DRIP IRRIGATION SYSTEM PERFORMANCE

A CASE STUDY - OUMDOM FARM

By

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Dedication

This work is dedicated to

The souls of my grandmother Bit Haj Idres, sister Hanan and my brother Mohamed.

My dear father, Ahmed ,

My gracious mother, Aziza,

My beloved Brothers and Sisters,

My sincere Teachers, Friends and Colleagues

With love and respect…

NAZAR

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Prays to Allah who gave me health and strength to complete this work.

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ABSTRACT

This study was conducted at the Farm of the Arab Company for Agriculture and Processing (Sudan). LTD, at Oumdom area with the objective was to evaluate the performance of the drip irrigation system which introduced and installed for production of vegetables for export.

The study included soil physical analysis, infiltration rate, field capacity, permanent wilting point and available water. Variables tested were uniformity of distribution, emitters discharge rate, depth of water applied, volume of water applied, duration of irrigation, discharge variations and drop, variation and loss of pressure and water loss. Crop grown was Tomato. Reference crop evapotranspiration was calculated and crop water was required accordingly.

The study showed that Oumdom scheme is dominated by sandy clay loam soil with a relatively high infiltration rate which suits the drip system. Also the result showed that the distribution efficiency (83.3%) obtained was relatively high and the water applied to the crop was higher than the crop water requirement.

The actual irrigation practice adopted at the site does not follow any prescribed pattern because the volume of application depth was merely based on visual assessment. The irrigation set time should be in daily frequency of one hour.

The discharge and pressure variation on the main, submain and lateral lines within the allowed variation of standard design of the drip irrigation system.

بسم ا الرحمن الرحيم

ملخص الأطروحة

أجريت هذه الدراسة في مزرعة الشركة العربية للإنتاج والتصنيع الزراعي في منطقة أم دوم وذلك بهدف تقويم نظام الري بالتنقيط الذي استخدم في إنتاج الخضروات بغرض تصديرها.

شملت الدراسة بعض الخصائص الفيزيائية للتربة، إنسياب الماء داخل التربة، كفاءة إضافة الماء، كفاءة التوزيع، كفاءة النقاطات، الإختلاف في الضغط ومعدل سريان الماء خلال خطوط النظام، فترات الري والإحتياجات المائية لمحصول الطماطم.

أوضحت الدراسة أن مشروع أم دوم الزراعي تسوده تربة ذات قوام رملي طيني وأن معدل التخلل عالي نسبياً وهي خاصية تناسب نظام الري بالتنقيط. وكذلك أوضحت الدراسة أن كفاءة توزيع الماء عالية نسبياً (83.3%) وأن كمية الماء المضافة للمحصول أعلى من الإحتياجات المائية للمحصول، وأن زمن الريّة بمعدل يومي يجب أن يكون ساعة واحدة.

عملية الري الحقيقية تجري دون إتباع طريقة علمية لأن كمية الماء المضافة تعتمد علي التخمين المرئي. والإختلاف في معدل السريان والضغط خلال خطوط النظام لا يتجاوز المدي المسموح به في التصميم المثالي لنظام الري بالتنقيط.

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a fixed percentage that accounts for losses from rainfall and deep percolation.
A the global area to be irrigated (m^2).
Bp bulk density of soil (gm/cm^3),
C a dimensionless pipe roughness factor.
C v manufacturer's coefficient of variation.
CWR crop water requirement.
d maximum amount (depth) of water to be applied (mm).
D the inside diameter (mm).
D the root zone depth (m).
D_c density of Paraffin wax (taken as 0.9 gm/cm^3).
Dw maximum diameter of wetted circle formed by a single emitter
dw soil surface wetted diameter (m).
$D_{w:}$ density of water (taken as 1.0 gm/cm^3),
E emitter efficiency (%) or (decimal).
ET_o reference crop evapotranspiration (mm day^{-1}).
Ea application efficiency (decimal)
ET_c crop evapotranspiration (mm / day).
Eu coefficient which reflects the uniformity of application.
F a dimensionless friction factor.
FC field capacity (cm/m).
G soil heat flux (Mj m^{-2} day^{-1}).
H pressure head at the emitter (m).
H_f the pipe friction loss (m).
Ig gross irrigation water requirement (L).
In net irrigation water requirement (L).
K constant (In metric system = 1).
K numerical constant for the emitter.
K_c crop Coefficient.
NCWR net crop water requirements
(ea–ed) vapor pressure deficit for measurement at 2m height.
Δ slope of vapor pressure curve (K Pa °C).
$\theta v\%$ percentage moisture content on volume basis

CHAPTER ONE

INTRODUCTION

Sudan is mainly an agricultural country rich in natural resources that need to be utilized efficiently for self- satisfaction and with substantial excess for export. 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 is consisting of annual crops (FAO, 1997).

Irrigation has played and will continue to play a critical role in agricultural development. Irrigation has often been defined as the method of applying water to soil to supplement that from rainfall for maximizing production per unit input. The purpose of irrigation generally is to facilitate the growth of crops to increase yields in areas where there is no enough rainfall for crop growth.

The increasing need for crop production for the growing population is causing rapid expansion of irrigation throughout the world. Large quantities of irrigation water are lost by seepage, evaporation and surface run-off. Improperly designed field irrigation systems and uncontrolled water application methods lead to huge losses of water by seepage and deep percolation representing the loss of a valuable resource, developed at a high cost.

Drip irrigation is not commonly used in crop production in the Sudan. It may be used in private small farms and gardens. Sudan has areas of land away from the Nile and rivers cultivated as rain fed. But these areas are of low productivity mainly because of their dependence upon the amount and distribution of rain fall. These areas can be irrigated using supplementary irrigation and water harvesting to improve their production.

Ahmed (1991) surveyed some areas in the Sudan which could be adapted to drip irrigation for their soil characteristics and lack of water as Northern State, North of Kordufan and Darfour to produce valuable crops.

Until recently the only irrigation method practiced in the Sudan is the surface irrigation where irrigation efficiency is low due to losses by run-off, deep percolation and over irrigation. This low efficiency leads to high cost of irrigation and water shortage. Also the labour cost of irrigation is very high compared with modern systems of irrigation such as drip irrigation system which has a high efficiency and minimum water losses.

Recently drip irrigation system has introduced in limited areas in the Sudan in the Farm of the Arab Company for Agricultural Production and Processing (Sudan), LTD at Oumdoum and Gandil Agricultural Company for dates palm and citrus production in the River Nile State. There is no much information about the system performance. This study is therefore, attempting to undertake research leading research project to evaluate the performance of the drip irrigation system under Oumdoum conditions. Therefore the objectives of this study were:

1. Estimation of reference crop evapotranspiration (ET_o) and tomato crop evapotranspiration (ET_c) grown in Oumdoum

project under drip irrigation system using Penman-Montieth method.

2. Evaluation of the performance of the drip irrigation system.
3. Evaluation of existing irrigation management practices at the farm.

CHAPTER TWO

LITERATURE REVIEW

2.1. General

Water is increasingly becoming a scarce resource. If farmers want to ensure their survival into the future, they must employ and adhere to stringent water conservation methods, (Arid land Technologies, 1998). A late estimate made by FAO (1993) for average irrigation water utilization showed that farm distribution losses constitute 15 percent of irrigation water, while field application system losses constitute 25 percent, irrigation system losses 15 percent and the water effectively used by crops constitutes only about 45 percent.

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 are not adequate to meet the moisture requirements of crops and irrigation is essential to raise necessary crops to meet the human need of food and fibre (Michael, 1978).

2.3. Irrigation Methods

Irrigation water may be applied to the crop by:

1. Flooding it on the field surface (Surface irrigation).
2. Applying it beneath the soil surface (Subsurface irrigation).

3. Spraying it under pressure (sprinkler).
4. Applying it in drops (trickle or drip irrigation).

2.3.1. Surface irrigation:

In surface irrigation water is applied directly to the soil surface from a channel at the upper reach of the field. Water may be distributed to the crop by any of the following systems as stated by Michael (1978):

a. Border strips.
b. Check basin.
c. Furrows.

2.3.2. Sub - irrigation

Water is applied below the ground surface. Water reaches the plant roots through the capillary action. Water may be introduced through open ditches or under ground pipelines (Michael, 1978).

2.3.3. Sprinkler irrigation

By sprinkler system water is sprayed in the air and allowed to fall. The spray is developed by the flow of water under pressure through nozzles (James, 1988).

2.3.4. Drip or trickle irrigation

Is one of the recent methods of irrigation which is becoming increasingly popular in areas with water scarcity and salt problems. It is a method of watering plants frequently and with volume of water approaching the consumptive use of the plant and would minimize such conventional losses as deep percolation, runoff and soil water evaporation (Michael, 1978).

2.4. Historical Background

Drip irrigation is described as the frequent slow application of water to soil through mechanical devices called emitters or applicators located at selected points along the water delivery lines (Howel, *et al.* 1980). Drip irrigation is sometime called trickle irrigation, a name suggested by the American society of Agricultural Engineers (ASAE, 1983), or localized irrigation, a name recommended by Food and Agriculture Organization (FAO, 1980). Originally, drip irrigation was developed as a subsurface irrigation system applying water beneath the soil (Davis, 1974). The first such experiment 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 pipe was 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).

2.5. Advantages of drip irrigation

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

a- Increased beneficial use of available water:

The primary reasons given for the water savings include irrigation of a smaller portion of the soil volume, decreased surface evaporation, reduced irrigation run off from the field and controlled deep percolation losses below the crop root–zone (Bucks *et al*, 1982).

Gruz and Auglto (1988), compared a well-designed drip irrigation system with conventional methods of irrigation in cotton fields in terms of water saving. Results showed that about 30% irrigation water can be saved through the use of well designed drip systems.

b- Enhanced plant growth and yield:

Wang *et al*. (2000) studied the interactive effect of soil water and temperature regimes in drip and sprinkler irrigation. They found that soil temperature was significantly higher in the drip than in the sprinkler plots, which led to a higher emergence rate and enhanced seedling growth.

c- Possible use of saline water:

Drip irrigation applies frequent light irrigations and this holds the salt concentration in the soil water to a minimum. Daily application and sufficient leaching keep the salt concentration in the soil water at almost the same level as in the irrigation water. This concentration can be held below damaging level (Haq, 1991).

d- Improved fertilizer and other chemicals application:

Drip irrigation offers considerable flexibility in fertilization (Howell *et al.* 1980). Frequent or nearly continuous application of water is feasible and appears to be beneficial for crop production. Beside fertilizers, other chemicals such as herbicides, insecticides, fungicides and carbon dioxide can be supplied to improve crop production using drip irrigation system (Bucks *et al*., 1982).

e- Limited weed growth:

Weed infestation may be reduced under drip irrigation because only a fraction of the soil surface is wetted (Shoji, 1977). Tabsh (1988) found the best results of weed control on green house tomatoes similar to hand weeding when he applied herbicides through drip irrigation system.

f- Reduction of labour expenses:

Drip irrigation system can be easily automated where labour is limited or expensive. AL- Amoud (1991) developed in Saudi Arabia a closed loop of remote sensing and control system for automatic drip irrigation system scheduling. The results showed that the system is an effective way of saving water, energy and labour requirements.

g- Decreased energy requirements:

Drip irrigation has a potential for reducing pumping energy cost, since operation pressures are considerably lower compared to other types of pressurized systems (Michael 1978)

h- Improved cultural practices:

Continuous cultural operations such as spraying, weeding, thinning and harvesting of plantss as row crops are possible without interrupting the drip cycle for prolonged periods of time (Haq, 1991).

i- Improved root penetration:

In some soils where root penetration is minimal or impossible at low moisture content, high soil moisture content maintained with drip system can alleviate this problem (Haq, 1991). Mannini *et al*. (1996) found that drip irrigated plants had the most developed roots in weight, length and density compared with sprinkler irrigated plants.

j- Better use of poor soils:

Vermeiren and Gobling (1980) reported that very heavy soils with infiltration rates of 0.2 to 0.5 cm/h could be difficult to irrigate by sprinkler methods. Furthermore, very light soils can not be successfully irrigated by surface methods. Drip irrigation system has been successfully used in both types of soils.

2.6. Disadvantages and potential problems of drip irrigation system

a- Sensitivity to clogging:

Clogging of the small conduits and openings in the emitters is the most serious problem. Sand and clay particles, debris, chemical precipitation and organic growth can block flow from emitters (Hansen *et al.,* 1980). Clogging will adversely affect the rate and uniformity of water application (Nakayama and Bucks, 1981), increases maintenance cost and results in crop damage and decreases yield.

The preventive maintenance (including filtration, flushing drip lines and field inspection) is probably the most effective solution to emitters clogging.

b- Salt accumulation near plant:

Accumulation of salts could be a problem if seeds are sown in zones of high salt concentration from the previous row crop (Bucks *et al*., 1982) or irrigated with saline water (Keller, 1991). Extensive leaching may be necessary before the next crop is planted (Davis, 1975).

c- Restricted soil water distribution and plant root development:

Because drip irrigation normally wets only part of the soil root volume, development of crop root system is limited to the area of moisture surrounding each emitter or along each line (Bucks *et al.,* 1982). So distribution of emitters should be a major consideration in the design process, since it is difficult to make later.

d- Economic and technical limitations:

Since equipment required for a drip irrigation system are numerous, initial investment and annual costs may be high (Schwab, *et al.,* 1981). A higher level of design, management and maintenance is required with drip than other irrigation methods. For this problem Polack *et al.,* (1997) suggested a low cost drip irrigation system for small farmers in developing countries. They made dripper lines moveable, so that each line reaches ten rows, and replaced emitters with holes punched by a heated needle and cloth filters in place of expensive filter systems. They tested it in many areas and found that the uniformity of flow from emitters was 73- 84%. Also small farmers reported that the low cost drip system cut labour requirement by half and doubled the area irrigated by the same amount of water.

e- Soil erosion:

With drip system the part of the soil surface which does not receive water may result in dust formation during mechanical operations. The dry soil may also be more susceptible to wind erosion.

f- Drip damage:

The plastic pipes of drip system are susceptible to damage by animals, rodents, coyotes, dogs, etc.

2.7. Components of drip irrigation system:

Drip irrigation uses small diameter plastic pipes or tubes with water emission devices at necessary spacing to deliver water to the soil near plants (Braud and Soon, 1981). As shown in Fig. 2.1 the primary components of drip irrigation system are:

1. Pump unit: The pump unit takes water from the source and provides the right pressure for delivery into pipe system.

2. Control unit: Filters, pressure regulators, flushing valves, time clock and automating control devices are desirable components of control unit. A filter is the most important component of the drip system because of emitter clogging (Bucks *et al.,* 1982).
3. Main, Submain and lateral lines to which the emitters are attached. These supply water from the control head into the field. These are usually made of black polyvinyl chloride (PVC) or polyethylene hose. The PVC material is preferred for drip system as it withstands saline water and is also not affected by chemical fertilizers.
4. Emitters: These are devices used to control water flow from the lateral line into the soil. They vary in types from porous wall (line source) units to individual (point source) units. Emitters decrease the pressure from the inside to the outside of lateral and allow water to emerge as droplets. Some emitters maintain a steady flow at different pressures by changing the length or cross-section of passageway. These are called pressure–compensating emitters (Tyson and Harrison, 1995).

2.8. Types of drip irrigation systems:

As described by the standards of ASAE (1983), drip irrigation encompasses a number of methods or concepts such as:

1. Surface drip irrigation system.
2. Subsurface drip system.
3. Bubbler irrigation.
4. Spray irrigation.

2.9. Hydraulics of drip irrigation system

2.9.1. Hydraulics of emitters

Emitters are devices, which allow water to flow from the supply lines to the soil. The hydraulic characteristics of the emitter determine the rate of water flow through the emitter (Howell *et al.,* 1980). In general, the equation for drip irrigation emitter flow has been shown by Wu and Gitlin (1974), Howell and Hiler (1974) and Karmeli (1977) to be:

$$Q = K H^x \quad (2.1)$$

Where:

Q = emitter flow (l/h).

K = numerical constant for the emitter.

H = pressure head at the emitter (m).

X = emitter discharge exponent.

2.9.2. Manufacture's variation

Some variation always exists between supposedly identical objects. The simulation in drip irrigation is such that emitter to emitter manufacturing differences are not negligible (Solomon, 1979). The manufacturer's coefficient variation of emitter is a term used to designate the anticipated variation in discharge of sample of new emitters when operated at any given pressure head.

The manufacturer's variation is determined from the statistical equation expressed by Wu and Gitlin (1979):

$$V_m = S_q/q_{ave} \quad (2.2)$$

Where:

V_m = manufacturer coefficient variation of emitter flow

S_q = standard deviation of emitter flow

q_{ave} = mean of emitter flow .

Wu and Gitlin (1979) reported that, the manufacture's coefficient of variation of emitter flow will be reduced if a number of emitters can be grouped and considered as a unit.

2.9.3. Hydraulics of lines (Lateral, submain and mainline)

The total discharge in the distribution networks (laterals, sub mains and mainlines) decreases with respect to distance from the pump (Wu and Gitlin, 1979). The laterals and submains have similar hydraulic characteristics and are designed to maintain a small pressure variation along the lateral line. The main line is designed in terms of input pressures and minimal required pressures at any submain line (Howel *et al.,* 1980).

Drip irrigation distribution lines are normally considered to be smooth pipes and either the Darcy–Weisbach or Hazen–William's equations can be used to compute friction losses for the pipe lines.

1. The Darcy – Weisbach equation is:

$$H_f = 6.38 \ f \ L \ D^{-5} \ Q^2 \quad (2.3)$$

Where:

H_f = the pipe friction loss (m).

L = the pipe length (m).

D = the inside diameter (mm).

f = a dimensionless friction factor.

Q = pipe flow rate (l / h).

An acceleration of gravity of 9.81 m/sec^2 was assumed in this equation. Watters and Keller (1978) proposed a simplified form of Darcy-Weisbach equation as:

$$H_{f} = 0.465\ LD^{-4.75}\ Q^{1.75} \qquad (2.4)$$

This equation incorporates a friction factor estimated from the Blasius equation for smooth pipes with water temperature of 20 Cº.

2. The empirically developed Hazen – Williams equation is:

$$H_f = 0.628\ LD^{-4.865}\ (100\ Q/C)^{1.852} \qquad (2.5)$$

Where:

C = a dimensionless pipe roughness factor.

Hazen–Williams equation is widely used because of its simplicity, although it has no correction for viscosity.

Howell *et al.* (1980) suggested that the best C values for drip irrigation systems were C = 130 for 13-14mm pipe, C = 140 for 18-19mm pipe and C= 150 for 25-27mm pipe. A low estimate of C will overestimate the friction loss, whereas a high estimate will result in a more conservative friction loss for design purposes.

2.10. Uniformity of drip system

The purpose of drip irrigation is to apply water to the base of the plants in frequent low volumes in an attempt to meet their consumptive use. With this purpose in mind, it is essential that the emitter flow variation and the uniformity of water distribution be known, particularly since irrigation time and rate are ultimately based upon these variables.

The uniformity coefficient is a quantitative evaluation of the emitter flow variation (Howell *et al.,* 1980). Nakayama *et al.* (1979) found the uniformity of emitters to be approximately:

$$E_u = I - (0.8\ C_v/n^{0.5}) \quad \text{..} \quad (2.6)$$

Where:

E_u = emission uniformity.

C_v = manufacturer's coefficient of variation.

n = number of emitters per plant.

Whereas for field tests E_u is stated as:

$$E_u = 100\ q_n / q_{ave} \qquad (2.7)$$

Where:

q_n = average rate of discharge of the lowest one – fourth of the field data emitters discharge reading (l/h).

q_{ave} = average discharge rate of all the emitters checked in the field (l / h).

The major factors affecting the uniformity of flow rates from emission devices are the designed emitter characteristics, pressure difference in the system due to friction losses, elevation differential and clogging (Solomon, 1979).

2.11. Soil moisture content

The soil moisture measurement and capacity of soils to store water is important to verify that the proper amount of water is being applied (Zoldoske *et al.,* 1990). It is expressed by a given amount of water contained in a unit mass or volume of soil or by stress or tension under which the water is held by the soil (Michael, 1978).

The common methods used for soil moisture measurement are:

1- Soil feel test.
2- Gravimetric method.
3- Tensiometers.
4- Electrical resistance blocks.
5- Neutron probe method.

2.11.1. Classes of soil moisture content

a- Field capacity:

Field capacity of the soil is the moisture content after drainage or gravitational water has become very slow and the moisture content has become relatively stable (Michael 1978). In practice field capacity is usually determined 2-3 days after irrigation by measuring soil moisture content (Hansen *et al.,* 1980). The moisture tension at field capacity ranges from 1/20 to 1/3 bar for sandy and clay soils, respectively.

b- Permanent wilting point:

Permanent wilting point is the soil moisture content at which plants can no longer obtain enough moisture to meet transpiration requirement (Michael, 1978). The moisture tension of soil at the permanent wilting point is generally considered to be 15 bars (Hansen *at al.,* 1980).

c- Available moisture :

Available moister is the difference in moisture content between field capacity and permanent wilting point. It represents the moisture which can be stored in the soil for use by plant. Available moisture can be expressed as percentage moisture, percentage volume and depth.

2.11.2. Soil moisture related to drip system

The distribution pattern of soil water resulting from trickle sources can be very different from those resulting from more conventional modes of irrigation. The volume of soil wetted by a single emitter has the most important consideration in design of drip system. This must be known in order to determine the total number of emitters required to wet a large enough volume of soil to ensure that the plant water needs are met.

2.12. Drip and plant rooting

Oliveira *et al.* (1996) studied tomato root distribution under drip irrigation where he found that the largest proportion of tomato roots was found in the top 40cm of the soil and rapidly decreased with depth. Most roots occurred in the emitter area. Also Vidhana (1998) found that 70–80% of roots were concentrated at a depth ranging from 20–100cm, with 5% of the roots beyond 100cm and 15-20% of the roots in the top layer (0-20cm) in coconut crop in gravelly soil under drip irrigation.

2.13. Drip irrigation system design

Drip irrigation systems are usually designed and managed to deliver frequent light application of water and to wet only a portion of soil surface.

A reasonable design objective for widely spaced crops such as plants is to wet at least one–third and as much as one–half of the potential horizontal cross-sectional area of the root system. However, in closely spaced crops with rows spaced less than 1.8m apart, the percentage of the wetted area often reaches 100% (Keller, 1991).

2.13.1. Crop water requirement

The crop water requirement (CWR) is defined as the depth of water needed to meet the water losses through evapotranspiration (ET_c) of a disease–free crop growing in large field under optimal soil conditions including water and fertility, and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977).

While reference crop evapotranspiration (ET_o) is defined as the rate of evapotranspiration from an extensive surface of 8 to 15cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water.

Adam and Farbrother (1977) stated that the crop water requirement is a complex function involving a large number of parameters concerning the weather , the status of available soil moisture , and the growth and development of the crop itself .

Crop water requirement which is equal to ET_c can be calculated according to the following equation:

$$ET_c = ET_o \times K_c \quad \text{..........}(2.8)$$

Where:

ET_c = Crop Evapotranspiration (mm/day)

ET_o = Reference crop Evapotranspiration (mm/day)

K_c = Crop coefficient

Reference crop evapotranspiration (ET_o) can be calculated according to the following Penman–Monteith formula as stated by Smith *et al*. (1991):

$$E\,T_o = \frac{0.408\Delta(Rn - G) + Y\dfrac{900}{T+273}U_2(ea - ed)}{\Delta + Y(1 + 0.34U_2)} \quad \text{..........}(2.9)$$

Where:

$E\,T_o$ = Reference crop evapotranspiration (mm day^{-1}).

Rn = Net radiation at crop surface (Mj m^{-2} day^{-1}).

G = Soil heat flux (Mj m^{-2} day^{-1}).

T = Average temperature at 2m height.

(ea–ed) = Vapor pressure deficit for measurement at 2m height.

U_2 = Wind speed at 2m height (m s^{-1}).

Δ = Slope of vapor pressure curve (K Pa ̊C).

Y = Psychometric constant (K Pa ̊C).

900 = Coefficient for the reference crop (Kj Kg day^{-1}).

0.34 = Wind coefficients for the reference crop (S m^{-1}).

The crop coefficients reflect the physiology of the crop, the degree of crop cover, and the reference evapotranspiration and they are empirical ratios of crop evapotranspiration (ET_c) to reference evapotranspiration (ET_o) (Burman, 1979).

2.13.2. The net crop water requirement (NCWR)

The net crop water requirement is the amount of water needed to supplement the effective rainfall in the crop root zone. Effective rainfall is the portion of rainfall that contributes to meet the evapotranspiration requirement of a crop (Hershfield, 1964).

In order to determine the effective rainfall, four different equations can be used as suggested by Smith *et al.* (1991) and FAO (1992):

1. Fixed percent of rainfall:

$$Pe = a \times P_{tot} \qquad (2.\ 10)$$

Where:

a = fixed percentage that accounts for losses from rainfall and deep percolation.

Pe = effective rainfall (mm / month).

P_{tot} = total rainfall in a given month (mm / month).

2. Dependable rainfall:

$$Pe = 0.6 \times P_{tot} - 10 \quad (2.11)$$

(For $P_{tot} \leq 70$ mm)

$$Pe = 0.8 \times P_{tot} - 24 \quad (2.12)$$

(For $P_{tot} \geq 70$ mm)

Where:

Pe and P_{tot} = are as defined before.

3. Empirical formula:

$$Pe = a \times P_{tot} + b \quad (2.13)$$

(For $P_{tot} \leq Z$ mm)

$$Pe = c \times P_{tot} + d \quad (2.14)$$

(For $P_{tot} \geq Z$ mm)

Where:

Pe and P_{tot} = are as defined before.

a, b, c and d = are correlation coefficients.

Z = is an empirically defined value of target rainfall characterizing the study locality.

4- USDA soil conservation services method:

$$Pe = P_{tot} (125 - 0.2 P_{tot}) / 125 \quad (2.15)$$

(For $P_{tot} \leq 250$ mm)

$$Pe = 125 + 0.1 P_{tot} \quad (2.16)$$

(For $P_{tot} \geq 250$ mm)

Where:

Pe and P_{tot} = are as defined before.

2.13.3. Gross irrigation requirement (Ig)

Irrigation requirement is the depth or volume of irrigation water required over the whole cropped area excluding contribution from other sources, plus water loss or operational wastes (Vermeiren and Gobling, 1980).

$$Ig = \frac{In}{Ea} + Lr \qquad (2.17)$$

Where:

Ig = gross irrigation water requirement (L).

In = net irrigation water requirement (L).

Ea = application efficiency (decimal)

Lr = extra amount of water needed for leaching (L).

2.13.4. Irrigation efficiency for drip system

Irrigation efficiency is defined as the ratio of the quantity of water effectively put into the crop root zone and utilized by growing crops to the quantity delivered to the field (Bos and Nugteren, 1990).

The overall application efficiency of drip irrigation (Ea) may be defined as stated by Vermeiren and Gobling, (1980) as follows:

$$Ea = Ks\ Eu \qquad (2.18)$$

Where

Ks = ratio between water stored in soil and that from field, expresses the water storage efficiency of the soil. It takes into account unavoidable deep percolation as well as other losses.

Eu = coefficient which reflects the uniformity of application.

2.13.5. Depth of water to be applied by irrigation

It is the amount of irrigation water required to bring the soil moisture content level in the effective root zone to field capacity. Vermeiren and Gobling (1980), proposed an equation to calculate the depth, considering that only part of the soil volume is to be wetted by drip irrigation as follows:

$$d = 10\,(FC - PWP) \times D \times Z \times P \qquad (2.19)$$

Where:

d = maximum amount (depth) of water to be applied (mm).

FC = field capacity (cm/m).

PWP = permanent wilting point (cm/m).

D = the root zone depth (m).

Z = the moisture depletion percentage allowed or desired (decimal).

P = the volume of soil wetted as a percentage of total volume (decimal).

As a general rule the allowable moisture depletion is often taken as 0.3 for drought- sensitive crops and up to 0.6 for non- sensitive crops (Vermeiren and Gobling, 1980).

The percentage of the wetted area (P) normally varies between 30–60% depending on the crop and its age. It will be larger for mature crops and crops with relatively close row spacing. For widely spaced crops such as vines, bushes and plant crops, 30 to 60% of the horizontal cross section of the root system should be irrigated to keep the surface area between rows relatively dry. The term (P) often approaches 100 percent for crops spaced less than 1.8m apart (James, 1988; Keller, 1991).

2.13.6. Irrigation set time

It is the time required to apply an irrigation. Vermeiren and Gobling (1980), stated that the estimation of the maximum time of application is based on providing water for the plant when it can use it.

$$T = \frac{ETc \times Se \times Sl \times k}{E \times Q} \quad \text{...} \quad (2.20)$$

Where:

T = irrigation set time (h).

ET_c = crop evapotranspiration (mm / day).

Se = emitter spacing along the lateral (m).

Sl = lateral spacing (m).

E = emitter efficiency (%) or (decimal).

Q = emitter discharge (L/h).

k = constant (In metric system = 1).

2.13.7. Emitter Spacing

Spacing between emitters depends on the volume of soil wetted per single emitter .Keller (1991) suggested the following equation to calculate spacing between emitters:

$$Se \leq 0.8\ dw \qquad (2.21)$$

Where:

Se=emitter spacing (m).

dw =soil surface wetted diameter (m).

2.13.8. Number of emitters per plant

James (1988) suggested an equation to calculate the number of emitters per plant as follows:

$$N = (1000\ P\ S\ L) / (dw\ Se) \qquad (2.22)$$

Where:

N = number of emitters per plant or emission points.

dw =maximum diameter of wetted circle formed by a single point emitter (cm).

Se = spacing between emitter (cm).

P = percentage of wetted area (decimal)

S = Spacing between emission points (m)

L = Spacing between plant rows (m)

2.13.9 System Capacity (Q)

System capacity depends on the irrigation application rate, time of irrigation and interval of irrigation (Wu, 1975). A simple equation stated by Wu and Gilitin (1975) could be used to calculate the system capacity as follows:

$$Q = \frac{Ig \times A}{T} \qquad (2.23)$$

Where:

Q = drip irrigation system capacity (m^3/h).

Ig = gross irrigation water requirement (m).

A = the global area to be irrigated (m^2).

T = irrigation time (h).

CHAPTER THREE

MATERIALS AND METHODS

Experiments were carried out during the period from May 2002 to October 2002 to evaluate the performance of a drip irrigation system located at Oumdom (Eastern Nile Locality). The field work which included determination of soil texture, soil bulk density, infiltration rate, field capacity and permanent wilting point was carried out. System variables tested were uniformity of distribution, emitters discharge rate, depth of water applied, volume of water applied, duration of irrigation, discharge and pressure variation and losses of water. Crop grown was Tomato and reference crop evapotranspiration and crop water requirements were also determined.

3.1. Location

The field was located at Oumdom area on the eastern bank of the Blue Nile, 35 km East of Khartoum, (Latitude 15^{o} $4^{\backslash}$ N and Longitude 32^{o} $32^{\backslash}$ E).

3.2. Soil Bulk Density

The soil bulk density was determined using the clod method described by Black (1965). Two locations were selected for soil sampling. Five soil samples were taken from each location from depths 0-20, 20-40, 40-60, 60-80 and 80-100cm. The clods were then coated with Paraffin wax. The clods were weighed in the air and weighed again when immersed in water.

The following formula was used for computing bulk density of the soil:

$$Bp = \frac{W}{\frac{W_a - W_w}{D_w} - \frac{W_a - W}{D_c}} \quad \text{.......................... (3.1)}$$

Where:

Bp = bulk density of soil (gm/cm^3),

W = weight of soil sample before coating (gm),

W_a = weight of soil sample coated with wax in air (gm),

W_w = weight of soil sample coated with wax in water (gm),

$D_{w:}$ = density of water (taken as 1.0 gm/cm^3),

$D_{c:}$ = density of Paraffin wax (taken as 0.9 gm/cm^3).

3.3. Soil Mechanical analysis

Three locations were selected to represent the soil under study. Five soil samples were taken from each location from depths 0-20, 20-40, 40-60, 60-80 and 80-100 cm. Soil texture was determined using the hydrometer method describe by Black, (1965).

3.4. Infiltration characteristics

Two representative sites were selected for measuring infiltration rate using the double-ring infiltrometer. The infiltrometer consisted of two cylinders made of 2mm rolled steel. Each cylinder was 25cm high. The inner cylinder from which the infiltration was measured was 30cm in diameter. The outer cylinder which acted as a buffer pond was 60cm in diameter. The cylinders were installed about 10cm deep in the soil. The cylinder was driven into the ground by using a hammer and a wooden plank to prevent damage to the edges of the cylinder. A plastic sheet was used to cover the soil surface confined by the inner cylinder before filling with water and starting reading. Readings were taken at 10 min. interval until a constant infiltration rate was reached. Then the data was tabulated and the average infiltration rate in cm/hr was determined.

3.5. Field Capacity and Permanent Wilting Point

Using a pressure plate equipment, the field capacity (FC) and permanent wilting point (PWP) were approximated as the moisture contents retained at 1/3 and 15 bars, respectively.

Soil samples were collected using an auger (7.5cm dia.) from three locations at depth intervals of 0.00-0.20, 0.20-0.40 and 0.40- 0.60m. The samples were dried, crushed, passed through 2mm sieve and used for determining FC and PWP. Available water was determined as the difference between field capacity and permanent wilting point (FC – PWP).

For each depth the mean soil moisture content at FC and PWP were determined by gravimetric method and averaged to represent FC and PWP.

3.6. Crop water requirement (CWR)

Crop water requirement was calculated according to the following equation:

$$ET_c = ET_o \times K_c \text{.......................(2.8)}$$

Where:

ET_c = Crop water requirement (mm/day)

ET_o = Reference crop evapotranspiration (mm/day)

K_c = Crop Coefficient.

Reference evapotranspiration (ET_o) was calculated according to Penman-Montieth formula as stated by Smith *et al.,* (1991) equation (2.8).

The following formula was used to adjust wind speed data from 20m high to standard height of 2 m:

$$U_2 = U_z \frac{4.85}{\mathrm{In}\left[\frac{Zm - 0.08}{0.015}\right]} \text{ .... (3.2)}$$

Where:

U_z = Mean wind speed measurement at height Z (m/sec);

U_2 = Mean wind speed measurement at 2 m height (m/sec).

Z_m = Height at which wind speed was measured (m).

The ET_o data for 30 years from 1971 to 2000 were computed by CROPWAT programme model (5.7) as described in FAO irrigation and drainage paper No. (46) using the mean meteorological data, based on Penman-Montieth equation (Smith *et al.,* 1991).

The crop water requirement for each month was calculated using the following equation:

$$CWR = ET_c \times \text{days of the month} \qquad (3.3)$$

Where:

ET_c = crop water requirement (mm/day).

3.7. The net crop water requirement (NCWR)

The net crop water requirement was calculated by subtracting the monthly effective rainfall (ERF) as :

$$NCWR = CWR - ERF \qquad (3.4)$$

The effective monthly rainfall (EFR, mm) was calculated from the total rainfall (TRF, mm) according to the following USDA soil conservation service (FAO, Doorenbos *et al*., 1986) empirical relationships, equation (2.14).

3.8. Emitters discharge rate

The discharge Q from 84 emitters randomly selected from different 84 laterals was measured using catch cans, a measuring cylinder and a stopwatch. The pressure was adjusted at 1 bar over all laterals.

3.9. The uniformity of the system

The discharge from 84 emitters (randomly selected) was used to test the uniformity of the system.

The uniformity of the system (E_u) was then calculated using the following formula:

$$Eu = 100\ qn/qave \quad (2.7)$$

3.10. Discharge variations

The average discharge Q of 12 emitters representing the beginning, middle and tail of the sub-main and lateral lines of the system were measured. The average values were computed in l/h and tabulated.

3.11. Pressure variations

The pressures at the beginning and at the end of the main, sub-main and lateral lines were determined using a pressure gauge. The values obtained were tabulated.

3.12. Depth of water applied (d)

The total amount of water applied to the root zone was determined using the equation (2.19).

3.13. Volume of water applied

The volume of water applied was determined by multiplying the depth of water applied by the area assigned to each plant.

3.14. Duration of irrigation (T)

The duration of irrigation was calculated by dividing the volume of water applied by the flow rate of the system.

3.15. Specification of the drip system

3.15.1. Equipment

a. Well and tank:

The drip under study was provided by water from a well in the farm. The water was pumped from the well to a storage tank (Plate 3.1). The storage tank was elevated 12m from the ground surface and its capacity was $54m^3$.

Plate (3.1): The tank

b. The pump unit:

A centrifugal pump driven by an electric motor (7.5kw) was used to draw irrigation water from the storage tank to supply the system. This setup gave a pressure of 3 bars in the main line (Plate 3.2).

c. Control unit:

The control unit consisted of the following (Plate 3.3):

1. Discharge valve to control the water moving in the system.
2. Pressure-reducing valve to control the pressure in the system.
3. Cleaning or flushing valve.
4. Execution valve.

d. Filtration (protection) system:

There were three types of filters in the system (Plate 3.4) as follows:

1. Screen filter.
2. Sand filter.
3. Disc filter.

e. The main line:

The main pipe line was made from polyvinyl chloride (PVC). The PVC pipe was buried under ground at a depth of 75cm to be protected from direct sunlight. The main line was 200m long and 75 mm (3") diameter (Plate 3.5 and Appendix A).

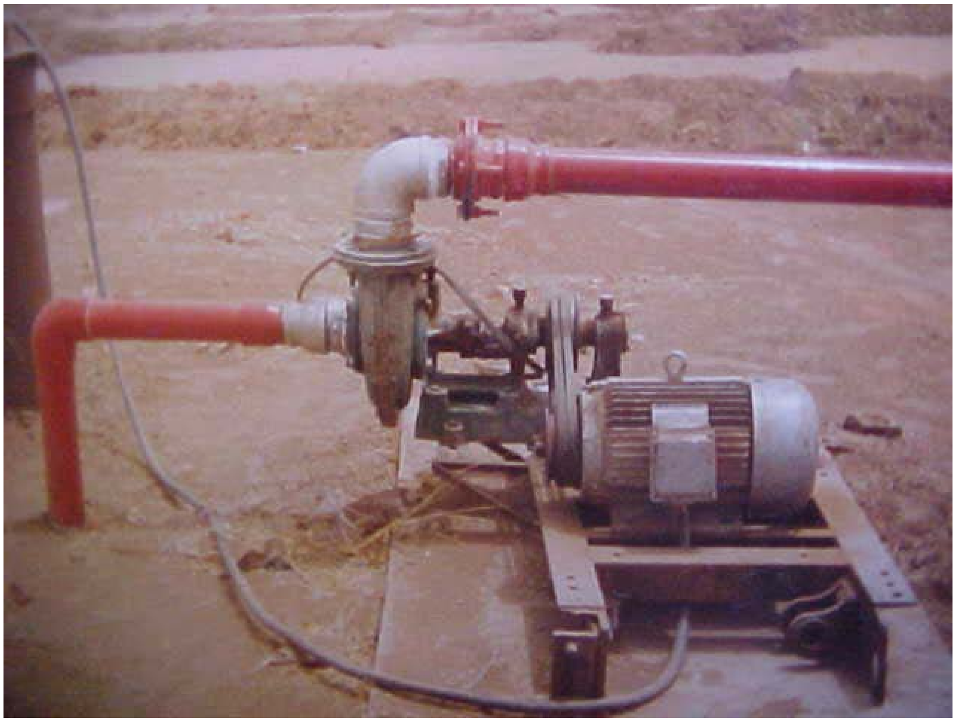

Plate (3.2): The pump unit

Plate (3.3): The control unit

Plate (3.4): The filtration system

Plate (3.5): The main line

f. Submain lines:

The sub-main pipe lines were also made from polyvinyl chloride (PVC). Two sub-mains (each 21m long and 50mm (2") in diameter) spaced 100m apart were fixed in each feddan. The sub-main pipes were buried under the ground (75cm) to protect them from direct sunlight. A control unit was fixed to each sub-main (Plate 3.6 and Appendix A).

g. The lateral lines:

The lateral pipes were made of black linear low density polyethylene (LLDPE). 56 laterals, each 50m long and 16mm inside diameter (28 laterals from each sub-main) were joined to the sub-main at 1.5m spacing between laterals using the straight connectors in each of the 7 feddans under the drip system (Plate 3.7 and Appendix A).

h. Emitters (drippers):

Individual or point source type emitters were used in this system. In three feddans emitters were fixed in each lateral with 30cm plant spacing and in another set of three feddans emitters were fixed in each lateral with 40cm plant spacing but in the last feddan emitters were fixed with 50cm plant spacing (Plate 3.8 and Appendix A).

Plate (3.6): The submain line

Plate (3.7.1): The lateral lines

Plate (3.7.2): The lateral lines

Plate (3.8): The emitters (drippers)

i. Fertilization unit:

Amiad fertilizer and chemical injectors were used in the drip system to supply fertilizers, herbicides, insecticides, fungicides, trace elements, nutrient solutions and acids with frequent or nearly continuous application along with irrigation water.

The fertilizer and chemical injectors contained a linear hydraulic motor powered by the hydraulic pressure of the irrigation system (Appendix B).

CHAPTER FOUR

RESULTS AND DISCUSSTION

4.1 soil physical properties

4.1.1 Soil textural class

Table 4.1 shows the percentage particle size distribution for increments of 0.20m down the soil profile to 1m depth. Clay percentage was found to increase with depth ,while silt percentage decreased with soil depth. Sand percentage was found to vary with location. According to the United States Department of Agriculture Soil Textural Classification Chart, the soil can be classified as sandy clay loam. This agrees with the results obtained by El Badawi (2001) for the same area.

4.1.2 Soil bulk density

Table 4.2 shows soil bulk density at two sites. The bulk density was found to be relatively constant with depth. The mean bulk density of the soil was found to be 1.54gm/cm^3. This agrees with the results of El Badawi (2001) who worked in the same area.

4.1.3 Infiltration rate

Fig. 4.1 shows that the initial infiltration rate for the two sites was high. This agrees with the results obtained by El Badawi (2001) who found high infiltration rate for the same location.

This indicates that the site under study is more suitable to be irrigated by drip irrigation system than surface irrigation method. Vermeiren and Gobling. (1980) mentioned that drip irrigation system is suitable to soils with high infiltration rates.

Table 4.1. The percentage particle size distribution of the farm of the Arab Company for Agricultural Production and Processing at Oumdom

Sites	Depth (m)	Clay %	Silt %	Sand %	Textural class
1	0.00-0.20	25.1	9.9	65.0	Sand clay loam
	0.20-0.40	26.9	7.2	65.9	Sand clay loam
	0.40-0.60	28.0	3.8	68.2	Sand clay loam
	0.60-0.80	29.2	2.5	68.3	Sand clay loam
	0.80-1.00	30.0	2.0	68.0	Sand clay loam
2	0.00-0.20	20.0	7.1	72.9	Sand clay loam
	0.20-0.40	22.0	5.5	72.5	Sand clay loam
	0.40-0.60	23.1	4.8	72.1	Sand clay loam
	0.60-0.80	24.8	3.3	71.9	Sand clay loam
	0.80-1.00	25.5	3.0	71.5	Sand clay loam
3	0.00-0.20	20.0	7.0	73.0	Sand clay loam
	0.20-0.40	22.0	6.9	71.1	Sand clay loam
	0.40-0.60	23.0	6.5	70.5	Sand clay loam
	0.60-0.80	25.0	5.0	70.0	Sand clay loam
	0.80-1.00	26.0	4.5	69.5	Sand clay loam

Table 4.2. The bulk density of two sites of the farm at the Arab Company for Agricultural Production and Processing at Oumdom

Sites	Depth (m)	Bulk density (gm/cm^3)
1	0.00-0.20	1.52
	0.20-0.40	1.52
	0.40-0.60	1.52
	0.60-0.80	1.52
	0.80-1.00	1.52
2	0.00-0.20	1.56
	0.20-0.40	1.56
	0.40-0.60	1.56
	0.60-0.80	1.56
	0.80-1.00	1.58
Mean		1.54 gm/cm^3

4.2 Field capacity

Table 4.3 shows that the field capacity value of the experimental site decreases with increase in depth. The mean field capacity was found to be 28% on volume basis (θv%). This result falls in the same range mentioned by Michael (1978) for sandy clay loam soils and agrees with the results obtained by Ahmed (2002) for the same type of soil (sandy clay loam).

4.3 Permanent wilting point (PWP)

Table 4.3 shows that the permanent wilting point value of the experimental site decreases with increase in depth. The mean permanent wilting point on volume basis (θv%) was found to be 20%. This agrees with the results obtained by Ahmed (2002) for the same type of soil (sandy clay loam).

4.4 Available water (AW)

Table 4.3 shows that the available water values of the experimental site increases with increase in depth. The mean available water on volume basis (θv%) was found to be 8% (FC – PWP). This means that the total available water on depth basis for 1m root – zone depth is 8cm/m. The readily available water (RAW) will be a fraction of the available water. This situation necessitates frequent irrigation or short irrigation intervals which is quite suitable to drip irrigation system as stated by Vermeiren and Gobling (1980).

Table 4.3. Moisture content at field capacity, permanent wilting point and available water on volume basis (θv%)

Depth (m)	FC (θv%)	PWP (θv%)	AW (cm/m, θv%)
0.00-0.20	29	22	7
0.20-0.40	28	20	8
0.40-0.60	27	18	9
Mean	28	20	8

4.5 Crop water requirement (CWR)

Table 4.4 shows the mean climatic data for 30 years from 1971 to 2000 (Appendix C) and the reference crop evapotranspiration (ET_o) calculated from data.

The results revealed that the mean reference crop evapotranspiration (ET_o) for six months (May, Jun., Jul., Aug., Sep. and Oct.) was found to be 7.9 mm/day.

Table 4.5 shows the calculated tomato crop water requirement for six months which was the length of the growing season. The results revealed that the mean crop water requirement (ET_c) was 4.7 mm/day and the mean monthly crop water requirement was 144.7 mm/month.

Table 4.6 shows the mean monthly data of the total rainfall (TRF) for 30 years from 1971 to 2000, the mean monthly effective rainfall (ERF) and the net tomato crop water requirement (NCWR) calculated from the total rainfall data. The results revealed that the mean effective rainfall and the mean net crop water requirement for the six months (May, Jun., Jul., Aug., Sep. and Oct.) were found to be 19mm and 127.6 mm for the month, respectively.

4.6 The discharge rate of emitters

Table 4.7 shows the discharge rate of 84 emitters in (l/h) representing emitters of the system. The results revealed that the mean discharge rate of the emitters was found to be 1.8 l/h.

Table 4.4 Mean monthly meteorological data and mean monthly reference crop evapotranspiration

Month	Mean temp. (ºC) (T.max.+T.min.)/2	Relative humidity %	Wind speed at 2m (km/day)	Sun shine (hr)	ET_o (mm/day)
May	34.6	20	231.5	9.8	8.8
Jun.	34.4	26	256.5	8.8	8.8
Jul.	32.3	42	282.5	8.1	7.9
Aug.	31.6	48	256.5	8.5	7.2
Sep.	32.5	41	231.5	8.8	7.3
Oct.	32.6	29	206.0	9.7	7.2
Mean	33.0	34.3	244.1	9.0	7.9

T. max = maximum temperature (ºC)

T. min = minimum temperature (ºC)

ET_o = reference crop evapotranspiration (mm/day).

Table 4.5. Crop water requirement for tomato crop (May, Jun., Aug., Sep., and Oct.)

Month (days)	ET_o (mm/day)	K_c	ET_c (mm/day)	Month ET_c (mm/month)
May (31day)	8.8	0.6	5.28	163.9
Jun. (30 days)	8.8	0.6	5.28	158.4
Jul. (31 days)	7.9	0.6	4.74	146.9
Aug.(31 days)	7.2	0.6	4.32	133.9
Sep. (30 days)	7.3	0.6	4.38	131.4
Oct. (31 days)	7.2	0.6	4.32	133.9
Mean	7.9	0.6	4.72	144.7

ET_c = Crop evapotranspiration.

ET_o = Reference crop evapotranspiration (mm/day).

K_c = Crop factor (Appendix D)

Table 4.6. Mean monthly meteorological data of the total rainfall (TRF, mm), mean monthly effective rainfall (ERF, mm) and the net tomato crop water requirement (NCWR, mm/month)

Month	The mean monthly total rainfall (TRF, mm)	The mean monthly effective rainfall (ERF, mm)	The mean monthly net crop water requirement (NCWR, mm/month) (ETc – ERF)
May	3.9	3.8	160.1
Jun.	4.2	4.1	154.3
Jul.	29.6	28.2	118.7
Aug.	48.3	44.6	89.3
Sep.	26.7	25.6	105.9
Oct.	7.8	7.7	137.0
Mean	20.1	19.0	127.6

4.7 The uniformity of the system

Table 4.7 revealed that the average discharge rate q_{ave} was found to be 1.8 l/h and the average discharge rate of the lowest one-fourth of the field data q_n was found to be 1.5 l/h. The unifomity of the system was then calculated using equation 2.7 (Appendix E) so the uniformity of the system was found to be 83.3%.

4.8 Discharge variation

4.8.1 Discharge variation in the submain line of the drip system

Table 4.8 shows that the discharge varied from 1.92 l/h at the head of the submain to 1.85 l/h at the middle and 1.84 l/h at the tail or the end of the submain line of the drip system.

The reasons of variation of discharge were due to friction and leakage at some of the connection points which was also stated by Vermeiren and Gobling (1980).

4.8.2 Discharge variation in the lateral lines of the drip system

Table 4.9 shows that the discharge varied from 1.98 l/h at the head of the lateral to 1.88 l/h at the middle of the lateral and 1.82 l/h at the tail or the end of the lateral. The reasons of variation of discharge rate were due to friction and leakage at some emitters of the lateral as stated in section 4.8.1.

Table 4.7. The discharge rate of 84 emitters (l/h)

2.68	2.34	2.34	2.19	2.16	2.16	1.56	1.53	1.77
2.58	2.16	2.1	2.04	2.04	2.04	1.56	1.53	1.53
2.58	2.01	2.01	1.95	1.86	1.74	1.68	1.53	1.71
2.58	2.01	1.98	1.74	1.53	1.50	1.53	1.38	1.41
2.58	1.95	1.53	1.68	1.53	1.77	1.56	1.41	1.56
2.58	1.89	1.68	1.59	1.71	1.50	1.53	1.77	1.53
2.46	1.53	1.50	1.56	1.50	1.68	1.74	1.53	1.53
2.40	1.50	1.80	1.50	1.53	1.50	1.80	1.59	1.53
2.37	1.56	1.56	1.53	1.80	1.53	1.50	1.53	1.74
2.37				1.65				1.53
Mean discharge								1.8 *l/h*

Table 4.8. Discharge variation in the submain of the drip system

Position	At the head of the submain	At the middle of the submain	At the tail of the submain
Discharge rate (l/hr)	1.92	1.85	1.84

Table 4.9. Discharge variation in the laterals of the drip system

Position	At the head of the lateral	At the middle of the lateral	At the tail of the lateral
Discharge rate (l/hr)	1.98	1.88	1.82

4.8.3 The effect of head, middle and tail of the submain and lateral lines on discharge

Table 4.10 shows the results of statistical analysis for discharge rate at the head, middle and tail on both submain and lateral lines using the completely randomized design.

The analysis of the data showed that no significant difference was found ($P \leq 0.05$) in submain line discharge due to the head, middle and tail (special), but highly significant difference ($P \leq 0.01$) was found in lateral line discharge rate due to head , middle and tail (location)(Appendix F).

4.9 The discharge drop in the submain and lateral line

Discharge drop in the submain line of the drip system (difference between discharge at the head of the submain line and discharge at the tail of the submain line) was found to be 4%. This percentage is lower than that allowed for discharge drop of standard design of drip irrigation system which is 10% as stated by Vermeiren and Gobling (1980).

The discharge drop in the lateral line was found to be 8% (Appendix G). This percentage is also lower than that allowed for standard design of drip irrigation system which is recommended (maximum difference of 10%) as stated by Vermeiren and Gobling (1980).

Table 4.10. The average effect of head, middle and tail on lateral and submain lines discharge (l/h)

The reach along the line	Lateral line	Submain line
Head (H)	1.93[a]	1.82[a]
Middle (M)	1.85[b]	1.82[a]
Tail (T)	1.68[c]	1.88[a]
F – calculated	10**	0.2[NS]
LSD	0.09	0.20
CV	5.49%	8.60%

N.S, ** = Not significant and significant at 0.05 level of probability, respectively.

4.10 Pressure variations

Table 4.11 shows the pressure variation between two points. The first and last point of the main, submain and lateral lines of the drip system.

The pressure head varied from 3 bars in the first point of the main line to 2.6 bars at the end point of the main line but in the submain line the pressure varied from 2.4 bars in the first point to 2 bars at the end point of the submain. Pressure head varied from 1 bar at the first point at the lateral to 0.8 bar at the end point of the lateral line.

The pressure variation in the main, submain and lateral lines was found to be 13.3%, 16.6% and 20%, respectively (Appendix H). The pressure variation in the main line (13.3%) and the submain line (16.6%) were lower than the maximum pressure variation allowed (20%). The pressure variation of 20% in the lateral line was equal to the maximum pressure variation allowed. So care should be taken in the design of the system to make pressure variation always less than the 20% as stated by Vermeiren and Gobling (1980).

4.11 Depth of water applied (d)

The depth of water applied was computed according to equation 2.18. The root - zone depth was assumed to be 1.0 m, the depletion factor was assumed to be 0.30 and the wetting ratio assumed to be 0.60 according to Vermeiren and Gobling (1980).

Table 4.11. The pressure variation in the main, submain and lateral lines reach of the drip system

Reach	The pressure at the first point (bar)	The pressure at the end point (bar)	Mean pressure (bar)	Pressure variation (%)
Main line	3	2.6	2.8	13.3
Submain line	2.4	2.0	2.2	16.6
Lateral	1	0.8	0.9	20.0

These values were substituted in the above mentioned equation. The depth of water to be applied per irrigation was found to be 14.4mm which is less than the water holding capacity of the soil. The amount of water to be applied per feddan per irrigation was found to be 60.48m^3 (Appendix I).

4.12 Irrigation management

4.12.1 Duration of irrigation

The irrigation set time for the 2 *l/h* flow rate was calculated using equation 2.19. The irrigation set time for daily frequency was found to be 1 hour (Appendix J). The actual set time by the irrigation manager at Oumdom scheme for daily frequency was 2 hours.

4.12.2 Volume of water applied

The proper volume of water to be applied was 2.1 *l*/day per emitter (Appendix K) while the volume of water actually applied by the irrigation authorities of the farm was 4.2 *l/day* per emitter.

The volume of water to be applied by each emitter was found to be 2.1 *l/h*. This means that to give the required amount of water to irrigate for one hour because in one hour the emitter flow rate was 2 *l/h*.

Also, results showed that the irrigation practices at Oumdom farm over irrigates by an amount of 2.1 *liter* of water per every emitter (100%).

The amount of water which should be applied per irrigation per feddan was found to 19.6m^3, while the amount actually applied per irrigation per feddan was 39.2m^3. So the irrigation authority of the farm over irrigated the farm by 100% (Appendix L)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

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

1. The performance of the drip irrigation system was found to be relatively suitable under Oumdom conditions.
2. Water was applied by the authorities whenever the crop shows signs of water shortage without considering crop water requirement or duration of irrigation.
3. One of the major problems of drip irrigation system evaluated in this study was emitters clogging.
4. The variation between emitters discharge was due to clogging which lowered the distribution efficiency.
5. The water applied by the authority of the project was approximately double the quantity of crop water requirement (CWR) and resulted in over irrigation and consequently water losses.

5.2. Recommendations

From the results and conclusions drawn from this study, the following recommendations can be made:

1. Drip irrigation system can be used efficiently to irrigate crops in the area of the study if proper irrigation water management practices are followed.
2. The crop water requirement should be calculated to reduce water losses through runoff and deep percolation.
3. The duration of irrigation should be calculated to irrigate at the right time.
4. Emitters clogging should be avoided by good filtration of the irrigation water and frequent flushing of the system.

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Appendix (A)

The layout sketch of the drip system

Appendix (F)

The effect of head, middle and tail of the submain and lateral lines on discharge

2.19	**2.19**
2.20	**2.20**
substitute	**substitute**

Appendix (K)

Irrigation management

(2) Volume of water applied:

the volume of water actually applied by the irrigation authorities of the farm was calculated as follows:

Volume of water applied = area of the plant × depth of water applied

Where:

Area of the plant = S_e X S_l = 1.5 × 0.3 = 0.45m^2.

Depth of water applied = ET_c = 4.72 mm/day

These values were substituted in the above mention equation as follows:

Volume of water applied = 0.45 × 4.72 = 2.1 *l/day*

Appendix (L)

Irrigation management

(3) Water losses:

The losses of water per feddan were calculated as follows:

Losses of water in one hour per feddan =

Discharge of emitter in hour X number of emitters per feddan

where:

Field discharge rate of emitter = 2.1 *l/h*.

Number of emitters per feddan = 9333 emitters

These values were substitute in the above mentioned equation as follows:

The water losses per feddan = 2.1 × 9333 = 19599.3 *l/day* = 19.6 m^3/day