Original Research Article

Enhancing water use efficiency of maize under deficit irrigation: the case of moisture deficit areas of Tigray, Ethiopia

Abstract

Maize (Zea Mays L.) is one of the most important food crops worldwide. In Ethiopia, it is one of the leading food grains selected to assume a national commodity crop to support the food self-sufficiency program of the country. Maize is fairly sensitive to water stress and excessive moisture stress. This is due to variation in sensitivity of different growth stages to water stress. The study was conducted to determine the water use efficiency of maize under deficit irrigation practice without significant reduction in yield and to identify crop growth stages which can withstand water stress. The experiment was conducted at the Alamata Agricultural Research center experimental site Kara Adishabo Kebele, Raya Azebo district. The experiment was laid out in randomized complete block design (RCBD) with three replications and six levels of irrigation water applications as possible treatments. Analysis was done to yield and water use efficiency of maize using R statistical software and the mean difference was estimated using the least significant difference (LSD) comparison. The highest grain (33.72qt/ha) and biomass yield (148.4qt/ha) was obtained from the 50% deficit irrigation at late growth. The maximum irrigation water use efficiency was obtained from both 50% deficit at all the four growth stages (0.5418 kg/ha) and at 50% deficit at late growth stage (0.446 kg/m3). And by comparing the grain yield obtained at the 50% deficit at late growth stage (33.72qt/ha) and grain yield obtained at 50% deficit at all growth stages (23.34 qt/ha), the 50% deficit at late growth stage shows better result. The 50% deficit of crop water requirement did not affect the yield components (plant height & number of cobs per plant) of maze. Therefore applying irrigation water by reducing the crop water requirement by 50% at the late growth stage has a significant contribution for sustainable and efficient irrigation water utilization at moisture deficient areas without a significant loss on grain and biomass yield.

Key words- Deficit irrigation, Maize, Raya Azebo, water use efficiency

1. Introduction

Maize (Zea Mays L.) is one of the most important food crops worldwide (Andy **et.al**, 2004). It has the highest average yield per hectare and is the third after wheat and rice in area and total production in the world (Andy **et.al**, 2004). In Ethiopia, it is one of the leading food grains selected to assume a national commodity crop to support the food self-sufficiency program of the country (Abate et.al, 2015).

Maize crop is fairly sensitive to water stress and excessive moisture stress. Water stress is the most limiting factor in maize production (Geerts and Raes, 2009). Moisture stress during establishment kills young plants and reduces plant density. During vegetative stage, it restricts leaf growth and expansion resulting in stunted growth. With increasing moisture stress, the dry matter production of the crop decreases directly by decreasing cell division and enlargement and indirectly by reducing rate of photosynthesis. Much of the past research on water stress on maize has consisted of full withholding of irrigation and conditions of severe water stress(Yenesew& Tilahun, 2009). At the same time, there is also indication that maize yield is just a linear function of seasonal Evapo-transpiration.

Deficit irrigation of maize distributed over the whole growing season might not always result in increasing crop water productivity. This is due to variation in sensitivity of different growth stages to water stress. It is essential to examine the effect of water stress at different growth stages on maize yield (Rusere et al,2012). Therefore, the study was conducted with the objectives of determining water use efficiency of maize under deficit irrigation practice without significant reduction in yield and to identify crop growth stages which can withstand water stress in the study area.

2. Material and method

2.1 Area description

The field experiment was conducted at the Alamata Agricultural Research center experimental site located at Kara Adishabo Kebele, Raya Azebo district during the cropping season of 2017 and 2018. Particularly the experiment site is located at point of geographical reference 12.69^0 N latitude and 39.66^0 E longitudes (Fig. 1).

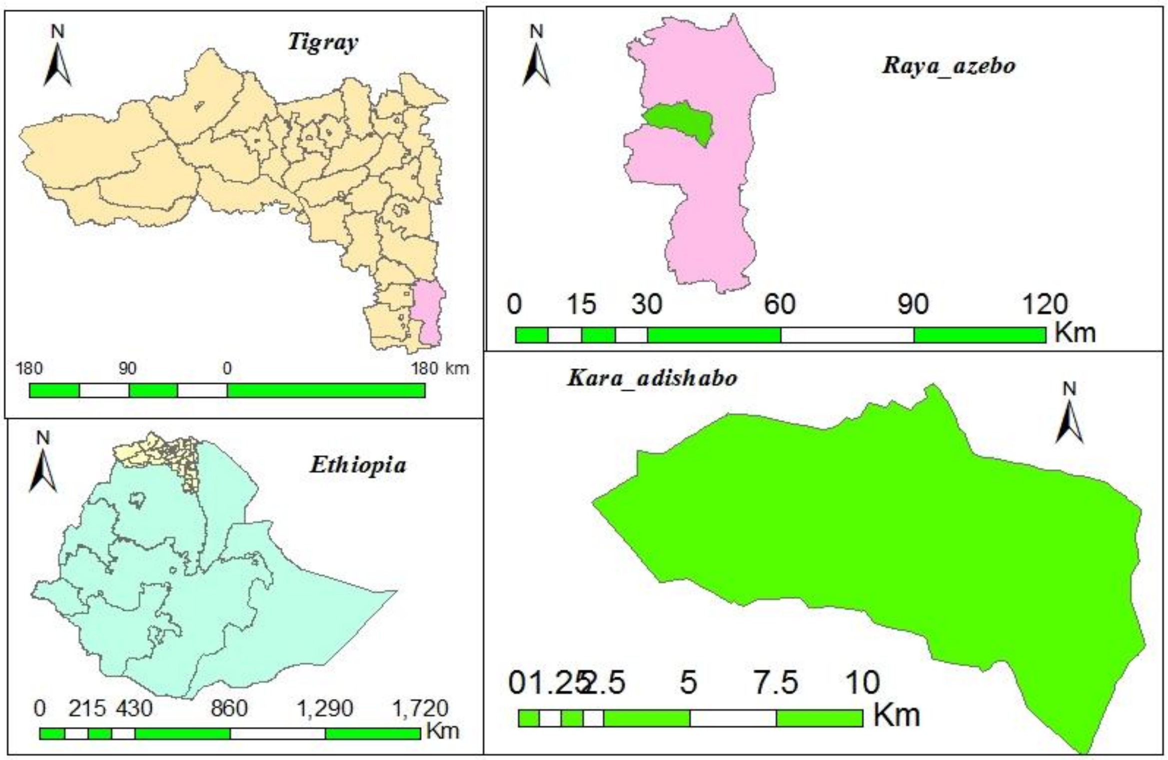

Fig1: Location map of the study area

The soil texture was taken medium (loam) type, the maximum infiltration rate (mm/day), total available soil moisture (mm/meter), maximum rooting depth (cm) and initial soil moisture depletion (% TAM) of the soil was considered as 40, 290, 900 and 0 respectively based on FAO recommendations. The main physical and chemical characteristics of the soil in the study area are shown in Table 1 (Brhane, 2016) during irrigation application, water was applied to refill up to soil field capacity.

Table 1: Physical and chemical properties of different soil layers of Kara Adishabo site

Soil depth	Texture class	pH	EC (dsm^{-1})	SAR	CEC
0-15	SL	8.6	0.30	1.02	60.99
15-30	SL	8.5	0.26	1.16	59.72
30-60	L	8.6	0.40	0.97	77.06

Note: Adopted from Brhane, 2016

The climatic condition of the research site is semi-arid. The mean minimum and maximum temperature of the region is 16 ^{0}C and 29 ^{0}C, respectively. The average annual precipitation of the area is 546 mm.

2.2 Experimental design

The experiment was laid out in randomized complete block design (RCBD) with three replications (**Error! Reference source not found.**). There were six levels of irrigation water applications as treatments. Each treatment was laid out on 3.5m x 4m plot size. The distance between plots and blocks were 1 and 2 meter respectively. The experiment was conducted for 50% deficit irrigation of water requirement per growing stages of the crop as treatments.

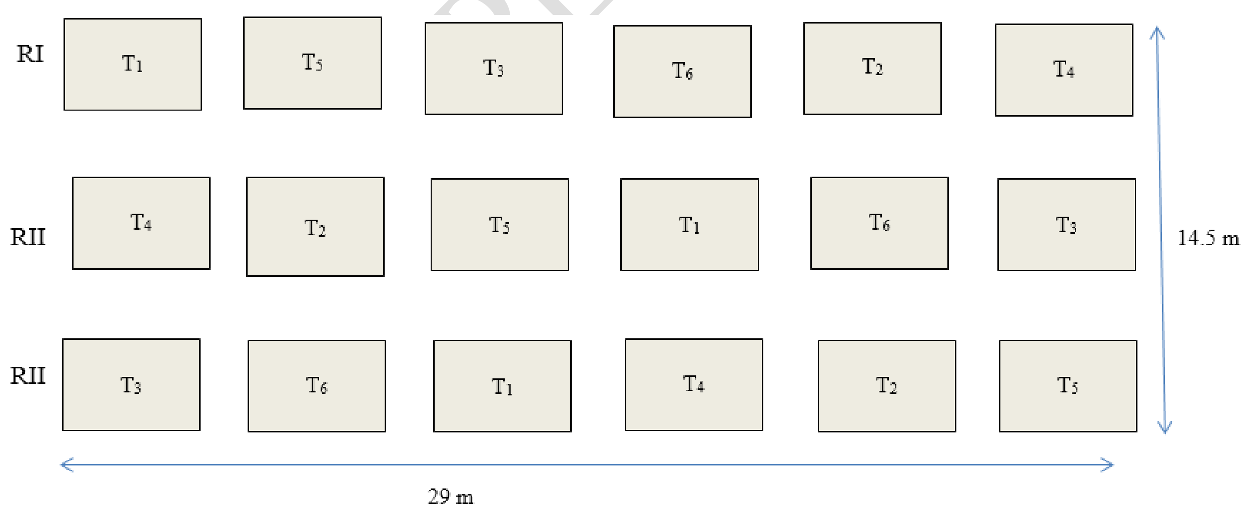

Fig 2: lay out of the experimental treatments

Enhancing yield and water productivity of maize at different deficit irrigation stages and levels starts from calculation of crop water requirement and irrigation scheduling. The crop water requirements, irrigation scheduling was determined for the four growing stages (initial, development, mid and late) of maize.

Table 2. Treatment levels of maize under deficit irrigation per growing stages

Treatment	Treatment name
T1	Farmers practices
T2	50 % deficit throughout all growing stages
T3	50% deficit at initial growth stage
T4	50% deficit at development growth stage
T5	50% deficit at mid growth stage
T6	50% deficit at late growth stage

The method of irrigation was furrow irrigation with application efficiency of 70%. Crop water requirement and irrigation schedule were estimated using CROPWAT 8.0 software (FAO. 1992).

2.3. Data collection and analysis

Composite soil sample were collected from the experimental site and analyzed at Mekelle soil research center. The soil samples were taken from two depths (0-25 cm and 25-50 cm) and analyzed separately. The major parameters analyzed in laboratory are EC, pH, organic matter, permanent wilting point, field capacity and bulk density. The total available water of the soil was computed from the results of field capacity and permanent wilting point. The relevant meteorological data like monthly minimum and maximum temperature, rainfall, relative humidity, sunshine hours and wind speed were collect from nearby Mychew and Chercher stations. These data are important input parameters for determination of reference crop evapo-transpiration.

The evapo-transpiration was calculated using Modified FAO Penman–Monteith method (Allen et al., 1998). Since there was no effective rainfall during the study period, 100% of crop water requirement was supplied by means of irrigation.

2.4.Statistical data analysis

Analysis was done to yield and water use efficiency of maize using R statistical software*(R Core Team., 2016)*. The data of the experiment was analyzed in randomized complete block design (RCBD), and the mean difference was estimated using the least significant difference (LSD) comparison.

3. Result and discussion

3.1 Irrigation water application

According to the result of CROPWAT 8 software the estimated maize crop water requirement was 642 mm. Irrigation water applications for each treatment were also determined. Table 3 shows the levels of water application in different growing stages of the crop for the treatments.

Table 3:Summery of water application for the experimental treatments

Treatment	Description	Water applied (m^3/ha)
T1	Farmers practices	5559
T2	50 % deficit throughout all growing stages	4312
T3	50% deficit at initial growth stage	7641
T4	50% deficit at development growth stage	7529
T5	50% deficit at mid growth stage	7289
T6	50% deficit at late growth stage	7563

3.2 Grain and biomass yield

3.2.1 Grain yield

The experiment was conducted for two consecutive years and the maximum grain yield and biomass yield was obtained from 50% deficit at late growth stage in both years (Table 4 and Table 5). The result of the treatments shows a significant difference in 2017 cropping season at (at P = 0.05). But in the next season there was no statically significant difference among the treatments.

Table 4. Effects of 50% irrigation deficit on Grain yield

Treatments	2017 Grain yield (qt/ha)	2018 Grain Yield (qt/ha)	Mean
Farmers practice	31.52ab	19.5	25.51b
50% deficit throughout all growth stages	24.25b	22.43	23.34b
50% deficit at initial stage	32.1ab	23.04	27.57ab
50% deficit at development growth stage	29.45ab	21.65	25.55b
50% deficit at mid growth stage	30.74ab	22.23	26.48ab
50% deficit at late growth stage	39.6a	27.84	33.72a
LSD	14.41	Ns	7.68
CV (%)	25.03	23.26	24.07

Note- 1 qt (quintal) = 100 Kg

Table 5. Effects of 50% irrigation deficit on Biomass yield

Treatments	2017 Biomass yield (qt/ha)	2018 BiomassYield (qt/ha)	Mean
Farmers practice	156ab	71.55	113.8b
50% deficit throughout all growth stages	136.2b	92.98	114.6b
50% deficit at initial stage	171.2ab	85.84	128.5ab
50% deficit at development growth stage	134.5b	87.03	110.8b
50% deficit at mid growth stage	158.1ab	97.74	127.9ab
50% deficit at late growth stage	193.1a	103.7	148.4a
LSD	43.38	Ns	29.83
CV (%)	16.08	29.1	20.37

3.3 Plant Height and Number of Cobs per Plant

The effect of the treatments on yield components (plant height and number of cobs per plant) did not show significant difference (at p = 0.05) in both cropping years, but the plant height parameter shows a significant difference in the combined analysis in which the 50% deficit at late growth stage shows maximum height (2.06m) (Table 6).

Table 6. Effects of 50% irrigation deficit on yield components

Treatments	2017		2018		Mean	
	PH(m)	Cobs/plant	PH (m)	Cobs/plant	PH(m)	Cobs/plant
Farmers practice	2.102	1.67	1.675	1.667	1.889ab	1.417
50% deficit throughout all growth stages	1.854	1.67	1.751	1.133	1.804b	1.15
50% deficit at initial stage	2.14	1.333	1.741	1.467	1.94ab	1.4
50% deficit at development growth stage	1.838	1.25	1.761	1.333	1.799b	1.292
50% deficit at mid growth stage	2.07	1.25	1.775	1.267	1.924ab	1.258
50% deficit at late growth stage	2.145	1.417	1.979	1.267	2.063a	1.342
LSD	Ns	Ns	Ns	Ns	0.217	Ns
CV (%)	7.12	12.41	8.17	13.24	9.68	18.93

3.4 Water use efficiency

Irrigation water use efficiency of the crop significantly affected by the use of different depth of water application (p = 0.05) for the two years experiment combined analysis (Table 7). The Irrigation water use efficiency was higher at 50% deficit throughout the whole growth stage and at 50% deficit at late growth stage.

Table 7. Effects of 50% irrigation deficit on Irrigation water use efficiency

Treatments	2017	2018	Mean
	IWUE (Kg/m^3)	IWUE (Kg/m^3)	IWUE (Kg/m^3)
Farmers practice	0.5671	0.3508b	0.4604ab
50% deficit throughout all growth stages	0.5623	0.5203a	0.5418a
50% deficit at initial stage	0.4201	0.3016b	0.3608bc
50% deficit at development growth stage	0.3912	0.2876b	0.3388c

50% deficit at mid growth stage	0.4217	0.3049b	0.3641bc
50% deficit at late growth stage	0.5236	0.3681b	0.4457abc
LSD	Ns	0.133	0.111
CV (%)	23.7	21.08	24.19

4. Conclusion

From the results obtained we can conclude that the grain, biomass yield and irrigation water use efficiency was affected by the depth of irrigation water application. The highest grain (33.72qt/ha) and biomass yield (148.4qt/ha) was obtained from the 50% deficit irrigation at late growth stage of maize. The maximum irrigation water use efficiency was obtained from 50% deficit at all the four growth stages (0.5418 kg/ha) and at 50% deficit at late growth stage (0.446 kg/m3). Comparing the grain yield obtained at the 50% deficit at late growth stage (33.72qt/ha) and grain yield obtained at 50% deficit at all growth stages (23.34 qt/ha), the 50% deficit at late growth stage shows better result. The 50% deficit of crop water requirement did not affect the yield components (plant height & number of cobs per plant) of maze.

Therefore applying irrigation water by reducing the crop water requirement by 50% at the late growth stage has a significant contribution for sustainable and efficient irrigation water utilization at moisture deficient areas without a significant loss on grain and biomass yield.

References

1. Abate T., Shiferaw, B., Menkir, A. et al. Food Sec. (2015) 7: 965. https://doi.org/10.1007/s12571-015-0488-z
2. Allen, R. G., Pereira, L. S., Raes, D., and Smith, M., 1998: Crop evapotranspiration: guidelines for computing crop water requirements, FAO Drainage and Irrigation Paper 56, Food and Agriculture Organization, Rome
3. Andy J Cherry, Agnassim Banito, Denis Djegui & Chris Lomer (2004) Suppression of the stem-borer *Sesamia calamistis*(Lepidoptera; Noctuidae) in maize following seed dressing, topical application and stem injection with African isolates of*Beauveria bassiana*, International Journal of Pest Management, 50:1, 67-73, DOI: 10.1080/09670870310001637426

4. Brhane, H., 2016. Salinity status of soils of Raya valley. MSc. Thesis. Haremaya University.
5. FAO. 1992. CROPWAT, a computer program for Irrigation planning and management by M. Smith. FAO Irrigation and Drainage Paper No. 26. Rome
6. FAO., 2002. Deficit irrigation practice. Water reports no. 22, Food and Agriculture Organization of the United Nations, Rome. 100 pp
7. Geerts, S., & Raes, D. (2009). Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural Water Management, 96, 1275-1284
8. R Core Team, 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
9. Yenesew, M., & Tilahun, K. (2009). Yield and water use efficiency of deficit-irrigated maize in a semi-arid region of Ethiopia. African Journal of Food, Agriculture, Nutrition and Development, 9(8).
10. Rusere, F., Soropa, G., Svubure, O., Gwatibaya, S., Moyo, D., Ndeketeya, A., & Mavima, G. A. (2012). Effects of deficit irrigation on winter silage maize production in Zimbabwe. International Research Journal of Plant Science, 3(9), 188-192.