academicresearchJournals

Vol. 6(6), pp. 305-311, July 2018
DOI: 10.14662/ARJASR2018.032

ISSN: 2360-7874
http://www.academicresearchjournals.org/ARJASR/Index.htm

Academic Research Journal of Agricultural Science and Research

Full Length Research

Response of Maize (Zea mays L.) to Supplementary Irrigation in Raya valley, Northern Ethiopia

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Accepted 29 July 2018

In the Raya Valley of Ethiopia, farmers mostly rely on rainfall for crop production. The erratic nature of rainfall causes frequent crop failures and alternative technologies to increase grain maize production under rainfed systems are right away needed, considering the low grain yield in small-scale farming. Supplemental irrigation, fertilizer application and tillage methods are valuable available farming technologies. A field experiment was carried out at Mehoni Agricultural Research Center, Raya Valley of Ethiopia, during 2013/14 to 2015/16 for the consecutive three season with objectives of to maximize crop productivity of rainfed agriculture, to determine the effect of supplementary irrigation on crop yield, to determine crop water requirement and to determine water use efficiency. The experiment were laid out in a random complete block design (RCBD) consisting of eight levels of irrigation treatment (full or 100%, 75%, 50%, 25%ETc, one SI at flowering stage, one SI at grain filing, two SI at flowering and grain filing stage and a control treatment (Rainfed agriculture) with three replications. Longer days to maturity, highest plant height and ear length was recorded when 100% ETc irrigation level applied and earlier day to maturity, smallest plant height and ear length were recorded with non-supplementary irrigation (rain fed). The highest grain and biomass yield were obtained at 100% ETc supplementary irrigation depth gives 23.2% and 24.4% greater than the control respectively. In terms of crop water use efficiency, the rainfed gave the highest irrigation water use efficiency and crop water use efficiency which was significantly superior to all other treatments. Therefore, it can be concluded that in the study area the rain fed amount were very inadequate and limited, supplementary irrigation with 100% ETc were help to increase crop productivity and minimize crop failure due to the low rainfed and decrease the deficit of food in the study area.

Keywords: Crop water use efficiency, Maize, Rainfed, Supplemental irrigation

Cite this article as: Mebrahtu, Y., Tamru, H., (2018). Response of Maize (Zea mays L.) to Supplementary Irrigation in Raya valley, Northern Ethiopia. Acad. Res. J. Agri. Sci. Res. 6(6): 305-311

INTRODUCTION

In the drier farming regions of the world, mainly with arid environments, crop production is heavily dependent on irrigation practice. Agricultural irrigation uses over 70% of the world supplies of developed water. Agricultural production is facing increased competition for limited water resources and it is expected to increase with the number of water deficit countries, population pressure and intensification tending towards desertification of most land. The efficiency of utilization of irrigation water is often low and around 50% of the increase in demand for water could be met by increasing the effectiveness of irrigation (Seckler et al., 1998). It is, therefore, important to improve the efficiency of water use and this can be done by approaching the economic maximum of plant material that will ensures high water use efficiency.

Water use efficiency nowadays is less improved hence, Mintesinot et al.; (2004) viewed that promoting its efficiency demands an urgent attention for improving productivity in dry environment. One of the methods for increasing water use efficiency is the adoption of cultural practices that will enhance production per unit of water. This can be achieved by crop-environment matching and by supplementing the cultural practice with irrigation.

Maize is one of the most important cereals cultivated in Ethiopia. It ranks second after teff in area coverage and first in total production. The results of the year 2011/12, Meher season post-harvest crop production survey indicate that total land areas of about 12,086,603.89hectares were covered by grain crops. Out of the total grain crop areas, 79.34% (9,588,923.71hectares) was under cereals. Of this maize covered 17% (about 2,054,723.69 hectares) and gave 6069413 tons of grain yields (CSA, 2012).

Despite the large area under maize, the national average yield of maize is about 2.95 t/ha (CSA, 2012). This is by far below the world's average yield which is about 5.21t/ha (FAO, 2011). The low productivity of maize is attributed to many factors like frequent occurrence of drought, declining of soil fertility, poor agronomic practice, limited use of input, insufficient technology generation, lack of credit facilities, poor seed quality, disease, insect, pests and weeds particularly, Striga (CIMMYT, 2004). Therefore, these experiments were conducted to maximize maize productivity of rainfed agriculture, determine the effect of supplementary irrigation on crop yield, to determine crop water requirement and determine water use efficiency maximizing the efficiency of water used for irrigation.

MATERIALS AND METHODS

Description of the experimental site

This study was conducted at the research station of Mehoni Agricultural Research Centre (MehARC) in the Raya Valley, Northern Ethiopia, located 668 Km from the capital Addis Ababa and about 120 Km south of Mekelle, the capital city of Tigray regional state. Geographically the experimental site is located at 12° 51'50'' North Latitude and 39° 68'08'' East Longitude with an altitude of 1578 m.a.s.l. The site receives a mean annual rainfall of 300 mm with an average minimum and maximum temperature of 18 and 32°C, respectively. The soil textural class of the experimental area is clay with pH of 7.1 - 8.1(MehARC, 2015).

Climatic Characteristics

The average climatic data (Maximum and minimum temperature, relative humidity, wind speed, and sun shine hours) on monthly basis of the study area were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software version 8. (Table 1 & 2)

Experimental Treatments

The experiment was conducted at Mehoni agricultural Research Center for the continuous of three year with eight treatments. The experimental design was laid out in random complete block design (RCBD) with three replications. The treatment combination was given in Tables 3.

Statistical analysis

The collected data were analyzed using SAS 9.1 statistical software was carried out using least significance difference (LSD) test at 5% probability level.

RESULTS AND DISCUSSION

Crop water and Irrigation Demand

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Based on this output, the seasonal irrigation requirement of maize was used 475.2 mm. This amount was needed for full irrigation level treatments (100% ETc) including the rainfed and supplementary irrigation. Accordingly, the 75, 50, 25, two supplementary irrigation at flowering and grain filling, one supplementary irrigation at grain filing, one supplementary irrigation at flowering and rainfed (non supplement) were applied 393.5, 311.9, 203.4, 222.6., 187.9, 185.6 and 148.5mm respectively. Crop water requirement (ETc) values were low at the beginning of the growing season, increased gradually to attain a maximum during mid season stage and subsequently decreased.

Effect of parameters to Maize in response of Supplementary irrigation

Days to Maturity

The different level of supplementary irrigation affected days to maturity (Table 4). Longer days to maturity was recorded when 100% ETc irrigation level applied and

Table1. Long term monthly average climatic data of the experimental area

Month	T_{min} °C	T_{max} °C	RH %	Wind km/hr	Sun hours	Rad MJ/m²/day	ETo mm/day
January	11.5	27.2	73	69	7.9	18.4	3.33
February	12.8	27.1	70	86	9.4	22.0	4.02
March	13.5	29.5	68	86	8.7	22.4	4.44
April	13.8	29.7	67	95	8.7	22.9	4.65
May	15.3	32.5	58	52	9.1	23.3	4.69
June	15.8	35.0	60	43	8.6	22.2	4.70
July	15.6	31.5	90	52	6.5	19.1	4.04
August	15.0	29.7	95	43	6.5	19.3	3.89
September	14.3	30.8	74	52	6.6	19.2	3.96
October	13.1	29.8	69	86	9.2	22.0	4.36
November	12.1	28.6	67	69	9.0	20.1	3.77
December	11.3	27.1	69	69	8.8	19.0	3.40

Source: FAO. 2005. New-LocClim, Local Climate Estimator.

Table 2. Physical characteristics of soil at the experimental site

Soil texture	Bulk density (g/cm^3)	Field capacity (%)	Permanent wilting point (%)	Total water holding capacity (mm)
Clay	1.1	45.47	28.47	170.02

Table 3. Treatment used in the experiment

Treatment	Combinations
T1	Rainfed / No supplementary irrigation (NS)
T2	Full SI/ 100 % ETc
T3	3/4 SI/ 75% ETc
T4	½ SI/ 50% ETc
T5	1/4 SI/ 25% ETc
T6	One supplementary irrigation at flowering stage (one SI at FS)
T7	One supplementary irrigation at grain filing stage (One SI at FRS)
T8	Two supplementary irrigation at flowering and grain filing stage(Two SI at FS and FRS)

followed by 75% ETC and 50% ETc with the value of 132,129 and 128 days respectively. Significantly earlier day to maturity of 119 were recorded with non-supplementary irrigation (rain fed).

This result is in agreement with that of Brewster (1994) who reported that treatments that lacked supplemental irrigation water advanced to maturity. Similarly, the findings of Solomon (2004) and Ahmed et al. (2008) also showed significant decrease in the number of days to flowering of haricot and faba beans under water stress. This could be due to the fact that plants under stress tend to complete their life cycle, which enables them escape from the unfavourable conditions by ending lifecycle few days earlier than those under normal or high soil moisture conditions, thereby ensuring perpetuation of the species (Al-Suhaibani, 2009).

Plant height

Mean values showed that plant height increased with each increment of irrigation from the full supplementary (100% ETc) to non supplementary or rainfed. When the amount of supplementary irrigation was increased from non-supplementary to 100% ETc, of supplementary irrigation plant height increased from 187.65 cm to 213 cm, respectively (Table 4). Compared to the control treatment, mean plant height was increased by 4.5%, 5.6% 7.7%, 7.8%, 8.9%, 9%, 10.5 and 13.5% for one

Table 4. Main effects of treatment on Maturity Day (MD, Ear Length (CL), Plant Height (PH), Grain Yield (GY), Biomass Yield (BY), and Crop Water Use Efficiency (CWUE) and of Maize

Tre	MD	PH(cm)	EL(cm)	GY (tones ha^{-1})	BY(tones ha^{-1})	CWUE (kg m^{-3})
100% Etc	132.2[a]	213.03[a]	28.62[a]	5.9419[a]	12.7729[a]	1.25[g]
One SI at FS & FRS	126.77[bc]	202.4[bcd]	27.46[ab]	5.5283[bc]	11.4411[d]	2.48[c]
One SI at FS	124.1[d]	198.2[de]	25.93[bc]	5.0403[e]	10.9433[e]	2.72[b]
75%Etc	129.66[b]	207.44[b]	27.86[a]	5.7549[ab]	12.301[b]	1.46[f]
50% Etc	128.77[b]	204.57[bc]	27.5[ab]	5.5153[bc]	11.826[c]	193.5[cd]
One SI at FRS	123[d]	196.25[e]	25.88[bc]	5.1322[de]	10.9488[e]	2.73[b]
25%Etc	126.4[bc]	202.27[cd]	27.48[ab]	5.3526[cd]	11.4627[d]	2.32[d]
Rainfed	119[e]	187.65[f]	25.2[c]	4.5623[f]	9.660[f]	3.07[a]
LSD (P=0.05)	1.67	5.06	1.7	2.7338	2.3714	0.1
CV	1.4	5.3	6.6	5.42	2.18	5.3

Means with the same letter (s) are not significantly different at P ≤ 0.05; NS= not significantly different from each other at P < 0.05; LSD= least significant difference; CV = Coefficient of variation.

supplementary irrigation at grain filling stage, one supplementary irrigation at flowering stage, 25% ETc, two supplementary irrigation at grain filing and flowering stage, 50% ETc, 75% ETc and 100% ETc treatments respectively. The increase in plant height with the increase in the amount of supplementary irrigation could be attributed to positive effect on vigorous vegetative growth due to more availability of soil moisture level throughout the growing period. The increase in plant height with respect to increased supplementary irrigation amount indicates maximum vegetative growth of the plants.

This result in line with the result of Singh and Singh (2002) that depth irrigation increasing plant height, size and total area of leaves, number and location of stomata, shoot growth and vigour of maize are affected by water availability.

Ear length of maize

The different level of irrigation treatments were affected ear length of maize Ear length was increased significantly with the increase in level of supplementary irrigation from the control (rain fed) to the 100% of supplementary irrigation. The highest ear length (28.6 cm) was recorded at a treatment of 100% ETc and the shortest ear length (25.2 cm) was recorded from the control treatment (Table 4). Compared to the 100% ETc, the mean ear length were decreased by 9.4%, 9.8%, and 12% under one supplementary irrigation at grain filling stage, one supplementary irrigation at flowering stage and no supplementary irrigation, respectively. Generally, the trend indicated consistent increment in ear length with increment of irrigation depth from control treatment (rainfed) to 100% ETc. In increase in ear length at higher

Levels of irrigation could be due to high available of soil moisture to the crop that allowed the plants to accumulate more biomass with higher capacity to convert more photosynthesis into sink resulting in longer ear per plant. This result was also in conformity with those reported by Jehan et al. (2007) and Ali and Raouf, (2012) who concluded that increase in irrigation levels also increased ear length.

Grain Yield

The irrigation levels significantly impacted maize grain yield for both irrigation treatments (Table 4). As can be observed from the table, grain yields decreased as the amount of supplementary irrigation water applied decreased. The highest yield, averaging 5.94 and 5.52 tone ha^{-} was obtained from the treatment of 100% ETc and 75% ETc of supplementary irrigation respectively, while rainfed or the control treatment produced the lowest yield of 4.5 tones ha^{-}. Although there were 9.9%, 13.6% and 15% difference for the treatments of 25% ETc, one supplementary irrigation at grain filing and one supplementary irrigation at flowering stage respectively as compare to the 100% ETc of supplementary irrigation

Katerji et al. (2008) reported that the critical growth stages which are sensitive to water deficits include the flowering stage (tasseling, silking, and pollination) and grain filling. Therefore, the result suggests that the full supplementary irrigation was maintaining a high grain yield and reduce crop water stress. This outcome has also been observed in other deficit studies for maize crop (Djaman et al., 2013; Igbadun et al., 2008). Higher yields were obtained from the non deficit irrigation.

Aslam et al. (2013) made a similar finding and attributed this to the fact that under water stress conditions, photosynthesis, transpiration and light interception are reduced, impacting the maize traits due to a reduction of translocated assimilates. Under supplemental irrigation, all these traits were improved compared with rainfed conditions.

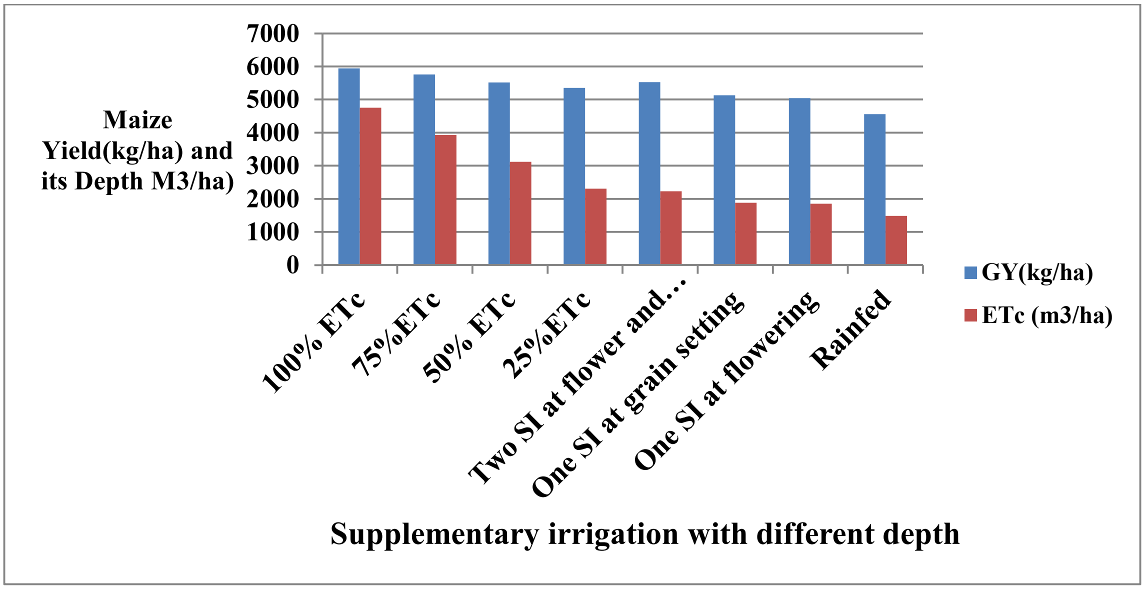

Figure 1: Effect of different depth of supplementary irrigation on maize grain yield

Biomass Yield

Maize biomass yield was significantly affected (*P ≤ 0.05*) by the different level of supplementary irrigation (Table 4).

Higher biomass yield was recorded when 100% ETc supplementary irrigation applied that gave 12. 77 tones ha^{-} and followed by 75%ETc, 50% ETc and 25% ETc with the value of 12.3 tones ha^{-}, 11.8 tones ha^{-} and 11.46 tones ha^{-} respectively. The lowest biomass yield of maize was obtained from the treatment of rainfed (non supplementary irrigation) with the value of 9.6 tones ha^{-1} followed by one supplementary irrigation at the grain filling stage and one supplementary irrigation at the flowering stage with the value of 10.94 tones ha^{-1}. There were no significance differences between the treatment of one supplement irrigation at the grain filling stage and one supplementary irrigation at the flowering stage.

The increment in biomass yield was might be attributed due to the application of supplementary irrigation. This is because that it encourages above ground vegetative growth and imparts high amount of leaves, which is important for more assimilate production and partition that favours maize growth (Brady, 1985). The increased total bulb yield by applying full (no deficit) irrigation could have better performance on vegetative growth like plant height, number of leaves and leaf length which increase photosynthetic capacity of the plant, which in turn can improve bulb weight and contribute to increment in total bulb yield.

As the supplementary irrigation increasing from one supplement at flowering stage to full (100%ETc) supplement the biomass yield of maize increased. This result was also in agreement with the findings of Ferreira and carr, (2002).

Crop water use efficiency (CWUE)

Changing from limited rainfed agriculture (non supplementary irrigation) to supplementary irrigation in the study area resulted decreased in average CWUE from 3.07 to 1.25 kg m^{-3} (Table 4). The results are comparable to increased average grain yield of 1.25 kg m^{-3} with 100% ETc supplementary to 3.05 kg m^{-3} with rain fed (Rockström et al. 2002). The yield improvement can be attributed to timely water application to crops to avoid water stress and availability of more soil water for the plant. The results indicate that water harvesting for dry spell mitigation can play a critical role in reducing the risk of crop failure during cropping seasons with severe dry spells.

Barron (2004) also reported that from the studies made in Kenya that the water productivity for maize with supplemental irrigation was 1796 m3/t of grain, and for maize without supplemental irrigation it was 2254 m3/t of grain, i.e. a decrease in water productivity by 25%. The study concluded that the water-harvesting system for supplemental irrigation of maize was found to be both biophysically and economically viable.

Maize water production function with grain yield

The results obtained in this experiment showed that water production function drawn on the basis of the amount of consumed water in different depth of supplementary irrigation. The figure shows that, as the amount of supplementary irrigation depth increased the grain yield of maize increase. As shown in figure 1, if the rainfed was insufficient during the crop cycle the crop was not fully develop resulting in low yield and high water productivity.

CONCLUSIONS

Soil water availability is a major limiting factor in agricultural production systems. Knowledge of crop response to water supply, full and limited, in localized environments can aid in the development of effective irrigation strategies for improving farm level water management and crop productivity. It is concluded that in the study area the rain fed amount were very inadequate and supplementary irrigation will help to increase crop productivity, Minimize crop failure due to the low rainfed and decrease the deficit of food in the study area.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Ethiopian Institute of Agricultural Research (EIAR) for funding this research project and financial support. The authors also truthfully appreciate Mehoni Agricultural Research Center (MeARC) for given that all necessary support during the implementation of the experiment.

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