

# The Effect of Deficit Irrigation on Maize Crop Under Conventional Furrow Irrigation in Adami Tulu Central Rift Valley of Ethiopia

**Zelalem Shelemew Furgassa**

Department of Soil and Water Engineering, Adami Tulu Agricultural Research Center, Adami Tulu, Ethiopia

**Email address:**

yewl.as.ge@gmail.com

**To cite this article:**

Zelalem Shelemew Furgassa. The Effect of Deficit Irrigation on Maize Crop Under Conventional Furrow Irrigation in Adami Tulu Central Rift Valley of Ethiopia. *Applied Engineering*. Vol. 1, No. 1, 2017, pp. 1-12. doi: 10.11648/j.ae.20170101.11

**Received:** March 10, 2017; **Accepted:** April 5, 2017; **Published:** May 15, 2017

---

**Abstract:** The expansion of irrigated agriculture in Ethiopia to feed the ever-increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand, the improvement of water use efficiencies in irrigated agriculture to ensure sustained production and conservation of this limited resource. A field experiment was conducted with objectives of identifying the level of deficit irrigation for achieving optimum crop yield and water productivity of Maize crop in Adami Tulu. The study was conducted using three levels of irrigation (50%ETc, 70%ETc, 85%ETc) and control irrigation 100%ETc arrangements in RCD with three replications. The analysis of variance for the result of the study indicated highly significant ( $P \leq 0.05$ ) differences for yield, yield components and WUE's. The highest yield of 4.52 ton/ha was obtained from the control with 100%ETc which was not significantly ( $P \leq 0.05$ ) different to the 85%ETc irrigation level. In terms of irrigation and water use efficiency, 50%ETc deficit irrigation application gave the highest IWUE which was significantly different from all other treatment combinations. Yield and water use efficiency based comparison had shown that there was significant difference between the yield, CWUE, and IWUE obtained in the treatment. Therefore, it can be concluded that increased water saving and associated water productivity through the use of 85%ETc with Conventional furrow irrigation, can solve problem of water shortage which improve WUE without significant reduction of yield. 85%ETc irrigation level water applied system appears to be a promising alternative for water conservation and labor saving with negligible trade-off in yield.

**Keywords:** Deficit Irrigation, Water Use Efficiency, Irrigation Water Use Efficiency, Yield

---

## 1. Introduction

Irrigation development is increasingly implemented in Ethiopia more than ever. The main objectives are to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure that agriculture plays the role of driving the economic development of the country. Expansion of irrigated area combined with efficient management of water will enhance the attainment of food security and poverty alleviation goals of the country. Although the country is well known for its vast water resources potential, its erratic distribution both in space and time coupled with limited capacity is the most challenging problem that limits the contribution of the resources to the socio-economic development of the country. Under conventional practices of irrigated agriculture,

agriculture is considered as the major consumer of water compared to other sectors. The expansion of irrigated agriculture to feed the ever-increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand, as well as increasing concerns for environment, necessitate the improvement of water use efficiencies in irrigated agriculture to ensure sustained production and conservation of this limited resource.

Maize (*Zea mays* L.) is the world's third most important cereal crop after wheat and rice grown primarily for grain and secondly for fodder [35]. The crop has tremendous potential as one of the main sources of food for the rapidly increasing population. The chances of increasing crop production in Sub-Saharan Africa seem to lie much in irrigated agriculture, as unreliable rainfall, both in terms of distribution and amount, is a major limitation to agriculture

in the region. Globally, irrigated corn is 17% of total acreage producing 40% of total grain yield [7, 41]. In Ethiopia, the crop is one of the leading food grains selected to assume a national commodity crop to support the food self-sufficiency program of the country. It is grown in moisture stress areas to high rainfall areas and from low lands to high lands [30].

The limited and/or expensive available water supply makes it impractical to irrigate the entire irrigable land area. Therefore, irrigators must decide between fully irrigating a small area for maximum production and reducing the depth of water applied per unit area in order to increase the area put under irrigation. The latter strategy is called deficit irrigation (DI), which will reduce reasonable crop yield per unit of land but increases the net return for the water applied. DI maximizes water productivity (WP), which is the main limiting factor [16]. So, the importance of this study is to identify the level of deficit irrigation for achieving optimum crop yield and water productivity of maize crop in the mid rift valley of Oromia, Ethiopia.

## 2. Research Methodology

### 2.1. Site Description

The experiment was carried out at Adami Tulu Agricultural Research Centre (ATARC). ATARC is located in the mid-rift valley region at the distance 167 km south of Addis Ababa on Hawassa road. It lies at latitude of 7°9' N and 36°39' E longitude. Its altitude is about 1650 meters above mean sea level. The long term mean minimum and the mean maximum temperatures are 12.6°C and 27°C respectively. It has unevenly distributed average annual rainfall of 760.9 mm.

Farmers grow crops twice a year, one during the dry season (October-April) by irrigation, the other during the rainy season (June-September) using rainfall.

### 2.2. Treatments

To identify the level of deficit irrigation for achieving optimum crop yield and water productivity of maize crop in mid rift valley of Ethiopia, conventional furrow irrigation systems were used with three deficit level and control which are 50%ETc, 70%ETc and 85%ETc and a control irrigation of 100%ETc making a total of four treatments. Depending up on irrigation level value there is no standard value put but different researcher use different values. The design of the level was in line with [24] he used the same level of deficit for the same crop type.

Control irrigation implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of CROPWAT program. The treatments were replicated three times resulting in a total of 12 plots. The plots and replications had a buffer zone of 1 m and 2 m between plots on none supplying and supplying canal sides, respectively, to eliminate influence of lateral water movement.

### 2.3. Agronomic Operations and Cultural Practice

The maize variety MELKASSA II was used for this experiment, a crop that is commonly grown in dry areas under moisture stress condition also mostly grow in Adami Tulu area. Planting was done on 29 January 2014 with plant spacing of 75 cm between rows and 25 cm between plants. Two seeds were planted per hole. The crop attained 100% germination and it was then thinned to one plant per stand. The recommended rate of fertilizer for maize in the area was 100 kg/ha diammonium phosphate (DAP) fertilizer at planting and urea at a rate of 50 kg/ha of Nitrogen in split application half at planting and half five weeks after planting recommends this level of fertilizer for maize [21].

Before planting, the entire plot was uniformly pre-irrigated and light irrigations were applied prior to starting treatment applications for three weeks after planting, until the plants well established.

Water applications for full irrigation treatments were based on the estimated (mean) crop water requirement calculated over the entire growing season and deficit treatments imposed less water as planned comprised of 50%, 70% and 85% of the full irrigation treatment (100% ETc).

The crop attained 100% germination 13 days after planting and was thinned to 1 plant per stand three weeks after planting. The plant population was about 44,450 plants/ha. Diammonium phosphate (DAP) fertilizer was applied at the rate of 50 kg/ha of  $P_2O_5$  at planting by placing the fertilizer 6-8 cm away from the hole where the seeds were placed. Top-dressing was carried out at five weeks after planting with urea fertilizer. The total amount of nitrogen applied from the two fertilizer applications was 100 kg N/ha according to the recommended rate of fertilizer for the area. Weeding was done four times before harvesting. *Celecron* insecticide was sprayed two times to control stem borers. The crop matured for harvest at about 126 days after planting, but was left on the field to dry until 10 June 2014 when it was harvested by cutting the aboveground biomass. After cutting, the crop was left on the field for one week for further drying before weighing and removing the cob maize from the stalks. The maize was dried in the open sun for 5 days, then threshed and weighed. The grain moisture content at threshing was determined in the laboratory and was found to be about 13.5%.

### 2.4. Procedure of the Experimental Study

The source of water which was used for the study was from stored water that pumped from the river to the tank and was brought to the field under gravity using closed pipe that run adjacent to experimental plots. Water is then directed to smaller supply channels that feed the furrows. Through careful opening and closure of channel banks, the water was supplied into furrows up to their storage capacity. Water was carefully controlled to avoid the flow of water into water deficit plots.

Before planting, the entire plot was uniformly pre-irrigated and light irrigations were applied prior to starting treatment

applications for three weeks after planting, until the plants reached the established stage. The treatment application started on 20 February 2014. Water applications for full irrigation treatments were based on the estimated (mean) crop water requirement calculated over the entire growing season and those deficit treatments (50%, 70% and 85%ETc) imposed less water as planned comprised of 50%, 70% and 85% of the full irrigation treatment (100%ETc). Irrigation frequencies were differ for all treatments according to their water demand in the whole growing season.

A 3 inch standard Parshall flume, manufactured in Melkasa Agricultural Research Center in mechanization research team laboratory based on standard design of with calibration was installed near the up-stream of the experimental field to measure irrigation water to be applied to individual plots. An average discharge of 4litres/sec was diverted into the experimental field from a tertiary canal. This discharge was allowed to flow into one plot at a time. An average time of 2.5 minutes was used to apply the desired depth of water into each plot. The point of water entrance into each plot was constructed with channel banks and the floor lined to avoid erosion. With the aid of a calculator and a stopwatch, the flow discharge into each plot and the time required to apply the desired depth of water was immediately calculated as soon as water was introduced into the plot. Water was allowed into the plot and each furrow for the time calculated. Immediately after the desired depth applied plots were closed with the channel banks for the close the entrance to stop water from entering the plots.

### 2.5. Data Collected

During the experiment important data like daily meteorological data, in situ and laboratory analysis data on soil physical and chemical properties and data on crop development relevant to assess the response of the crop to irrigation treatments were collected.

Data collection started two weeks after the treatments were applied. Growth and yield parameters recorded at different stages of crop growth and development and the treatments were compared based on grain yield and yield components, which include kernel number per ear row (KNER), and kernel number per column (KNC), plant height, number of leaves, leaf area, ear length, ear girth, number of kernels per ear, weight of grains per ear, weight of grain per plot, weight of 1000-grain, and grain yield.

### 2.6. Climate Data

Long term daily climatic data (1994-2013) records such as rainfall, maximum and minimum temperature records, wind speed, relative humidity, and sunshine duration were used for the experimental.

### 2.7. Soil Sampling and Analysis

The soil was characterized in terms of its physical and chemical properties. The soil properties analyzed include, texture, organic carbon, electrical conductivity, bulk density,

water retention at FC and PWP and pH. The samples were taken from the experimental plot of each individual plot and from four depths (0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm). The soil samples were taken at these depths because of the root system of maize goes up to on meter.

Double ring infiltrometer was used to measure basic infiltration rate of the soil. The test was done at three locations in the experimental plot. Before starting the experimental plots, preparation test of infiltration rate was done at three diagonal located points in the experimental field using double ring infiltrometer. The first sample was taken five meters from lower border, the second at the center and the third five meters from the top border. The rings had 30 cm and 40 cm diameters and they were driven 15 cm deep into the soil by hammer in order to prevent lateral flows. Infiltration measurement was taken for the total of 180 minute continuously until the last two readings after 180 minute were same. The depths of water levels infiltrated were measured at increasing time intervals starting from 1 minute to 30 minute.

### 2.8. Soil Moisture Determination

Soil samples were taken before watering the plot and two days after irrigation from the middle furrow of each plot. The wet soil samples were placed in an oven set at a temperature of 105°C and dried for 24 hrs. Its gravimetric water content was then determined using the expression.

$$\theta_{dw} = \frac{W_{ws} - W_{ds}}{W_{ds}} \times 100 \quad (1)$$

Where:

$\theta_{dw}$  = water content expressed on weight basis in (%)

$W_{ds}$  = weight of dry soil (g)

$W_{ws}$  = weight of wet soil (g),

and the volumetric water content was calculated from the gravimetric water content using the following expression

$$\theta_v = \frac{\rho_b}{\rho_w} \times \theta_{dw} \times 100 \quad (2)$$

Where:

$\theta_v$  = water content expressed on weight basis in (%)

$\rho_b$  = soil bulk density (g/cm<sup>3</sup>), and

$\rho_w$  = water density g/cm<sup>3</sup> (1g/cm<sup>3</sup>)

$\theta_{dw}$  = volumetric moisture content in (%)

The soil samples were taken with augers from three depths: 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm for moisture content determination.

### 2.9. Water Use Efficiency

The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water used.

Crop water use efficiency: The crop water use efficiency is the yield harvested per ha-mm of total water used.

$$CWUE = \frac{Y}{ET_c} \quad (3)$$

Where:

CWUE = crop water use efficiency (kg/ha-mm)

Y = grain yield in kg ha<sup>-1</sup> and

ET = evapotranspiration (mm)

Field water use efficiency: field water use efficiency is the yield harvested per ha-mm of net depth infiltrated.

$$FWUE = \frac{Y}{I_g} \quad (4)$$

Where:

FWUE = field water use efficiency (kg/ha-mm)

Y = grain yield in (kg/ha)

I<sub>g</sub> = gross irrigation in (mm)

### 2.10. Statistical Analyses

The data collected were subject to statistical analysis

**Table 1.** Mean daily weather conditions prevailed during the experiments at Adami Tulu, compared to the Long-run means (1994–2013).

Parameter	Months				
	January	February	March	April	May
	2014				
Min temperature (°C)	9.39	11.88	11.42	12.58	14.15
Max temperature (°C)	29.73	29.59	31.00	32.02	29.42
Relative humidity (%)	55.26	60.54	57.87	56.77	65.26
Wind speed at 2 m height (km h <sup>-1</sup> )	3.88	3.75	4.38	4.86	7.76
Sun shine (hr)	8.81	8.57	8.80	8.97	8.76
Rain-fall (mm)	0.00	2.23	1.19	0.19	5.36
	1994-2013				
Min temperature (°C)	10.35	11.75	13.17	14.30	15.17
Max temperature (°C)	28.41	29.78	30.24	30.04	29.27
Relative humidity (%)	51.00	43.50	51.10	54.90	59.00
Wind speed at 2 m height (km h <sup>-1</sup> )	6.27	6.40	5.90	5.94	6.50
Sun shine (hr)	9.00	9.29	8.60	8.05	8.15
Rain fall (mm)	9.92	16.12	57.62	72.94	80.22

However, monthly air temperature and relative humidity were different from the long-run averages. Table 1 shows the seasonal variation of some climatic parameters during the experiment years. Annual rain amounted 658 mm in 2014 and was 14.6% lower than the long-run average (769 mm) of Adami Tulu.

### 3.1. Soil Texture of the Experimental Area

Results of the particle size distribution are presented in Table 2. According to USDA soil textural classification system, the texture (34.98% sand, 45.65% silt, 19.39% clay), (30.17% sand, 48.00% silt, 21.82% clay), (43.12% sand, 41.37% silt, 15.51% clay) at a depth of 0-30 cm, 30-60 cm, 60-90 cm, respectively. The soil of the experimental field is loam at all depths.

**Table 2.** Particle size distribution.

Depth (cm)	Particle size distribution (%)			
	Sand	Silt	Clay	Textural class
0-15	37.70	42.90	19.41	Loam
15-30	32.25	48.39	19.36	Loam
30-60	30.17	48.00	21.82	Loam
60-90	43.12	41.37	15.51	Loam

Texture influences the ease with which soil can be worked, the amount of water and air it holds and the rate at which

appropriate to RCBD design. SAS software version 9.2 for windows was used for analysis [43]. Whenever the treatment effects were found significant, Tukey's test at 1 and 5% was performed to assess significant difference among treatments means. Simple correlation analysis was also used to see the association of maize growth parameter, agronomic character, and yield and water use efficiencies.

## 3. Results and Discussion

Weather conditions prevailed during the experiments was compared with the long-run averages recorded at Adami Tulu (Table 1). The growing period from January to May was cooler and wetter in 2014 as compared to during 1994-2013.

water can enter and move through soil. Loam soils are best for plant growth because sand, silt and clay together provide desirable characteristics.

### 3.2. Field Capacity, Permanent Wilting Point, Bulk Density and pH

The results of field capacity, permanent wilting point, bulk density and pH are presented in Table 3.

**Table 3.** Results of laboratory analysis of some physical soil properties.

Depth (cm)	FC (%)		PWP (%)		TAW	BD
	W/W	V/V	W/W	V/V	mm/m	(gm/cm <sup>3</sup> )
0-15	34.94	38.08	18.27	19.91	181.70	1.09
15-30	32.23	35.78	19.90	22.09	136.90	1.11
30-60	30.15	34.07	20.74	23.44	106.30	1.13
60-90	25.33	29.13	14.62	16.81	123.20	1.15

Note: FC- Field capacity, PWP-Permanent wilting point, TAW-Total available water, pH-the pH of Soil

The moisture content at field capacity varied with the depth between 38.08% and 29.13% on volume basis. The top 0-30 cm had a larger average field capacity value of 36.93% while the sub surface 60-90 cm had a lower value of field capacity (29.13%).

The moisture content at permanent wilting point also shows variation with depth with an average value of 21% at

the top 0-30 cm, at 30-60 cm had a highest permanent wilting point with a value of 23.44% and at the sub surface 60-90 cm was the lowest permanent wilting point with the value of 16.81% on volume basis.

Total available water (TAW) which is the amount of water that a crop can extract from its root zone is directly related to variation in field capacity and permanent wilting point. As a result, high value of TAW was found in top soil, whereas lower values were found in the subsurface soil. Average value of TAW at the top 0-30 cm was 181.70 mm/m, whereas 106.33 mm/m and 123.17 mm/m at depths of 30-60 cm and 60-90 cm, respectively (Table 3).

Bulk density varies between 1.09 to 1.15 gm/cm<sup>3</sup> and generally the top surface of the soil has slightly lower bulk density than the sub surface.

### 3.3. Chemical Properties of Soil

**Table 4.** Results of laboratory soil chemical properties.

Soil depth (cm)	pH	EC (dS/m)	OC (%)	OM (%)	P (ppm)	K (ppm)	N (%)
0-15	7.54	0.22	4.60	7.90	17.50	345.00	0.11
15-30	7.59	0.18	3.80	6.60	8.10	255.00	0.08
30-60	7.70	0.19	3.20	5.50	6.30	270.00	0.07
60-90	7.52	0.19	2.86	4.90	4.20	245.00	0.06

The soil pH of the study area varied with depth. From Table 4, the pH was having an average of about 7.57 at a

depth of 0-30 cm, 7.70 at a depth of 60-90 cm and 7.52 at a depth of 60-90 cm indicates that the soil is alkaline and these soils may have problems with deficiencies of nutrients such as zinc, copper, boron and manganese. Most soils have pH values between 3.5 and 10. In higher rainfall areas the natural pH of soils typically ranges from 5 to 7, while in drier areas the range is 6.5 to 9. According to the result showed on the Table 4 the pH of the site was suitable for crop production.

The Electrical conductivity of the solution extract of the soil on average was 0.19 dS m<sup>-1</sup>. The average organic carbon was found between 2.86 and 4.6%. The OM content and OC content of the soil had average values of 6.2% and 3.6%, respectively. Similarly the P, K and N content of the soil had average values of 9.03 ppm, 279 ppm, and 0.08% respectively.

### 3.4. Crop Water Requirement of Maize

Crop water requirement is the quantity of water, regardless of its source, required by a crop in a given period of time for its normal growth under field conditions at a place.

#### 3.4.1. Reference Evapotranspiration (ET<sub>o</sub>)

To know the crop water requirement of maize in the growing period, the meteorological data collected were used as input for the CROPWAT model and the reference evapotranspiration of the study area was computed and the result is presented in Table 5.

**Table 5.** Reference evapotranspiration of the study area.

Months	Max. temp (°C)	Min. temp (°C)	RH (%)	WS (m/s)	Sunshine hour (hrs)	ET <sub>o</sub> (mm/day)
January	28.25	10.67	51.75	6.53	8.87	4.54
February	29.37	12.19	45.40	6.53	8.99	5.16
March	30.21	13.19	50.70	6.04	8.60	5.16
April	29.92	14.36	54.50	6.11	8.12	5.04
May	29.24	15.04	57.95	6.60	8.11	4.92
June	28.04	15.01	62.30	8.81	7.53	4.79
July	25.02	14.89	68.90	8.36	5.65	3.89
August	25.29	14.63	70.45	6.78	6.20	3.93
September	26.46	13.76	67.15	4.97	6.75	4.05
October	28.05	11.70	56.35	5.23	7.94	4.48
November	27.79	10.11	51.05	6.74	9.56	4.72
December	27.21	9.57	50.85	6.68	9.41	4.49

Note: - WS-wind speed, RH-relative humidity, ET<sub>o</sub>-Reference Evapotranspiration

As shows in Table 5 the minimum reference evapotranspiration was occurred in the month of July 3.89 mm/day and the maximum occurred in February and March (5.16 mm/day).

#### 3.4.2. Crop Water Requirement

The values of ET<sub>o</sub> estimated by using CROPWAT model

based on climatological parameters need to be adjusted for actual crop ET. The crop water requirement (ET<sub>c</sub>) of maize crop was calculated by multiplying the reference evapotranspiration (ET<sub>o</sub>) with crop coefficient (K<sub>c</sub>), for the maize crop, ET<sub>o</sub> and ET<sub>c</sub> for a time step of 7 days during the period of growing season are presented in Table 6.

**Table 6.** Irrigation event and crop water requirement.

Date	ET <sub>o</sub> (mm/period)	Crop K <sub>c</sub>	CWR (ET <sub>c</sub> ) (mm/period)	Irrigation requirement (mm/period)
22/2/14	29.19	0.50	14.60	14.60
29/2/14	30.20	0.50	15.10	15.10
5/3/2014	31.50	0.50	15.75	15.75
12/3/2014	25.60	0.56	14.34	14.34
19/3/14	30.50	0.62	18.91	18.91
26/3/14	33.80	0.68	22.98	22.98
5/4/2014	35.66	0.75	26.75	26.75

Date	ET <sub>o</sub> (mm/period)	Crop Kc	CWR (ETc)(mm/period)	Irrigation requirement (mm/period)
12/4/14	36.76	0.81	29.78	29.78
19/4/14	29.84	1.03	30.74	30.74
26/4/14	36.10	1.20	43.32	43.32
2/5/2014	33.98	1.20	40.78	40.78
9/5/2014	33.88	1.20	40.66	40.66
16/5/14	36.74	1.17	42.99	42.99
23/5/14	39.19	1.13	44.28	44.28
30/5/2014	34.25	1.09	37.33	37.33
Total	497.19		438.29	438.29

The crop water requirement and irrigation requirement values are the same because of the net of water which is applied by the amount of on which the crop requires through all the growing stage.

### 3.5. Irrigation Water Amount

Water applied for maize throughout the growing season by the three of irrigation furrow systems was calculated (Table 7).

Table 7. Irrigation water amounts.

Irrigation furrow system	Water application depth (mm)			
	100%	85%	70%	50%
CFI	625.00	515.30	405.40	284.60

### 3.6. Effects of Deficit Irrigation on Agronomic Characteristics of Maize

#### 3.6.1. Days to Tasseling, Silking and Maturity

Deficit irrigation levels were significantly different from each other in days to tasseling, silking and days to maturity at ( $P < 0.05$ ). Significantly higher 68.33 days to tasseling, 79.89 days to silking and 123.89 days to maturity were recorded by 50% of irrigation level, followed by 70% of irrigation level with 67.44, 79.11 and 122.44 days, respectively. 100% of irrigation level on the other hand took the lowest number of 66.11 days to tasseling, 78.44 days to silking and 100% of irrigation level took 119.89 days to maturity, respectively. Tassel flowering was longer with increasing water stress. [38]Reported that corn grain yield is particularly sensitive to water deficits that coincide with the tasselling-silking period and emergence of tassels was delayed more than two weeks. [15]Reported that tassel flowering period was longer due to water stress conditions.

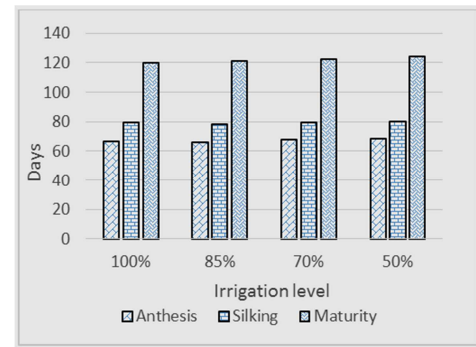


Figure 1. Effects of irrigation level on days to tasseling, silking and maturity of maize.

#### 3.6.2. Plant Height

The irrigation levels were no significantly different from each other in plant height at ( $P > 0.05$ ). Significantly higher plant height of 180.37 cm was recorded by 100%ETc (full irrigation) of irrigation depth of water applied while 50%ETc of irrigation depth of water applied recorded the lowest plant height of 172.74 cm.

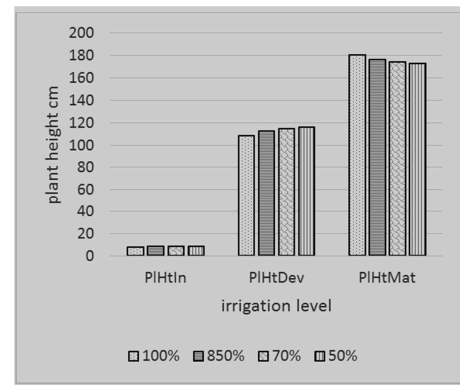


Figure 2. Effects of irrigation level on plant height.

Table 8. Effects of deficit irrigation on agronomic characteristics component of maize.

Treatments	LA (cm <sup>2</sup> )	LAI	NoLevpPl	Plant height (cm)			Days		
				PIHtIn	PIHtDev	PIHtTas	Anthesis	Silking	Maturity
100%	711.4a	0.4a	13.0a	8.0a	108.8a	180.4a	66.8ab	79.7a	119.9c
85%	693.3a	0.4a	13.2a	8.9a	112.4a	176.1a	66.1b	78.4b	120.8c
70%	680.1a	0.4a	12.7a	8.6a	115.1a	174.1a	67.4ab	79.1ab	122.4b
50%	672.6a	0.4a	12.7a	8.8a	116.2a	172.7a	68.3a	79.9a	123.9a
LSD 0.05	50.6	0.1	0.5	0.9	14.1	10.8	1.78	1.2	1.2
CV	7.4	7.3	4.2	10.6	12.7	6.3	2.71	1.6	1.0

### 3.6.3. Number of Leaves per Plant, Leaf Area and Leaf Area Index

There is no significance difference on number of leaves per plants. As Deficit irrigation 85%ETc of water applied 13.17 were the highest while the lowest value 12.66 was observed in 50%ETc of water applied.

Leaf area: Leaf surface area decreases as the amount of water applied to the crop also decreases. There is no significance difference in leaf area in deficit irrigation. The maximum value 711.44 cm<sup>2</sup> recorded on full irrigation and 693.33 cm<sup>2</sup>, 680.11 cm<sup>2</sup> and 672.56 cm<sup>2</sup> were observed 85%ETc, 70%ETc and 50%ETc of irrigation water applied respectively. Canopy photosynthesis is reduced by moisture stress due to reduced stomatal conductance and reductions in leaf area. As moisture stress increases, stomata start closing as a mechanism to reduce transpiration. As a consequence, the entry of carbon dioxide is also reduced [42].

Leaf area expansion depends on leaf turgor, temperature and assimilates supply for growth, which are all affected by drought. Leaf and stem morphology are Altered by water stress. Continuous water deficit results in fewer and smaller leaves, which have smaller and more compact cells and greater specific leaf Weight [10].

Leaf area index: There was no significance difference on deficit levels as shows in Table 8. The maximum value 0.39 were observed in full irrigation water applied (100%ETc) while the lowest 0.36 were also obtained in treatment less irrigation water (50%ETc) of deficit irrigation level were applied. Water stress reduces leaf area index (Table 8).

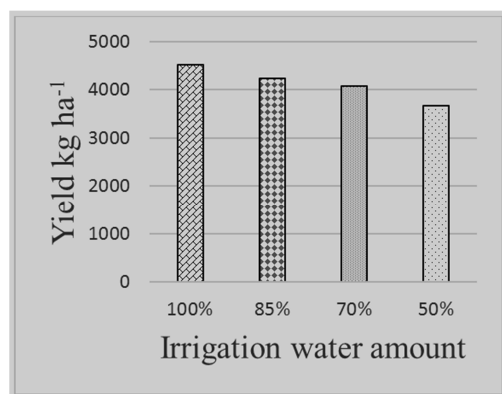


Figure 3. Effects of irrigation water amount on yield of maize.

## 3.7. Effects of Deficit Irrigation on Maize Yield and Yield Component

### 3.7.1. Grain Yield

Irrigation amount increased grain yield significantly ( $P < 0.05$ ), producing higher grain yield of 4522.8 kg ha<sup>-1</sup> with 100%ETc and significantly lower yield of 3668.8 kg ha<sup>-1</sup> with 50% of ETc.

### 3.7.2. Grain Weight per Cob, 1000 Grains Weight and Dry Matter

Grain weight per cob: Irrigation level as shows in Table 9 there is highly significance difference among irrigation level

on grain weight per cob at ( $P < 0.05$ ). The highest weight per cob 134.33 gm was recorded on irrigation level of 85%ETc and the lowest value 118.78 gm was observed in 70%ETc of water applied. 85%ETc produced the grain weight per cob of 0.41%, 11.58% and 6.78% more than irrigation level of 100%ETc, 70%ETc and 50%ETc, respectively. [14] Stated that water deficiency at grain filling period reduces kernel weight per ear values. The potential yield of maize is determined by kernel weight [26], it is a certainty that shortage of water stress reduces grain yield by reducing kernel weight per ear [32]. [29] Reported that grain yield reduced to 37% under water stress conditions. This reduction was due to a decline of 18% kernel weight and 10% in kernel number as a response to water deficit.

1000-grain weight: Deficit irrigation level showed no significant effect on 1000-grain weight. Decreasing in irrigation level increased the 1000-grain weight to some extent. Maximum 1000-grain weight (312.78 gm) attained in 70%ETc which was reduced by further increase or decrease of irrigation level. The lowest 1000-grain weight (293.33 gm) was produced in 100%ETc (full irrigation).

Total dry matter accumulation: The potential of a crop is depended upon its biomass production, which is related to the total dry matter (TDM) production. The effect of irrigation levels on the accumulation of TDM showed a sharp increase in TDM by decreasing irrigation levels to some extent then highly decreased as the irrigation level decreased (Table 9). The maximum TDM (8.89 ton/ha) at final harvest was accumulated by 85%ETc of irrigation level, followed by 100%ETc which gave 8.49 ton/ha. The minimum value (8.04 ton/ha) of TDM was founded by 50%ETc of irrigation water applied. Generally, the dry matter production under the 85%ETc irrigation was significantly higher ( $P \leq 0.05$ ) than those under the deficit irrigation treatment. Differences among treatments for TDM accumulation were due to shortage of water.

### 3.7.3. Number of Row per Ear and Number of Kernel Per Row

No of rows per ear was not affected by irrigation depth (Table 9). The highest numbers of rows per ear were recorded 13.78 when 85%ETc water applied whereas the lowest were observed 13.36 when 70%ETc were applied.

Irrigation level was highly significance difference on number of grains per row at ( $P \leq 0.05$ ). Significantly higher number of grain per row 38.22 recorded on which the irrigation amount of water 100%ETc (full irrigation) applied and the lowest value 36.84 were recorded 50%ETc of water amount Applied. Because the quantity of grains per row is one of the most important bases of yielding components and is related to the general function directly, more the quantity of grains per row, better the function grain. In which deficit irrigation will lead to a delay in insemination and the distribution of granules will encountered with problem [12, 45] and finally the number of grains per row and total number of grains will decrease.

**Table 9.** Effects of deficit irrigation on yield and yield component of maize.

Treatments	NoKepRo	NoRopEa	NoGrpCo	NoCopPl	1000 grains weight(gm)	Grain Weight per Cob(gm)	Yield(ton/ha)
100%	38.2a	13.7a	493.9a	1.4ab	293.3a	133.8ab	4.5a
85%	38.1a	13.8a	480.7ab	1.4a	299.1a	134.3a	4.2a
70%	37.3ab	13.4a	450.3b	1.3ab	312.8a	118.8b	4.1ab
50%	36.8b	13.7a	461.9ab	1.2b	294.7a	125.2ab	3.7b
LSD	1.2	0.6	34.1	0.2	41.7	15.4	0.5
CV	3.2	4.7	7.4	14.2	14.2	12.4	12.6

\* NoRopEa = number of rows per ear, NoKepRo = number of kernel/grain per ear (cob)

#### 3.7.4. Number of Cob per Plant and No of Grain Per Cob

Irrigation level significantly differs on number of cobs per plant at (P 0.05). The highest number of cob per plant observed 1.39 in 85%E<sub>Tc</sub> of irrigation water applied and the lowest value 1.18 take on which 50%E<sub>Tc</sub> of water amount applied. In comparisons 85%E<sub>Tc</sub> have no significant difference with the water amount on which 100%E<sub>Tc</sub> (full irrigation) and 75%E<sub>Tc</sub> except 50%E<sub>Tc</sub> applied.

Number of grains per cob: Irrigation amount highly significance difference on number of grains per cob at (P ≤ 0.05). The highest number of grains per cob was 493.91 recorded on 100%E<sub>Tc</sub> (full irrigation) and the lowest value 450.29 recorded on 70%E<sub>Tc</sub> of water amount applied. 100%E<sub>Tc</sub> (full irrigation) producing 2.7%, 8.8% and 6.5% more kernel per cob (ear) as the amount of water applied in which 85%E<sub>Tc</sub>, 70%E<sub>Tc</sub> and 50%E<sub>Tc</sub> respectively. Number of kernels per ear decreased with increasing deficiency in irrigation water (Table 9). Similar findings were reported by [14], [5] and [39]. Number of kernels is closely associated with yield of maize and the number of kernels per ear is a yield component that varies markedly with stress [19]. [23] Mentioned that water stress caused failure of kernel

development, its number, size and weight.

#### 3.8. Effects of Irrigation System and Deficit on Maize Yield and Water Use Efficiency

The yield of maize grain yield decreased as the irrigation level decreased. Decreasing applied water by 15%, 30% and 50% of E<sub>Tc</sub> led to decreased grain yield of corn by 6.3%, 9.9%, and 18.88% with conventional furrow irrigation system, respectively. Some researchers stated that yield decreased with reduced irrigation ([14], [39][44]).(Table 10).

The data indicated in Table 10 illustrate that the highest value of corn grain yield at 100% of E<sub>Tc</sub> was 4522.8 kg/ha obtained followed by 4237.4 kg/ha with 85% of irrigation level, 4073.3 kg/ha with 70% E<sub>Tc</sub> and 3668.8 kg/ha of 50%E<sub>Tc</sub> of irrigation level.

Maize grain yield is sensitive to water stress from just before silking through grain filling [46], with the greatest degree of sensitivity occurring during the period of kernel number determination [4]. [22] Indicated that filled kernel number was most sensitive to stress from tasselling to just after silking. This results are support this study on kernel yield with reducing soil moisture.

**Table 10.** Effects irrigation level on grain yield, dry matter (DM), CWUE, IWUE and harvest index (HI).

	Treatment	Grain yield kg/ha	DM ton/ha	CWUE kg/m <sup>3</sup>	IWUE kg/m <sup>3</sup>	HI
Levels	100%	4522.80a	8.49ab	0.77d	0.54d	0.54a
	85%	4237.40a	8.89a	0.94c	0.66c	0.48a
	70%	4073.30ab	8.08b	1.12b	0.78b	0.51a
	50%	3668.80b	8.04b	1.37a	0.96a	0.46a
	LSD	509.89	0.76	0.15	0.10	0.08
	CV	12.64	9.25	14.13	14.14	12.20

#### 3.8.1. Harvest Index

Irrigation depth: Irrigation level on harvest index not significantly different at (P ≤ 0.05) but producing higher HI of 54% with 100% of E<sub>Tc</sub>, which was not significantly different from the HI of 51% recorded at 70% of E<sub>Tc</sub>. The lowest HI of 46% was recorded in plots where 50% of E<sub>Tc</sub> irrigation water was applied (Table 10).

#### 3.8.2. Crop Water Use Efficiency

CWUE significantly change when irrigation amount increased. However, CWUE values ranged from 0.77 kg m<sup>-3</sup> for 100%E<sub>Tc</sub> irrigation depth of water applied to 1.37 kg m<sup>-3</sup> 50%E<sub>Tc</sub> of irrigation depth of water applied. Little higher CWUE values were obtained from 70%E<sub>Tc</sub> and 50%E<sub>Tc</sub>, as 1.12 and 1.37 kg m<sup>-3</sup>, respectively. Previous studies indicated

that CWUE ranged from 0.41 to 2.71kg m<sup>-3</sup> ([25]; [39]; [47]; [39]; [37]; [27]; [11]; [34]). My results are in agreement with [20] who reported that WUE values decreased with increasing water use.

#### 3.8.3. Irrigation Water Use Efficiency

Irrigation water use efficiency (IWUE) is a concept that compares crop production to water used and has been defined in numerous ways. In this research, IWUE was defined as relative grain yield per unit of irrigation. The best irrigation strategies were considered to be the ones that resulted in a high IWUE; that is, they produced a relatively large yield for a given amount of irrigation. Irrigation efficiency represents the ratio between the grain yield returns and the irrigation amount. In this experiment, IWUE values varied according to the irrigation amount. The highest IWUE was registered in



well irrigation treatment, the maize plant using better the water applied in small quantities and often. The highest

IWUE value under limited water supply, i.e.  $0.96 \text{ kg/m}^3$ , was observed to the 50% irrigation level (Figure 4).

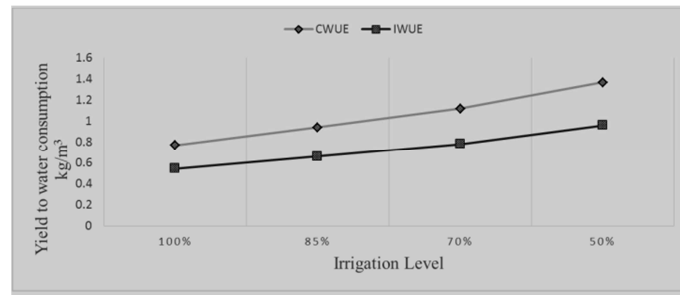


Figure 4. Effects of irrigation level on water use efficiency and irrigation water use efficiency.

Generally, CWUE and IWUE are influenced by crop yield potential, irrigation method, estimation and measurement of ET, crop environment, and climatic characteristics of the region. The results related to the efficiencies shows that when irrigation water is limited, 50% deficit irrigation can be applied for increase the water use efficiencies. [33] Reported that irrigation water can be conserved and yields maintained in maize plant (as sensitive crop to drought stress) under water limited conditions through improved fertilizer managements and selecting more tolerant hybrids. On the other hand, the feasibility of increasing either the CWUE or IWUE is a decision that needs to be based not only on the biophysical response of the crop but also on economic factors. Often the objective of producers is not to increase yields but to increase profits [40]. Determining the level of irrigation needed to optimize profits can be complex and depends on both biophysical and economic factors ([36]; [17]; [40]).

Table 11. Correlation among deficit irrigation with agronomic characteristics of maize crop.

	Irrigation level
DT	0.31 ns
DCI	0.05 ns
DMA	0.61**
PIHt	-0.22 ns
LA	-0.08 ns
LAI	-0.09 ns
No Lev	0.24 ns
NoCopPI	-0.39*
NoKepRo	-0.36*
NoKepEa	-0.37*
NoRopEa	-0.10 ns
1000SedWt	-0.41*
WtpEa	-0.22 ns

	Irrigation level
DM	-0.29 ns
HI	-0.20 ns
YIELD	-0.34*
CWUE	0.71**
IWUE	0.70**

Ns- no significant, \*\*- highly significant, \*- significant

### 3.9. Correlation Among Growth, Agronomic Character, Yield and Water Use Efficiency

As shown in Table 11, correlations among irrigation level and growth parameter and agronomic characteristics. Deficit irrigation positively correlated with growth parameter of DI, DCI, DMA and NoLev and with both water use efficiency, but statistically significant except days to tasseling, days to cob initiation (anthesis) and number of leaves and negatively correlated with the agronomic character of maize crop, but statistically no significant except number of cob per plant, number of kernel per row, number of kernel per ear (cob) and yield.

### 3.10. Yield Response Factor (Ky)

The magnitude of Ky value indicates the sensitivity of the irrigation protocol for water stress and subsequent yield decrease. Results of the analysis of yield and water, as indicated in Table 12 below, shows that the highest Ky was 0.31 attained at 50%ETc this indicates that the highest value of the Ky the more the tolerance of the crop to water deficit and the lowest was 0.22 observed at 85%ETc also indicates that the tolerance of the crop to water deficit. According to [31], the Ky value for field crops goes from 0.2 to 1.15 which agrees with the reported result.

Table 12. The yield response factor values for irrigation treatments.

Deficit level	Yield (ton/ha)	Eta (mm)	ETa/ETm (mm)	Ya/Ym	1-( ETa/ETm)	1-( Ya/Ym)	Ky
100%	4.87	422.00	1.00	1.00	-	-	-
85%	4.66	358.70	0.82	0.96	0.18	0.04	0.22
70%	4.46	295.40	0.67	0.92	0.35	0.08	0.24
50%	4.08	211.00	0.48	0.84	0.54	0.16	0.31

### 3.11. Water Production Function

The results obtained in this research shows that water

production function in Figure 4 drawn on the basis of the amount of consumed water in different deficit levels. The figure shows that, as the amount of deficit irrigation water increases yield production function is increased.

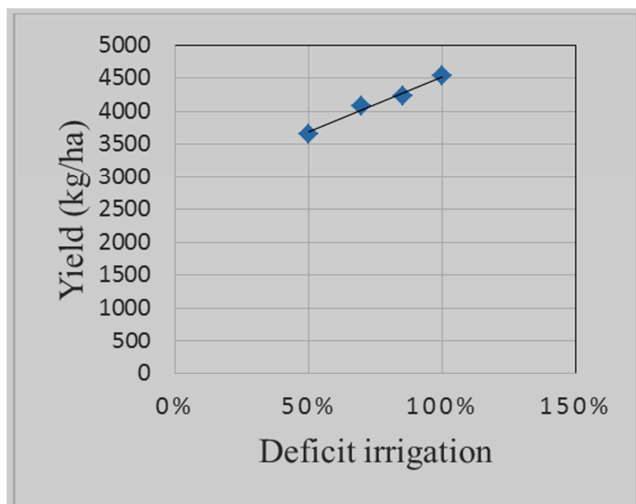


Figure 5. Water production function graph with deficit irrigation.

Considering the relationship of deficit irrigation and water productivity result in this research given that there is no significant difference in grain yield between water levels of 85% and 100% water requirement, conventional furrow system of applying mild deficit irrigation 85% water requirement is recommended for maize in the region.

As shown in figure above if insufficient water is applied during the crop cycle the crop will not fully develop resulting in low quality of yield then the WP is low. And crop yield and water productivity can be increased if a considerable amount of water is added.

#### 4. Conclusion

The water productivity associated with irrigation treatments were evaluated by CWUE, IWUE.

The relative yield decrease for a unit deficit in evaporation requirement, described by crop response factor  $K_y$ , was highest for 50%ETc, low for 75%ETc and lowest for 85%ETc. Deficit application of 85%ETc was very effective and statistically significant in maintaining the same yield as the full irrigation (100%ETc). Most importantly, the CWUE and IWUE obtained due to significant water saving at this new irrigation schedule were significantly high.

In this research, the yield production functions toward the deficit irrigation of maize in the Adami Tulu were investigated. The results showed that the curves of the yield production function are under the influence of the irrigation water on the consumed water use meaningfully. The yield and its components are increased by increasing the amount of water up to the optimal consumption level, and if the irrigation water is used more than the maize's requirement, further run off over irrigation will cause the reduction of the yield and loss of water.

Generally, optimum application of deficit level applied was efficient in conserving significant irrigation water at the same time attaining higher yield.

#### Recommendation

Based on the findings obtained from the research, the following recommendations are made:

Maize response to water deficit has a major importance for establishing the priorities in water application in where water stress/shortage areas.

According to the results of this research deficit irrigation based on 85% of full Maize water requirement could be recommended under dry year's condition.

#### Acknowledgements

Authors acknowledge the immense help received from the scholars whose articles are cited and included in references of this manuscript. The authors are also grateful to authors/editors/publishers of all those articles, journals and books from where the literature for this article has been reviewed and discussed.

I also would like to thank Oromia Agricultural Research Institute (OARI) for funding this research and also Adami Tulu Agricultural Research Centre for providing office and facilitating necessary material for the accomplishment of this study.

#### References

- [1] Abdrabbo, A. and Kheira, A. Comparison among different irrigation systems for deficit- irrigated corn in the Nile Valley. Agricultural Engineering International: *The CIGRE Journal of Scientific Research and Development*. Manuscript LW 08 010. Vol. XI. 2009.
- [2] Allen, R., Pereira, L. A., Raes, D. and Smith, M. Crop evapotranspiration. Irrigation and Drainage Paper No. 56. FAO. Rome. 1998.
- [3] Ali, M. A., Hoque, M. R., Hassan, A. A., and Khair, A. Effects of deficit irrigation on yield, water productivity, and economic return of wheat. *Agric. Water Manage.* 92: 151-161. 2007.
- [4] Andrade, F. H., Vega, C., Uhart, S., Cirilo, A., Cantarero, M., and Valentinuz, M. Kernel number determination in maize. *Crop Sci.* 39: 453-459. 1999.
- [5] Braunworth, J. R., and Mack, H. J. Effect of deficit irrigation on yield and quality of sweet corn. *J. Amer. Soc. Hort. Sci.* 112. 1987.
- [6] Cakir, R. Effect of water stress at different development stages on vegetative and reproductive growth of corn. *Field Crops Research.* 89: 1-16. 2004.
- [7] Carbtree, R. J., Yassin, A. A., Kargiugou, I., and Mcnew, R. W. Effect of alternate furrow irrigation: water conservation on the yield of two Soybean Cultivars. *Agric. Water Manage.*, 10(3): 253-264. 1985.
- [8] Central Statistical Agency (CSA). Report on area and production of crops (Private Peasant Holdings, Meher Season). The Federal Democratic Republic of Ethiopia Central Statistical Agency. Agricultural Sample Survey. Statistical Bulletin388: I. 2007.

- [9] Chung, S. Y., Vercellotti, J. R., and Sanders, T. H. Increase of glycolytic enzymes in peanuts during peanut maturation and curing: evidence of anaerobic metabolism. *Journal of Agricultural and Food Chemistry*. 45: 16–21. 1997.
- [10] Cui, N., Du, T., Kang, S., Li, F., Zhang, J., Wang, M., and Li, Z. Regulated deficit irrigation improved fruit quality and water use efficiency of pear-jujube trees. *Agr. Water Manage.* 95: 698–706. 2008.
- [11] Dagdelen, N., Yilmaz, E., Sezgin, F., and Gurbuz, T. Water–yield relation and water use efficiency of cotton (*Gossypium Hirsutum* L.) and second crop corn (*Zea mays* L.) in western Turkey. *Agric. Water Manage.* 82 (1–2): 63–85. 2006.
- [12] Denmead, O. T., and Shaw, R. H. 2002. The effects of soil moisture stress at different stages of growth on the development and yield of corn. *Agron. J.* 52: 272–274.
- [13] Eck, H. V. Irrigated corn yield response to nitrogen and water. *Agron. J.* 76: 421–428. 1984.
- [14] Eck, H. V. Effect of water deficit on yield, yield components and water use efficiency of irrigated corn. *Agron. J.* 78: 1035–1040. 1985.
- [15] Edmeades, G. O., Bolanos, J., and Lafitte, H. R. Selecting for drought tolerance in maize adapted to the Lowland tropics. The 4<sup>th</sup> Asian Regional Maize Workshop, Sept. 23–27, 1990, Islamabad, Pakistan. 1990.
- [16] English, M. J. Deficit irrigation of analytical framework. *J. Am. Sot. Civil Eng.*, 116 (IR3): 399–412. 1990.
- [17] English, M. J., Solomon, K. H., and Hoffman, G. J. A paradigm shift in irrigation management. *J. Irrig. Drain. Eng.* 128: 267–277. 2002.
- [18] FAO (Food and Agricultural Organization). AQUASTAT-FAO's information systems on water and agriculture. 2001. <http://www.wcaifonet.org/cds> static/en/qstat faoinformationssystem\_water\_ethiopia\_en\_569\_14376.
- [19] Fischer, K. S., and F. E. Palmer. Tropical Maize. *In: The Physiology of Tropical Field Crops*. Goldsworthy, P. R., N. M. Fischer, (Eds.), Wiley, New York. pp. 213–248. 1984.
- [20] Gençoglan, C., and Yazar, A. The effects of deficit irrigations on corn yield and water use efficiency. *Turkish J. Agric. Forest.* 23: 233–241. 1999.
- [21] Getachew Sime and Jens B. A. Maize Response to Fertilizer Dosing at Three Sites in the Central Rift Valley of Ethiopia. *Agronomy*. 4: 436–451. 2014.
- [22] Hall, A. J., Lemcoff, J. H., and Trapani, N. Water stress before and during flowering in maize and its effects on yield, its components, and their determinants. *Maydica*. 26: 19–38. 1981.
- [23] Harder, D., Carlson, R. E., and Shaw, R. H. Yield and yield components and nutrient content of corn grain as influenced by post-silking moisture stress. *Agron. J.* 174: 275–278. 1982.
- [24] Heidari, H. Alternate Furrow Irrigation Effect on Yield, Yield Components and Seed Germination of Foxtail Millet (*Setaria Italica*) In Double Cropping System. *International Research Journal of Applied and Basic Sciences*. 3(1): 64–69. 2012.
- [25] Howell, T. A., Yazar, A., Schneider, A. D., Dusek, D. A., and Copeland, K. S. Yield and water use efficiency of corn in response to LEPA irrigation. *Trans. ASAE*. 38(6): 1737–1747. 1995.
- [26] Jacobs, B. C., and Pearson, C. J. Potential yield of maize determined by rate of growth and development of ears. *Field Crops Res.* 27: 281–298. 1991.
- [27] Kar, G., and Verma, H. N. Phenology based irrigation scheduling and determination of crop coefficient of winter maize in rice fallow of eastern India. *Agric. Water Manage.* 75: 169–183. 2005.
- [28] Karajeh, F., Mukhamedjanov, V., and Vyshepol'skiy, F. On-farm water and drainage management strategy in Kazakhstan's Arys-Turkestan area. *Taraz, Kazakstan*. 49: 35–50. 2000.
- [29] Karam, F., Breidy, J., Stephan C., and Roupheal, J. Evapotranspiration, yield and water use efficiency of drip irrigated corn in the Bekaa Valley of Lebanon. *Agric. Water Management*. 63(2): 125–137. 2003.
- [30] Kebede Mengesha, Bogale Gashaw, Tolessa Birhanu, Worku Malesse., Desalegne Yirga, and Afeta Aman. Maize production trends and research in Ethiopia, pp. 4–12. *In* B. Tolessa, and J. K. Ransom (eds.). *Proceedings of the First National Maize Workshop of Ethiopia*. IAR/ CIMMYT. Addis Ababa, Ethiopia. 1993.
- [31] Kirda, C., and Kanber, R. Water, no longer a plentiful resource, should be used sparingly in irrigated agriculture. *In: C. Kirda, P. Moutonnet, C. Hera & D. R. Nielsen, eds. Crop yield response to deficit irrigation*, Dordrecht, The Netherlands, Kluwer Academic Publishers. 1999.
- [32] Kirtok, Y. Corn production and use. Kocaoluk Press, Istanbul, Turkey pp. 445. 1998.
- [33] Mansouri-Far, C., Sanavy, S. A. M. M., and Saberali, S. F. Maize yield response to deficit irrigation during low-sensitive growth stages and nitrogen rate under semi-arid conditions. *Agric. Water Manage.* 97: 12–22. 2010.
- [34] Mengü, G. P. and Özgürel, M. An evaluation water–yield relation in maize (*Zea mays* L.) in Turkey. *Pakistan J. Bio. Sci.*, 11(4): 517–524. 2008.
- [35] Nelson, R. L. 2005. Tassel emergence and pollen shed. *Corny news network*.
- [36] Norton, N. A., Clark, R. T., and Schneekloth, J. P. Effects of alternative irrigation allocations on water use, net returns, and marginal user costs. *In* 2<sup>nd</sup> edition: *Western Agricultural Economics Association Annual Meetings*, Vancouver, British Columbia, p.13. 2000.
- [37] Oktem, A., Simsek, M., Oktem, A. G. Deficit irrigation effects on sweet corn (*Zea mays saccharata* Sturt) with drip irrigation system in a semi-arid region. I. Water-yield relationship. *Agric. Water Manage.* 61: 63–74. 2003.
- [38] Otegui, M. E., Andrade, F. H., and Suero, E. E. Growth, water use, and kernel abortion of maize Subjected to drought at silking. *Field Crops Res.* 40(2): 87–94. 1995.
- [39] Pandey, R. K., Maranville, J. W., and Admou, A. Deficit irrigation and nitrogen effects on maize in a Sahelian environment I. Grain yield and yield components. *Agric. Water Management* 46: 1–13. 2000a.
- [40] Payero, J. O., Tarkalson, D. D., Irmak, S., Davison, D., and Petersen, J. L. Effect of irrigation amounts applied with subsurface drip irrigation on corn evapotranspiration, yield, water use efficiency, and dry matter production in a semiarid climate. *Agric. Water Manage.* 95: 895–908. 2008.

- [41] Popova, Z., Varlev, I., Kutev, V., and Ikonomova, E. Irrigation and cropping techniques to prevent natural water pollution. Papers of the 1st Inter-Regional Conference "Environment - Water: Innovative Issues in Irrigation and Drainage, Lisbon, pp. 6-13. 1998b.
- [42] Reddy, T. Y., Reddy V. R., and Anbumozhi, V. Physiological responses of groundnut to drought stress and its amelioration: a critical review. *Plant growth regulation*. 41: 75-88. 2003.
- [43] SAS Institute SAS Users' guide. Version 6 SAS Institute Cary, NC. (1996).
- [44] Viswanatha, G. B., Ramachandrappa B. O. K., and Nanjappa, H. V. Soil -plant water status and yield of sweet corn as influenced by drip irrigation and planting methods. *Agric. Water Management*. 55: 85-91. 2002.
- [45] Wasson, J. J., Schumacher, R., and Wicks, T. E. Maize water content and solute potential at three stages of development. University of Illinois, Dept. of Agronomy. 2002.
- [46] Westgate, M. E. and Boyer J. S., Reproduction at low silk and pollen water potentials in maize. *Crop Sci* 26, 951-956. 1986.
- [47] Yazar, A., Sezen, S. M., and Gencel, B. Drip irrigation of corn in the Southeast Anatolia Project (GAP) area in Turkey. *Irrig. and Drain*. 51: 293-300.2002.