higher in drip irrigation but over a long period, the yield is sustainable. Dagdelen *et al*. (2009) found in an economic viewpoint, 25.0% saving in irrigation water 75% resulted in 34.0% reduction in the net income. However, the net income of the 100% treatment is found to be reasonable in areas with no water shortage. Capra *et al*. (2008) reported the cost functions had a quadratic form during 2005 and a linear form during 2006. In the land-limiting condition the optimal economic levels fit the agronomic ones well. In the water-limiting condition, ranges of water deficit of 15-44% and 74-94% were as profitable as full irrigation, thus contributing to appreciable water savings. Hanson and May (2004) observed profits under drip irrigation were 867 to 1493 $\$/ha^{-1}$ more compared to sprinkler irrigation, depending on the amount of yield increase and the interest rate used in the economic analysis. Styles *et al*. (1997) reported profit was 1623 US$/ha for the drip system, 1249 US$ /ha for the improved furrow system, and 1457 US$ /ha for the historic furrow system. Muralikrishnasamy *et al*. (2006) reported the mean Benefit: Cost ratio was 1.87 in drip irrigation at 75% PE +100% N and K through fertigation. Fulton *et al*. (1991) reported profit was 990 US$ /ha for the furrow systems and 504 US$ /ha for drip irrigation. Raina *et al*. (1998) reported the benefit cost ratio of pea cultivation under drip irrigation alone, drip plus plastic and surface irrigation was 2.06, 2.11 and 1.93, respectively. Tiwari and Ajai Singh (2003) reported the highest benefit cost ratio of 8.17 was obtained for furrow irrigation followed by 6.99 for drip irrigation.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Experimental site

The experiment was established in the Horticultural Research Centre Farm, at Wad Medani, Sudan (latitude 14° 23´ N, longitude 33° 29´ E, altitude 405 m above mean see level) during16th November 2009 and 16th October 2011.

3.1.1. The climatic

The climatic zone of the study area is dry, characterized by a warm summer. The summary of the meteorological data for Wad Medani as average of thirty years (Adam, 2008) is shown in (Appendix.1).

3.1.2. The soil

The soil used on the experimental site is silty clay loam soils with high silt content (68%) and low clay (26.7%). Soil samples were collected from auger pits at 0-30 and 30-60cm soil depths. Physical and chemical properties of soil are shown in (Appendix .2). The soil analyses indicated that the soil is moderately alkaline, non saline, non sodic, has medium available phosphorous and low organic carbon. Appendix. 3 showed that the soil is suitable for growing bananas as compiled by Sys (1985).

3.2. Land preparation

The experimental area was ploughed and then harrowed after introducing 0.5 m depth silty clay loam on top of the heavy clay soils. Holes for transplanting were cubic meters filled by fermented organic manure.

3.3. Infiltration characteristics

Three representative sites were selected for measuring infiltration rate using the double ring infiltrometer as described by Micheal (1978). The infiltrometer consists of two cylinders made of 2 mm rolled steel. Each cylinder was 25 cm high. The inner cylinder from which the infiltration rate was measured was 30 cm in diameter. The outer cylinder, which acted as a buffer pond was 60 cm in diameter. The cylinders were installed about 10 cm deep in the soil. The cylinders were driven into the ground by a hammer and a wooden plank to prevent damage to the edges of the cylinder. Plastic sheet was used to cover the soil surface confined by the inner cylinder before filling with water and starting reading. Reading was taken every five minutes until a constant infiltration rate was reached. Then the data was tabulated and the average infiltration rate in cm/h was determined (Appendix.4). The basic infiltration rate for various soil types as shown in appendix.5.

3.4. Planting material

Three months old planting material of banana cv. Grand Nain, propagated by tissue culture, was transplanted in the field on 16th of November, 2009 at spacing of 3×3 meter (1111 mother plants/ha) spacing of 3×3m recommended for banana (Hamid, 1995a). Holes were slightly dug wider than the planting materials and seedlings were planted 10 cm deeper than their level in bag. The holes were filled with the manure and soil to the surface. Irrigation was applied immediately after planting.

Three month after planting, two suckers were left at flowering giving 2222 plants/ha. This plant population was maintained thereafter (Plate 3.1). The special horticultural practices, viz, weed control, leaf removal, mulching, desuckering, bunch propping, removal of male bud, wind beaks, etc. were carried out as recommended.

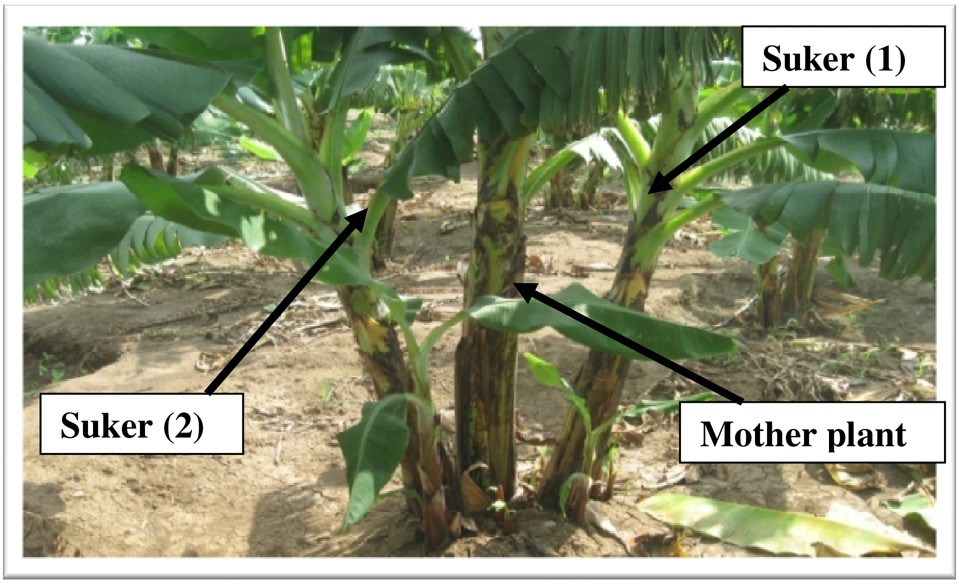

Plate 3.1 Two suckers with mother plant

3.5. Drip system description

A drip irrigation system was designed and installed in on area of 2145 m^2. The system consisted of the following components:

3.5.1. Water source

The drip irrigation system under study was supplied with water from a well in the farm, through a storage tank of 30 m^3 capacity. Well water was analyzed and the data are presented in table 3.1. The water analyses indicated no salinity, moderate total soluble solids, normal range of Acidity/Basicity, no bicarbonate, chloride and sodium absorption ratio. The results of irrigation water analysis indicated that the test water in the usual range. Table (3.2) demonstrated the normal range of irrigation water quality parameters (Ayers and Westcot 1985).

Table 3.1 Analysis of irrigation water

No	Analysis		Value
1	Electrical conductivity	(dS/m)	0.4
2	Total soluble solids	(mg/l)	489
3	pH		7.3
4	Calcium	(meq/l)	0.1
5	Magnesium	(meq/l)	0.05
6	Carbonate	(meq/l)	0.0
7	Bicarbonate	(meq/l)	0.75
8	Chloride	(meq/l)	0.22
9	Sodium	(meq/l)	0.65
10	Potassium	(meq/l)	0.16
11	Sodium absorption ratio	SAR	0.87

Table 3.2 Laboratory determinations needs to evaluate common irrigation water quality problems

No	Water parameters		Usual range in irrigation water
1	Electrical conductivity	(dS/m)	0 - 3
2	Total soluble solids	(mg/l)	0 - 2000
3	pH		6.0 - 8.5
4	Calcium	(meq/l)	0 - 20
5	Magnesium	(meq/l)	0 - 5
6	Carbonate	(meq/l)	0 - 1
7	Bicarbonate	(meq/l)	0 -10
8	Chloride	(meq/l)	0 - 30
9	Sodium	(meq/l)	0 - 40
10	Potassium	(mg/l)	0 - 2
11	Sulphate	(meq/l)	0 - 20
12	Nitrate-Nitrogen	(mg/l)	0 - 10
13	Ammonium-Nitrogen	(mg/l)	0 - 5
14	Phosphate- phosphorus	(mg/l)	0 - 2
15	Boron	(mg/l)	0 - 2
16	Sodium absorption ratio	(meq/l)	0 - 15

Source: Ayers and Westcot (1985).

3.5.2. Control head (head unit)

- Discharge valve to control the water flow in the system.
- Flowmeter to measure the water flow in the system.
- Vacuum breaker to remove the air from the system.
- Screen filter to clean the water.
- Pressure gauge to measure the pressure in the system.
- Fertilizer system (fertilizer tank to apply the fertilizer through the irrigation system) (Plate 3.2).

Plate 3.2 Fertilizer system

3.5.3. The main line

The main pipe line was made of Polyvinyl chloride (PVC) and buried under ground at depth of 50 cm, running for 90 m length and 3 inch diameter.

3.5.4. The sub-main line

The sub-main pipe line was also made of Polyvinyl chloride (PVC) and buried under ground at depth of 50 cm. There were 3 sub-main lines, each 60 m length and 1.5 inch diameter to deliver water from the main line to the lateral line.

3.5.5. The lateral lines

Lateral lines were made of black low density polyethylene (L.D.P.E) built in at 13 mm diameter. There were 14 lateral lines in each sub-main pipe line, which line were connected by grommets. At the end of each lateral, there was an end stop to block the lateral line, thereby preserving water supply.

3.5.6. Emitters (drippers)

Two pressure compensating drippers per plant were used (the discharge of one emitter 8 l/h) at 50 m spacing between them (Plate 3.3).

Plate 3.3 polyethylene fittings

3.6. Hydraulics of drip irrigation system

3.6.1. The emission uniformity

For computing emission uniformity, four lateral lines were selected from each sub-main line. Out of four, two were selected from middle and two from outside. Then these lateral lines were divided into four sections along each lateral line resulting in 16 parts. Two successive emitters from each part were selected to measure the discharge (liter per hour). The mean values of the two successive emitters were taken. The field emission uniformity was calculated using the formula (2.6), the absolute emission uniformity using the formula (2.7) and the design emission uniformity using the formula (2.8) according to Choudhary and Kadam (2006).

3.6.2. Irrigation efficiency

The overall application efficiency of drip irrigation (Ea) is defined by Vermeiren and Gobling (1980) as follows:

$$Ea = Ks \times Eu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where:

Ks = ratio between water stored and that diverted from the field. It expresses the water storage efficiency of the soil. It takes into account unavoidable deep percolation as well as other losses. Table (3.3) showed values of Ks for different soil types.

Eu = emission uniformity of drip irrigation system.

Table 3.3 Water storage efficiency and types of soil

Types of soil	Water storage efficiency (Ks)
Clay	100
Mixed silt, clay and loamy	95
Loamy	90
Sandy	87

Source: Vermeiren and Gobling (1980)

3.7. Irrigation treatments

Five drip irrigation treatments were used in this experiment. These were 40%, 60%, 80%, 100% and 120% of crop evapotranspiration (ET_c) in comparison with traditional surface irrigation method (farmerś practice).

Water was applied every other day in drip irrigation system. Surface irrigation was applied every 3 days at the beginning. Then the interval was increased gradually to every 5-10 days depending on the prevailing weather conditions. During the rainy season irrigation was applied only when necessary. The surface irrigation treatments were surrounded by a thick Polyethylene sheet at depth of 0.8 m to stop the lateral water infiltration. Every drip irrigation treatment contained 13 mm valve made of black low density polyethylene (L.D.P.E) to control the entering water.

Treatments were replicated four times in a randomized complete block design (RCBD) and four plant constituted experimental plot.

3.8. Fertilization

Fertilizer recommended dose was applied at 400 g/urea/plant/year splitted in two doses at December and June (Hamid, 1995b). The fertilizer dose was added by fertigation in drip irrigation treatments and applied manually on the control (surface irrigated).

3.9. The crop water requirement

Crop water requirement was expressed in units of water volume per unit land area (m^3/ha), depth per unit time (mm/day) according to Jensen (1993). A crop water requirement was calculated according to Allen *et al.* (1998) using the following formula

$$ET_c = ET_0 \times Kc \qquad (3.2)$$

Where:-

ET_c = crop evapotranspiration [mm d^{-1}],

K_c = crop coefficient [dimensionless],

ET_o = reference crop evapotranspiration [mm d^{-1}].

3.9.1. Reference evapotranspiration calculated

The daily metrological data (maximum and minimum air temperature, relative humidity, sunshine duration and wind speed at 2 meter height) from Wad Medani Metrological Station were recorded during the study period to compute the daily reference evapotranspiration (ET_o) by *REF-ET* software version 2.0 developed by Allen (2000).

3.9.2. Adjustment of FAO crop coefficient

The standard K_c for every growth stage (initial, mid and end) of banana was taken from FAO-56 documentation (Table 12), and adjusted to local field (Table 3.4). The K_c for the mid- growth stage of banana was adjusted to the local climatic conditions by using the climatological data (wind speed at 2 meter height and minimum relative humidity). The maximum mean height of banana plants was taken from the field weekly. The adjusted K_c values of the mid- growth stage of banana was computed the equation (2.4) according to Allen *et al.* (1998).

Table 3.4 FAO 56 banana crop coefficient

	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$
First year	0.50	1.10	1.00
Second year	1.00	1.20	1.10

Source: FAO-56 documentation table 12

The crop water requirement (CWR) for every other day drip irrigation was calculated using the following equation:

$$CRW = ET_c \times 2 \ldots\ldots\ldots\ldots\ldots (3.3)$$

The emission uniformity was 90.9% and overcome losses in discharge the gross depth (dg).

$$dg = \frac{ET_c \text{ mm}}{0.9} \ldots\ldots\ldots.. (3.4)$$

3.10. Volume of water to be applied in Liter/plant

$$V = A \times AW \times dg \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where:-

V = Volume of water in liter per plant.

A = Plant area (Row spacing m × Plant spacing m).

Aw = Wetted area (0.76).

dg = Net depth required, mm.

3.11. Time of irrigation

$$\text{Time of irrigation} = \frac{\text{Volume of water to be applied (liter)}}{\text{Emitter discharge rate (l/h)}} \ldots\ldots\ldots.. (3.6)$$

3.12. Data collection

3.12.1. Growth parameters

3.12.1.1. Pseudostem height and girth

Pseudostem height was measured from ground level to the point where the bunch stalk (peduncle) comes out of the pseudostem before it bends to support the bunch, using a tape meter at the time of flowering. Pseudostem girth was measured at 5 cm from the level of soil surface, using a tape meter at flowering time. The pseudostem height of the first sucker was measured at the time of flowering of its mother plant, from the base of the pseudostem to the point of intersection of the petioles of the two youngest leaves.

3.12.1.2. Number of green leaves at shooting

The number of intact functional leaves of the mother plant crop, the first ratoon crop and the second ratoon crop was counted and recorded at shooting time.

3.12.1.3. Leaf area (m^2)

Leaf length and width of the fourth leaf below the inflorescence were measured for the mother plant crop and first ratoon crop at shooting time. The length was measured from the lamina tip while the width was measured at the widest part of the leaf, using a tape meter. The leaf area was calculated according to Murry (1960) as follows:

$$\text{Leaf area } (m^2) = \text{length} \times \text{width} \times 0.8 \ldots\ldots\ldots\ldots \quad (3.7)$$

3.12.1.4. Number of days from planting to shooting and harvesting

Days required from planting of main crop to flowering (shooting) of the plant crop, from shooting of plant crop to shooting of the first ratoon and from shooting to harvesting of plant crop and first ratoon were recorded.

3.12.2. Yield and yield components

3.12.2.1. Bunch weight (kg)

Mature bunches were harvested when they reached full three-quarter shape. Yield and yield components were taken from mother plant, first ratoon and second ratoon crop. Ten centimeters of the stalk were left with the bunch to facilitate handling. Bunch weight was determined by weighing individual bunches with a balance. Second hand of freshly harvested bunch was used to measures the fruit characteristics according to Dadzie and Orchard (1997).

3.12.2.2. Number of hands and fingers per bunch

Number of hands and fingers were obtained by counting the number of hands and fingers on each bunch on the mother plant and first ratoon crop.

3.12.2.3. Finger weight (g), length (cm) and girth (cm)

Finger weight was determined by weighing individual fruit from the second hand on a balance. Fruit length was determined by measuring the outer curve of individual fruit with a tape from the distal end to the point at the proximal end where the pulp is judged to terminate. Fruit girth was determined by measuring individual fruit with a tape at the widest midpoint of each fruit.

3.12.3. Total water applied

Total water applied was measured in the surface and drip irrigation treatments using flowmeter.

3.12.4. Irrigation water productivity

Irrigation water productivity (IWP) was calculated as the ratio of the crop yield to seasonal irrigation water applied according to Al-Jamal *et al*. (2001) using the following formula.

$$\text{IWP (kg/m}^3\text{)} = \frac{\text{yield (kg ha}^{-1}\text{)}}{\text{Total water applied (m}^3\text{ha}^{-1}\text{)}} \quad \ldots\ldots\ldots\ldots\ldots (3.8)$$

3.12.5. Nutrient use efficiency

Nutrient use efficiency (NUE) was calculated as the partial factor productivity ((PFP) kg crop yield per kg nutrient applied) using the following formula according to Mosier *et al*. (2004).

$$\text{PFP (\%)} = \frac{\text{yield (kg ha}^{-1}\text{)}}{\text{Total nutrient applied (kg ha}^{-1}\text{)}} \quad \ldots\ldots\ldots\ldots\ldots (3.9)$$

3.12.6. Economics analysis

The cost of cultivation was worked out by considering various inputs used drip irrigation system and surface irrigation during cultivation of main and ratoon crops. Yield was calculated as ton per hectare and income was worked out at the rate of 500 SDG per ton in the field. Dominance, partial budget and marginal rate of returns analysis, as described by CIMMYT (1988), were used to evaluate the profitability of the drip irrigation regimes compared to surface irrigation based on the field information and data collected.

3.12.7. Statistical analysis

CropStat statistical program was used for analysis of data and Least Significant Difference Range Test was used for mean separation at the probability level of 0.05.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Crop coefficient

The K_c values were computed for the two growth stages of banana the crop development stage and the mid- season stage. The mean values of K_c and stage duration (days) were presented in table 4.1. Fig. (4.1) showed that the K_c values of crop developmental stages increased linearly with time till it reached the mid- stage where the $K_{c\ mid}$ remained constant (represented by a horizontal straight line). The late season stage $K_{c\ end}$ runs from the start of maturity to harvest but banana was harvested at start of maturity. The K_c in the second year was constant at the value 1.2 because every three months two suckers were left and the ground cover is more than 60% which indicated that no initial stage at second year.

Table 4.1 The mean values of crop coefficient and stage duration days

Crop stage	Stage duration (days)	Calculated crop coefficient (K_c)
Initial (1st year)	105	0.5
Crop development (1st year)	140	0.8
Mid season (1st year)	120	1.1
Total (1st year)	365	-
2nd year	-	1.2

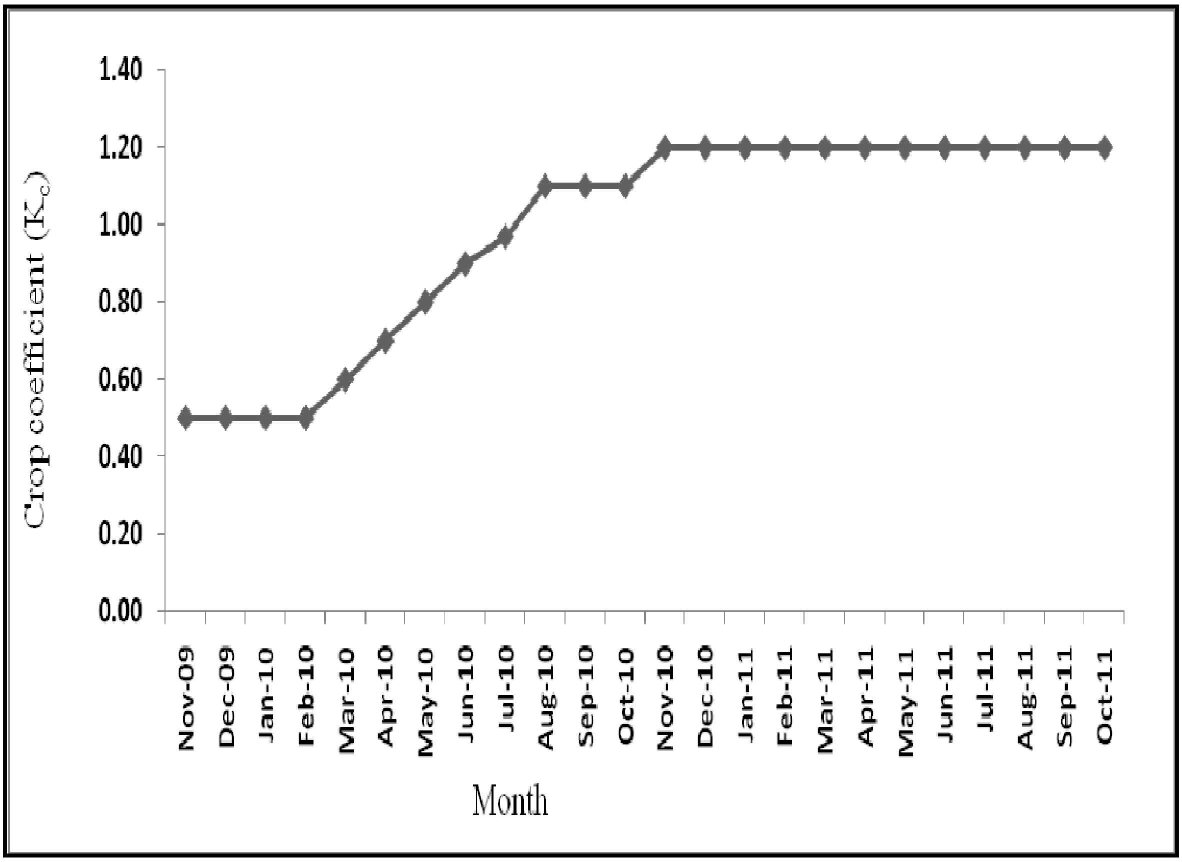

Figure 4.1 Crop coefficient of the mother plant and the first ratoon crops of banana cv. Grand Nain

4.2. Reference evapotranspiration

The climatic data used for calculation of reference evapotranspiration (ET_o) included, maximum and minimum air temperature, relative humidity, sunshine duration and wind speed from November 2009 to October 2011 as shown in Appendix. 6. Fig (4.2) showed the reference evapotranspiration from November 2009 to October 2011. The reference evapotranspiration increased from February and reached the maximum in May then it decreased in July to reach the minimum in August every year.

4.3. Crop evapotranspiration

The crop evapotranspiration (ET_c) is a term that describes the water consumed by a crop during the growing season. Fig. 4.3 showed the average monthly crop evapotranspiration (mm/day) for the mother plant and the first ratoon crops of banana. The crop evapotranspiration started with low value (3.1 mm/day) during the initial stage and then increased to a peak (7.5 mm/day) in June. The consumption of water in the second year was greater (10.7 mm/day in June) than in the first year because the number of plants per pit were more than three. The average value of crop evapotranspiration of banana was 6.5 mm/day.

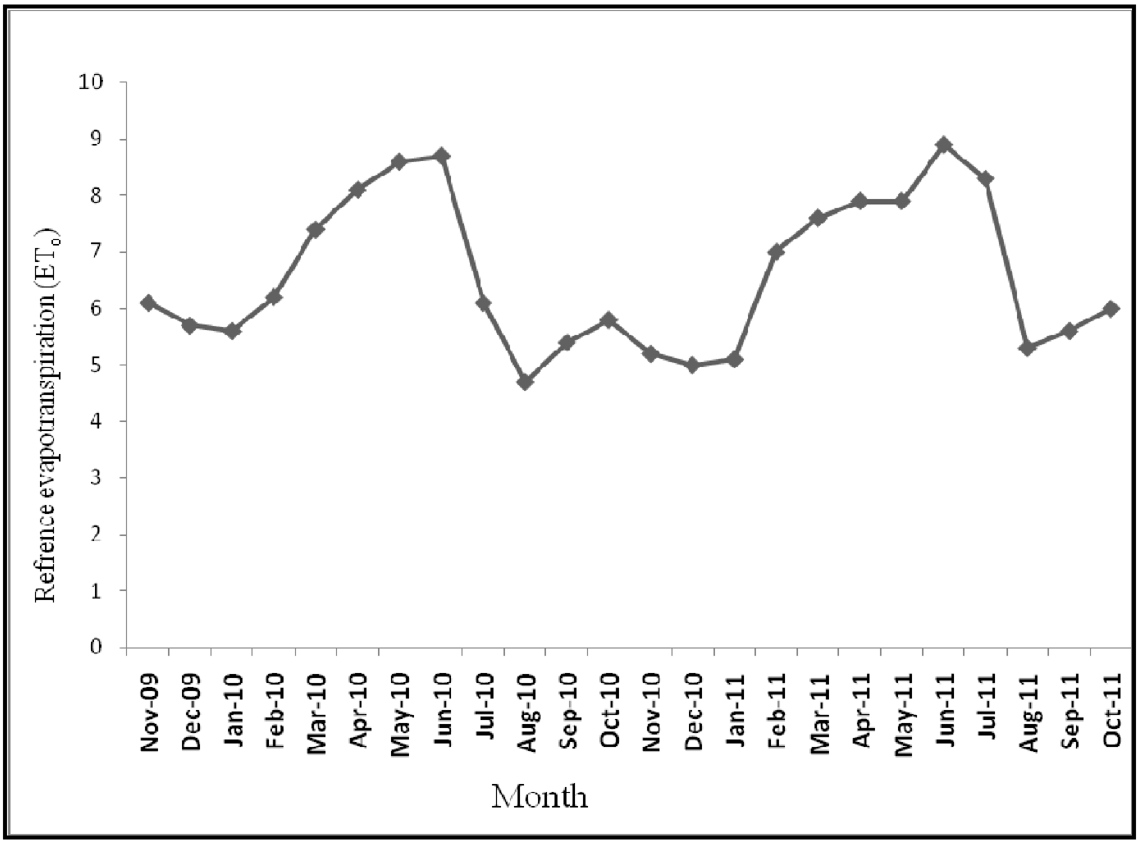

Figure 4.2 Reference evapotranspiration of the mother plant and first ratoon crops of banana cv. Grand Nain from November 2009 to October 2011

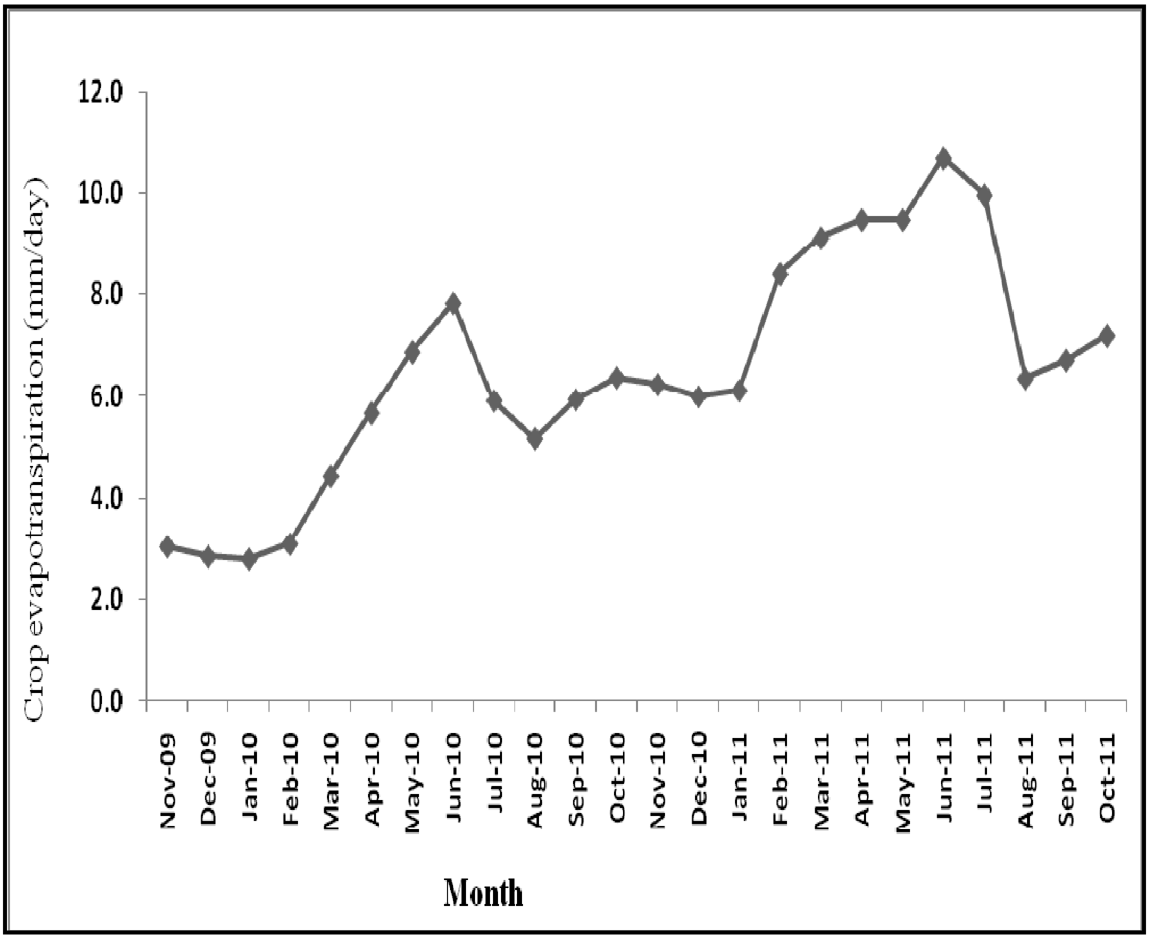

Figure 4.3 Crop evapotranspiration of the mother plant and first ratoon crops of banana cv. Grand Nain from November 2009 to October 2011

4.4. The hydraulics of drip irrigation system

4.4.1. Emission uniformity

The results on the hydraulic characteristic of drip irrigation system (Table 4.2) gave 7.9 l/h for average emitters discharge, 90.9% filed emission uniformity, 91% absolute emission uniformity and 91.9% design emission uniformity. The field emission uniformity was excellent, absolute emission uniformity was good and design emission uniformity was excellent as reported by Choudhary and Kadam (2006). They reported that 90% is excellent, (80-90%) is good and (70-80%) is acceptable but less than 70% is not acceptable.

On the other hand Phocaides (2000) reported the uniformity of surface irrigation to be about 50-60%.

Table 4.2 The discharge rate of 16 emitters in the field (l/h)

No of emitters	Line (1)	Line (2)	Line (3)	Line (4)
1	8.8	7.9	8.3	8.7
2	7.8	7.4	7.2	8.7
3	7.8	8.4	7.2	7.8
4	7.4	8.4	7.6	7.2

4.4.2. Irrigation efficiency

The irrigation efficiency of drip irrigation system was 81.9%. Drip irrigation has the potential to increase irrigation efficiency because it can apply water both precisely and uniformly at a high irrigation frequency compared with surface irrigation. Shashidhara *et al*. (2007) reported that the irrigation efficiency was 91.1% under drip irrigation. Al-Omran *et al*. (2005) reported 89% irrigation efficiency with the drip system while it was 50% under the surface irrigation.

4.5. Effect of irrigation treatments on growth parameters

The results showed that the effect of irrigation treatments was significant on Pseudostem height, Pseudostem girth, leaf area and number of green leaves of the mother plant crop and the first ratoon crops of banana cv. Grand Nain (Table 4.3, Fig.4.4, Fig.4.5 and Plate 4.1). However, applying water at 100% and 120% of ET_c under drip irrigation was not significantly different from surface irrigation in all growth parameters suggesting that the water applied to the surface irrigation treatment might have created a microclimate that reduced canopy temperature. The growth parameters increased with the increase of the quantity of water applied under drip irrigation system and the stress was clearly observed on 40% and 60% compared to 100% of ET_c on all growth parameters. These results are in agreement with those of Hegde and Srinivas (1991) who reported that the plants were 3% taller under the drip irrigation than the basin irrigation. The results under drip irrigation treatments indicated that application of water up to the optimum crop water requirement may promote plant growth parameters (Table 4.3, Fig.4.4, Fig.4.5 and Plate 4.1). These results are in agreement with those of Goenagea and Irizarry (2000) who reported that irrigation according to increasing pan factors from 0.25 to 1.25 resulted in increase in the number of functional leaves at flowering of banana. Similar results were obtained by different researchers for different crops. Bozkurt *et al*. (2009) indicated that irrigation levels had significant effects on yield and yield components of lettuce crop, except for plant dry weight. Olanrewaju *et al*. (2009) found that plant height and stem diameter of cassava were higher under full treatment of available water. Karam *et al*. (2002) reported that water stress caused by the deficit irrigations significantly reduced leaf number, leaf area index and dry matter accumulation of lettuce. Dagdelen *et al*. (2009) found leaf area index and dry matter yields increased with increasing water for treatments of cotton.

Table 4.3 The effect of irrigation treatments on Pseudostem height and Pseudostem girth of the mother plant and first ratoon crops of banana cv. Grand Nain

Irrigation treatments	Pseudostem height (cm)		Pseudostem girth (cm)	
	MP	FR	MP	FR
40% of ET_c under drip	155 **c**	206 **d**	47 **c**	60 **c**
60% of ET_c under drip	158 **c**	210 **cd**	51 **bc**	61 **c**
80% of ET_c under drip	174 **b**	215 **bc**	57 **b**	64 **b**
100% of ET_c under drip	180 **ab**	222 **ab**	53 **b**	66 **b**
120% of ET_c under drip	192 **a**	231 **a**	61 **a**	70 **a**
Surface irrigation	190 **a**	217 **bc**	64 **a**	66 **b**
Significance level	***	***	**	***
SE±	**4.10**	**3.0**	**2.49**	**0.97**
CV%	**4.7**	**2.7**	**9.0**	**3.0**

MP= Mother plant. FR= First ratoon crops

, **, * and NS: indicated significance at P≤0.05, P≤ 0.01, P≤ 0.001 and not significant, respectively. Means within each column followed by the same letters are not significantly different according to Least Significant Difference Range Test.*

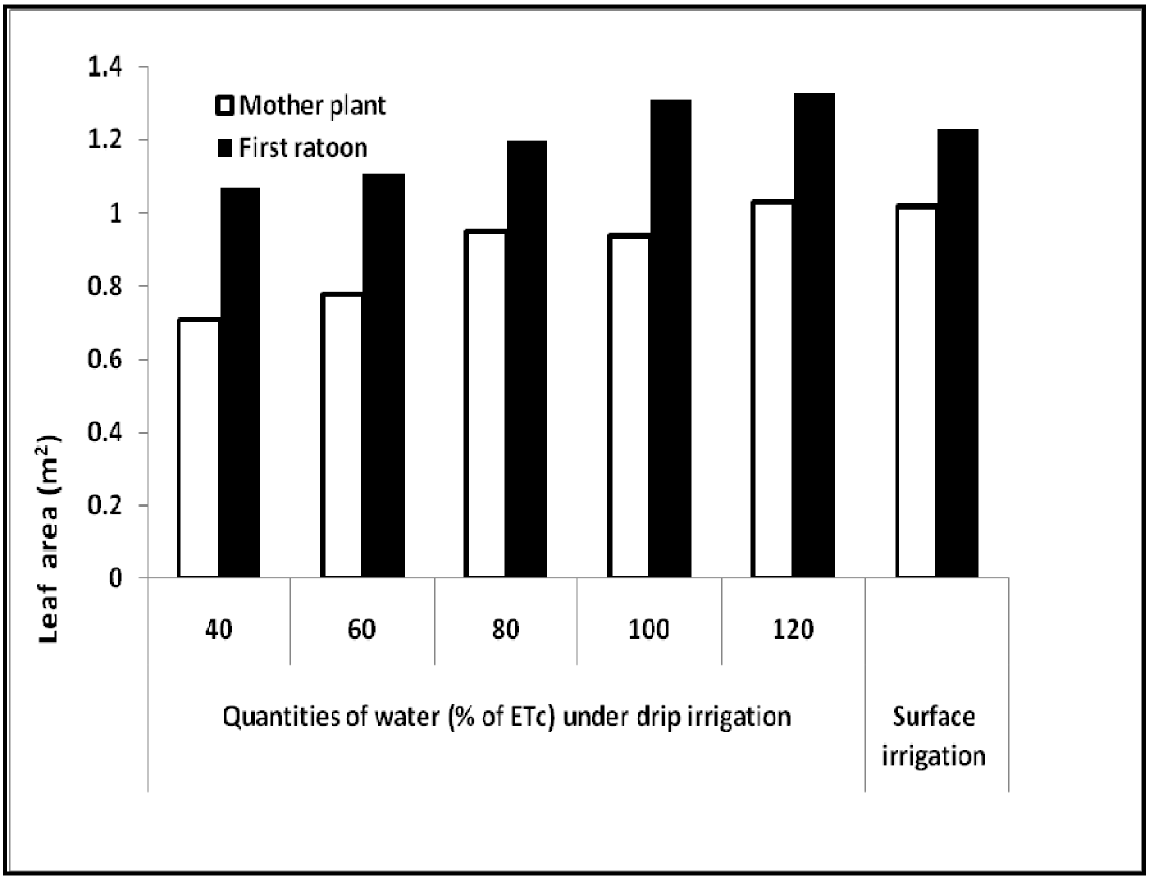

Figure 4.4 Effect of irrigation treatments on leaf area (m^2) of the mother plant and first ratoon crops of banana cv. Grand Nain

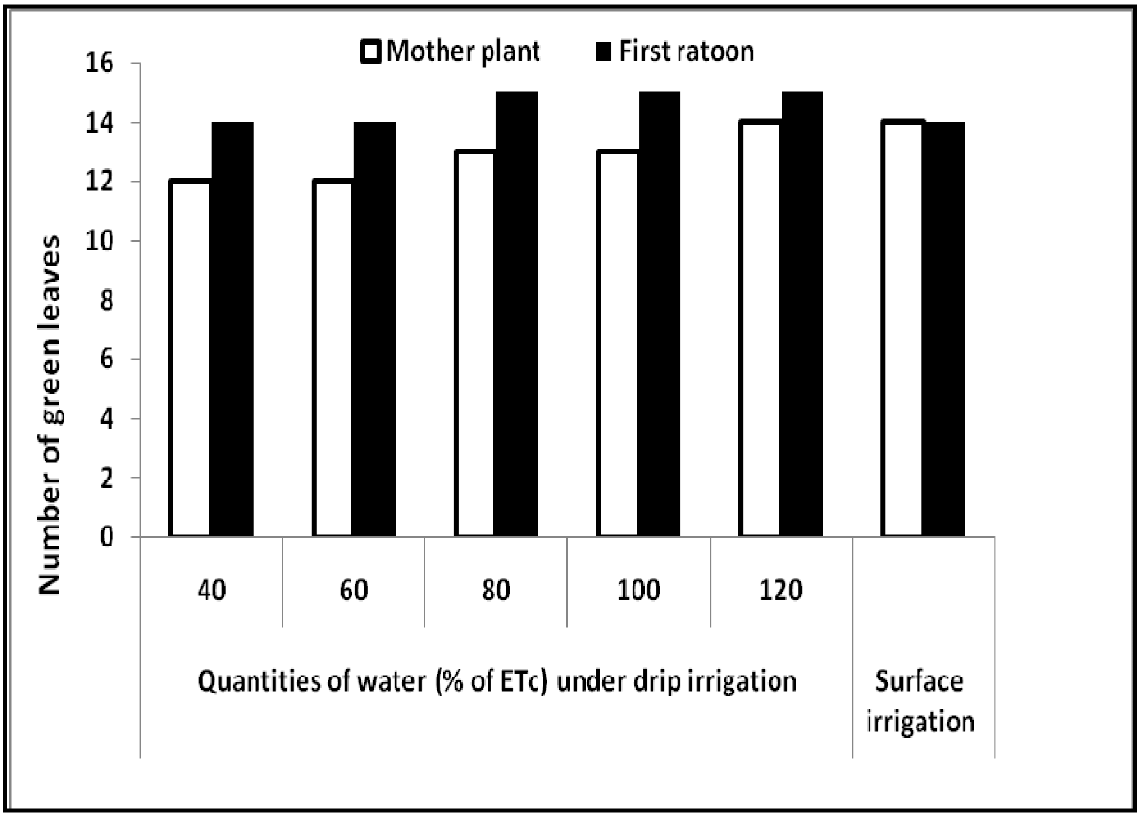

Figure 4.5 Effect of irrigation treatments on the number of green leaves of the mother plant and first ratoon crops of banana cv. Grand Nain

1- 40% ET_c

2- 60% ET_c

3- 80% ET_c

4- 100% ET_c

5- 120% ET_c

6- Surface irrigation

Plate 4.1 The effect of irrigation treatments on growth parameters of the mother plant and first ratoon crops of banana cv. Grand Nain

4.6. Effect of irrigation treatments on crop duration

For the mother plant crop, results indicated no significant differences among the different irrigation treatments on the number of days from planting to flowering, but there were significant differences in the number of days from flowering to harvest (Table 4.4). Moreover, for the first ratoon crops the differences were significant on the days from planting to flowering and no significant differences on the days from flowering to harvest. Forty percent of ET_c and surface irrigation treatment were comparable on the number of days to flowering for first ratoon crops and delayed days to harvesting of mother plant and first ratoon crops significantly (Table 4.4). Fewer days from flowering to harvest were observed the mother plant crop and first ratoon crops on the 100% of ET_c compared to surface irrigation but no significant differences between the 80% and 100% of ET_c on mother plant and first ratoon crops were observed (Table 4.4). These results were in agreement with those of Shashidhara *et al*. (2007) who found that the drip irrigation minimized the days to harvest (398 days) as compared to surface method of irrigation (435 days). Goenaga *et al*. (1995) reported that the increase in the pan factor treatment caused reduction in the number of days required to flowering (bunch shooting) and consequently the planting to harvest cycle was shortened in both plantain and banana.

Table 4.4 Effect of irrigation treatments on days from planting to flowering and days from flowering to harvest of the mother plant and first ratoon crops of banana cv. Grand Nain

Irrigation treatments	Days to flowering		Days to harvest	
	MP	FR	MP	FR
40% of ET_c under drip	295	114 **a**	120 **a**	125
60% of ET_c under drip	290	84 **ab**	113 **ab**	131
80% of ET_c under drip	298	73 **b**	106 **b**	122
100% of ET_c under drip	298	71 **b**	105 **b**	115
120% of ET_c under drip	301	86 **ab**	103 **b**	123
Surface irrigation	308	105 **ab**	117 **a**	121
Significance level	NS	*	*	NS
SE±	**5**	**11.9**	**4**	**5.9**
CV%	**3.3**	**27**	**7.3**	**10.5**

MP= Mother plant. FR= First ratoon crops

**, ** and NS: indicated significance at P≤0.05, P≤ 0.01 and not significant, respectively. Means within each column followed by the same letters are not significantly different according to Least Significant Difference Range Test*

4.7. Effect of irrigation treatments on yield and yield components

4.7.1. Bunch weight

Yield and yield component, as the most important economic traits, were very highly influenced by the amount of water applied. Very highly significant differences for the bunch weight of the mother plant and the first ratoon crop of banana were observed (Table 4.5 and Plate 4.2). No significant differences were found between 100% and 120% of ET_c under drip irrigation system on mother plant bunch weight. Moreover, for the first ratoon crops there were highly significant differences between 100% and 120% of ET_c under drip irrigation system compared to surface irrigation. These results were in agreement with those of Cevik *et al*. (1985) who compared drip and basin methods of irrigation in banana crop. Shmueli and Goldberg (1971) reported that drip irrigation produced higher yield than furrow. Hegde and Srinivas (1991) indicated an increase in the banana yield under drip irrigation compared to the basin irrigation. The highest bunch weight was obtained with 120% of ET_c while the lowest bunch weight was obtained on 40% and 60% of ET_c under drip irrigation system because the water stress affected yield negatively (Table 4.5). Similar results were reported by Goenagea and Irizarry (1998) who found that yield and yield components for the mother and ratoon crops were significantly improved with an increase in water applied. The highest marketable yield of banana was obtained with the application of A pan factor of 1.0.

Table 4.5 Effect of irrigation treatments on bunch weight (kg) and total yield (ton/ha) of the mother plant and first ratoon crops of banana cv. Grand Nain

Irrigation treatments	Bunch weight (kg)		Total yield
	MP	FR	(ton/ha)
40% of ET_c under drip	5 **b**	5 **e**	19 **e**
60% of ET_c under drip	7 **b**	10 **d**	24 **d**
80% of ET_c under drip	10 **a**	13 **bc**	37 **c**
100% of ET_c under drip	10 **a**	15 **ab**	43 **b**
120% of ET_c under drip	12 **a**	16 **a**	47 **a**
Surface irrigation	10 **a**	11 **cd**	35 **c**
Significance level	***	***	***
SE±	**0.7**	**0.8**	**1.01**
CV%	**16**	**13**	**5.9**

MP= Mother plant. FR= First ratoon crops

****: indicated significance at P≤ 0.001. Means within each column followed by the same letters are not significantly different according to Least Significant Difference Range Test*

4.7.2. Total yield

Total yield of banana crop was highly affected by shortage of irrigation water. There was a very highly significant difference for the total yield of the mother plant and the first ratoon crop of banana (Table 4.5).

The percentage of total yield reduction amounted to 46% and 31% for 40% and 60% of ET_c treatments, respectively compared to surface irrigation. The total yield of 80% of ET_c treatment (37 t/ha) was approximately equal to that of the surface irrigation treatment (35 t/ha) with only 6% increase. For the treatments 100% and 120% of ET_c the percentage increase in total yield was equal to 23% and 34%, respectively as compared to the surface irrigation (Table 4.5). These results revealed that higher yields were produced under drip irrigation than the surface irrigation. Shashidhara *et al.* (2007) reported that drip irrigation increased yield of banana to the extent of 5.94% and 3.54%, respectively as compared to surface irrigation. Thadchayini and Thiruchelvam (2005) reported 31% higher banana yield in drip irrigation compared to surface irrigation. Raina *et al.* (1998) reported that drip irrigation gave 49.5% higher yield than the surface irrigation of pea crop.

4.7.3. Number of hands and fingers per bunch

The results showed that the treatments differences were very highly significant in the number of hands per bunch and number of fingers per bunch of the mother plant and the first ratoon crops of banana (Table 4.6 and Plate 4.2). The number of hands per bunch on 80% and 120% of ET_c under drip irrigation system and surface irrigation were significantly greater than others irrigation treatments of the mother plant crop. Also the highest numbers of fingers per bunch were observed on 120% of ET_c under drip irrigation system and surface irrigation of the mother plant crop. However, the highest number of hands per bunch and number of fingers per bunch of the first ratoon crops were obtained with 100% and 120% of ET_c under drip irrigation compared to surface irrigation (Table 4.6 and Plate 4.2). Similar results were reported by Shashidhara *et al*. (2007) who reported that drip irrigation system had more number of hands per bunch and fingers per bunch of banana compared to surface irrigation. Bhella (1985) found that drip irrigation increased fruit size when compared with no irrigation.

The maximum number of hands per bunch and number of fingers per bunch were obtained with 100% and 120% of ET_c under drip irrigation system for first ratoon crop (Table 4.7 and Plate 4.2). These results are in agreement with those reported by Bozkurt *et al*. (2011) who found that irrigation levels had statistically significant effect on fresh and dry above ground biomass production of corn and the highest yield components were found in 120% while the lowest were found in 20% of evaporation from a Class A Pan.

Table 4.6 Effect of irrigation treatments on the number of hands and number fingers per bunch of the mother plant and first ratoon crops of banana cv. Grand Nain

Irrigation treatments	No. of hands per bunch		No. of fingers per bunch	
	MP	FR	MP	FR
40% of ET_c under drip	5 **c**	7 **c**	53 **c**	113 **b**
60% of ET_c under drip	6 **b**	8 **b**	67 **b**	119 **b**
80% of ET_c under drip	7 **a**	8 **b**	78 **b**	121 **b**
100% of ET_c under drip	6 **b**	9 **a**	71 **b**	146 **a**
120% of ET_c under drip	7 **a**	9 **a**	88 **a**	140 **a**
Surface irrigation	7 **a**	8 **b**	97 **a**	126 **b**
Significance level	***	***	***	***
SE±	**0.20**	**0.25**	**3.91**	**4.7**
CV%	**7**	**6.1**	**10.7**	**7.3**

MP= Mother plant. FR= First ratoon crops

****: indicated significance at P≤ 0.001. Means within each column followed by the same letters are not significantly different according to Least Significant Difference Range Test*

1- 40% ET_c

2- 60% ET_c

3- 80% ET_c

4- 100% ET_c

5- 120% ET_c

6- Surface irrigation

Plate 4.2 Effect of irrigation treatments on yield and yield components of the mother plant and first ratoon crops of banana cv. Grand Nain

4.7.4. Finger length, girth and weight

The results in this study showed no significant differences among irrigation treatments regarding finger length and girth on the mother plant and highly significantly difference were observed on the first ratoon crops. Finger weight was significantly variable on mother plant crop and first ratoon crops in response to irrigation treatments (Table 4.7 and Fig.4.6). The best finger length and finger girth were obtained with 120% of ET_c under drip irrigation. However, the values were not significant differences from 100% of ET_c except for finger girth of the first ratoon crops (Table 4.7). These results are in agreement with those of Shashidhara *et al*. (2007) who reported higher length of fruit and fruit thickness of banana under drip irrigation compared to surface irrigation. Goenagea and Irizarry (1998) reported that irrigation according to increasing class A pan factors resulted in increase in length, diameter and weight of fruits. Goenagea and Irizarry (2000) found that irrigation according to increasing class A pan factors increased fruit length, diameter and weight.

Table 4.7 The effect of irrigation treatments on finger length (cm) and girth (cm) of the mother plant and first ratoon crops of banana cv. Grand Nain

Irrigation treatments	Finger length (cm)		Finger girth (cm)	
	MP	FR	MP	FR
40% of ET_c under drip	19	19 **c**	11	11 **c**
60% of ET_c under drip	19	19 **c**	12	11 **c**
80% of ET_c under drip	22	20 **bc**	12	12 **b**
100% of ET_c under drip	22	21 **ab**	12	12 **b**
120% of ET_c under drip	24	22 **a**	13	13 **a**
Surface irrigation	21	20 **bc**	12	12 **b**
Significance level	NS	**	NS	**
SE±	**1.47**	**0.48**	**0.57**	**0.2**
CV%	**14**	**4.8**	**9.4**	**3.9**

MP= Mother plant. FR= First ratoon crops

**, ** and NS: indicated significance at P≤0.05, P≤ 0.01 and not significant, respectively. Means within each column followed by the same letters are not significantly different according to Least Significant Difference Range Test.*

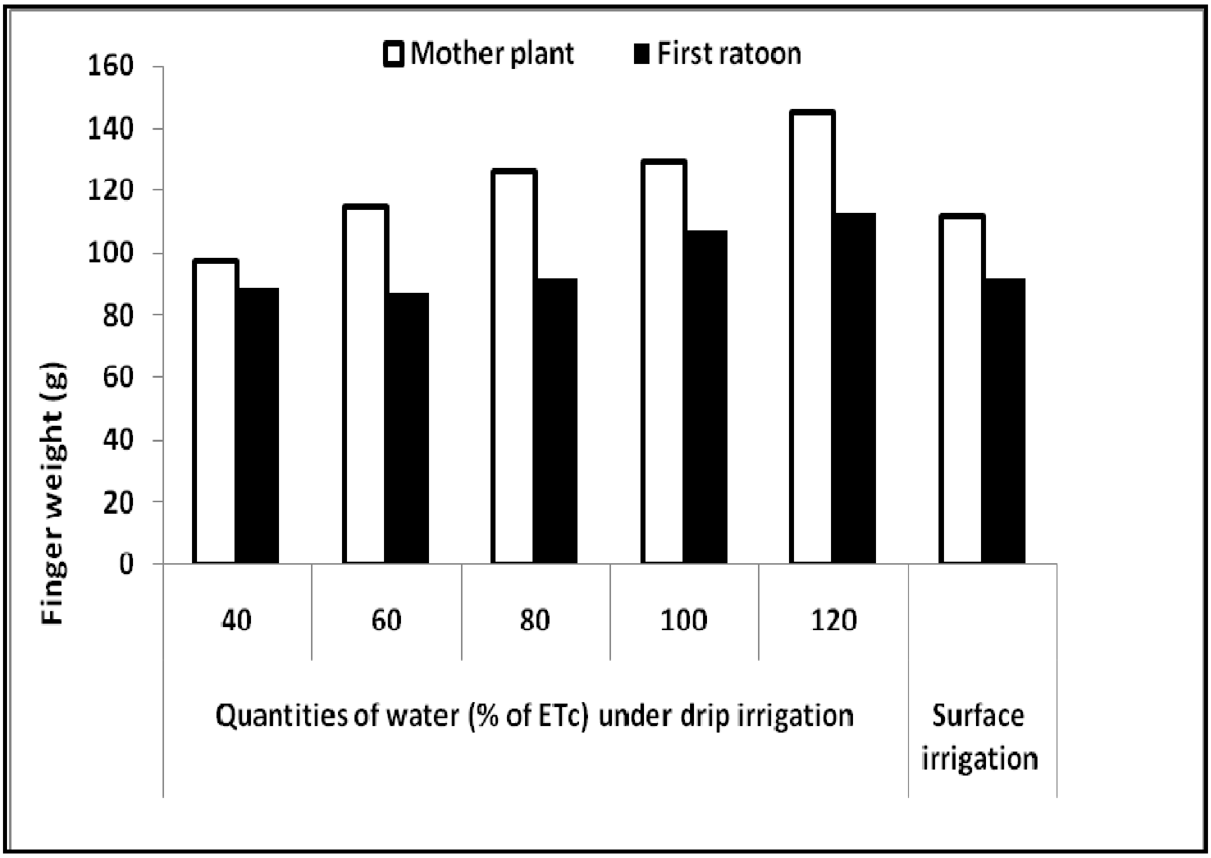

Figure 4.6 Effect of irrigation treatments on the Finger weight (g) of the mother plant and first ratoon crops of banana cv. Grand Nain

4.8. Total water applied

The quantities of water applied to banana plants were **15964** m^3/ha, **20201** m^3/ha, **27642** m^3/ha, **30635** m^3/ha and **32928** m^3/ha under drip irrigation regimes 40%, 60%, 80%, 100% and 120% of (ET_c), respectively compared to **116905** m^3/ha for surface irrigation. The percentage of the applied water saved were 76%, 74% and 72% for the 80%, 100% and 120% of ET_c, respectively under drip compared to surface irrigation (Table 4.8). Narayanamoorthy (2003) reported that the water saving due to drip method of irrigation is about 47% for sugarcane and nearly 30% for banana. Moreover, Sharmasarkar *et al*. (2001) reported that the amount of applied irrigation water with the drip system was lower than that applied by surface irrigation. Bashour and Nimah (2004) reported that the trickle irrigation saved about 50% of the water used in surface irrigation. Similarly, Fulton *et al*. (1991) found that more water was applied with the furrow systems compared to the drip system. Aujla *et al*. (2007) reported a saving of 25% water on drip irrigation compared with furrow irrigation. All in all, the results of this study indicated that drip irrigation can safe water, time and energy.

Table 4.8 Total water (m^3/ ha) applied by drip and surface irrigation

Month	Drip irrigation (% of ET_c)					Surface irrigation
	40	60	80	100	120	
Nov - 09	1083	1083	1083	1083	1083	5625
Dec - 09	1653	1653	1653	1653	1653	5781
Jan -10	1104	1104	1104	1104	1104	5469
Feb - 10	701	764	833	896	958	6875
Mar - 10	396	590	792	986	1187	6875
Apr - 10	556	826	1104	1382	1660	7344
May - 10	682	993	1341	1675	2008	6285
Jun - 10	740	1101	1455	1816	2171	6306
Jul - 10	656	948	1233	1566	1802	5041
Aug - 10	623	893	1116	1442	1713	2667
Sep - 10	613	912	1210	1502	1801	3803
Oct - 10	465	991	1311	1637	1963	5143
Nov - 10	639	972	1292	1611	1930	5313
Dec - 10	632	944	1257	1569	1889	3750
Jan -11	604	910	1215	1521	1819	3750
Feb - 11	778	1173	1562	1951	2340	5000
Mar - 11	993	1493	1993	2486	2986	7813
Apr - 11	951	1430	1910	2389	2861	8594
May - 11	949	1421	1894	2366	-	9221
Jun - 11	1146	-	2284	-	-	6250
Total	**15964**	**20201**	**27642**	**30635**	**32928**	**116905**

4.9. Effect of irrigation treatments on irrigation water productivity

The highest irrigation water productivity (1.43 and 1.40 kg/m^3) was obtained with 120% and 100% of ET_c under drip irrigation and the lowest was (0.30 kg/m^3) with surface irrigation (Fig.4.7). The irrigation water productivity was higher on all drip irrigation treatments compared to surface irrigation. These results are in agreement with those reported by Hassanli *et al*. (2009) who stated that the maximum irrigation water use efficiency was obtained with the drip irrigation and the minimum was obtained with the furrow method. Similarly, Muralikrishnasamy *et al*. (2006) found that the maximum irrigation water use efficiency was recorded on drip irrigation compared with surface irrigation.

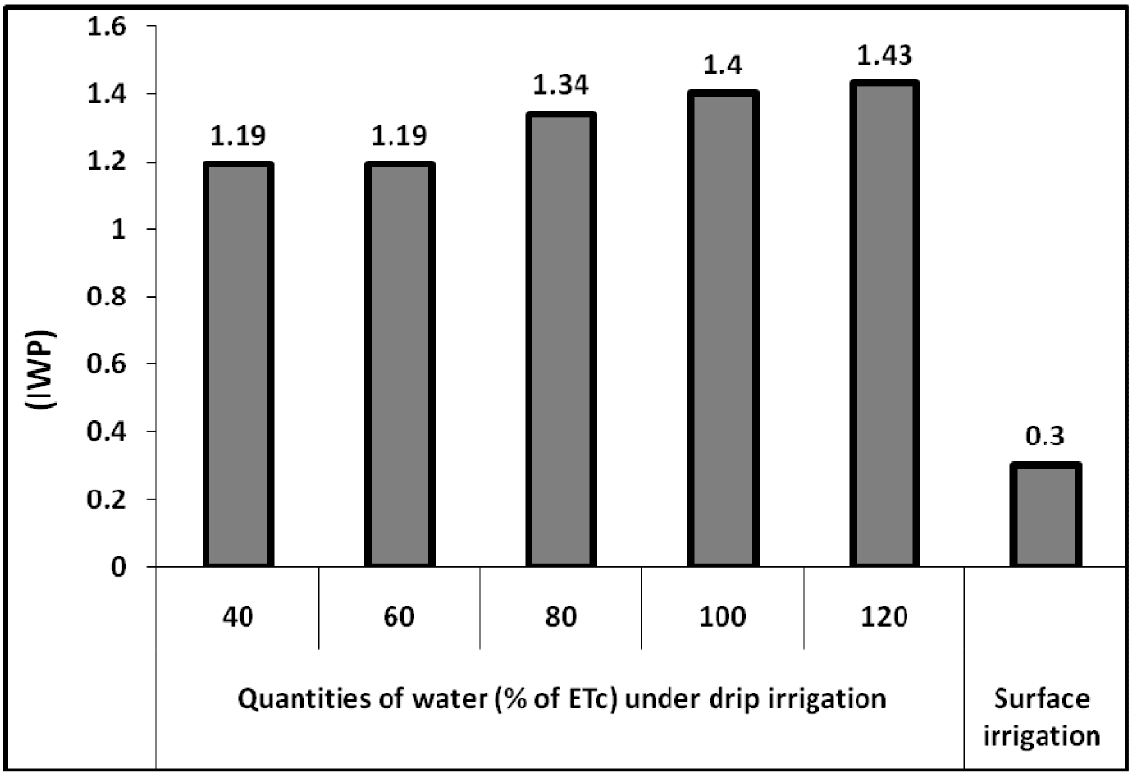

Figure 4.7 Irrigation water productivity (IWP) of different irrigation treatments

4.10. Effect of irrigation treatments on partial factor productivity

The partial factor productivity of banana plants was higher with 80%, 100% and 120% of (ET_c) under drip irrigation regimes compared to surface irrigation because the fertigation ensures that the fertilizer will be carried directly to the root zone (Fig.4.8). Fertigation saves from 20% to 50% of applied fertilizers and thus improves the yield and quality as compared with the common methods of fertilizer application (Malakouti, 2004). Arscott (1970) reported that the application of urea through drip irrigation system was more efficient than hand broadcasting on soil surface on banana. More yield and significantly higher number of hands per bunch were obtained with fertigation. Papadopoulos (1998 and 1999) studied the effect of fertigation of chemical fertilizers on the fertilizer use efficiency as well as the yield of potato, tomato, carrot, cucumber, watermelon and strawberry. The study approved that the yield and fertilizer use efficiency were higher in fertigation compared with surface application.

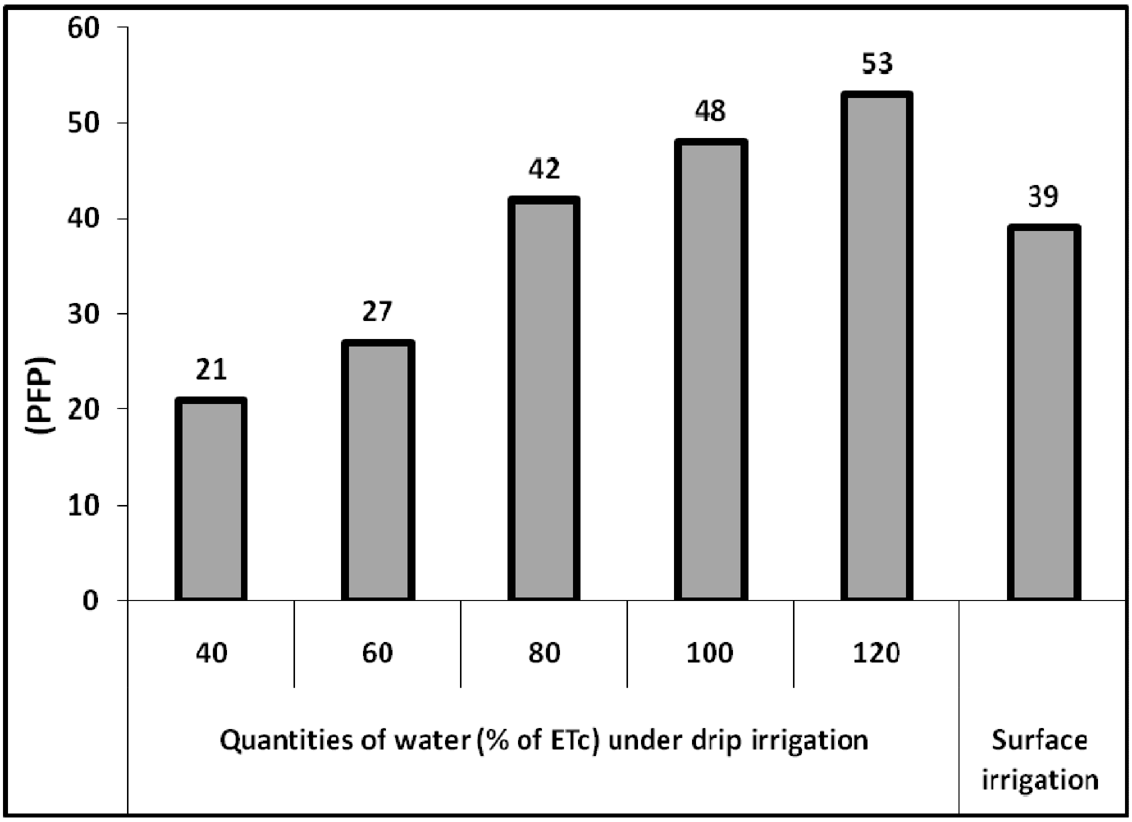

Figure 4.8 The partial factor productivity (PFP)

4.11. Economic analysis

The initial cost of installing drip irrigation system is high but over a period of time the costs were recovered and benefit was also derived, which was higher than the surface irrigation benefits. Fixed cost reflects the amount of capital investments for the drip set (drippers, lateral line, sub-main line, main line and filter) (Appendix.7). Variable cost includes labour, fuel or power, operation and maintenance of drip irrigation and surface irrigation in banana cultivation are shown in table 4.9.

Dominance analysis indicated that the significant yield advantage was obtained by increasing applied water under drip irrigation system but no significant differences between 100 and 120% of ET_c were observed under drip irrigation (Table 4.10). Therefore, the 80% of ETc under drip irrigation dominated the surface irrigation treatment as it produced higher net returns at a lower cost. The marginal analysis showed that 100% of ET_c under drip irrigation are the most economic form and had higher net benefit and high marginal rate of return compared to other treatments (Table 4.11). These results indicated that the initial investment cost was higher in drip irrigation and over the long run the yield will be sustainable. These results are in agreement with those reported by Basavarajappa *et al.* (2010) who found that the highest net returns and the benefit cost ratio were obtained in the drip irrigation treatment which received irrigation at 100 % of crop ET and the lowest were obtained in the furrow irrigation treatment. Shashidhara *et al.* (2007) found that drip irrigation had higher benefit cost ratio as compared to surface irrigation.

Table 4.9 Variable cost of the mother plant and the first ratoon crops of banana cv. Grand Nain per hectare with surface and drip irrigation system under different quantities of water

No.	**Particulars**	**Surface irrigation**	**(% of ET_c) under drip irrigation**				
			120	**100**	**80**	**60**	**40**
1	Variable cost (SDG/ha)						
	a. Irrigation system	-	3100	3100	3100	3100	3100
	b. Weeds control	1000	200	200	200	200	200
	c. Fertilizer application	300	-	-	-	-	-
	d. Canals maintenance	900	-	-	-	-	-
	e. Others cultural practices	250	200	200	200	200	200
	f. Power (SDG/ha)	5456	1534	1424	1286	937	747
2	Total cost	7906	5034	4924	4786	4437	4247
3	Banana yield (t/ha)	35	47	43	37	24	19
4	Gross return (SDG/ha)	17500	23500	21500	18500	12000	9500
5	Net return (SDG/ha)	9594	18466	16576	13714	7563	5253

Table 4.10 Dominance analysis on the mother plant and the first ratoon crops of banana cv. Grand Nain per hectare effect of drip irrigation system under different quantities of water and surface irrigation

Irrigation Treatments	Average yield (t/ha)	Gross return (SDG/ha)	Variable cost (SDG/ha)	Net return (SDG/ha)	Dominance
40% of ET_c under drip	19	9500	4247	5253	
60% of ET_c under drip	24	12000	4437	7563	
80% of ET_c under drip	37	18500	4786	13714	
100% of ET_c under drip	43	21500	4924	16576	
120% of ET_c under drip	47	23500	5034	18466	
Surface irrigation	35	17500	7906	9594	D

Table 4.11 Marginal analysis of the mother plant and the first ratoon crop of banana cv. Grand Nain per hectare with drip irrigation system under different quantities of water

Irrigation Treatments	Average yield (t/ha)	Variable cost (SDG/ha)	Net return (SDG/ha)	MC	MNR	MRR
40% of ET_c under drip	19	4247	5253	-	-	-
60% of ET_c under drip	24	4437	7563	190	2310	1216
80% of ET_c under drip	37	4786	13714	349	6151	1762
100% of ET_c under drip	43	4924	16576	138	2862	2074
120% of ET_c under drip	47	5034	18466	110	1890	1718

MC: Marginal cost.
MNR: Marginal net return.
MRR: Marginal rate of return.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND FUTUER WORK

5.1. Conclusions

From the results of this study the following conclusions can be drawn:

- Results of this study showed a variation of K_c values with different growth stages of banana. In the first year, the calculated K_c values were found to be 0.5, 0.8 and 1.1 for $K_{c\ ini}$, $K_{c\ dev}$ and $K_{c\ mid}$ respectively, but in the second year it was constant at value 1.2.
- The crop water requirement of the mother banana plant and first ratoon crops in the study area of Gezira under drip irrigation system was 30336 m^3/ha from transplanting to harvest.
- The best yield and yield components were obtained with 120% and 100% of ET_c under drip irrigation system.
- Drip irrigation treatments 100% and 120% of ET_c increased the total yield of banana crop by 23% and 34% and at the same time saved irrigation water by 74% and 72%, respectively compared to surface irrigation.
- The highest irrigation water productivity (1.43 and 1.40 kg/m^3) was obtained with 120% and 100% of ET_c under drip irrigation and the lowest was (0.30 kg/m^3) with surface irrigation.
- The partial factor productivity of banana plants was higher with 80%, 100% and 120% of ET_c under drip irrigation regimes compared to surface irrigation.

- The highest marginal rate of return was obtained from the 100% of ET_c under drip irrigation system.

5.2. Recommendation

Based on the yield data and economic analysis drip irrigation treatment of 100% of ET_c is recommended and suggested for banana production.

5.3. Future work

The future works along similar lines are:

- To test the drip irrigation system for producing vegetables and other field crops.
- Promotion of drip irrigation system among growers and stakeholders through demonstration and extension services.
- To evaluate the uniformity coefficient and water distribution efficiency of emitters and sprinklers.
- To test the performance of bubbler irrigation on different fruits trees.
- To determine the effects of fertigation frequency on crop yield and fruit quality of banana and other crops.
- To develop the best management guidelines for fertigation frequency for different vegetables crops in greenhouses.
- Designing and installing different types of a family drip system for some high value crops.

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APPENDIXES

Appendix. 1. Monthly average climatic parameters (1971-2000).

Month	Max temp °C	Min temp °C	Humidity %	Wind speed $Kmday^{-1}$	Sunshine hrs	ET_o (mm/day)
Jan	32.9	14.1	34	168	88	5.7
Feb	34.7	15.9	27	168	83	6.4
March	38.1	18.9	22	168	84	7.4
April	41.2	21.8	21	144	83	7.6
May	41.5	24.6	32	144	74	7.5
June	40.3	25.1	42	240	70	8.5
July	36.6	23.4	59	240	55	6.7
Aug	35.1	22.6	68	216	61	6.0
Sept	36.2	22.3	65	144	71	5.8
Oct	38.3	22.0	50	96	79	5.5
Nov	36.7	18.4	36	144	88	5.8
Dec	33.7	15.4	37	144	88	5.3
Year	**37.1**	**20.4**	**41**	**168**	**77**	**6.5**

Source: Adam, (2008)

Appendix .2 Analysis of Physical and chemical properties of used soil

2.1 Physical properties

No	Analysis		Value		
			0-30 cm	30-60 cm	60-90 cm
1	Mechanical Analysis	(%)			
	Coarse sand		4	2	4
	Find sand		1	2	3
	Silt		66	70	68
	Clay		29	26	25
2	Saturation		65	62	65
3	Bulk density	(g cm^{-3})			
	Dry		1.82	1.77	1.76
	Moisture		1.22	1.30	1.24
4	Hydraulic conductivity	(cm hr^{-1})	1.33	1.35	1.30

2.2 Chemical properties

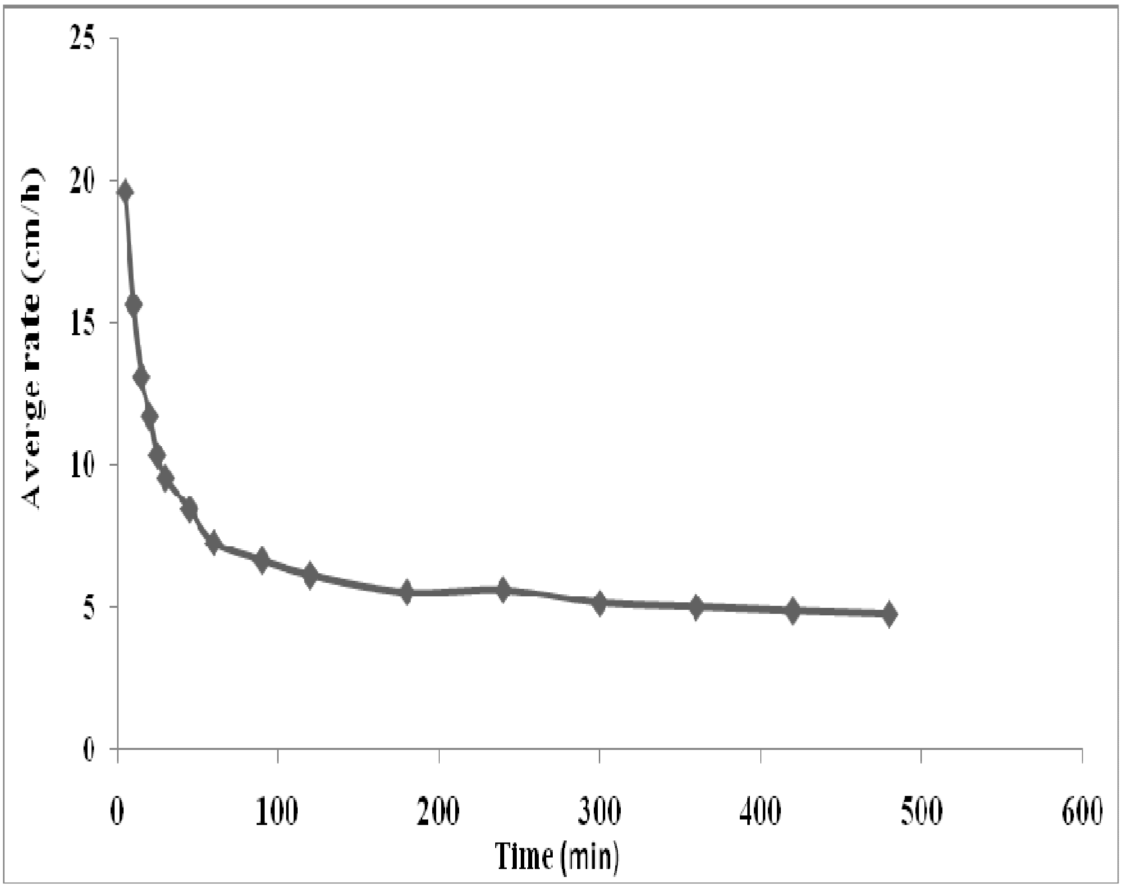
No	Analysis		Value		
			0-30 cm	30-60 cm	60-90 cm
1	pH paste		7.9	7.9	7.9
2	Electrical conductivity	(dS m^{-1})	0.6	0.6	0.6
3	Carbon : Nitrogen ratio	(%)	12	12	15
4	Soluble Na^+	($meql^{-1}$)	4	4.1	4
5	Soluble Ca^{++}	($meql^{-1}$)	1.5	1.5	1.5
6	Soluble Mg^{++}	($meql^{-1}$)	0.5	0.5	0.5
7	Soluble Cl^-	($meql^{-1}$)	2.1	2	2.3
8	Soluble HCO_3	($meql^{-1}$)	2	2	2
9	Soluble SO_4	($meql^{-1}$)	0	0	0
10	Calcium carbonate	(%)	0.8	1.6	3.6
11	Organic carbon	(%)	1.139	1.183	1.217
12	Total nitrogen	(%)	0.096	0.102	0.079
13	Available phosphorous	(mg kg^{-1} soil)	18.4	18	16.4
14	Sodium absorption ratio	(SAR)	4	4	4
15	Cation exchange capacity	(cmol(+) kg^{-1} soil)	45	43	44
16	Exchangeable sodium ratio	(cmol(+) kg^{-1} soil)	4	4	4
17	Exchangeable sodium	(cmol(+) kg^{-1} soil)	1.9	1.9	1.93
18	Exchangeable potassium	(cmol(+) kg^{-1} soil)	0.63	0.64	0.65

Appendix. 3. Soil characteristics for suitable for growing bananas

No	Soil characteristics		Value
1	Coarse fragments	(vol %)	< 15
2	Soil depth	(cm)	>75
3	Calcium carbonate	(%)	<5
4	Gypsum	(%)	<1
5	Electrical conductivity	(ohms/cm)^{1}	< 2
6	Base saturation	(%)	> 35
7	Organic carbon (0-15 cm)	(%)	> 1.5
8	CEC	(meg/100 g clay)	>16
9	Exchangeable sodium	(%)	< 4

Source: Sys (1985).

Appendix. 4. Average infiltration rate for three reprehensive sites



Appendix .5. Basic infiltration rate for various soil types

Soil types	Basic infiltration rate mm/h
Sand	Over than 30
Sand loam	20 - 30
Loam	10 - 20
Clay loam	5 - 10
Clay	1 - 5

Source: Brouwer *et al*. (1985)

Appendix .6. Mean monthly meteorological data and mean monthly reference evapotranspiration (ET_o)

6.1 Meteorological data (year one)

Month	Temperature C°		Relative humidity (%)	Wind speed 2m (m/s)	Sunshine (hours)	Total rainfall (mm)	ET_o (mm/day)
	Max	Min					
Nov - 09	37.5	19.2	31	1.92	10.3	0	6.1
Dec - 09	34.2	14.0	27	1.73	10.9	0	5.7
Jan -10	35.6	18.6	27	1.8	10.0	0	5.6
Feb - 10	37.4	19.2	26	1.92	9.8	0	6.2
Mar - 10	39.2	20.2	23	2.3	8.9	0	7.4
Apr - 10	43.2	23.2	23	2.0	10.7	0	8.1
May - 10	43.9	25.5	28	2.5	9.6	18	8.6
Jun - 10	40.9	25.6	44	4.2	7.5	30	8.7
Jul - 10	36.1	23.2	63	3.8	5.1	105	6.1
Aug - 10	35.1	22.1	68	3.0	3.8	89	4.7
Sep - 10	36.8	22.3	63	2.1	7.7	28	5.4
Oct - 10	39.0	22.4	47	1.4	10.4	23	5.8
Average	**38.2**	**21.3**	**39.2**	**2.4**	**8.7**	**293**	**6.5**

6.2 Meteorological data (year two)

Month	Temperature C°		Relative humidity (%)	Wind speed 2m (m/s)	Sunshine (hours)	Total rainfall (mm)	ET_o (mm/day)
	Max	Min					
Nov - 10	39.1	19.6	32	1.7	10.5	0	5.2
Dec - 10	35.5	16.1	32	1.5	10.4	0	5.0
Jan -11	32.7	12.5	34	1.8	10.7	0	5.1
Feb - 11	37.6	17.3	28	2.3	10.7	0	7.0
Mar - 11	37.7	14.3	29	2.4	10.6	0	7.6
Apr - 11	41.9	22.4	30	2.1	10.1	0	7.9
May - 11	42.3	25.4	34	2.5	8.7	6	7.9
Jun - 11	41.9	26.8	39	3.7	7.7	0	8.9
Jul - 11	39.4	24.9	44	4.4	5.9	149	8.3
Aug - 11	35.1	21.9	67	3.1	7.9	132	5.3
Sep - 11	36.4	28.0	55	2.0	8.3	0.3	5.6
Oct - 11	40.0	22.3	44	2.0	10.2	12	6.0
Average	**38.3**	**21.0**	**38.9**	**2.5**	**9.3**	**299**	**6.7**

Appendix .7. Fixed cost for the drip irrigation system components for the 1 hectare banana depending to the recent prices

No	Particulars	Quantities	Price unit (SDG)	Price (SDG)
1	Fertilizer system	1	2000	2000
2	Main line pipe (PVC) 3″ diameter	25	60	1500
3	Fittings (PVC) 3″ diameter	37	10	370
4	Valves 3″ diameter	2	90	180
5	Other (PVC) 3″ diameter	10	25	250
6	Sub main line pipe (PVC) 1.5″ diameter	105	35	3500
7	Fittings (PVC) 1.5″ diameter	195	3	585
8	Valves 1.5″ diameter	15	35	525
9	Valves boxes	15	40	600
10	CPVC cement	20	15	300
11	Lateral line 13 mm	16	420	6720
12	Fittings 13 mm	800	1	800
13	Drippers	2222	0.5	1111
14	Filters 3″	1	1400	1400
15	Labours	work	2000	2000
16	Installation	work	2000	2000
17	Total (Twenty three thousand eight hundred forty one Sudanese pounds)			**23841**
18	Lateral line 13 mm after 5 years			**7259**
19	Total (Thirty one thousand one hundred Sudanese pounds)			**31100**

The life of main and sub main 10 years
The life of lateral line 5 years