بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Agricultural Studies

Department of Agricultural Engineering

Effects of Deficit Irrigation on Yield and Water Use of Grown Squashes (*Cucurbita pepo*) in the Arid Region

آثار الري بالتنقيط على العائد واستخدام المياه لنبات الكوسة (*Cucurbita pepo*) في المنطقة القاحلة

Submitted as a final year project to fulfill the requirement of BSc (honor) in
Agricultural Engineering

By

Alla Yousif Omer

Supervised by:

Dr. Abbas Elshaikh Rahma

November 2018

Dedication

To my Family,

To my Teachers,

To my Friends,

Acknowledgements

First of all, I render my gratitude and praise to the Almighty Allah (S B T).

I wish to express my sincere gratitude to my supervisor **Abbas Elshaikh Rahma** for his helpful guidance, encouragement and supervision of this research.

Table of Contents

List of Tables

Table No. **Title** **Page No.**

List of Figures

Abstract

This study examines deficit irrigation on field grown squash in the arid area The level of fulfillment of water requirements was used as a gauge to differentiate four border irrigation treatments. Fresh fruit yields were highly influenced by the total volume of irrigation water at every growth stage. The treatment with minimum irrigation water applied had the lowest productions. The mathematical functions that better fit for the production obtained with the water volume received were linearism, but the functions of evapotranspiration (ET) and yield were second- degree polynomials. The water use efficiency (WUE) and irrigation water use efficiency (IWUE) decreased with the increase of irrigation water applied from stem fruiting to the end, significantly since harvest of zenith fruits. But WUE and IWUE were ascending with the increase of irrigation water from squash field setting to first fruit ripening. Well irrigation along the whole cycle was a clearly advisable irrigation regime. On the other hand, the least advisable regimes were those that lead to deficiencies from harvest of the first fruit to the zenith fruits. But we strongly recommend actions be taken to limit the inefficient soil evaporation that resulted from higher temperature at thelast growth stages in order to improve WUE and IWUE.

Keywords: Deficit irrigation; field grown squash ; Water use efficiency; Production function

الملخص

هذه الدراسة تختبر الري الناقص على حقل مزروع بالكوسة في المناطق الجافة، مستوى الحد الأقصى للاحتياجات المائية. استخدم كمقياس للتفريق بين المعاملات لثلاثة أحواض الري وإنتاجية الثمار وتأثرت كثيرا بالحجم الكلي لمياه الري لكل مراحل النمو.

المعاملات التي طبق عليها أقل كميات من الري كانت إنتاجيتها الأقل. المعادلة الرياضية الأفضل لبيان الإنتاجية المتحصل عليها مع حجم الماء المستخدم كانت خطية، بينما معادلات التبخر نتح (ET) والإنتاجية كانت معادلة من الدرجة الثانية متعددة الحدود. كفاءة باستخدام المياه (WUE) وكفاءة باستخدام مياه الري (IWUE) تناقصتا مع زيادة حجم مياه الري المطبقة منذ إزهار الساق وحتى النهاية بمعنوية عالية في أوج الحصاد. لكن كفاءة استخدام المياه (WUE) وكفاءة استخدام مياه الري (IWUE) تصاعدت مع زيادة مياه الري منذ بداية الإثمار وحتى نضوج أول ثمار. نظام الري الجيد طول دورة المحصول يوصى بها بوضوح بالمقابل نظم الري التي لا يوصى بها هي تلك التي تقود إلى نقص الإنتاجية من أول حصاد وحتى قمة الإنتاج.

لكن نحن نوصي بشدة بأخذ الاعتبارات التي تحد من قة كفاءة تبخر نتح التربة الناتجة من ارتفاع درجات الحرارة في أواخر مراحل النمو وذلك لتحسين كفاءة استخدام المياه (WUE) وكفاءة استخدام مياه الري (IWUE).

CHAPTER ONE

INTRODUCTION

Water scarcity is a real threat to food production for millions of people in arid and semiarid areas. Rising of the world population from 6.8 billion today to 9.1 billion and fastest growth of Sub-Saharan Africa's population (up 108%, 910 million people in 2050) will further make worse the problem of water scarcity. Irrigation water managements and crop water productivities are poor (Sisay *et al*., 2011). Several measures (Stress-tolerant crop varieties that produce more marketable yield per unit of water consumed; Farm practices that optimize water use; Management techniques that give farmers timely access to water; and Policies and institutions that help farmers to take advantage of the above advances) have been suggested to tackle the problem of poor water productivity (Kijne *et al*., 2003; Sharma, 2006). Deficit irrigation is one of the options and practices to maximize productivity per unit of water used in dry areas. Hence, rainfall and irrigation water must be used more efficiently and crop water productivity should be increased. Increasing the productivity in agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security.

Agriculture needs to increase its production for the growing world population *(*Howell, 2001). As the current percentage of 72% of the world’s fresh water (Rosegrant and, Cai 2003). consumed by agriculture is decreasing (Kirda and Kanber, 1999), sustainable methods to increase food production need to be adopted (Smith, 2000). Drought mitigation and the increase of crop water productivity are ways to achieve this (Kijne *et al.* 2003) and will be very important strategies for agricultural water management in drought prone semi-arid and arid regions (Debaeke and Aboudrare, 2004).

For many years, the main aim of agricultural research was to maximize total production, but now the focus is shifted to most restrictive factor in production systems: the availability of either land or water. Within this context deficit irrigation (DI) is now widely investigated as a valuable production strategy for dry regions (English and Raja, 1996; Kirda and Kanbre, 1999; Pereira *et al*, 2002) where water is the restrictive factor for crop cultivation.

Objectives

The purpose of this study is to demonstrate the effects of different irrigation levels on the yield, irrigation water use efficiency (IWUE) and water use efficiency (WUE) at different growth stages in filed grown squashes and clarify squash irrigation schedule

CHAPTER TWO

LITERATURE REVIEW

2.1 Irrigation definition

Irrigation generally is defined as application of water to soil for the purpose of supplying

moisture for plant growth. However, a broader and more inclusive definition is that irrigation is the application of water to the soil for any number of the following six purposes *(*Israelsen1962):- Add water to soil to supply the moisture essential for plant growth. Provide crop insurance against short duration droughts. Cool the soil and atmosphere, this making more favorable environment for plant growth. Wash out or dilute salts in soil.- Reduce the hazards of soil piping.
- Soften tillage pans.

2.2 Irrigation methods

Irrigation water may be applied to the crop by:
- Flooding it on the field surface (surface irrigation).
- Applying it beneath the soil surface (subsurface irrigation).
- Spraying it under pressure (sprinkler).
- Applying it in drops (trickles or drip irrigation).

2.3 Deficit Irrigation

2.3.1 Concepts

Deficit irrigation (DI) is an irrigation practice whereby water supply is reduced below maximum level and mild stress is allowed, during non-sensitive growth stage or throughout the growing season, without significant yield penalty (Geerts and Raes, 2009*; Y*enesew and Ketema, 2009; Mekonnen, 2011). Outside drought-sensitive growth stages, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phonological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While these inevitable results in plant drought stress and consequently in production loss, DI maximizes water productivity, which is the main limiting factor (English, 1990*)*. In other words, DI aims at stabilizing yields and at obtaining maximum WP rather than maximum yields (Zhang and Oweis, 1999). The main approach in deficit irrigation is to save water, labor and energy, by eliminating those irrigations with minimal effects on yield .Reasons for increase in water productivity under deficit irrigation Water productivity (WP) increases under deficit water management, as suggested by literatures, due to the following main reasons: (I) reduce water loss through evaporation and deep percolation; (ii) avoids the negative effect of drought stress during specific phonological stages on dry matter partitioning between reproductive and vegetative dry matter (Fereres and Soriano, 2007; Hsiao *et al.*, 2007; Reynolds and Tuberosa, 2008), which stabilizes or increases the number of reproductive organs and/or the individual mass of reproductive organs (Karam *et al.*,2009). (iii) WP for the net assimilation of dry matter is increased as drought stress is mitigated or crops become more hardened. This effect is thought to be rather limited given the conservative behavior of dry matter growth in response to transpiration *(*Steduto *et al.*, 2007). WP for the net assimilation of biomass is increased due to the synergy between irrigation and fertilization (Steduto and Albrizio, 2005). Negative agronomic conditions are avoided during crop growth, such as anaerobic conditions in the root zone due to water logging, pests, diseases (for instance, less humid environment around the crop than full rrigation decreases the risk of fungal diseases), etc. *(*Pereira *et al.*, 2002; Geerts *et al.*, 2008; Geerts and Raes, 2009).

2.3.2 Management of deficit irrigation

Managements of deficit irrigation differ from traditional water applying practices. The manager needs to know the level of transpiration deficiency allowable without significant reduction in crop yields as the main objective of deficit irrigation is to increase the water use efficiency (WUE) of a crop by eliminating irrigation's that have little impact on yield. The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices (Kirda, 2002).Before implementing a deficit irrigation program, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda and Kanber, 1999). High-yielding varieties are more sensitive to water stress than low-yielding varieties; for example, deficit irrigation had a more adverse effect on the yields of new maize varieties than on those of traditional varieties (Doorenbos and Kassam, 1979). Crops or crop varieties that are most suitable for deficit irrigation are those with a short growing season and are tolerant of drought (Stewart and Musick, 1982). To increase the profits gained from deficit irrigation, it is necessary to consider the water retention capacity of the soil. In sandy soils, plants may undergo water stress quickly under deficit irrigation, whereas plants in deep soils of fine texture may have ample time to adjust to low soil water metric pressure, and may remain unaffected by low soil water content. Therefore, success with deficit irrigation is more probable in finely textured soils, and under deficit irrigation practices. Agronomic practices may require modification, e.g. decrease plant population, apply less fertilizer, adopt flexible planting dates, and select shorter-season varieties (Kirda, 2002).

2.4 Crop Water Productivity

Water productivity (WP) or water use efficiency (WUE) mainly refers to the ratio between output derived from water use and the water input (volume or value of water depleted or diverted) (Clement *et al.,* 2011*)*. The output could be biological goods or products such as crop (grain, fodder) or livestock (meat, egg, fish) and can be expressed in terms of yield, nutritional value or economic return. The output could also be an environment services or functions. Crop per drop approach, for instance, focuses on the amount of product per unit of water. Other approaches consider differences in the nutritional values of different crops, or that the same quantity of one crop feeds more people than the same quantity of another crop; and the social benefit of agricultural water productivity (Sharma, 2006). WP can be quantified at different scales (at farm level, irrigation scheme level and basin level). Water productivity can be further defined in several ways according to the purpose, scale and domain of analysis. The value for numerator might depend on the focus as well as the availability of data and the denominator also might depend on the scale, the point of view and the focus. At basin level, the choice might be between water diverted from the source and the same minus water restored, whereas at field level one might consider useful rain, irrigation water and supplemental irrigation *(*Pereira *et al.,* 2009a). Water productivity is dependent on several factors, including crop physiological characteristics, genotype, water management and agronomic practices, soil characteristics such as soil water holding capacity, meteorological conditions, and the economic and policy incentives to produce (Sharma, 2006).In general, WP can be categorized into three broad classes. These are agricultural WP (crops, fisheries, livestock, agro-forestry, and mixed systems), domestic and industrial WP, and environmental WP. However, based on the numerator and denominator used, water productivity analysis is categorized in to three: physical water productivity, economic water productivity and non-economic water productivity (Abdullaev and Molden, 2004;). Non-economic water productivity is the net social and environmental benefits per unit of water consumed. It is not much important index at farm level and also difficult to value. Hence, only the physical and economic aspects of crop water productivity are discussed under the following sub sections.

2.5 Physical water productivity

Physical water productivity (WP) in agriculture refers to obtaining more crop production from the same amount of water. It takes account of water with yield which is defined as the ratio between the actual yield achieved and the total water use (TWU) (Pereira *et al.*, 2009a; Yenesew and Ketema 2009; Araya *et al.*, 2011). However, other researchers defined WP as 6 the ratio between actual marketable yield and actual seasonal crop water evapotranspiration (Kipkorir *et al.*, 2002; Zwart and Bastiaanssen, 2004; Geerts and Raes, 2009; Sisay *et al.*, 2011). Here after, in this work the later definition was used.

$$\mathrm{CWP} = \frac{\mathrm{Y_a}}{\mathrm{ET_a}} \qquad (2.1)$$

Where,

CWP = crop water productivity (Kg/m3)

Ya = the actual marketable crop yield (kg/ha) and

ETa = the actual seasonal crop water consumption (m^3/ha).

To maximize crop water-productivity it is necessary to shift irrigation water management policy from ‘maximum irrigation-maximum yield’ to ‘less irrigation-maximum CWP’ (Mekonnen, 2011). Deficit irrigation is believed to be one way in doing so.

2.6 Squash, (genus *Cucurbita*), genus of flowering plants in the gourd family (Cucurbitaceae), many of which are widely cultivated as vegetables and for livestock feed. Squashes are native to the New World, where they were cultivated by native peoples before European settlement. The fruit of edible species is usually served as a cooked vegetable, and the seeds and blossoms may also be cooked and eaten.

Summer squashes, such as zucchini, globe squash, pattypan, and yellow crookneck squash, are quick-growing, small-fruited, nontrailing or bush varieties of *Cucurbita pepo*. Plants are upright and spreading, 45 to 75 cm (18 to 30 inches) high, and produce a great diversity of fruit forms, from flattened, through oblong, to elongate and crooked fruits, coloured from white through cream to yellow, green, and variegated. Fruit surfaces or contours may be scalloped, smooth, ridged, or warty. The fruits develop very rapidly and must be harvested a few days after they form (before the seeds and rinds harden) and used soon after harvest. The rind is generally considered edible.

Plate (1) summer squash

CHAPTER THREE

MATERIAL AND METHODS

Material and Methods Plant material and experimental design

3.1 Experimental site

The field experiments were conducted at Shambat at Sudan University of Science and Technology - College of Agricultural Studies experiment demonstration farm -.is located at 15°40′N latitude, 32°32′E

The area is among the semi-arid regions .The mean minimum and maximum monthly temperatures of the area are27 °C and 41 °C respectively. Squash is one of the common crops grown in the area that is considered as a reliable and low-risk crop. It is grown during the summer from February to May. The texture of the soil is Clay soil . The physical and chemical properties of the soil under experiment are shown in Table 2. The soil texture is mostly heavy with high clay and loam and poor in organic matter (<1%). Sampling was conducted from 80 cm soil depth table 3.1

3.2 Climatic data collection and analysis

Climate data including daily rainfall, maximum and minimum temperature, relative humidity, sunshine hours and wind speed were obtained from Shambat meteorological station near the experimental field table (3.2). The ETo calculator was used to determine the daily reference evapotranspiration (ETo) for the growing season of 2017/2018 ET_o calculator is software developed by the Land and Water Division of FAO. Its main function is to calculate Reference evapotranspiration (ET_o) based oncomputation guidelines detailed in (Raes, 2009).

Table (3. 1) Soil properties of the experimental field

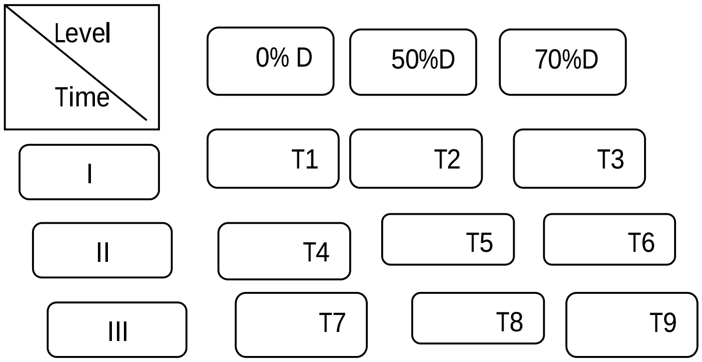
Soil depth	Soil texture	Sand (%)	Silt (%)	Clay (%)	BD (g cm-3)	Organic matter (%)	EC (ds m-1)	FC (%)	PWP (%)	θs (cm3 cm-3)	K (cm d-1)
0-20	S.C.L	59.6	17.8	22.6	1.41	0.44	4.3	0.25	0.10	0.427	30.27
20-40	C.L	40.2	26	33.8	1.56	0.18	2.6	0.24	0.08	0.427	30.27
40-60	C.L	33	30.2	36.8	1.63	0.19	2.2	0.28	0.13	0.427	30.27
60-80	C 2.4	26.8	33	40.2	1.62	0.2	2.4	0.33	0. 19	0.427	30.27

Table (3. 2) Table 3.2 The average of some climate data at the experiment site

year	Maximum (oC) Temperature	Minimum(oC) Temperature	Wind(M.P.H)	Relative% Humidity	Sun shine hours	Rainfall(mm)
2018	41.78	27.34	3.47	25.85	9.7	0.0

3.3 Field experiments

The field experiments were carried out in the dry season of 2017/2018.A Our deficit irrigation treatments were from 10 February to next 29 May, total 90 days since Squash plant field setting. Based on squash appearance, we divided the whole experimental period into three stages namely S1, S2 and S3. S1 was the first stage from Squash r field setting to first fruit ripening, which was 10 February to 28 March. S2 was the second stage after harvest of the first fruit till the zenith fruits, which was 1 March to 12 April. S3 was from the harvest of zenith fruits to the end, which was 13 April to 29 May in our experiment. Water meters were used to control the amount of irrigated water. Soil water content was measured at intervals of 0.1 m down to 1 m, using neutron probes (IH-II, Didcot, Wallingford, UK), once every 5 days during the growing stages; before start, end of stages and irrigation, the measurements were added once. the soil water content determined gravimetrically at the experimental sites and readings were taken at 64 s selected combination of depth of irrigation water application (amount) and growth stage (time) of Squash was used as experimental design in order to determine the optimum water application depth at specific growth stages that results in optimum crop water productivity (CWP). This research investigated the sensitivity of each growing stage to drought stress in detail. Three different levels of irrigation water supply were scheduled, full crop water requirement 0% deficit (ETc), 50% deficit (applying 50% of crop water requirement), and 75% deficit (applying 25% crop water requirement).In Figure T1 to T9refers to different treatments (crop stands) under various combinations of three growth stages (I to III) and irrigation applications starting from no deficit (0%D) to the maximum of 75% deficit (75%D).The phenological cycle was divided into phases which are considered to be most relevant from the viewpoint of their response to irrigation, i.e. initial stage (P1),development stage (P2), and late season stage (P3). A three by three factorial combination of nine treatments with three replications was set in the experimental field to make a total of twenty seven trials (Figure.1). Each set of these 27 trials was tested at seeding rates of 2kg/ha. Thus the total field experimental plots established in Sudan University of Science and Technology at experiment demonstration at College of agricultural studies.



Level / Time	0% D	50%D	70%D
I	T1	T2	T3
II	T4	T5	T6
III	T7	T8	T9

Field experimental set-up for assessing crop sensitivity to different water application scenarios fig (1)

Determination of Flow Rate

Flow rate must not exceed the maximum allowable non-erosive value. Maximum non-discharge was determined using the following formula (Cuenca, 1989) .erosive

=

$$Q_{max}\left(\frac{l}{s}\right)=\frac{c}{s_o\ (\%)} \qquad (3.1)$$

where ,

Qmax = maximum non-erosive flow rate in l/s ;

c = unit constant (l/s) and

So = furrow slope in the direction of flow

Before the experiment will be started the estimated maximum flow rate had been tested in the field to determine the optimum stream size. Testing of the flow rate in the field be a allowed it non-erosive and a discharge which satisfied the soil intake rate.

3.4. irrigation scheduling

FAO CROPWAT model for window 8.0 was used to determine ETo using 15 years climatic 2data of the area from national meteorological station. Kc for every growth stage will adopted from Allen et al. (1998) and then, ETc was calculated .

$ETC = ETo*Kc$ (3.2)

Where ,

;(ETc = crop evapotranspiration (mm)

(ETo = reference evapotranspiration (mm)

Kc = crop factor

The net irrigation requirement was calculated using the following equation .

$NIR = ETc – Pe$ (3)

where ,

NIR = net irrigation water requirement (mm)

ETc = crop water requirement (crop evapotranspiration) (mm)

Pe = effective rainfall (mm)

The amount of water applied during an irrigation event (gross irrigation) is equal to the net irrigation required between irrigation and that needed for efficiencies in the irrigation system .In this experimental setup, water was applied with precise measurement; border were short and end-diked .A higher value of application efficiency (60%) was adopted

GIR= NIR/ ε (3.4)

Where ,

GIR = gross irrigation requirement ;

NIR = net irrigation water requirement; and

ε(= water application efficiency)

The calculated gross irrigation water depth was delivered to basin using V- weir structure to calculate the water discharge by using equation

$$Q=8/15\ cd\sqrt{2g} * \overset{5/2}{H} \qquad (3.5)$$

Q = discharge (m3/s)

(cd = coefficient of discharge (0.65)

A = cross sectional area of the siphon (m2)

g = gravitational acceleration (m/s ^{2})

(h = hydraulic head (m)

The time required to deliver the desired depth of water into each furrow using rigid siphon will be calculated from the following equation

$$t = \frac{d * w * l}{6 * q} \qquad (3.\ 6)$$

where ,

(d = gross irrigation water depth to be applied (cm) (t = application time (min)

(l = furrow length in (m)

w = furrow spacing in (m), and

q = flow rate (discharge) (l/s)

Data Collection, Computations and Analyses.

Evapotranspiration (ET) was calculated from the water balance equation

ET = I+=Δ DSW+ D, where :ET is the evapotranspiration (m3), I the amount of irrigation water applied (m3), DSW the soil water content changes (m3), and D the deep water percolation. The amount of irrigation water was controlled, so, deep percolation was assumed to be zero. The experiential field was divided into ten separated blocks. The experimental design was in random blocks with two repetitions for each of five water treatments tested. The treatments were devised according squash's water requirement disciplinarian (Table 1). The soil was calcaric fluisol (FAO, 1990) and the soil texture was light loam with bulk density of 1.35 g cm3 in the top of 40 cm and 1.55 g cm3 between 40 and 100 cm. And the soil field capacity and wilting point were 23–26% and 8–10% by volume, respectively. WUE and IWUE were calculated as fresh fruit squash yield divided by ET and irrigation water applied volume, respectively. The herbicides and fertilizers were uniformly managed according to standard management practices.

3.5 Agronomic data

Crop parameters were measured during different stages of growth. The crop data including sowing date, harvest date, crop yield and yield components per plot were recorded from the central ridge (row) of each treatment .Determination of above ground dry matter yield. Above ground dry matter per plant was also be determined.

3.6 Crop production function

The relationship between crop production and water received is called the crop–water

Production function. Crop water production function (CWP) was developed by fitting crop yield and seasonal water requirement (ETc) into various regression equations and the one with highest determination coefficient was adopted. The constants of the selected function were used as the coefficients of the CWPF.

3.7 Water productivity and yield response factor

Physical Water productivity (CWP_{ETC}) was computed by dividing the mass of the product to the volume of water consumed (Zwart and Bastiaanssen, 2004)

$$\text{CWP (kg/m}^3) = \frac{\text{Total grain produced (kg/ha)}}{\text{ET}_c\text{ (m}^3\text{/ha)}} \tag{3.7}$$

Economic water productivity (EWP)

was determined by dividing the gross benefit to volume of water consumed was determined by dividing the gross benefit to volume of water consumed .

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Responds of yield to water stress

Squashes have moderately deep roots and long taproots as well as shallow fibrous root systems but do not seem to be as extensive as others in this family. Most of the fibrous feeders are in the top 60 cm and the active roots are concentrated between 20 and 30 cm. And squash is a quick growing crop that produces a lot of succulent growth the crop must be supplied with plenty of moisture for its vigorous growth. Irrigation is important for its plant and fruit growth. At different growing stages, different irrigation water amount was applied according to our design in this study (Table 2). Because our irrigation control was not so strict that irrigation data were not same with Table 1. Squashes(Cucurbita pepo) response to irrigation deficit varied in different growth stages. The higher the amount of irrigation water applied, the higher fresh fruits of squash was obtained. Irrigation could increase the yield of fresh squash on every growing phase arid region . The maximum and minimum total yields were 193999.5 kg ha1 and 137,877 kg ha1 , respectively, under T4 and T1—the most and lowest irrigation water applied. With regard to fresh weight, the mathematical functions obtained depended on experimental data, showed the highly linear relationships between irrigation water amounts applied with yields at different phenomenal stages (Table 3). The initial yield required minimum irrigation of 797 m3 ha1 in S1; however, after that, if there were no irrigation water applied any more, it would harvest 5.576 and 7.1167 kg m2 at S2 and S3, respectively, estimated from the intercept of the regression lines.

Table (4. 1) Irrigation water applied (I, m3 ha1) and fresh fruits yields (Y, kg ha1) of Squashes(*Cucurbita pepo*) at different crop growth stages

Treatments	S1		S2		S3		Total	
	I	Y	I	Y	I	Y	I	Y
T1	114.9	279.45	251.25	8626.2	360	10155.75	726.15	19399.95
T2	105.6	618	219	8145.75	330	9028.5	654.6	17583
T3	103.65	408.75	198.75	7292.25	210	8870.25	512.4	16457.7
T4	96.9	295.2	127.5	7287.45	120	8620.5	344.4	16187.55

4.2. ET and the relationship with yield

Between 10 February and 28 March , Squashes (*Cucurbita pepo*) smaller plant seedlings required less water and lower evaporation resulted from lower temperature at first, with the result that ET increased moderately. After the squash fruit appearance on stems, more Squashes (Cucurbita pepo) plants blossomed and more fruits appeared. Plants needed more water to meet the needs of more succulent fruits and higher soil evaporation that resulted from higher temperature. So water requirement increased dramatically. At S3, a number of squash plants waned and field yields were less but the temperature was higher and the Squashes(*Cucurbita pepo*) needed a greater quantity of water. ET was equal to total crops' water consumption in the field, decided by air temperature, crop varieties, soil texture, soil moisture and solar radiation etc. In order to clarify the effects of irrigation on ET, regression analysis was carried out. There was high linear relationship irrigation water amount with ET at 0.001 significant levels as following:

$$ET = 66.5 + \mathrm{I}\ 0.83 \ , R^2 = 0.9879 \qquad (4.1)$$

where ET is total water consumption (m3 ha1) and I the total irrigation water applied in growth period of squash (m^3 ha^1). Among all treatments in our experiments, the maximum and minimum ET were obtained under

T4 and T1 both at S3 (Table 4). But for deficit irrigation treatments T1, T2 and T3, their biggest ET were obtained at the growth stage S2. For T3 and T4, the biggest ET was at S3. The higher water consumption at S3 for high levels of irrigation treatments could be related to higher soil evaporation resulting from wetting soil surface a few times more. Regression equations fit for ET with fruit yields showed the same increase of ET would induce different improvement on squash fruit yields at different growing stages (Fig. 1); the most increase on yield would be produced at S2, therefore, S2 was the most water sensitive period for Squashes (Cucurbita pepo).

Table (4. 2) Linear model regression equations for fresh Squashes (Cucurbita pepo) yield response to irrigation water applied[a]

Growth stages	Equation	R^2	Significance
S1	$Y = -12896.2+17928X$	0.8384	0.01
S2	$Y = 55760.1 + 1.747X$	0.8524	0.01
S3	$Y = 71167.06 + 7.55 X$	0.7808	0.05
Whole growth period	$Y = 119619.1 + 9.51 X$	0.8852	0.01

a Y is the fresh squash fruit yield (kg ha1), X the irrigated water applied (m^3 ha1).

Table (4. 3) Average ET rate under different irrigation levels at different growing stages (mm per day)

Treatments	S1	S2	S2	Average
T1	2.0	2.6	1.5	2.0
T2	2.3	2.8	2.4	2.5
T3	2.7	4.3	4.2	3.3
T4	2.2	4.4	6.6	4.4

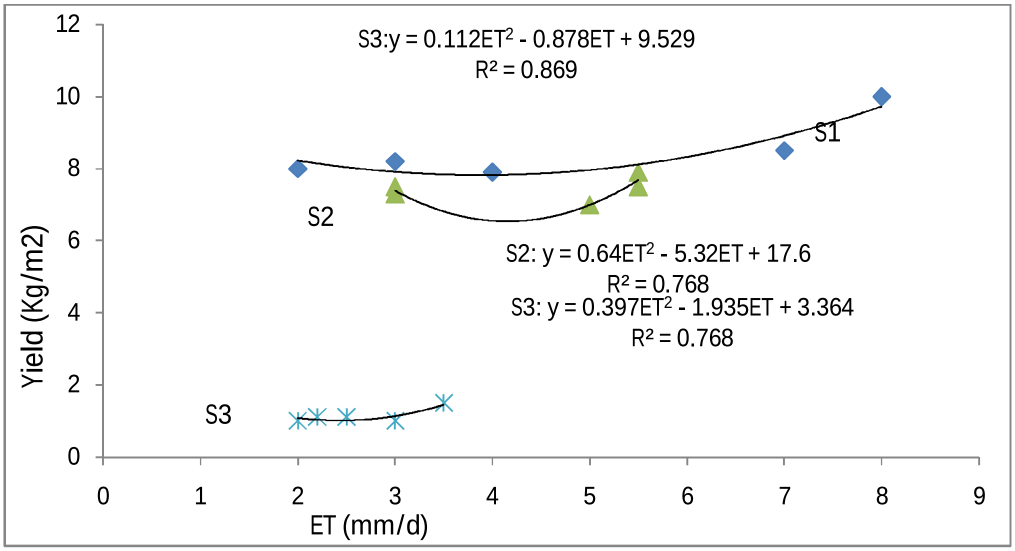
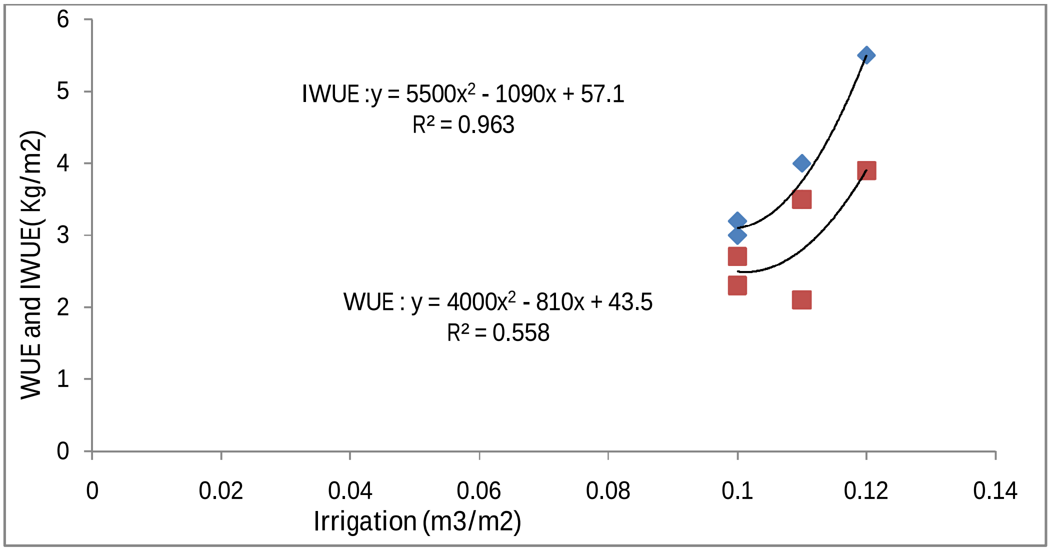


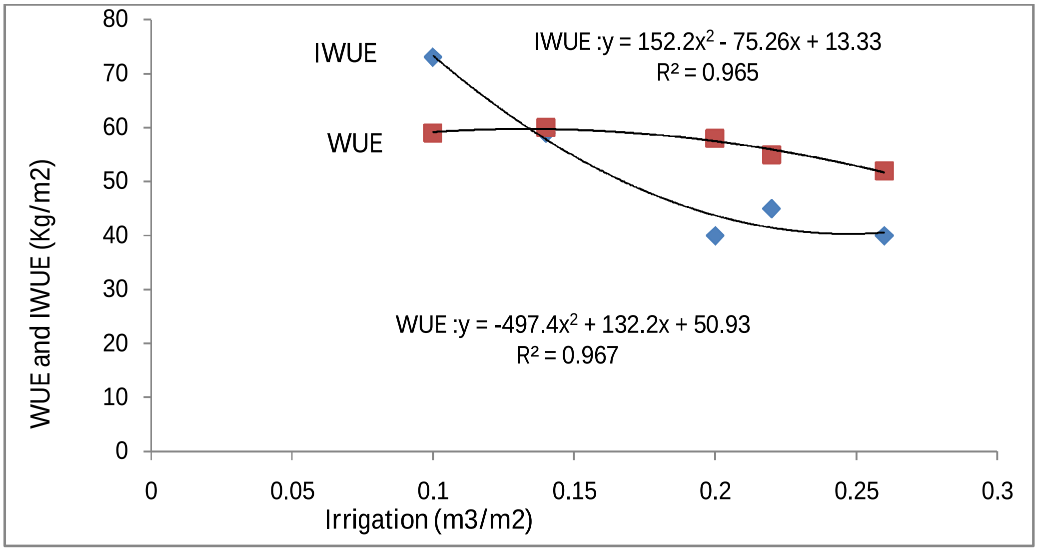
Fig. 1. The relationships between fresh Squashes (Cucurbita pepo) yields and ET.

Table (4. 4) WUE and IWUE at different growth stages under deficit irrigation

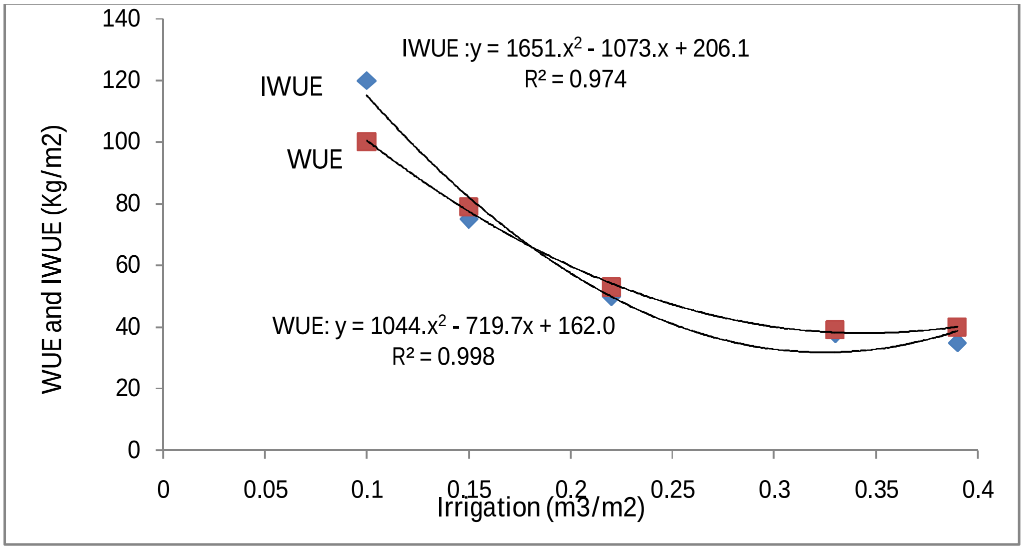
Treatments	S1		S2		S3		Total	
	IWUE	WUE	IWUE	WUE	IWUE	WUE	IWUE	WUE
T1	2.98	2.79	57.64	71.58	117.78	98.76	56.56	48.66
T2	2.89	2.46	57.16	60.13	71.84	74.93	47.00	46.28
T3	2.85	2.17	36.69	56.59	42.24	45.31	32.12	35.73
T4	3.87	3.66	37.20	42.86	27.36	28.98	26.86	28.67



(a) Fig. 2. The effects of irrigation on WUE and IWUE at S1 (a), S2 (b) and S3 (c).



(b) Fig. 3. (Continued)



(C) Fig. 4. (Continued).

3.3. WUE and IWUE

WUE ranged from 2.79 to 98.76 kg m^3 under deficit irrigation regime T1. The maximum WUE and IWUE appeared at S3 under T1, but minimum WUE and IWUE were at S1 under T3. Irrigation under T3 and T4 significantly increased WUE and IWUE at S1, but reverse at S2 and S3 perhaps due to higher evaporation. WUE and IWUE increased dramatically with the squash plants growth under T1, but they were not the same significant under, T3 and T4. The higher soil evaporation due to higher temperature would result in low WUE and IWUE under T4 and T5 at the last growing stage (Table 5). Fig. 2 implied that irrigation could increase Squashes (Cucurbita pepo). WUE and IWUE at S1 (Fig. 2(a)), but WUE and IWUE decreased with the increase of irrigation at S2 and S3 (Fig. 2(b) and (c), respectively), more significant at S3 due to higher evaporation. It was necessary to reduce evaporation and irrigation water amount at S3 in order to improve WUE and IWUE.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusions Squashes (Cucurbita pepo) grown in irrigated in the arid reigion Sudan showed good production responses. This research enables us to infer that yield is considerably higher when Squashes (Cucurbita pepo) receives a total quantity of water of 6500–7500 m3 ha1 . The experiment carried out did not enable us to know what response would have been if irrigation above 7500 m3 ha1 , but the fresh yields did decrease when irrigation received only 2400 m3 ha1 . These results showed that moderate irrigation was essential. The analysis of water applied in each of crop's growth stages made it possible to classify their effects on the development of the yield. S2 was the most sensitive stage to water stress. The WUE and IWUE found in this experiment showed that the most deficit irrigation strategies turn out to be the most efficient at S2 and S3 but, S1 was somewhat different which could only be accounted for the higher yields obtained. When we attempted to select a strategic course of action recommendable for controlled deficit irrigation, we should point out that, with seasonal total volumes of water received ranging from 1500 to 2000 m3 ha1 for the last two stages, respectively, and 1000– 1200 m3 ha1 at S1, we could obtain 8.0–8.5 kg m2 at the last two growth stages and 5.0 kg m2 at the first stage. And ET should be controlled to 2.2–2.5 mm per day for S1 and early phase of S2 and 4–5 mm per day from late phase of S2–S3, respectively. It is very important to limit soil inefficacy evaporation for irrigation water saving and WUE and IWUE improvement, mainly at the last growth stage.

References

Abdullaev, I. and D. Molden, 2004. Spatial and temporal variability of water productivity inthe Syr Darya Basin, Centeral Asia. *Water Resour. Res.* 40 (10): 1029-1038.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop Evapotranspiration Guidelines for Calculating Crop Water Requirements. FAO Irrigation and Drainage Paper 56. FAO,Rome, Italy.

Araya, A., L. Stroosnijder, G. Girmay and S.D. Keesstra, 2011. Crop coefficient, yield response to water stress and water productivity of teff (*Eragrostis tef* Zucc.). *Agri. waterManage.* 98: 775–783.

Debaekea .P and Aboudrareb. A 2004. Adaptation of crop management to water-limited environments. Europ. J. Agronomy 21 ,433–446

Doorenbos, J. and A.H. Kassam, 1979. Yield response to water. FAO Irrigation and DrainagePapers 33. FAO, Rome, Italy.

English, M., 1990. Deficit irrigation. In Analytical framework. *Irrig. and Drain. E*. ASCE.116: 399–412.

English, M. and S.N. Raja, 1996. Perspectives on deficit irrigation. *Agri. water Manage*. 321-14.

Fereres, E. and M.A. Soriano, 2007. Deficit irrigation for reducing agricultural water use.

Special issue on ‘Integrated approaches to sustain and improve plant production under drought stress’. *J. Exp. Bot*. 58: 147–159.

Geerts, S. and D. Raes, 2009. Deficit irrigation as an on-farm strategy to maximize crop waProductivity in dry areas. *Agri. water Manage*. 96: 1275–1284.

Geerts, S., D. Raes, M. Garcia, J. Vacher, R.J. Mamani, R. Mendoza, B. Huanca, R. MoraleJ. Cusicanqui and C. Taboada, 2008.

Introducing deficit irrigation to stabilize yields of quinoa(Chenopodium quinoa Willd.). *Eur. J. Agron.* 28: 427–436.

Howell, T.A. 2001. Enhancing water use efficiency in irrigated agriculture. Agron. J. 93(2):281-289.

Hsiao, T., P. Steduto and E. Fereres, 2007. A systematic and quantitative approach to improvwater use efficiency in agriculture. Irrig. Sci. 25: 209–231.

Karam, F., R. Kabalan, J. Breidi, Y. Rouphael and T. Oweis, 2009. Yield and water production functions of two durum wheat cultivars grown under different irrigation and nitrogen regimes. Agri. water Manage. 96: 603–615.

Kijne, J.W., TP Tuong, J Bennett,B Bouman, and T. Oweis, 2003. Ensuring Food Security viaImprovement in Crop Water Productivity. In: Challenge Program on Water and Food Background Papers. Colombo, Sri Lanka: CPWF. pp. 3-42.

Kirda, C. and R. Kanber, 1999. Water, no longer a plentiful resource, should be used sparingly in irrigated agriculture 268 p. In: C. Kirda, P. Moutonsnet, C. Hera & D.R. Nielsen(eds.). Crop yield response to deficit irrigation. Dordrecht, the Netherlands, Kluwer AcademicPublishers.

Kirda, C., R. Kanber and K. Tulucu, 1999. Yield response of cottons, maize, soybean, sugar beet, sunflower and wheat to deficit irrigation p. 21-39. In: C. Kirda, P. Moutonsnet, C. Hera & D.R. Nielsen (eds.). Crop yield response to deficit irrigation. Dordrecht, the Netherlands,

Kirda, C., 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. Cukuroya University, Adana, Turkey.

Mekonnen Ayana, 2011. Deficit irrigation practices as alternative means of improving wateruse efficiencies in irrigated agriculture: Case study of maize crop at Arba Minch, Ethiopia.African J. of Agri. Res. 6(2): 226-235.

Pereira, L.S., I. Cordery, and Iacovides 2009a. Coping with Water Scarcity. Addressing theChallenges. Springer, Dordrecht. -96 (5):382-391.

Pereira L.S., P. Paredes, E.D. Cholpankulov, O.P. Inchenkova, P.R. Teodoro and M.G. Horst,2009b. Irrigation scheduling strategies for cotton to cope with water scarcity in the Fergana Valley, Central Asia. *Agri. water Manage.* 96: 723–735.

Pereira, L.S., T. Oweis and A. Zairi, 2002. Irrigation management under water scarcity. *Agri.Water Manage*. 57: 175–206.

Sharma, B.R., 2006. Crop Water Requirements and Water Productivity: Concepts and Practices. College of Agricultural Engineering, Punjab Agricultural University, Ludhiana.

Seleshi Bekele Awulachew, Aster Denekew Yilma, Mekonnen Loulseged, W. Loiskandl, Sisay Demeku Dirib, K. Descheemaeker, Amare Haileslassie and Tilahun Amade, 2011.

Irrigation water productivity as affected by water management in a small-scale irrigation scheme in the Blue Nile Basin, Ethiopia. *Expl. Agri.* 47 *(*Sl): 39–55.

Smith, M., E. Fereres and A. Kassam, 2002. Crop water productivity under deficient watersupply. FAO Scheme Activity in Support of the Global Water Action Plans.

Steduto, P. and R. Albrizio, 2005. Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea II. Water use efficiency and comparison with radiation use efficiency. *Agri. Forest Meteorol.* 130: 269–281.

Steduto, P., T.C. Hsiao and E. Fereres, 2007. On the conservative behavior of biomass waterproductivity. *Irrig. Sci.* 25: 189–207.

Stewart, B.A. and J.T. Musick, 1982. Conjunctive use of irrigation and rainfall in semi-aridregions. *Advances in Agronomy*. 1: 1-23.

Rosegrant, M.W., Cai, X.M., 2002. Global water demand and supply projections: part 2. Results and prospects to 2025. Water International 27 (2), 170–182

Yenesew Mengiste and Ketema Tilahun, 2009. Yield and water use efficiency of deficit irrigated maize in a semi-arid region of Ethiopia. African J. of Food Agri. Nutrition and Development. 9 (8): 1635–1651.

Zhang, H. and T. Oweis, 1999. Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agri. water Manage. 38: 195–211.

Zwart, S.J. and G.M. Bastiaanssen, 2004. Review of measured crop water productivity values