Effect of Growth Stage Moisture Stress on Maize (Zea Mays L.) Yield and Water Use Efficiency at West Wellaga, Ethiopia

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Abstract
Often scarcity of water is the most severe constraint for development of agriculture in arid and semi-arid areas. Under this condition, the need to use the available water economically and efficiently is unquestionable. Based on the actual crop need, the irrigation management has to be improved so that the water supply to the crop can be reduced while still achieving high yield. The purpose of this study was to investigate the effect of moisture stress on four growth stage of BH-660 hybrid maize variety. A field experiment was conducted at Jimma Agricultural Research Centre at Haru agricultural research sub-centre station. A randomized complete block design (RCBD) with three replications was used. Sixteen treatments which combined and imposed at four growth stages were used. The two years combined result indicated that there were a significant ($P<0.05$) variation among treatments for yield, biomass and plant height and water use efficiency. The yield of maize was significantly ($P<0.05$) affected due to moisture stress imposed at different growth stages. Accordingly, the highest grain yield was obtained from irrigating all growth stage treatment (8357 kg ha^{-1}) followed by irrigating all stage except initial stage (6887.6 kg ha^{-1}). In contrast, imposing moisture stress at all growth stage was recorded the lower yield relatively, which followed by irrigating only at initial. The crop water use efficiency was the lowest (0.50 kg/m^3) at optimum irrigation water application and the highest (2.65 kg/m^3) at stress at development, mid-season and late season stage. Therefore, imposing moisture stress during the three growth stages except initial and no irrigation treatments had significantly reduce the yield of maize but stressing only initial stage gave higher yields , so depriving irrigation at initial stage helps to save extra water without greater yield penalty.
Keywords: Growth stages, Moisture stress, Maize, Water use efficiency

1. Introduction

The increasing global demand for food and other agricultural products calls for urgent measures to increase water use efficiency. As land pressure raises more and more marginal area is being used for agriculture. Much of this land is located in the arid or semiarid belt where rain falls irregularly and much of the precious water is soon lost as surface runoff. Therefore the great challenge for the coming decades will be the task of increasing food production with less water particularly in areas with limited water, land resource and inefficient water use.

In the context of improving water productivity, there is a growing interest in deficit irrigation, an irrigation practice whereby water supply is reduced below maximum level and mild stress is allowed with minimal effects on yield (Kirda, 1999). Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains by maximizing yield per unit of water. Therefore, in areas with water shortage, it is important to see what level of stress at different growth stages result in high water use efficiency. This enables irrigators to know not only a critical growth stage but also the optimum magnitude of stress to be imposed.

Maize (*Zea Mays L.*) is one of the most important food crops worldwide. It has the highest average yield per hectare and is the third after wheat and rice in area and total production in the world. It has multiple uses, including for human foods, animal feeds, and the manufacture of pharmaceutical and industrial products. Maize is very sensitive to water stress (Pandey *et al*., 2000). Payero *et al.* (2008) reported that water stress can effect growth, development and physiological processes of maize plants, which reduce biomass yield. In general, the life cycle of the maize crop depends on the availability water, the water deficit at any phonological stage i.e. vegetative, reproductive and maturity stages have different response and can damage the grain yield (Cakir, 2004).

Therefore, determination of the effect of stage wise deficit irrigation on water productivity is important to utilize the limited water resource without significantly affecting irrigated crop yield. Taking into account the scarcity of irrigation water and the sensitivity of the crop for moisture deficit, this research was aimed to determine the effect of moisture deficit on water productivity of irrigated maize at different growing stage.

2. Materials and Methods

2.1. Description of the study site

The experiment was conducted at Haru agricultural research sub-centre during the growing season of 2014 and 2015. It was found in west wellaga zone Gimbi area. The rainfall pattern of the area is bimodal with a short rainy season from February to March and the main rainy season from June to September. The most dominant soil type of the area is clay loam.

2.2. Treatments and design

A field experiment was carried out in three seasons of 2014 and 2015. This experiment was laid out in RCBD with three replications. The treatments which are presented in table 1 consisted of fifteen soil moisture stress levels and a check which imposed at four growth stages.

Table 1: Treatments combination

Number	Treatments
1	Irrigate all growth stages (Check)
2	Irrigate all stages except initial stage
3	Irrigate all stages except development stage
4	Irrigate all stages except mid-season stage
5	Irrigate all stages except maturity stage
6	Irrigate all stages except initial and development stages
7	Irrigate all stages except initial and mid-season stage
8	Irrigate all stages except initial and maturity stages
9	Irrigate all stages except development and mid-season stages
10	Irrigate all stages except development and maturity stages
11	Irrigate all stages except mid-season and maturity stages
12	Irrigate only at maturity stage
13	Irrigate only mid-season stage
14	Irrigate only development stage
15	Irrigate only initial stage
16	No irrigation (Control)

Each individual plots had area of 3m X 3m = 9m^2, which consists of 5 rows. The hybrid BH-660 maize cultivar (*Zea mays* L.) was used as seed source. The recommended spacing of 75 and 25cm between row and plant was employed; two maize seeds were planted per hill, which consists of 53,333 plants population/ha. Each experimental treatment was fertilized with recommended fertilizer application, that was 150kg/ha and 200kg/ha of DAP and Urea respectively. The full dose of DAP was applied at sowing, whereas Urea was applied by splitting into two parts, half first and the rest just at 35 days after weeding. All cultural practices were done to all treatments in accordance to the recommendation made for the area. Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity.

2.3. Data collection

Yield, yield component and growth parameters were recorded and the treatments were compared based on grain yield and yield components, which includes plant height, ear height, above ground biomass yield, grain yield and yield response factor. Also, water use efficiency of the crop was estimated.

Grain yield was calculated by harvesting the total number of plants in the net plot (5.625 m^2) and grain yield per plot was measured using electronic balance and then adjusted to 12.5% moisture 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. The yield response factor (Ky) of maize was estimated using the following equation which is formulated by Doorenbos and Kassam (1979).

$$\left(1-\frac{Y_a}{Y_m}\right) = Ky\left(1-\frac{ET_a}{ET_m}\right) \quad \ldots\ldots (1)$$

Where: Ya = actual yield (kg/ha), Ym = maximum yield (kg/ha), ETa = actual evapotranspiration (mm), ETm= maximum evapotranspiration (mm), and Ky = yield response factor

The crop water use efficiency was calculated by the ratio of harvested yield per total water used.

$$WUE = \frac{harvested\ grain\ yield}{total\ water\ used} \quad \ldots\ldots (2)$$

The data were statistically analyzed combined for both years by SAS software. SAS software version 9.2 for windows was used for analysis (SAS Institute, 1996). Whenever the treatment effects were found significant, GLM test at 1 and 5% was performed to assess significant difference among treatments means.

3. Result and Discussion

3.1. Plant Height

The analysis of variance revealed that there is a highly significant ($P<0.01$) difference among treatments due to moisture deficit at different growth stage. From the table 2 irrigating all growth stages gave the highest over years mean plant height followed by irrigating all growth stage except initial stage and irrigating all stage except maturity stage. The minimum plant height was obtained from no irrigation treatments. From the result, moisture stress (at development and mid season stage with any of the combination reduced plant height significantly. Sammis *et al.,* (1988) reported that plant height could change at different level water deficiency. The result of the experiment was also in agreement with the findings of (Bozkurt *et al.,* 2006; Cakir, 2004; Istanbulluoglu *et al.,* 2002) who reported that, plant heights were reported to be higher with full irrigation and slightly deficit irrigation throughout the crop growing season.

3.2. Grain Yield

The result over years mean indicated moisture stress happened at different maize growth stages had a significant effect on grain yield (Table 2). The over years analysis of mean grain yield indicated that irrigating during all four growth stages gave a maximum grain yield (8357.7 K.g/ha) followed by irrigating all stages except initial stage (6887.6 K.g/ha). However, the minimum grain yield was obtained from no irrigation (1021.6 K.g/ha) followed by irrigating only initial stage (1826.7) which showed statistically no significant difference. The result revealed that when moisture stress happens both at development and mid season stages in combination, yield and yield parameter influenced extremely. These results are consistent with findings of Farre and Faci (2009), Ko and Piccinni (2009) and Mansouri *et al.,* (2010), who showed that grain yield was affected by irrigation water amount. Some researchers stated that yield decreased with reduced irrigation (Viswanatha *et al.,* 2002). Moisture Stress at flowering and pollination could result in unfilled kernels on the cob. This can reduce grain yield by 6% to 8% each day the plant is stressed. If the plant is stressed after flowering, kernel size is reduced (NWS, 2009). Former report by Farshad *et al.,* (2008) also showed lowest grain yield was obtained by applying water stress at silking growth stage which is equivalent with the mid season stage. Moreover, different stress level at different stages affect the yield of maize and even different cultivars have different tolerance level for moisture stress leads to a decrease of chlorophyll content which will reduce the amount of food produced in the plant (Adel *et al.,* 2013). The yield obtained from irrigating only one stage was much lower than those of the yield obtained during stress occurring at individual growing stage of initial, development, mid season and late season stages. From the above result, it could be seen that it is better to stress the crop at its specified growing stage especially at initial and maturity stage rather than totally stressing. The ability of crops to partially recover the effect of early water stress has also been observed in other studies (Kirda *et al.,* 1999). These studies revealed that under limited water condition, it is better to start by subjecting the crops to stress early in the season. By doing so, the crop adapts to limited watering conditions with the stress not being severely concentrated in any one time period.

3.3. Above ground dry biomass yield

Moisture stress at different growth stages had a highly significant influence ($p<0.001$) on maize above ground dry biomass production. The above ground dry biomass yield of maize ranged from the highest 1.4 t/ha to the lowest 2.1 t/ha in full irrigation treatments and no irrigation treatments, respectively (Table 2). From the result, irrigating maize at all growth stages provided the highest above ground dry biomass yield. Stressing the maize at all growth stages and only irrigating the initial stage were relatively scored the lowest above ground dry biomass. These findings were in agreement with the experimental results reported by Pandey *et al.,* (1983b). Lower leaf production and dry matter is attributed to water stress (El-Bagoury and Shakeen, 1977). Stone *et al.,* (2001) and Moser *et al.,* (2006), also reported that biomass was reduced by moisture stress. The combined stress imposing at different growth stages significantly reduced the above ground dry biomass of maize. However, imposing moistures stress during initial stage was not significantly reduced above ground dry biomass. This agrees with work of Ersel *et al.,* (2010) on maize, the trend of biomass production shows decreasing with increasing of moisture stress indicating well irrigated maize yields higher biomass production. Similarly, Rusere *et al.,* (2012) investigated that, 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.

3.4. Water use efficiency

The water use efficiency was significantly affected by imposition of moisture stress at different growth stages (Table 2). As application water becomes reduced the water use efficiency significantly increased. Irrigating all four growth stages had recorded the lowest water use efficiency due to maximum irrigation application. Whereas, the combined moisture stresses imposition at different growth stages could highly increased water use efficiency. Stressing maize during three growth stage (mid, development and late season) can considerably increased the water use efficiency. The maximum crop water use efficiency was obtained from irrigating only initial stage (2.65 $K.g/m^3$) whereas; the minimum was obtained from irrigating all four growth stages (0.50 $K.g/m^3$). Yensew and Tilahun (2009) noted that practicing deficit irrigation by reducing the amount of water per irrigation results in a decline of grain yield, increase in irrigated area and high water use efficiency. Previous studies indicated that crop water use efficiency ranged from 0.41 to 2.71 kg/m^3 (Pandey *et al.,* 2000; Kar and Verma, 2005; Dagdelen *et al.,* 2006; Mengü and Özgürel, 2008) which is in agreement with the current findings.

Table 2: Agronomic Performance of Maize on Moisture Stress Condition

Treatments	Mean Grain Yield (K.g/ha)	Mean Plant Height (cm)	Mean Above Ground Biomass (t/ha)	Mean Crop Water Use Efficiency (K.g/m^3)
Irrigate All Growth Stages	8357.7^{a}	209.8^{a}	1.4^{a}	0.50^{h}
Irrigate All Stages Except Initial Stage	6887.6^{b}	192.5^{b}	1.3^{b}	0.57^{h}
Irrigate All Stages Except Development	4411.8^{de}	179.5^{c}	7.8^{ef}	0.57^{h}
Irrigate All Stages Except Mid-Season Stage	4575.5^{d}	172.6^{d}	7.1^{f}	0.95^{e-g}
Irrigate All Stages Except Maturity stage	5705.0^{c}	191.3^{b}	1.1^{c}	0.94^{fg}
Irrigate All Stages Except Initial and Development stages	4674.4^{d}	153.1^{e}	7.2^{fg}	0.97^{e-g}
Irrigate All Stages Except Initial and Mid-Season stages	5376.0^{cd}	153.5^{e}	8.1^{de}	1.28^{de}
Irrigate All Stages Except Initial and Maturity stages	5391.7^{cd}	169.3^{d}	8.7^{d}	0.84^{gh}
Irrigate All Stages Except Development and Mid-Season stages	3011.6^{ef}	131.6^{g}	5.3^{h}	0.72^{gh}
Irrigate All Stages Except Development and Maturity stages	3456.9^{ef}	142.8^{f}	8.0^{de}	0.82^{gh}
Irrigate All Stages Except Mid-Season and Maturity stages	4059.5^{de}	139.0^{f}	8.2^{de}	1.84^{c}
Irrigate Only at Maturity Stage	3213.2^{ef}	73.3^{i}	4.5^{i}	1.35^{d}
Irrigate Only Mid-Season Stage	3872.7^{e}	83.1^{h}	4.4^{i}	1.22^{d-f}
Irrigate Only Development Stage	3770.1^{ef}	82.3^{h}	3.4^{j}	2.29^{b}
Irrigate Only Initial Stage	1826.7^{g}	69.5^{i}	3.2^{j}	2.65^{a}
No Irrigation	1021.6^{gh}	57.3^{j}	2.1^{k}	-
LSD at 1%	1025.2	5.6	0.68	0.34
CV %	18.77	9.5	9.8	21.15

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

3.5. Yield response factor (Ky)

The magnitude of K_y value indicates the sensitivity of the irrigation protocol for water stress and subsequent yield decrease. Form the result shown below; the highest K_y was 1.15, 1.09 and 1.07 attained at the treatment of irrigating all stages except development and mid season, development stage and mid-season stage, respectively. The higher K_y values could be an indication of severity water stresses at that stage on maize grain yield. The lowest 0.54 was observed at irrigating all stage except initial stage indicating that the water deficit at this stage did not affect maize grain yield significantly. This implies that the rate of relative yield decrease resulting from water stress is proportionally lower to the relative evapotranspiration deficit. From table 3, moisture stress happened at development and mid season stages the yield reduction rate is extremely higher than stressed the crop at initial and maturity stage. According to Kirda *et al.,* (1999), the K_y value for field crops goes from 0.2 to 1.15 which agrees with the reported result.

Table 3: Maize Yield Response Factor on Moisture Stress Condition

Treatment	Y_a / Y_m	ET_a / ET_m	$1-\left(\frac{Y_a}{Y_m}\right)$	$1-\left(\frac{ET_a}{ET_m}\right)$	K_y
Irrigate All Growth Stage	1.00	1.00	0.00	0.00	-
Irrigate All Stage Except Initial Stage	0.88	0.78	0.12	0.22	0.54
Irrigate All Stage Except Development	0.55	0.59	0.45	0.41	1.09
Irrigate All Stage Except Mid-Season Stage	0.54	0.57	0.46	0.43	1.07
Irrigate All Stage Except Maturity	0.68	0.66	0.32	0.34	0.94
Irrigate All Stage Except Initial & Development	0.56	0.44	0.44	0.56	0.79
Irrigate All Stage Except Initial & Mid-Season	0.64	0.41	0.36	0.59	0.61
Irrigate All Stage Except Initial & Maturity	0.65	0.53	0.35	0.47	0.74
Irrigate All Stage Except Development & Mid-Season	0.30	0.39	0.70	0.61	1.15
Irrigate All Stage Except Development & Maturity	0.41	0.40	0.59	0.60	0.98
Irrigate All Stage Except Mid-Season And Maturity	0.49	0.36	0.51	0.64	0.80
Irrigate Only At Maturity Stage	0.38	0.31	0.62	0.69	0.90
Irrigate Only Mid-Season Stage	0.46	0.42	0.54	0.58	0.93
Irrigate Only Development Stage	0.45	0.35	0.55	0.65	0.85
Irrigate Only Initial Stage	0.10	0.15	0.90	0.85	1.06

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

4. Conclusion

From the experiment, the maximum grain yield was obtained from full irrigation followed by irrigating all stage except initial stage. Whereas, the minimum was obtained from no irrigation and irrigating only initial stage. For crop water use efficiency the maximum water productivity obtained from irrigating only initial stage, but the minimum was obtained from full irrigation. In addition, stressing the maize plant at development and mid-season stage resulted in high yield loss. Therefore, it can be concluded that imposing moisture stress at initial stage was not significantly reduced the maize grain yields and dry biomass yield production however, it exhibited lower water use efficiency. Moreover, stressing moisture at development and mid-season crop growth stage while irrigating the rest of growth stages leads to wastage of water used for irrigation by decreasing the productivity of water in relation with the yield obtained. To enhance maize crop productivity both in irrigated and rain-fed agriculture, application of irrigation water to enhance the soil moisture at development and mid season growth stage is vital where supplementary irrigation from available water source is possible. Therefore, in area where irrigation water is scarce one can use with holding irrigation water at initial stage strategy to save considerable amount of water but the water resource is not scarce application of full crop water requirement is recommended.

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