Effect of Moisture Stress on Maize (*Zea Mays* L.) Yield and Water Productivity

Robel Admasu[1]*, Abraham W Michael[2] and Tilahun Hordofa[3]

[1]*Irrigation Researcher, Jimma Agricultural Research Center, Ethiopia*

[2]*Bio-System and Environmental Engineering, Hawassa University, Ethiopia*

[3]*Senior Irrigation Researcher, Melkassa Agricultural Research Center, Ethiopia*

*Corresponding author: Robel Admasu, Irrigation Researcher, Jimma Agricultural Research Center, P.box 192, Jimma, Ethiopia

Abstract

Presently and in the future, irrigated agriculture faces water scarcity. Irrigation management will shift from emphasizing productivity per unit area to maximizing the production per unit of water consumed. Field experiment was carried out to determine the water use efficiency of maize under moisture stress condition and to identify the critical depth of application with limited effect on yield. The experiment was conducted at Awash Melkassa agricultural research center farm. The experiment was carried out in RCBD with three replications. Treatments include seven moisture stress levels and a control treatment (full irrigation, 85% ETc, 75% ETc, 65% ETc, 55% ETc, 45% ETc, 35% ETc and 25% ETc). The different levels of irrigation had a highly significant (p>0.01) effect on maize grain yield, above ground biomass yield and harvest index. The highest grain yield was obtained from full irrigation (5524.8 Kg/ha) which was not significantly different with 85% ETc application (5206.5 Kg/ha). In terms of water productivity, 25% ETc gives the highest water productivity and significantly different to all other treatments. In terms of yield, 85% ETc application gave better water use efficiency and had no significant difference with all treatments except with 100 and 25%ETc application. Hence, increased water saving, and associated water productivity can be achieved with the application of 85% ETc, without significant reduction on yield. In areas where water scarcity is high, 35 to 75% ETc application appears to be promising to depend on the availability of water resources with negligible trade-off in grain yield and water use efficiency.

Keywords: Moisture stress; ETc; Maize; Water productivity; Irrigation application

Introduction

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 [1]. 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 [2]. Nevertheless, the production and productivity are strongly challenged by the rapidly dwindling water resources and the growing increase in competition for water.

Water scarcity is a global problem [3]. As cities grow and populations increase, the problem worsens since needs for water increase in households, industry and agriculture. Climate change has also contributed significantly to the water scarcity problem (WHO, 2009). Irrigation uses take almost 60% of all the world's freshwater withdrawals. It is therefore not surprising that irrigated agriculture, especially in arid and semi-arid areas, is facing pressures to reduce its water use in order to also cater for other water users.

In Ethiopia, irrigation development is increasingly implemented more than ever to supplement the rain-fed agriculture but due to the development of other water use sectors as well as increasing concerns for environment water has become increasingly a scarce resource. Among the different river basin found in Ethiopia, Awash River basin is one of the most utilized river basins for irrigated agriculture. Excessive water abstraction without properly assessing the available water resources in the basin contributes to water scarcity. This water shortage has motivated some researchers and farmers to find ways to produce crop with less irrigation water and changing from fully-irrigated to deficit irrigated cropping system.

Deficit irrigation has been widely investigated as a valuable and sustainable production strategy in arid and semi-arid regions. It is one of the ways of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied (Kirda, 2002). Many studies have shown that there is a significant yield and yield component reduction occurs when maize produce under deficit irrigation. Maize is very sensitive to water stress [4,5]. Payero et al. (2008) reported that water stress can affect growth, development and physiological processes of maize plants, which reduce biomass yield.

Different works have been done on maize moisture deficit based on decreasing the amount of irrigation water. However, much work has not been done to determine the critical depth water application where, the yield is not significantly affected. Therefore, considering the scarcity of irrigation water in the region, this research was aimed to determine the critical depth of water application and to evaluate the effect of deficit irrigation on water productivity of irrigated maize.

Material and Methods

Description of experimental site

The experiment was conducted at experimental farm of Melkassa Agricultural Research Center (8°24′ N latitude and 39°35′E longitude at an altitude of 1,550 m.a.s.l. The site is situated in the upper Awash River Basin, the Central Rift Valley of the country. The long-term climate data of the area indicate is semi-arid and has an average annual rainfall is about 822.3mm, concentrated from December to April with irregular distribution. The textural class of the soil of the study area is clay loam with 163.3mm/m total available water. The climate water balance of the study area (Figure 1) shows that there is a need for irrigation water for almost the year round except for the months July to September.
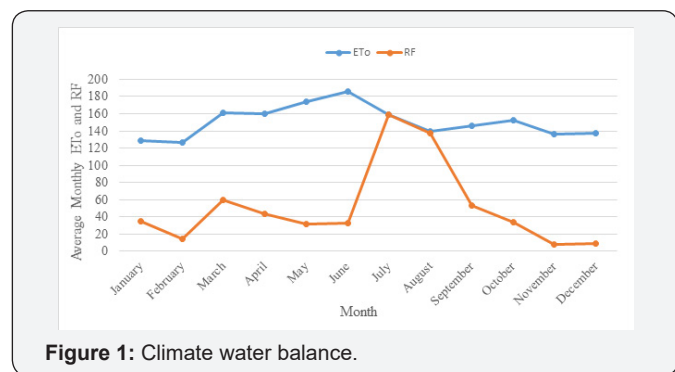

Figure 1: Climate water balance.

Experimental design and treatment combination

The experiment was conducted by using furrow irrigation methods and it includes seven moisture stress level viz., 85% ETc, 75% ETc, 65% ETc, 55% ETc, 45% ETc, 35% ETc and 25% ETc and a control irrigation of 100% ETc making a total of eight treatments. For control irrigation, irrigation water was applied to refill the soil to its field capacity based on allowable soil moisture depletion level of the crop. The rest treatments were taking the assigned percentage of the full irrigation water. The experiment was laid out in randomized complete block design (RCBD) with three replications resulting in a total of 24 plots. Melkassa II maize variety was used for this experiment, a crop that is commonly grown in dry areas under moisture stress condition also mostly grow in Melkassa with plant spacing of 75cm between rows and 25cm between plants.

Procedure of the experimental study

The source of irrigation water used for this experiment was brought from the Awash River. 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 two weeks after planting, until the plants reached the established stage. A 3-inch standard Parshall flume used to measure irrigation water to be applied to individual plots. Water was allowed into the plot for the time calculated for its desire depth of application.

Data collection

yield and yield component parameters were recorded, and the treatments were compared based on above ground biomass yield, grain yield, yield response factor and harvest index. Also, water productivity was estimated.

Grain yield obtained from net harvested plot was adjusted to 12.5% moisture content and converted to hectare basis. Above ground biomass was determined by harvesting fifteen plants from the net plot area at physiological maturity and weighed after sun drying to a constant weight and converted to hectare basis. Harvest index was calculated as the ratio of grain yield to total above ground dry biomass yield multiplied by 100. The yield response factor (K_y) of maize which relates relative yield decrease to relative ET deficit under this study was estimated using the following equation [7]:

$$1-\left(\frac{Y_a}{Y_m}\right) = K_y\left(1-\frac{ET_a}{ET_m}\right) \dots\dots\dots\dots(1)$$

Where: Y_a = actual yield (kg/ha), Y_m = maximum yield (kg/ha), ET_a = actual evapotranspiration (mm), ET_m= maximum evapotranspiration (mm), and Ky = yield response factor

The water productivity was calculated by the ratio of harvested yield per total water used (Zwart and Bastiaanssen, 2004).

$$WP = \frac{Y}{ET} \dots\dots\dots\dots(2)$$

Where, WP is water productivity (kg/m³), Y crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m³/ha).

Data analysis

The collected data were subject to statistical analysis appropriate to RCBD design. SAS software version 9.2 for windows was used for analysis [8]. Whenever the treatment effects were found significant, GLM test at 1 and 5% was performed to assess significant difference among treatments means.

Result and Discussion

Grain yield

The grain yield in the experiment was proportional to the availability of water but as stress intensity increased grain yield decreased (Table 1). The analyzed result indicated that there is

a highly significant (P<0.01) difference among moisture stress treatments on grain yield (Table 1). From table 1, the control treatment (i.e. 100% ETc) gave the highest yield (5524.8 Kg ha^{-1}) followed by moisture stress treatment of 85% ETc (5206.5Kg ha^{-1}) which was not statistically different. The minimum grain yield was recorded from moisture stress treatment of 25% ETc (1468.6Kg ha^{-1}) and this was statistically inferior to all other treatments (Table 1). Decreasing applied water by 25, 35, 45, 55, 65 and 75% of ETc led to decreased grain yield of corn by 12.2, 26.4, 36.1, 53.21, 61.8 and 73.4%, respectively. These results are consistent with findings of Mansouri et al. [9], who showed that grain yield was affected by irrigation water amount. Different researches conducted on sorghum (Klocke et al., 2012) and wheat (Meskelu et al., 2013) revealed that, as the moisture stress level increased the production of the crop will declined, which agreed with the current finding. Also, Karasu et al. [10] stated that deficit irrigation applications from full irrigation to no irrigation decreased the grain yield by 60%.

Above ground dry biomass yield

There is a highly significant (P<0.01) difference among moisture stress treatments on above ground biomass yield. The result in table 3, showed that full irrigation has the highest biomass yield (12.1t ha^{-1}) followed by moisture stress level of 85% crop water requirement (11.7t ha^{-1}) which was not statistically different. From the result, the minimum above ground biomass yield obtained from treatment received 25% of its crop water requirements through the whole growing season (6.7t ha^{-1}) and this was statistically inferior to all other treatments (Table 1). The above ground biomass production in the experiment was proportional to the availability of water i.e. as the stress intensity increased biomass production decreased.

From the current finding, water supply reduced from 100 to 25% ETc the above ground dry biomass yield decreased by 44.6%. These findings agreed with the experimental results reported on maize by Pandey et al, [11]. Lower leaf production and dry matter is attributed to water stress [12]. Moser et al. [13], also reported that biomass was reduced by moisture stress.

The analysis of variance indicated that soil moisture stress had a highly significant (p<0.01) effect on harvest index of maize (Table 1). The highest harvest index of maize was recorded from control treatment (100% ETc) and it had no significant difference with treatments received 85 and 75% of its crop water requirements for all growing periods, while the lowest harvest index was recorded from treatment received 25% of its crop water requirements for the whole growing seasons and had no significant difference with treatments received 35, 45, and 55% of its crop water requirement for the whole growing seasons. Increasing irrigation from 25% ETc to 100% ETc harvest index significantly increased and the increment was consistent. This result implied that, grain formation was highly and strongly affected by moisture content (Table 1).

Table 1: Effect of moisture stress on maize grain yield, biomass yield and harvest index.

Treatments	Grain Yield (Kg ha^{-1})	Above Ground Dry Biomass Yield (t ha^{-1})	Harvest Index
100% ETc	5524.8[a]	12.1[a]	0.46[a]
85% ETc	5206.5[a]	11.7[a]	0.44[ab]
75% ETc	4851.0[b]	10.9[b]	0.44[ab]
65% ETc	4064.1[c]	10.8[b]	0.38[b]
55% ETc	3528.6[d]	10.1[c]	0.35[bc]
45% ETc	2585.0[e]	9.2[d]	0.28[c]
35% ETc	2108.1[f]	8.9[d]	0.24[cd]
25% ETc	1468.6[g]	6.7[e]	0.22[cd]
LSD (0.01)	335.9	0.5	0.07
CV	5.2	4.7	6.2

*Means followed by the same letters in a column are not significantly different from each other at a 1% probability level.

Water productivity

Analysis of variance revealed that moisture stress levels were significant in affecting water use efficiency on grain yield production of maize (Table 2). The highest water productivity was obtained from treatment of 25% ETc followed by 35% and 85% ETc while, the lowest water productivity was obtained from the control treatment (i.e. 100% ETc). From the result, water use efficiency decreased with increasing water supply and reduction of yield. Previous studies indicated that water productivity ranged from 0.41 to 2.71kg m^3 [14-16] which agrees with these finding.

Table 2: Effect of moisture stress on water productivity.

Treatments	Water productivity (kg/m^3)
100% ETc	0.67[c]
85% ETc	0.78[b]
75% ETc	0.78[b]
65% ETc	0.75[bc]
55% ETc	0.77[b]
45% ETc	0.75[b]
35% ETc	0.81[b]

25% ETc	0.98[a]
LSD (0.05)	0.07
CV	7.82

*Means followed by the same letters in a column are not significantly different from each other at a 5% probability level.

Yield response factor (K_y)

The magnitude of K_y 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 3, showed that the highest K_y was 0.98 and 0.97 attained at 25% ETc and 45% ETc respectively. The higher K_y values of 0.98 and 0.97 could be an indication of severe water stresses. This implies that the rate of relative yield decrease resulting from water stress is proportionally the same to the relative evapotranspiration deficit. The lowest yield response factor 0.38 was observed at 85% ETc and it indicated that the water deficit level does not have a significant impact on maize grain yield when compared with optimum irrigation. According to Kirda et al. [17], the K_y value for field crops goes from 0.2 to 1.15 which agrees with the reported result [18-33].

Table 3: Yield response factor values for moisture stress treatments.

Treatment	Y_a (Kg/ha)	ET_a (mm)	ET_m (mm)	Y_m (Kg/ha)	$1-\left(\dfrac{Y_a}{Y_m}\right)$	$1-\left(\dfrac{ET_a}{ET_m}\right)$	K_y
100% ETc	5524.8	760.3	760.3	5524.8	0	0	-
85% ETc	5206.5	646.2	760.3	5524.8	0.06	0.15	0.38
75% ETc	4851	570.2	760.3	5524.8	0.12	0.25	0.49
65% ETc	4064.1	494.2	760.3	5524.8	0.26	0.35	0.76
55% ETc	3528.6	418.2	760.3	5524.8	0.36	0.45	0.8
45% ETc	2584.9	342.1	760.3	5524.8	0.53	0.55	0.97
35% ETc	2108.1	266.1	760.3	5524.8	0.62	0.65	0.95
25% ETc	1468.6	190.1	760.3	5524.8	0.73	0.75	0.98

Where Y_a – actual grain yield, Y_m – maximum grain yield, ET_m – maximum evapotranspiration, ET_a – actual evapotranspiration and K_y – yield response factor.

Conclusion

A study was conducted to determine the effect of moisture stress on maize yield, yield components and water use efficiency. Data on plant height, thousand seed weight, number of kernels per ear, grain weight per cob, grain yield, biomass yield, harvest index and yield response factor were used to compare the difference in crop yield and yield components. In addition, the water productivity associated with irrigation treatments were also evaluated by water productivity.

The study result indicated that there is no significant difference among full irrigation and 85% ETc on average grain yield and above ground biomass yield. The maximum grain yield and above ground biomass yield was obtained from full irrigation followed by 85% ETc. whereas the minimum was obtained from 25% and 35% ETc. Also, Water use efficiency was significantly influenced by variation in the level of irrigation water. 25% ETc gives the highest WUE followed by 35% ETc and 85% ETc. Therefore, it could be concluded that the critical depth of water application for moisture stress area should not be below 85% of full maize water requirement for obtaining relatively good grain yield with a better improvement on water productivity.

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