# Response of Maize (*Zea mays* L.) for Moisture Stress Condition at Different Growth Stages

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***Abstract:*** **A field experiment was conducted for two consecutive seasons (2011/12 and 2012/13) at Koka Research Station of Wondo Genet Agricultural Research Center, Ethiopia 8°26' N latitude, 39°2' E longitude and 1602masl altitude with the objective to identify maize growth stages sensitive to soil moisture stress, determine critical time for irrigation application for limited water resources and productivity of water. Fifteen treatments was used depriving irrigation on combination of four growth stages of maize (*Zea maize* L.) Variety Melkass-II. Randomized completely block design (RCBD) with three replication was used. Results indicated that both years plant height, 1000 seed weight, above ground biomass, grain yield and water use efficiency (WUE) were significantly ($p<0.001$) affected by depriving irrigation water at different maize growth stage during both years. In addition to this during the first year cob length and harvesting index were significantly ($p<0.01$) affected, whereas cob diameter was affected significantly ($p<0.05$). During the second year cob diameter and cob length were affected significantly ($p<0.001$) and harvesting index (HI) was significantly ($p<0.05$) affected. The study had shown that during both the first and second year maximum grain yield (9253kg/ha and 11748kg/ha) was obtained due to stressing maize only at initial stage enhance grain yield which indicated that stressing moisture only at initial stage enhance grain yield. Moisture stress at mid-season should be avoided especially when combined with moisture stress at development stage. Moreover, moisture stress at initial and late seasons enhance water use efficiency without significantly reducing the yield from the higher yielding treatments.**

***Keywords:*** **Depriving irrigation, growth stages, maize, moisture stress.**

## I. INTRODUCTION

The rapid inclination of population growth worldwide in general and in developing countries in particular forces to increase food production and expansion of agricultural lands. To feed the entire nation, the enhancement of agricultural land alone will not satisfy the food demand without intensification of modern agricultural crop production techniques. However, for the intensification of agriculture one of the main limiting factors is the temporal and spatial variation of rainfall distribution and amount of rainfall which supply the moisture content of the soil during the entire cropping season when irrigation is not available. Nearly 40% of food and agricultural commodities are produced through irrigated agriculture on about only 17% of agricultural land (M.G. Bos *et al*., 2008). In contrary to the water need for irrigation of agricultural land for enhancing crop production, there is an increasing demand for limited water resource for municipality, industries and for natural resource rehabilitation. Moreover, agriculture is the highest water consuming sector worldwide (Biswas, 1997).

In Ethiopia there is a decreasing trend in rainfall amount and the distribution is erratic especially in arid and semi-arid regions of the country. This need special emphasis since moisture stress occurs at the main cropping season reduce yield of crops which directly affect the livelihood of the community engaged on agriculture. The country receives adequate rainfall for crop production if annual rainfall average is considered in most of the areas. However, the production of sustainable and reliable food supply is challenged by temporal and spatial variation in rainfall distribution and erratic rainfall (Woldeamlak, 2009). Crop failure due to moisture stress in Ethiopia is common experience especially in moisture stress area of the country which caused by low and erratic rainfall distribution. Different researchers worldwide and in the country also show the diverse effect of moisture stress on crop production (Ersel *et al*., 2010, Marouf *et al*., 2013 and Yenesew and Tilahun, 2009). To enhance crop yield in such areas, the moisture stress occurs should be avoided by irrigating the crop especially during sensitive stages (Wing *et al*., 2008). According to a study made by Engida Mersha (2003) the research area is characterized by having highly variable initial and conditional probability of the threshold limit of 30mm per decade rainfall. This shows how risky the area is for crop production in rain-fed agriculture and the occurrence of moisture stress during sensitive growth stage of the crop is high.

Depriving irrigation in some growth stages of a crop leads to higher water use efficiency and economical cost of crop production. Many studies have shown that there is a significant yield and yield component reduction occurs when maize stressed at different growth stages. This makes an increase in water use efficiency when moisture stress happens in some non sensitive stages (Yenesew and Tilahun 2009). Different crops response for moisture stress differently. Crops less sensitive to stress such as cotton, maize, groundnut, wheat, sunflower and sugar beet can adapt well to deficit irrigation practices provided good management practices can be secured (FAO 2002). Moreover, maize is one of the major food crops in Ethiopia. According to Central Statistic Authority (CSA) 2011/12 *Meher* season post harvest crop production survey, next to teff, maize was higher (17%) in area coverage which is about 2,054,723.69hectar and the highest in grain yield engaging the highest number of householders (9,154,883) among all crop types (CSA, 2012).

Different works have been done on maize moisture stress at different growth stage based on decreasing the amount of irrigation water given on few combinations of growth stage especially on seed formation and initial stage. However, much work has not been done on effect of moisture stress at different maize growth stages like initial, development, mid-season and late-season stages and their combinations with fully missing irrigation. Therefore, these field experiments were conducted to identify the most sensitive stage of maize crop, to avoid the risk of crop yield reduction and maximizing the efficiency of water used for irrigation.

## II. MATERIALS AND METHODS

***Description of the experimental area***

Field experiments were carried out for two consecutive year on dry season of 2011/12 and 2012/13 at Koka Research Station of Wondo Genet Agricultural Research Center. The farm is located in Ethiopia 8°26’ N latitude, 39°2’ E longitude and 1602m above sea level altitude. Climate of the area is semiarid with total annual precipitation of 831.1mm and 132.0mm of rainfall expected in the dry season from October to March (Table 1). The soil type of the experimental area was clay in texture and the available water holding capacity per unit meter of the soil profile is 170 mm. Some physical characteristics of soil, such as field capacity, wilting point and total available water holding capacity of the experimental site are presented in Table 2.

***Treatment and experimental design***

Randomized complete block design with three replications were used following the procedure of Gomez and Gomez (1984). The experiment included 15 treatments (factorial of depriving irrigation on four growth stages) randomized in plots as follows: 1) irrigated all stages as control (no stress), 2) depriving irrigation at initial stage only (I), 3) depriving irrigation at development stage only (D), 4) depriving irrigation at mid season stage only (M), 5) depriving irrigation at late season stage only (L), 6) depriving irrigation at initial and development stages (ID), 7) depriving irrigation at initial and midseason stages (IM), 8) depriving irrigation at initial and late season stages (IL), 9) depriving irrigation at development and midseason stages (DM), 10) depriving irrigation at development and late-season stages (DL), 11) depriving irrigation at mid-season and late season stages (ML), 12) depriving irrigation at initial, development and midseason stages (IDM), 13) depriving irrigation at initial, development and late season stages (IDL), 14) depriving irrigation at initial, midseason and late season stages (IML) and 15) depriving irrigation at development, midseason and late seasons (DML).

**Table 1. Long-term monthly climatic data of the experimental area**

| Month | $T_{max}$ ($^OC$) | $T_{min}$ ($^OC$) | RH (kpa) | U (m/s) | N (%) | RF (mm) |
|---|---|---|---|---|---|---|
| January | 27.4 | 11.3 | 1.34 | 4.04 | 75 | 13.5 |
| February | 28.3 | 12.6 | 1.39 | 4.08 | 76 | 26.1 |
| March | 30.0 | 14.4 | 1.50 | 4.64 | 74 | 51.5 |
| April | 30.3 | 15.2 | 1.64 | 3.80 | 71 | 58.5 |
| May | 30.9 | 15.1 | 1.63 | 3.98 | 68 | 48.5 |
| June | 30.0 | 15.5 | 1.70 | 4.91 | 65 | 72.7 |
| July | 26.7 | 15.0 | 1.74 | 4.30 | 54 | 212.7 |
| August | 26.3 | 15.1 | 1.75 | 3.15 | 53 | 202.4 |
| September | 27.8 | 14.9 | 1.79 | 2.30 | 57 | 104.3 |
| October | 28.3 | 12.7 | 1.48 | 3.50 | 73 | 21.1 |
| November | 27.4 | 11.3 | 1.30 | 4.09 | 83 | 9.9 |
| December | 26.1 | 11.0 | 1.26 | 4.19 | 76 | 9.9 |

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

**Table 2. Physical characteristics of soil at the experimental site**

| Soil texture | Bulk density (g/cm3) | Field capacity (%) | Wilting Point (%) | Available water holding capacity (mm) |
|---|---|---|---|---|
| Clay | 1.17 | 34.5 | 17.5 | 170 |

***Experimental procedure and management practice***

Grains of maize (*Zea mays* L.) variety Melkassa-II was sown during the first week of November in 2011 and last week of October in 2012 of each experimental year. A row spacing of 0.75m and within-row spacing of 0.30m were used. Maize plots were fertilized with 46kg/h P as DAP and 23kg/ha N as Urea before sowing and, additional 23kg/ha N was applied as Urea when maize plant with knee height. The plot size used was 3.00m x 3.00 m. Furrow irrigation method was used, and the amount of water applied was measured using 2 inch Parshal flume. Irrigation scheduling was done based on soil water depletion replenishments using the CROPWAT program and adopting ten day irrigation interval. Crop water requirement was calculated using CROPWAT program based on the FAO Penman-Monteith method. Soil water level was monitored by using the gravimetric soil moisture content determination method. Soil sample was taken from well irrigated plots just before irrigation to check the moisture content at management allowable depilation level and two day after irrigation to check the moisture content to field capacity level. The regular tillage and agricultural operations of growing maize of the location were followed. All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and one irrigation after germination.

***Data collection***

Representative five maize plant samples were cut at ground level after plant height recorded and collected per plot from the center 150 days from sowing after physiologically matured. Above ground biomass weight recorded after the maize harvested with cob. Data on maize yield and yield parameter like plant height, total biomass, cob length, cob diameter, grain yield and 1000 seed weight was collected.

***Calculation of water use efficiency and harvesting index:-***

Water use efficiency (WUE) is the amount of maize grain yield per millimeter of irrigation water applied.

$$WUE = \frac{Y}{I}$$

Where: WUE – Water use efficiency (kg/mm)
Y – Yield of maize (kg/ha)
I – Total irrigation water applied (mm/ha)

Harvesting index (HI) is the amount of maize grain yield production per biomass production

$$HI = \frac{Y}{BM}$$

Where: HI – Harvesting index (decimal)
Y – Yield of maize (kg/ha)
BM – above ground biomass of maize (kg/ha)

***Data analysis***

Data collected were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

## III. RESULTS AND DISCUSSION

***Plant height***

Plant height was significantly influenced ($p<0.001$) due to moisture stress at different growth stage. The maximum plant height of 169cm was obtained during 2011/12 by treatment no stress and 194.6cm by stressing only at mid season during 2012/13 experiment year. The minimum plant height of 76.3cm and 114.5cm were observed during the first and second year, respectively was due to stress at three stages (initial, development and mid season). The data indicated plant height for treatments stressed at development seasons with any combination are inferior to other treatments. This confirms that plant height associated with the water applied at development stage.

**Table 3: Effect of moisture stress at different growth stage on maize yield components 2011/2012**

| Stages of moisture stress | Plant height (cm)*** | Cob diameter (cm)* | Cob length (cm)** | 1000 seed weight (g)*** |
|---|---|---|---|---|
| no stress | $169^{a}$ | $4.63^{ab}$ | $18.3^{ab}$ | $492.3^{a}$ |
| I | $163.7^{a}$ | $4.80^{a}$ | $18.7^{a}$ | $494.7^{a}$ |
| D | $120.1^{de}$ | $4.11^{ab}$ | $14.6^{abcd}$ | $382.1^{bc}$ |
| M | $157^{ab}$ | $4.20^{ab}$ | $16.5^{abc}$ | $470.3^{ab}$ |
| L | $167^{a}$ | $4.67^{ab}$ | $17.9^{ab}$ | $435.7^{ab}$ |
| ID | $92.9^{fg}$ | $3.74^{abc}$ | $14.5^{abcd}$ | $428.9^{abc}$ |
| IM | $134.3^{bcd}$ | $3.78^{abc}$ | $15^{abcd}$ | $401.1^{abc}$ |
| IL | $137.3^{bcd}$ | $4.46^{ab}$ | $16.9^{ab}$ | $396.9^{bc}$ |
| DM | $102.2^{ef}$ | $3.17^{abcd}$ | $10.5^{cde}$ | $409.4^{abc}$ |
| DL | $126.3^{cde}$ | $4.32^{ab}$ | $17.3^{ab}$ | $437.5^{ab}$ |
| ML | $146.7^{abc}$ | $3.06^{bcd}$ | $12.2^{bcde}$ | $336.0^{cd}$ |
| IDM | $76.3^{g}$ | $2.41^{cd}$ | $8.9^{de}$ | $274.7^{d}$ |
| IDL | $93.2^{fg}$ | $3.79^{abc}$ | $15.8^{abc}$ | $408.1^{abc}$ |
| IML | $133.7^{bcd}$ | $3.66^{abc}$ | $14.8^{abcd}$ | $424.9^{abc}$ |
| DML | $94.1^{fg}$ | $1.99^{d}$ | $6.4^{e}$ | $263.7^{d}$ |
| CV (%) | 11.8 | 26.1 | 26.1 | 14.0 |
| $LSD_{0.05}$ | 25.3 | 1.66 | 6.2 | 94.6 |

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. *Significant at $p<0.05$, **significant at $p<0.01$ and *** significant at $p<0.001$.

***Cob diameter and cob length***

Moisture stress at different maize growth stage had a significant influence (p<0.05 and p<0.01) on cob diameter and cob length during the first year and affect significantly (p<0.001) during the second year. Treatment that moisture stress occurs only at initial stage was superior during the first season scoring 4.80cm and 18.7cm on cob diameter and cob length respectively. During the second season, treatment which only stressed at late season was superior on both cob diameter and cob length of 4.85cm and 17.8cm respectively. However, in both years the two treatments were statistically the same on both parameters. The minimum cob diameter of 1.99cm and cob length 6.4cm was scored by treatment that stressed three stages (development, mid season and late season) during the first season. In the second season minimum cob diameter of 3.64cm was due to treatment that stressed at development, midseason and late season stage and cob length of 10.6cm due to treatment stressed at initial, development and midseason stages. Generally treatments of DM, IDM and DML scored the minimum cob diameter and cob length. This revealed that when combined moisture stress at development and mid season growth stage happen, cob diameter and cob length are highly affected which have a direct relation with grain yield.

**Table 4**: **Effect of moisture stress at different growth stage on maize biomass, grain yield, water use efficiency and harvesting index 2011/2012**

| stage of moisture stress | Biomass (kg/ha)*** | Grain yield (kg/ha)*** | Water use efficiency (kg/mm)*** | Harvesting index (%)** |
|---|---|---|---|---|
| no stress | 34668$^{a}$ | 7098$^{ab}$ | 10.8$^{abc}$ | 20.2$^{cde}$ |
| I | 33740$^{a}$ | 9253$^{a}$ | 15.1$^{a}$ | 27.2$^{abc}$ |
| D | 16062$^{b}$ | 5301$^{bcd}$ | 8.3$^{bcd}$ | 31.9$^{ab}$ |
| M | 29653$^{a}$ | 4710$^{bcde}$ | 12.9$^{ab}$ | 15.3$^{e}$ |
| L | 27222$^{a}$ | 6147$^{bc}$ | 11.3$^{ab}$ | 22.9$^{bcde}$ |
| ID | 14596$^{bc}$ | 3623$^{cde}$ | 8.5$^{bcd}$ | 25.0$^{bcd}$ |
| IM | 17972$^{b}$ | 2448$^{efg}$ | 6.2$^{cde}$ | 13.6$^{e}$ |
| IL | 18983$^{b}$ | 4934$^{bcde}$ | 9.9$^{bc}$ | 25.9$^{abcd}$ |
| DM | 11695$^{bcd}$ | 2727$^{defg}$ | 10.5$^{abc}$ | 22.6$^{bcde}$ |
| DL | 17675$^{b}$ | 4580$^{bcde}$ | 12.6$^{ab}$ | 21.1$^{cde}$ |
| ML | 18954$^{b}$ | 3175$^{def}$ | 9.6$^{bc}$ | 16.9$^{de}$ |
| IDM | 6855$^{d}$ | 840$^{fg}$ | 4.0$^{de}$ | 14.3$^{e}$ |
| IDL | 11567$^{bcd}$ | 4676$^{bcde}$ | 14.9$^{a}$ | 34.8$^{a}$ |
| IML | 16693$^{b}$ | 2976$^{def}$ | 10.6$^{abc}$ | 18.2$^{cde}$ |
| DML | 7190$^{cd}$ | 257$^{g}$ | 1.8$^{e}$ | 3.7$^{f}$ |
| CV (%) | 24.3 | 37.4 | 28.4 | 26.7 |
| $LSD_{0.05}$ | 7669.9 | 2614.8 | 4.6 | 9.3 |

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. * Significant at p<0.05, **significant at p<0.01 and *** significant at p<0.001.

***Thousand seed weight***

Moisture stress at different maize growth stage had a significant influence (p<0.001) on 1000 seed weight both season. Treatment moisture stress happen only at initial stage was superior (494.7g) during the first year. During the second year, treatment moisture stress happen only at late season stage was the highest scoring 528.1g. The least thousand seed weight of 263.7g was obtained due to treatment at which moisture stress happen at development, mid season and late season stage during first year and 340.1g by stressing at initial, development and mid-season stages during the second year. The data revealed that, minimum 1000seed weight associated with combined moisture stress at development and mid-season stages. In addition to this, treatments which moisture stress happens at three growth stages IDM and DML are statistically similar in most of the parameters.

**Table 5: Effect of moisture stress at different growth stage on maize yield components 2012/2013**

| Stages of moisture stress | Plant height (cm)*** | Cob diameter (cm)*** | Cob length (cm)*** | 1000 seed weight (g)*** |
|---|---|---|---|---|
| no stress | 177.8$^{abc}$ | 4.41$^{bc}$ | 16.4$^{ab}$ | 456.9$^{abc}$ |
| I | 188.3$^{ab}$ | 4.65$^{ab}$ | 16.5$^{ab}$ | 471.5$^{ab}$ |
| D | 146.2$^{de}$ | 4.53$^{ab}$ | 15.7$^{abc}$ | 445.7$^{abcd}$ |
| M | 194.6$^{a}$ | 4.43$^{bc}$ | 14.7$^{bc}$ | 428.0$^{bcd}$ |
| L | 178.1$^{abc}$ | 4.85$^{a}$ | 17.8$^{a}$ | 528.1$^{a}$ |
| ID | 144.5$^{def}$ | 4.12$^{cd}$ | 14.1$^{c}$ | 431.6$^{bcd}$ |
| IM | 178.6$^{abc}$ | 4.12$^{cd}$ | 15.3$^{bc}$ | 431.3$^{bcd}$ |
| IL | 161.4$^{bcd}$ | 4.42$^{bc}$ | 16.3$^{abc}$ | 412.4$^{bcde}$ |
| DM | 142.5$^{efg}$ | 4.06$^{cd}$ | 11.7$^{d}$ | 380.7$^{cde}$ |
| DL | 149.7$^{cde}$ | 4.38$^{bc}$ | 15.4$^{bc}$ | 486.8$^{ab}$ |
| ML | 178.8$^{abc}$ | 4.26$^{bcd}$ | 14.9$^{bc}$ | 421.3$^{bcde}$ |
| IDM | 114.5$^{f}$ | 3.96$^{de}$ | 10.6$^{d}$ | 340.1$^{e}$ |
| IDL | 135.9$^{def}$ | 4.43$^{bc}$ | 15.6$^{abc}$ | 405.6$^{bcde}$ |
| IML | 189.3$^{ab}$ | 4.30$^{bcd}$ | 15.7$^{abc}$ | 440.1$^{bcd}$ |
| DML | 122.7$^{ef}$ | 3.64$^{e}$ | 11.3$^{d}$ | 363.6$^{de}$ |
| CV (%) | 11.3 | 5.5 | 9.2 | 12.2 |
| $LSD_{0.05}$ | 30.4 | 0.4 | 2.3 | 87.7 |

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. * Significant at p<0.05, **significant at p<0.01 and *** significant at p<0.001.

***Above ground biomass yield***

Moisture stress at different growth stage had a significant influence (p<0.001) on maize biomass production. Maximum biomass yield of 34668kg/ha and 37889kg/ha were obtained in the first and second cropping season due to no stress treatment and moisture stress only at late season treatment, respectively. The two treatments were statistically the same during both years (Table 4 and Table 6). During the first year minimum above ground biomass of 6855kg/ha was obtained due to moisture stress at initial, development and mid-season stages. Whereas in the second year minimum above ground biomass of 10128kg/ha was collected from treatment with moisture stress happened on three growth stages (development, mid season and late season). Both treatments were statistically the same both years. The trend of biomass production shows decreasing with increasing of moisture stress indicating well irrigated maize yields higher biomass production. This is in agreement with former reports of Ersel *et al*. (2010) on maize.

***Harvesting index (HI)***

Moisture stress at different growth stages had significantly (p<0.01 and p<0.05) influence on maize harvesting index during the first and the second year, respectively. Maximum HI of 34.8% was obtained due to moisture stress at initial, development and late season stages during the first year and 40.8% due to moisture stress at initial and late season growth stages during the second year. Whereas the minimum HI of 3.7% was due to DML treatment and 25.2% due to DM treatment during the first and the second years, respectively. The study showed that combined moisture stress during initial and late season maximize the harvesting of maize. This is due to the moisture stress happen at combined stages of initial and late season affect the biomass than grain yield when compared with other treatments. However, combined moisture stress at development and mid-season growth stages significantly reduce harvesting index. This revealed that moisture stress happen at combined development and mid-season growth stage affect the grain yield than the biomass when compared with other treatments.

**Table 6: Effect of moisture stress at different growth stage on maize yield, water use efficiency and harvesting index during 2012/2013 growing season**

| stage of moisture stress | Biomass (kg/ha)*** | Grain yield (kg/ha)*** | Water use efficiency (kg/mm)*** | Harvesting index (%)* |
|---|---|---|---|---|
| no stress | 36209[a] | 11408[a] | 9.09[efg] | 33.1[abc] |
| I | 33988[ab] | 11748[a] | 9.81[defg] | 34.9[abc] |
| D | 27122[abcd] | 8413[b] | 8.40[efg] | 31.0[bcd] |
| M | 28291[abc] | 7623[b] | 9.68[defg] | 27.8[cd] |
| L | 37889[a] | 11734[a] | 12.94[cde] | 31.2[bcd] |
| ID | 18096[cdef] | 6474[bc] | 6.85[g] | 35.5[abc] |
| IM | 22796[bcd] | 6957[b] | 9.52[defg] | 31.2[bcd] |
| IL | 24296[bcd] | 8684[b] | 10.22[defg] | 40.8[a] |
| DM | 16913[def] | 4231[cd] | 7.90[fg] | 25.2[d] |
| DL | 22665[cd] | 8074[b] | 12.33[cdef] | 36.1[ab] |
| ML | 18679[cdef] | 6799[bc] | 15.45[bc] | 36.1[ab] |
| IDM | 10961[ef] | 3330[d] | 6.96[g] | 30.8[bcd] |
| IDL | 22104[cde] | 8378[b] | 14.02[cd] | 39.6[a] |
| IML | 20890[cdef] | 7303[b] | 19.07[ab] | 35.8[ab] |
| DML | 10128[f] | 3850[d] | 20.50[a] | 37.3[ab] |
| CV (%) | 28.8 | 20.2 | 23.7 | 14 |
| $LSD_{0.05}$ | 11266 | 2594 | 4.56 | 7.9 |

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. *Significant at p<0.05, **significant at p<0.01 and *** significant at p<0.001.

***Grain yield production***

The result of both year and pooled mean indicated moisture stress happened at different maize growth stages had a significant effect (p<0.001) on grain yield per hectare. The pooled mean indicated that maximum grain yield of 10500kg/ha was obtained when moisture stress applied at initial stage only, which decrease with different moisture stress happen at different maize growth stage reaching minimum of 2053kg/ha due to moisture stress happen at development, mid-season and late season stages. Both year maximum grain yield of 9253kg/ha during the first year and 11748kg/ha during the second year was obtained due to treatment stress only at initial stage (Table 4, Table 6 and Table 7). This may be due to stressing moisture at initial stage after establishment enhances root development and which further enhance the capacity of the crop to up take both nutrient and moisture after growth. This is in line with former reports (FAO, 2002) on groundnut. The minimum grain yield of 257kg/ha was obtained by moisture stress at three stages (development, mid-season and late season) treatment during the first year and 3330kg/ha due to treatment of moisture stress occurs at three stages (initial, development and mid season) during the second year. But as most parameters, grain yield was also statistically the same in the poor performed treatments of stress happen at initial, development and mid season stages treatment and stress happen at development, mid-season and late season treatment and scoring average of 2085kg/ha and 2053kg/ha, respectively . These two treatments were performed poor both seasons in most of the parameters. The study revealed that when moisture stress happens both at development and mid season stage in combination, yield and yield parameter influenced extremely. Fairly higher grain yield associated with higher irrigation water applied treatments even though the variation exist due to moisture stress happen at different growth stages. Former report by Farshad *et al*. (2008) also shows 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). Another report by Ersel *et al*. (2010) also shows moisture stress occurring during vegetative and tasseling stage reduce grain yield significantly. A research conducted on tomato also shows moisture stress at vegetative and flowering stage significantly reduce the yield (Vijtha and Mahendra, 2010). This revealed that moisture stress occurs at mid-season especially when combined with development stage, the yield significantly reduced.

**Table 7: Effect of moisture stress at different growth stage on average maize grain yield and water use efficiency (WUE) during 2011/2012 and 2012/2013 growing season**

| Treatments | Grain yield (kg/ha)*** | WUE (kg/mm)*** |
|---|---|---|
| no stress | 9253[a] | 9.9[cde] |
| I | 10500[a] | 12.5[abc] |
| D | 6857[bc] | 8.4[def] |
| M | 6167[c] | 11.3[bcd] |
| L | 8940[ab] | 12.1[abc] |
| ID | 5049[cd] | 7.7[ef] |
| IM | 4703[cd] | 7.9[def] |
| IL | 6809[bc] | 10.1[cde] |
| DM | 3479[de] | 9.2[cde] |
| DL | 6327[c] | 12.5[abc] |
| ML | 4987[cd] | 12.5[abc] |
| IDM | 2085[e] | 5.5[f] |
| IDL | 6527[c] | 14.5[ab] |
| IML | 5140[cd] | 14.8[a] |
| DML | 2053[e] | 11.1[bcde] |
| CV (%) | 22.2 | 19.6 |
| $LSD_{0.05}$ | 2198.4 | 3.5 |

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. * Significant at p<0.05, **significant at p<0.01 and *** significant at p<0.001.

***Water use efficiency***

Moisture stress at different growth stage had a significant (p<0.001) influence during both years. Water use efficiency was higher for moisture stress only at initial stage scoring15.1kg/mm during 2011/12 and 20.5kg/mm due to moisture stress happen at development mid-season and late season stages during 2012/13. The minimum water use efficiency was due to moisture stress happen at development, mid-season and late season stage scoring 1.8kg/mm during 2011/12 and moisture stress happen at initial and development stage scoring 6.85kg/ha during 2012/13 season. The study revealed that pooled mean of WUE of maize was maximized when moisture stress happen at three growth stages due to minimum water applied. However, when moisture stress happen in combined initial, development and mid-season growth stages, WUE was affected highly scoring only 5.5kg/mm.

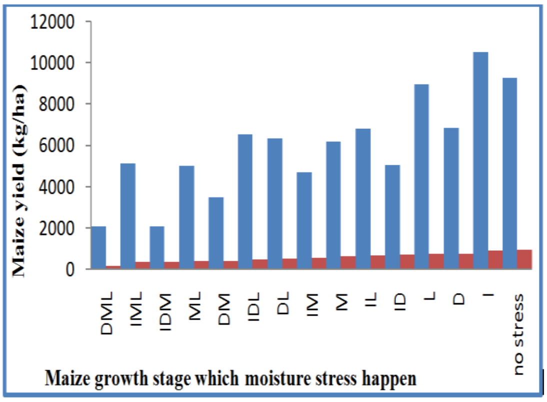


**Fig. 1:** Effect of moisture stress at different growth stages on average grain yield as the amount of irrigation water applied increase (average of 2011/12 and 2012/13)

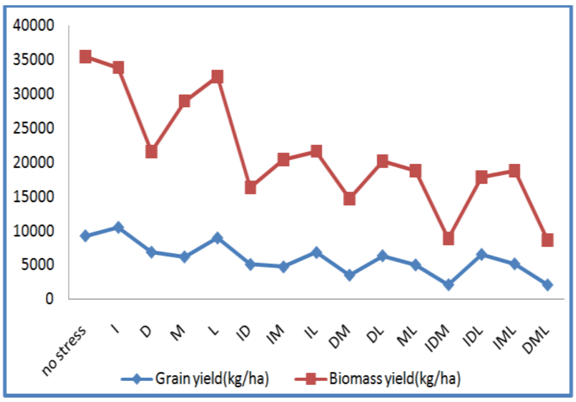


**Fig. 2:** Effect of moisture stress on grain yield and biomass production (2011/12 and 2012/13)

The pooled mean showed that maximum WUE of 14.8kg/mm was obtained due to moisture stress happen at initial, mid-season and late season growth stages. Generally higher water use efficiency was associated with lower water application showing moisture stress at different growth stage enhance water productivity. This is in agreement with former reports FAO (2002) on wheat, cotton and other crops, Ismail (2010) on bird pepper (*Capsicum annuum* L.) production, Romulus *et al*., (2009) on spearmint and R. Huang (2006) on maize production. Better water use efficiency without significantly reducing the grain yield was obtained due to treatments in which moisture stress happen only at initial stage and treatment in which moisture stress happen only at late season stage.

## IV. CONCLUSION AND RECOMMENDATION

The results of the study revealed that, moisture stress applied at some growth stages enhance water use efficiency of maize without significantly reducing the yield from the higher yielding treatments. Stressing moisture for maize (*Zea maize* L) Melkassa-II variety at initial stage for about 25 to 30 days after germination and well established which the crop has only 7 to 8 leaf stage and irrigating all the other stage until maturity will give good yield with relatively higher water use efficiency than the all irrigated one. Moreover, stressing moisture at development and mid-season crop growth stage while irrigating the rest of growth stages will 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 mid season growth stage is vital where supplementary irrigation from available water source is possible. Our finding on both years shows that maximum grain yield was obtained by depriving irrigation water at initial stage and irrigating the rest of crop growth stages (development, mid-season and late season). However, combined moisture stress at development and mid season stage critically influenced the yield and water use efficiency. Moreover, the combined moisture stress significantly affect cob diameter, cob length and 1000seed weight as well. Generally WUE is lower for well irrigated maize and inferior especially when moisture stress happens consecutively on development and mid-season stages. Likewise stress at development stage has great influence on plant height and biomass with every combination. So it can be concluded that the critical sensitive stages are the combined development and mid-season stages. Moreover, to enhance the water use efficiency in maize production without affecting the grain yield, maize can be irrigated after stressing at the initial stage and late season stage.

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