*J. Agr. Sci. Tech. (2022) Vol. 24(6): 1487-1500*

# Effects of Different Water Stress Levels on Biomass, Root Yield, and Some Physiological Parameters of Sorghum

E. Gonulal[1]

## ABSTRACT

**This study was conducted under water stress conditions for two years (2017-2018) to investigate the effects of different water stress levels on biomass yield, root yield, root/shoot ratio, some physiological characteristics, Water Use Efficiency (WUE), seasonal water consumption, and yield reduction ratio of silage sorghum. Experiments were conducted in randomized blocks design. There were four different irrigation treatments including $I_1$: Full irrigation; $I_2$: 75% of $I_1$; $I_3$: 50% of $I_1$, and $I_4$: 25% of $I_1$).). In 2017, dry biomass yields varied between 14.11 ($I_4$) and 26.02 t ha$^{-1}$ ($I_1$), stomatal conductance between 72.2 ($I_4$) and 147.8 mmol m$^{-2}$ s$^{-1}$ ($I_1$), chlorophyll contents between 37 spad ($I_4$) and 42.1 spad ($I_1$), canopy temperatures between 27.2 ($I_1$) and 31.3°C ($I_4$), and WUE between 4.5 ($I_1$) and 5.5 kg m$^{-3}$ ($I_3$). In 2018, dry biomass yields varied between 14.51 ($I_4$) and 25.92 t ha$^{-1}$ ($I_1$), stomatal conductance between 69.9 ($I_4$) and 129.5 mmol m$^{-2}$ s$^{-1}$ ($I_1$), chlorophyll contents between 39.7 spad ($I_4$) and 43.9 spad ($I_1$), canopy temperatures between 30.0 ($I_1$) and 34.5 °C ($I_4$), and WUE between 4.2 ($I_1$) and 4.9 kg m$^{-3}$ ($I_4$). Based on two-year averages, dry root yields varied between 8.15 ($I_4$) and 13.27 t ha$^{-1}$ ($I_1$), root/shoot ratios between 0.51($I_1$) and 0.57 % ($I_3$-$I_4$), seasonal water consumptions between 281($I_4$) and 598 mm ($I_1$). Water stress reduced biomass yield, root yield, stomatal conductance, and chlorophyll contents, and increased WUE and root/shoot ratios. Biomass yields decreased with increase in water stress, but this decrease was lower compared to the decrease in applied irrigation water quantities.**

**Keywords:** Climate change, Drought, Irrigation, Yield reduction ratio.

## INTRODUCTION

In recent years, impacts of climate change are encountered worldwide, especially on agriculture. Together with increasing populations, such a case exerts serious threats on sustainable food supply. It is expected that present climate change and global warming will result in droughts in agricultural lands, and especially Mediterranean climate zone will be more influenced by these negative factors. Drought stress reduces plant water and nutrient uptake and reduces food supply, thus exerts serious threats on sustainability of plant production activities. (Du *et al*., 2010). Water is the most important input affecting and limiting agricultural productions. It is expected that 35% of cultivated and irrigated lands could not be irrigated if current water use ratios continued, and thus productions will decrease seriously (Haacker *et al*., 2016). Besides, groundwater is withdrawn from deeper aquifers and such a case increased irrigation and, consequently, production costs. Therefore, under these circumstances, alternative less-water-using species should be encouraged in irrigated lands and water use ratios of currently cultivated species should be reduced (Chaves and Davies, 2010).

Potential droughts and deficit water supplies will influence field crops the most and will then generate a risk for food safety (Alghabari *et al*., 2016). In this sense, taking

---

[1] Bahri Dagdas International Agriculture Research Institute, 42031, Konya, Turkey. e-mail: erdalgonulal@hotmail.com

[ DOI: 10.52547/jast.24.6.1487 ]

the future projections into consideration, sorghum and similar drought-resistant species with less water use should be cultivated to meet silage and roughage needs of livestock in regions with less precipitation and insufficient water resources within the scope of adaptation of climate change. Sorghum has less water use than maize, which was used for similar purposes. It is also resistant to various abiotic stress factors, especially to water stress, and can reliably be grown in marginal lands at low costs. Sorghum has quite high water use efficiency under water stress conditions (Li *et al*., 2010). Sorghum is largely grown especially in the USA and in the other parts of the world and used for various purposes (human nutrition, animal feeding, bioethanol, and cellulose production). Silage maize is also largely used in animal feeding, but maize is highly sensitive to water deficits and has quite high crop water consumption levels. Thus, it is hard to achieve sustainable water management in maize culture in semi-arid regions (Saneoka *et al*., 1996). Sorghum with a deep root structure, waxy shoot structure, and upright leaf structure could produce better biomass and use water more efficiently than maize under water stress (Begg, 1980). In previous studies on water stress in sorghum, Vasilakoglou *et al*. (2011), Tariq *et al*. (2012), and Dahmardeh *et al*. (2015) reported that the biomass yield decreased with the decreasing amount of irrigation and the highest biomass yield was obtained from full irrigation subjects. In previous studies on the effect of water stress on physiological properties of sorghum, Vasilakoglou *et al*. (2011), Dahmardeh *et al*. (2015), and Bhattarai (2019) reported that stomatal conductivity values decreased in sorghum under water stress conditions. El-Mageed *et al*. (2018) and Bhattarai (2019) reported that the chlorophyll value decreased, while the canopy temperature increased with water stress. In many studies carried out with different soil and water regimes in sorghum, root yield decreased in decreasing irrigation water amount or drought conditions, but this decrease was lower than biomass yield (Creelman et al., 1990; Bibi *et al*., 2010; Yin *et al*., 2014). Root/shoot ratio is a reliable parameter used in estimation of drought resistance. It is a measure of dry matter distribution in root and shoot systems and a good indicator of the effects of stress on root and shoot dry matter (Boutraa *et al*., 2010). Nour and Weibel (1978) indicated that root/stem ratio of sorghum varied with the varieties, and drought-resistant varieties had greater root/stem ratio and reported root/shoot ratios of sorghum between 0.39 - 0.65.

Root experiments are time and labor-consuming processes. Therefore, the majority of root yield experiments are conducted under pot conditions and root characteristics are mostly investigated at early growth stages (Takele, 2000). Root studies, which are mostly carried out under pot conditions, should also be tested under field conditions. The most different aspect of the present study from similar studies is that root experiments were conducted under field conditions instead of pots.

This research aimed to study sorghum in a semi-arid region of Turkey within the Mediterranean basin with irregular precipitation regime and ever decreasing water resources to determine biomass yield, root yield, root/shoot ratio, water consumption, water use efficiency, yield decrease ratio, and some physiological characteristics of silage sorghum under different water stress conditions.

## MATERIALS AND METHODS

### Experiment Area

Experiments were conducted in 2017 and 2018 for two years over the experimental fields of Konya-Karapınar Desertification and Erosion Research Center ($37^0$ 41' 12.20" N and $33^0$ 30' 13.37" E). The study area had a semi-arid climate with an annual total precipitation of less than 300 mm, mostly falling between the months November –

[ DOI: 10.52547/jast.24.6.1487 ]

April. Annual total precipitation was measured as 249.6 mm (64.8 mm between May-August) in 2017 and 286.7 mm (69.2 mm between May-August) in 2018. Long-term annual average total precipitation is 291 mm (71.3 between May-August) (Table 1).

Characteristics of experimental soils are provided in Table 2. Experimental soils were poor in organic matter, high in lime and pH, free of salinity problems and had sandy texture in upper layers.

Some properties of irrigation water used in the study are given in Table 3, which shows that irrigation water was in the T2A1[(In irrigation water medium salt content (T2) and low sodium content (A1)] class. Irrigation water is groundwater with a low SAR value, dominated by bicarbonate and sulfate ions**.**

## Cultural Practices and Plant Material

Early Sumac sorghum variety largely grown in the region was used as the plant material of the study. Initial soil tillage was performed with moldboard plow and the second tillage was performed before sowing. At soil tillage, based on soil analysis results, 90 kg ha$^{-1}$ $P_2O_5$ and 30 kg ha$^{-1}$ nitrogen fertilizer were applied as base fertilizer. The rest of nitrogen was applied in splits through drip lines to complete the nitrogen to 150 kg ha$^{-1}$. Sowing was performed on 10th May in 2017 and 13th of May in 2018. Experimental plots were 8 m long and 2.7 m wide (21.6 m$^2$). Each plot had 6 rows and sowing was performed at 45 cm row spacing and 5 cm on-row plant spacing. Side rows and 1 m sections from the top and bottom of the plots were omitted to consider side effects and harvest was performed from 10.8 m$^2$ plot area. Mechanical and chemical weed control was practiced.

## Water Stress Treatments

Pressure regulated drip irrigation was used for irrigations. A drip line with 1.6 L h$^{-1}$ discharge drippers spaced 20 cm apart was placed along each row. There were four different irrigation treatments: $I_1$: Full irrigation, deficit moisture was completed to field capacity when the 40-45% of available moisture within the root zone was depleted; $I_2$: 75% of $I_1$; $I_3$: 50% of $I_1$; and I4: 25% of $I_1$. Before the initiation of experimental irrigation treatments, 30 mm irrigation water was applied in the first year and 40 mm in the second year to bring the soil moisture to

**Table 1.** Precipitation amounts of the growing season.

| Years | | Months | | | | |
|---|---|---|---|---|---|---|
| | | May | June | July | August | Total annual precipitation |
| 1963-2018 | Precipitation (mm) | 35.4 | 23.8 | 8.0 | 4.1 | 291 |
| 2017 | Precipitation (mm) | 23.0 | 15.6 | 7.6 | 18.6 | 249.6 |
| 2018 | Precipitation (mm) | 30.5 | 25.2 | 10.1 | 3.4 | 286.7 |

**Table 2**. Some soil properties of the experimental area.

| Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture | Field Capacity (% Pw) | Wilting Point (% Pw) | Bulk Density (g cm$^{-3}$) | pH | EC (dSm$^{-1}$) | Lime (%) | Organik Matter (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-30 | 58.1 | 22.8 | 19.1 | SCL | 20 | 9.6 | 1.37 | 7.8 | 0.42 | 33.5 | 1.3 |
| 30-60 | 30.1 | 20.3 | 49.6 | C | 24.5 | 12.6 | 1.30 | 8.1 | 0.45 | 28.7 | 1.1 |
| 60-90 | 16.0 | 24.4 | 59.6 | C | 28 | 15.4 | 1.22 | 8.2 | 0.44 | 29.4 | 0.6 |

[ DOI: 10.52547/jast.24.6.1487 ]

**Table 3.** Quality parameters of the irrigation water used in the study.

| pH | EC (dS m$^{-1}$) | Cation (me L$^{-1}$) Na | K | Ca | Mg | Anion (me L$^{-1}$) $CO_3$ | $HCO_3$ | Cl | $SO_4$ | SAR |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.80 | 0.533 | 0.21 | 0.01 | 1.79 | 6.38 | 0.01 | 4.02 | 0.02 | 1.13 | 0.12 |

**Table 4.** Irrigation water amount, precipitation, change in soil water, and evapotranspiration.

| Years | Irrigation Levels | Irrigation water(mm) | Precipitation (mm) | Change in soil water (mm) | Evapotranspiration (mm) |
|---|---|---|---|---|---|
| 2017 | $I_1$ | 480 | 64.8 | 31.1 | 575.9 |
| | $I_2$ | 368 | 64.8 | 44.9 | 477.7 |
| | $I_3$ | 255 | 64.8 | 50.4 | 370.2 |
| | $I_4$ | 143 | 64.8 | 60.2 | 268 |
| 2018 | $I_1$ | 510 | 69.2 | 40 | 619.2 |
| | $I_2$ | 390 | 69.2 | 46.8 | 506 |
| | $I_3$ | 270 | 69.2 | 55.4 | 394.6 |
| | $I_4$ | 150 | 69.2 | 75.6 | 294.8 |

field capacity for homogeneous germination and emergence. Soil moisture at 0-90 cm soil profile (effective root depth of sorghum) was monitored with the use of gravimetric method and amount of water to be applied in each irrigation was determine and measured with a water meter. The first irrigation was practiced on 7th of June in 2017 and 11th of June in 2018. During the growing season, 12 and 14 irrigations were made in 2017 and 2018, respectively.

In the present study, soil moisture within 90 cm soil profile was measured and $I_1$ (full irrigation) treatment was performed to bring the soil moisture to field capacity when 40-45 % of available moisture was depleted. Amount of irrigation water applied in each treatment, amount of precipitation, changes in soil moisture between sowing and harvest, and water consumptions of experimental treatments are provided in Table 4.

Amount of irrigation water applied varied between 143 mm ($I_4$) and 480 mm ($I_1$) in the first year and between 150 mm ($I_4$) and 510 mm ($I_1$) in the second year. Total water consumptions varied between 268 mm ($I_4$) and 575.9 mm ($I_1$) in the first year and between 294.8 mm ($I_4$) and 619.2 mm ($I_1$) in the second year (Table 4).

### Evapotransprasyon (ET), Water Use Effiency (WUE) and Yield Redution Ratio (YRR)

Evapotranspiration was calculated according to Equation (1), considering the moisture content in the 90 cm soil profile (Doorenbos and Kassam, 1979).

$$ET= I+P-Dp \pm CSW \qquad (1)$$

Where, ET= Evapotranspiration (mm), I= Irrigation water quantity (mm), P= Precipitation (mm), Dp= Deep percolation (mm), CSW: Change in Soil Water storage (mm) between planting and harvest.

In the study, WUE value (Howell *et al*. 1990) and Yield Reduction Ratios (YRR) (Araghi and Assad, 1998) expressing the proportional decrease in biomass yield against unit decreasing water were calculated according to the following equations.

$$WUE= Y/ET \qquad (2)$$

Where, WUE= Water Use Efficency (kg.m$^{-3}$), Y= Dry biomass yield (kg ha$^{-1}$), and ET= Evapotranspiration (mm).

$$YRR= 1-(Ys/Yp). \qquad (3)$$

Where, YRR= Yield Reduction Ratio (%); Ys= Yield under stress conditions (kg ha$^{-1}$); Yp= Yield under non stress conditions (kg ha$^{-1}$).

[ DOI: 10.52547/jast.24.6.1487 ]

### Biomass Yield and Physiological Properties

For Fresh Biomass Yield (FBY), harvest was performed at milk-dough stage from 10.8 $m^2$ plot area on $20^{th}$ of August in the first year and $27^{th}$ of August in the second year. Harvested herbage was weighed to get fresh biomass yield. For Dry Matter Ratio (DMR), 500 g fresh sample was dried in an oven at 70°C until a constant mass. Resultant masses were converted into hectares to get Dry Biomass Yield (DBY). Physiological observations were made at flowering period. Stomatal Conductance (SC) and Chlorophyll Content (CC) were measured on five different plants in four replicates. Chlorophyll and stomatal conductivity measurements were made between $11^{00}$ and $15^{00}$ hours during the day on the 3rd fully developed leaf from the top at the time of flowering (Kumar *et al*. 2013). Canopy Temperature (CT) was measured between $12^{00}$- $14^{00}$ hours from north and south directions and average of measurements were taken (Gonulal *et al*., 2021). SPAD readings were taken using the SPAD 502 Chlorophyll meter (Minolta Corporation, Ramsey, NJ). Stomatal conductivity measurements were made with a leaf porometer device (Decagon Model SC-1) and canopy temperatures were made with an infrared thermometer (Fluke 574).

### Root Biomass Yield and Root/Shoot Ratio

For Fresh Root Yield (FRY), following the fresh biomass harvest, 90 cm soil profiles were opened and 40×40 cm root cross-sections were taken from 3 different locations. Roots were cleared from the soil and weighed to get fresh root yield. Fresh root samples were dried in an oven at 70°C until a constant mass. Resultant masses were converted into hectares to get Dry Root Yield (DRY) (Gonulal *et al*., 2021).

Root/shoot ratio was calculated with the following equation:

Root/Shoot Ratio (RSR)= Dry root biomass yield/Dry biomass yield

### Experimental Design and Statistical Analysis

Experiments were conducted in randomized blocks design with 3 replications. Irrigation treatments were randomly distributed into blocks. There were 12 plots including 4 irrigation treatments and 3 replications. Experimental data were subjected to variance analysis with the use of JMP 11.1 statistical software and significant means were compared with the use of LSD test. The GGE-biplot analysis method was used to visually evaluate the relationship between the properties examined at different irrigation levels and the clustering and relationships formed by the characteristics at the irrigation levels (Yan and Tinker, 2006; Akcura, 2011).

## RESULTS AND DISCUSSION

### Biomass Yield

Fresh biomass yield, dry biomass yield and dry matter ratios of silage sorghum under different water stress levels are provided as the two-years average in Table 5. The differences in biomass yields of irrigation treatments were found to be significant in both years ($P< 0.01$). In the first year, the greatest fresh biomass yield was obtained from $I_1$ treatment (93.07 t $ha^{-1}$), but $I_2$ treatment (84.77 t $ha^{-1}$) was also placed into the same statistical group and the lowest yield was obtained from $I_4$ treatment (43.33 t $ha^{-1}$). In 2018, the greatest fresh biomass yield was obtained from $I_1$ treatments (96.57 t $ha^{-1}$) and the lowest from $I_4$ treatment (47.25 t $ha^{-1}$). Dry biomass yields varied between 14.11 ($I_4$) and 26.02 t $ha^{-1}$ ($I_1$) in 2017 and between 14.51 ($I_4$) and 25.92 t $ha^{-1}$ ($I_1$) in 2018 (Table 5). The differences in dry matter ratios of irrigation

[ DOI: 10.52547/jast.24.6.1487 ]

treatments were found to be significant at P< 0.05 in 2017 and at P< 0.01 in 2018. In both years, the greatest values were obtained from $I_4$ treatments (32.3 and 30.7%) and the lowest values were obtained from $I_1$ treatments (27.9 and 26.7%) (Table 5).

Water stress reduced leaf area index, plant height, number of leaves and leaf width of several plant species and decreased biomass yields through leaf aging (Razmi and Ghasemi, 2007; Kuscu *et al*.( 2014). In previous studies on water stress in sorghum, Vasilakoglou *et al*. (2011), Tariq *et al*. (2012), and Dahmardeh *et al*. (2015) reported decreasing biomass yields with decreasing irrigation water quantities and obtained the greatest biomass yield from full-irrigation treatments. Nejad *et al*. (2014) reported the greatest dry biomass yield of sorghum as 17.94 t ha$^{-1}$ under full irrigation and the lowest as 11.27 t ha$^{-1}$ under water stress, and reported the fresh biomass yields as between 54.57 and 33.55 t ha$^{-1}$. These findings revealed that water stress influenced biomass yield of sorghum at certain levels, but irrigation costs should be taken into consideration in silage sorghum cultivation.

## Physiological Characteristics

Stomatal conductance, chlorophyll content, and canopy temperature of sorghum under different irrigation levels are presented in Table 6. While the differences in stomatal conductance and canopy temperatures of irrigation treatments were significant in both years (P< 0.01), the differences in chlorophyll contents were significant in 2017 (P< 0.01), but insignificant in 2018. Decreasing stomatal conductance and chlorophyll contents and increasing canopy temperatures were

**Table 5.** Fresh/dry biomass yield and dry matter ratio.

| Irrigation levels/Years | Fresh biomass yield (t ha$^{-1}$) | | Dry biomass yield (t ha$^{-1}$) | | Dry matter ratio (%) | |
|---|---|---|---|---|---|---|
| | 2017** | 2018** | 2017** | 2018** | 2017* | 2018** |
| $I_1$ | 93.07 a | 96.57 a | 26.02 a | 25.92 a | 27.9 c | 26.7c |
| $I_2$ | 84.77 a | 86.37 b | 24.51 ab | 23.06 b | 28.9 bc | 26.9 c |
| $I_3$ | 66.22 b | 63.47 c | 20.39 b | 18.57 c | 30.8 ab | 29.3 b |
| $I_4$ | 43.33 c | 47.25 d | 14.11 c | 14.51 d | 32.3 a | 30.7 a |
| Means | 71.85 | 73.42 | 21.25 | 20.51 | 30.0 | 28.4 |
| CV | 9.5 | 6.4 | 11.7 | 6.3 | 4.0 | 1.7 |
| LSD | 13.62 | 9.32 | 4.98 | 2.57 | 2.4 | 0.94 |

** Significant at P≤ 0.01, * Significant at P≤ 0.05.

**Table 6.** Effects of different water stress levels on some physiological characteristics.

| Irrigation levels/Years | Stomatal conductivity (mmol m$^{-2}$ s$^{-1}$) | | Canopy temperature ($^{o}$C) | | Chlorophyll content (spad) | |
|---|---|---|---|---|---|---|
| | 2017** | 2018** | 2017** | 2018** | 2017** | 2018$^{ns}$ |
| $I_1$ | 147.8 a | 129.5 a | 27.2 b | 30.0 d | 42.1 a | 43.9 |
| $I_2$ | 107.3 b | 104.9 b | 28.1 b | 30.9 c | 40.1 b | 43.0 |
| $I_3$ | 101.2 b | 98.6 b | 30.6 a | 31.8 b | 39.6 b | 42.5 |
| $I_4$ | 72.2 c | 69.9 c | 31.3 a | 34.5 a | 37.0 c | 39.7 |
| Means | 107.1 | 100.7 | 29.3 | 31.8 | 39.7 | 42.3 |
| CV | 6.4 | 5.5 | 1.8 | 0.9 | 2.2 | 4.2 |
| LSD | 13.7 | 11 | 1.00 | 0.56 | 1.75 | ns |

** Significant at P≤ 0.01; * Significant at P≤ 0.05, ns: Non significant.

[ DOI: 10.52547/jast.24.6.1487 ]

[ DOI: 10.52547/jast.24.6.1487 ]

observed with decreasing irrigation water quantities. The greatest and the lowest stomatal conductance values were obtained from, respectively, $I_1$ (147.8 mmol $m^{-2}$ $s^{-1}$) and $I_4$ (72.2 mmol $m^{-2}$ $s^{-1}$) treatments in 2017 and again from $I_1$ (129.5 mmol $m^{-2}$ $s^{-1}$) and $I_4$ (69.9 mmol $m^{-2}$ $s^{-1}$) in 2018 (Table 6). In 2017, the greatest canopy temperature was obtained in $I_4$ (31.3°C) and the lowest from $I_1$ (27.2°C). Similarly, in 2018, the greatest canopy temperature was obtained from $I_4$ (34.5°C) and the lowest from $I_1$ (30.0°C) (Table 6). In 2017, the greatest chlorophyll content was observed in $I_1$ (42.1 spad) and the lowest in $I_4$ (37spad). In 2018, despite the insignificant differences, the greatest value was observed in $I_1$ (43.9 spad) and lowest in $I_4$ (39.7spad) (Table 6).

Stomatal conductance is an indicator of $CO_2$ assimilation and water loss (Messina *et al*., 2015) and decreasing stomatal conductance is observed with increasing water stress. Vasilakoglou *et al*. (2011), Dahmardeh *et al*. (2015), and Bhattarai (2019) reported decreasing stomatal conductance values in sorghum under water stress conditions. Bhattarai *et al*. (2020) reported stomatal conductance of sorghum as between 359 -243 mmol $m^{-2}$ $s^{-1}$. Retarded aging and prolonged stay-green durations increase drought resistance of sorghum and such a resistance is related to high chlorophyll content (Harris *et al*., 2006). It was reported by El-Mageed *et al*. (2018) and Bhattarai (2019) that increasing water stress reduced water uptake, nitrogen accumulation in leaves, and ultimately chlorophyll contents. Vasilakoglou *et al*. (2011) indicated that chlorophyll contents varied with the growth stages under water stress conditions, chlorophyll contents were lower under full irrigation than under water stress at flag leaf stage, but greater at flowering period.

Chlorophyll contents at full irrigation and water stress were reported as, respectively, 38 and 25 (Rostampour *et al*., 2012) and 46.9 and 41.1 (Keten, 2020). Canopy temperature designates plant resistance to drought stress and higher values are expected under water stress conditions. Such lower values indicate greater yield levels. Blum *et al*. (1989) reported canopy temperature of sorghum as 25.8°C under full irrigation and as 26.8°C under water stress. Similar to the present findings, El-Mageed *et al*. (2018) and Bhattarai (2019) reported increasing canopy temperatures with increasing water stress.

## Root Biomass Yield and Root/Shoot Ratio

Fresh and dry root yield and root/shoot ratios of sorghum under different irrigation levels are shown in Table 7. While the differences in fresh and dry root yields of irrigation treatments were significant in both years ($P< 0.01$), differences in root/shoot ratios were not significant in 2017, but significant in 2018 ($P< 0.05$).

The greatest fresh and dry root yields were obtained from $I_1$ (57.86 and 13.48 t $ha^{-1}$ in 2017; 56.61 and 13.05 t $ha^{-1}$ in 2018) and the lowest values were obtained from $I_4$ (32.20 and 7.85 t $ha^{-1}$ in 2017; 33.93 and 8.45 t $ha^{-1}$ in 2018) (Table 7). Despite the insignificant differences in 2017, the greatest root/shoot ratio was obtained from $I_4$ (0.56) and the lowest from $I_2$ (0.51). In 2018, the greatest and the lowest root/shoot ratios were observed in, respectively, $I_3$ (0.59) and $I_1$ (0.51) (Table 7).

Previous researchers also reported decreasing sorghum root yields with water stress in pot experiments (Bibi *et al*., 2012; Yin *et al*., 2014). However, increasing root yields were reported with water stress. Despite widened leaves and reduced biomass with increasing water stress, roots continued to grow and were less influenced by water stress (Bibi *et al*., 2010). Stress conditions were first confronted by the roots, thus it is expected that roots sensed the stress and responded accordingly (Xiong *et al*., 2006; Khodarahmpour, 2011). Although a decrease is observed in fresh and dry root yields, such a decrease is less than the decrease in biomass (Creelman *et al*., 1990). Root/shoot ratio is a reliable parameter used in estimation of drought resistance. It is a measure of dry

**Table 7.** Effects of different water stress levels on fresh and dry root biomass yield.

| | Fresh root biomass yield ($t\ ha^{-1}$) | | Dry root biomass yield ($t\ ha^{-1}$) | | | Root/Shoot ratio (%) |
|---|---|---|---|---|---|---|
| Irrigation levels | 2017** | 2018** | 2017** | 2018** | 2018* | $2017^{ns}$ |
| $I_1$ | 57.86 a | 56.61 a | 13.48 a | 13.05 a | 0.51 c | 0.52 |
| $I_2$ | 50.16 b | 50.94 b | 12.45 ab | 12.15 b | 0.53 bc | 0.51 |
| $I_3$ | 44.81 c | 45.84 c | 11.15 b | 10.95 c | 0.59 a | 0.55 |
| $I_4$ | 32.20 d | 33.93 d | 7.85 c | 8.45 d | 0.58 ab | 0.56 |
| Means | 46.26 | 46.83 | 11.23 | 11.15 | 0.55 | 0.54 |
| CV % | 5.7 | 6.8 | 6.2 | 7.4 | 5.4 | 5.6 |
| LSD | 3.59 | 2.58 | 1.41 | 0.84 | 0.06 | ns |

** Significant at $P \leq 0.01$, * Significant at $P \leq 0.05$, ns: Non significant.

matter distribution in root and shoots systems and a well indicator of the effects of stress on root and shoot dry matter (Boutraa *et al*., 2010). Nour and Weibel (1978) indicated that root/shoot ratio of sorghum varied with the varieties, drought-resistant varieties had greater root/shoot ratio and reported root/shoot ratios of sorghum between 0.39 - 0.65. Together with deep roots, high root/shoot ratios are also important mechanisms for prevention of negative impacts of droughts in several species. Greater decrease was seen in shoot yield than root yield with water stress, root/shoot ratio was higher and such a ratio resulted from decreasing shoot growth under stress rather than an absolute increase in root growth (Assefa *et al*., 2010). Similar to the present findings, several other researchers (Takele 2000; Younis *et al*., 2000; Munamava and Riddoch, 2001) reported increased root/shoot ratios in sorghum under water stress conditions, but Ahmed *et al*. (2011) reported decreased root/shoot ratios with water stress. Takele (2000) reported root/shoot ratio as 0.47 at 25% FC, 0.32 at 45% FC, 0.27 at 65% FC, and 0.21 at 85% FC, and indicated increasing root/shoot ratios with decreasing irrigation water quantity.

## Water Use Efficiency and Yield Reduction Ratio

The Water Use Efficiency (WUE) and Yield Reduction Ratio (YRR) of sorghum under different irrigation levels are shown in Table 8. Increasing WUE values were observed with decreasing irrigation water quantities. In 2017, the highest WUE was obtained from $I_3$ (5.5 kg $m^{-3}$) with 370.2 mm ET and 20.39 t $ha^{-1}$ of biomass yield. Although the biomass yield decreased as the irrigation water and ET decreased, the efficiency of irrigation water use was high. However, WUE value had the lowest value in $I_1$ (4.5 kg $m^{-3}$), where full irrigation (ET: 575.9 mm) was made and the highest biomass yield (26.02 t $ha^{-1}$) was obtained. Similarly in 2018, $I_4$ (4.9 kg $m^{-3}$) with the lowest ET (294.8 mm) and biomass yield value (14.51 t $ha^{-1}$) had the highest WUE value, while the $I_1$ (4.2 kg $m^{-3}$) with full irrigation (ET:619.2 mm) and higher biomass yield (25.92 t $ha^{-1}$) had the lowest WUE value (Tables 4 and 8).

When WUE value is evaluated together with biomass yield, ET and yield reduction rate, it is seen that the decrease in biomass yield is less than the decrease in irrigation water and water is used more effectively. About 11% decrease was observed in dry biomass yield with 25% decrease in irrigation water quantity, 28.4% decrease was observed with 50% decrease in irrigation water and 44% decrease was observed in dry biomass yield with 75% decrease in irrigation water quantity (Table 8). This feature shows that sorghum can use irrigation water effectively.

WUE is used to determine dry matter quantity produced per unit of water and it is among the most important parameters used in generation of irrigation strategies. WUE is an unstable parameter and varies with the years, environmental conditions, growth stages, soil moisture and nitrogen contents. Different WUE values were reported for sorghum in previous studies (4.1-6.0 kg $m^{-3}$ by Mastrorilli *et al*., 1999;

[ DOI: 10.52547/jast.24.6.1487 ]

**Table 8.** Effects of different water stress levels on WUE and yield reduction ratio.

| Irrigation levels/Years | WUE (kg $m^{-3}$) |  | Yield reduction ratio (%) |  |
|---|---|---|---|---|
|  | 2017 | 2018 | 2017 | 2018 |
| $I_1$ | 4.5 | 4.2 | 0 | 0 |
| $I_2$ | 5.1 | 4.6 | 5.8 | 11.0 |
| $I_3$ | 5.5 | 4.7 | 21.6 | 28.4 |
| $I_4$ | 5.3 | 4.9 | 45.8 | 44.0 |
| Means | 5.1 | 4.6 | 24.0 | 27.8 |

4.4-5.5 kg $m^{-3}$ by Steduto and Albrizio, 2005; 6.5- 8.6 kg $m^{-3}$ by Saeed and El-Nadi, 1998). There are different opinions about the effects of water stress on WUE values. Similar with the present findings, Aishah *et al.* (2011) indicated that sorghum was able to use soil moisture more efficiently until severe deficits and increase WUE through prevention of yield loss. Besides, Jahansouz *et al.* (2014) and Bhattarai (2019) reported decreasing WUE values with decreasing irrigation water quantities and Garofalo and Rinaldi (2013) indicated insignificant effects of water stress on WUE and reported that full irrigation reduced WUE in some years. Uzun *et al.* (2017) reported a yield reduction of between 20.1- 46.3% in sorghum. Jahansouz *et al.* (2014) reported 28% yield reduction in sorghum with 25% reduction in irrigation water quantity.

Under stress conditions, sorghum plants usually have longer stay-green durations, get into dormant state and reduce water use, then respond to subsequent irrigations quickly with deep and intense root system, thus keep growing and reduce yield loss (Afshar *et al.*, 2014). Seasonal water consumption of sorghum was reported between 521-553 mm by Lamm *et al.* (2010); between 227-517 mm by Hao *et al.* (2014) and between 446–683 mm by Wagle *et al.* (2016).

## Correlations between Irrigation Levels and Investigated Traits

The correlation analysis performed to determine the relationship between the traits in the study is given in Table 9.

FBY had positive and significant correlations with DBY (r:0.99), SC (r:0.88), CC (r:0.80), FRY (r:0.96), and DRY (r:0.96) traits and negative-significant correlations with CT (r:-0.97), DMR (r:-0.89), and RSR (r:-0.83) traits. As with the FBY feature, the DBY feature had similar correlation values (Table 9).

Also, a biplot graph was generated to present the relationship among the investigated traits and clusters formed by the traits at different irrigation levels. Two-year averages were used in biplot graph (Figure 1).

The first principle component explained 91.5% and the second principle component explained 6.1% of total variation (97.6% of total variation was explained by the first two principle components) (Figure 1). Such a case is desired in biplot graphs and such high rate of explanation allows researchers to better interpret the correlations among the investigated traits (Akcura, 2011). The biplot graph was composed of four sections and the investigated traits were clustered in sections in which $I_1$ and $I_4$ treatments were the diagonals. In the first section with $I_1$ treatment as the diagonal, DBY, FBY, CC, SC, FRY, and DRY traits were placed. The angles between these trait vectors were acute angles indicating positive correlations among them. In the fourth section with $I_4$ treatment as diagonal, CT, DMR, WUE, and RSR traits were placed and again vector angles were acute, indicating positive correlations between them. In general, diagonal treatments are superior in trait/traits of the same section over the other treatments and there are significant positive correlations between them, the angles between trait vectors are acute and such traits are placed close to each other (Yan and Tinker, 2006; Akcura, 2011). According to the present biplot, biomass yield had positive

[ DOI: 10.52547/jast.24.6.1487 ]

**Table 9.** Relationship between traits in sorghum.

| Traits[a] | FBY | DMR | DBY | SC | CC | CT | WUE | FRY | DRY |
|---|---|---|---|---|---|---|---|---|---|
| FBY | 1 | | | | | | | | |
| DMR | -0.89** | 1 | | | | | | | |
| DBY | 0.99** | -0.83** | 1 | | | | | | |
| SC | 0.88** | -0.82** | 0.87** | 1 | | | | | |
| CC | 0.80** | -0.81** | 0,77** | 0.83** | 1 | | | | |
| CT | -0.97** | 0.89** | -0.96** | -0.90** | -0.78** | 1 | | | |
| WUE | -0.27$^{ns}$ | 0.55$^{ns}$ | -0.18$^{ns}$ | -0.50$^{ns}$ | -0.50$^{ns}$ | 0.34$^{ns}$ | 1 | | |
| FRY | 0.96** | -0.89** | 0.95** | 0.93** | 0.89** | -0.94** | -0.34$^{ns}$ | 1 | |
| DRY | 0.96** | -0.85** | 0.96** | 0.90** | 0.85** | -0.95** | -0.22$^{ns}$ | 0.98** | 1 |

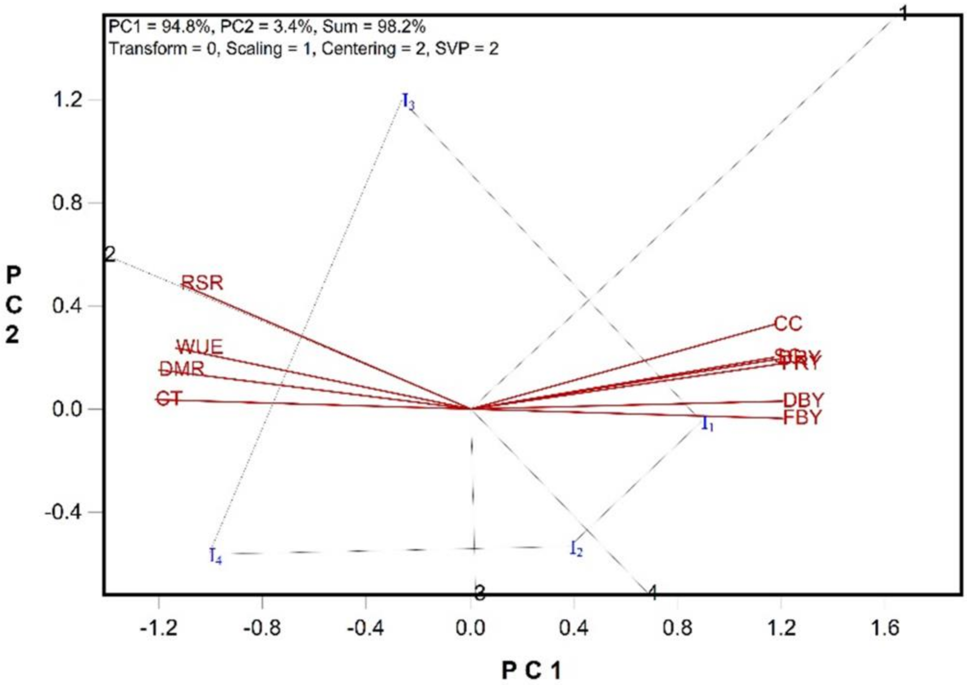

**Figure 1.** GGE-biplot analysis to visually evaluate the relationship between the traits examined at different water stress levels. FBY: Fresh Biomass Yield; DBY: Dry Biomass Yield; FRY: Fresh Root Yield; DRY: Dry Root Yield; RSR: Root/Shoot Ratio; WUE: Water Use Effiency; DMR: Dry Matter Ratio; CT: Canopy Temperature; SC: Stomatal Conductade; CC: Chlorophyll Contents.

correlations with CC, SC, FRY, and DRY traits and negative correlations with CT, DMR, WUE, and RSR traits.

## CONCLUSIONS

This study was conducted for two years to determine the effects of different water stress levels on biomass yield, root yield, root/shoot ratio, water consumption, water use efficiency, yield reduction ratio, and some other physiological characteristics of sorghum plants. Present findings revealed that the investigated parameters were influenced by water stress levels. Water stress reduced biomass yield, root yield, stomatal conductance, and chlorophyll contents, but increased water use efficiency and root/shoot ratios. Biomass yields decreased with water stress, but such a decrease was lower as compared to the decrease in applied irrigation water quantities. Based on our findings, it was concluded that deficit irrigation could be practiced in sorghum cultivation and irrigation costs should be taken into consideration.

[ DOI: 10.52547/jast.24.6.1487 ]

## REFERENCES

1. Ahmed, M., Hassen, F. and Khurshid, Y. 2011. Does Silicon and Irrigation Have Impact on Drought Tolerance Mechanism of Sorghum? *Agric. Wat. Manag.,* **98**: 1808– 1812.
2. Afshar, K.R., Jovini, M. A., Chaichi, M. R. and Hashemi, M. 2014. Grain Sorghum Response to Arbuscular Mycorrhiza and Phosphorus Fertilizer under Deficit Irrigation. *Agron. J.,* **106(4):** 1212-1218.
3. Aishah, S., Saberi, H. A. R., Halim, R. A. and Zaharah, A. R. 2011. Yield Responses of Forage Sorghums to Salinity and Irrigation Arequency. *Afr. J. Biotech.,* **10**: 4114-4120.
4. Akcura, M. 2011. The Relationships of Some Traits in Turkish Winter Bread Wheat Landraces. *Turk. J. Agric. For.,* **35(2**): 115-125.
5. Alghabari, F., Ihsan, M. Z., Khaliq, A., Hussain, S., Daur, I., Fahad, S. and Nasim, W. 2016. Gibberellin-Sensitive Rht Alleles Confer Tolerance to Heat and Drought Stresses in Wheat at Booting Stage. *J. Cereal Sci.,* **70**: 72–78.
6. Araghi, S. G. and Assad, M. T. 1998. Evaluation of Four Screening Techniques for Drought Resistance and Their relationship to Yield Reduction Ratio in Wheat. *Euphytica*, **103**: 293–299.
7. Assefa, Y., Staggenborg, S. A. and Prasad, V. P. V. 2010. Grain Sorghum Water Requirement and Responses to Drought Stress: A Review. Online. Crop Manag., **9(1):** 1-11
8. Begg, J. E. 1980. Morphological Adaptation of Leaves to Water Stress. In: "*Adaptation of Plants to Water and High Temperature Stress*", (Eds.): Turner, N. C. and Kramer, P. J. John Wiley & Sons. New York.
9. Bhattarai, B., Singh, S., West, C.P., Ritchie, G. L. and Trostle, C.L. 2020. Effect of Deficit Irrigation on Physiology and Forage Yield of Forage Sorghum, Pearl Millet, and Corn. *Crop Sci.,* **60(4):** 2167-2179.
10. Bhattarai, B. 2019. Silage Production Potential of Forage Sorghum, Pearl Millet and Corn under Limited Irrigation. Master Thesis, Faculty of Texas Tech University.
11. Bibi, A., Sadaqat, H. A., Akram, H. M. and Mohammed, M. I. 2010. Physiological Markers for Screening Sorghum (*Sorghum Bicolor*) Germplasm under Water Stress Condition. *Int. J. Agric. Biol.,* **12:** 451–455.
12. Bibi, A., Sadaqat, H. A., Tahir, M. H. N. and Akram, H. M. 2012. Screening of Sorghum (*Sorghum Bicolor* var. Moench) for Drought Tolerance at Seedling Stage in Polyethylene Glycol. *J. Anim. Plant Sci.,* **22(3):** 671-678.
13. Blum, A., Mayer, J. and Golan, G. 1989. Agronomic and Physiological Assessments of Genotypic Variation for Drought Resistance in Sorghum. *Aust. J. Agric. Res.,* **40:** 49-61.
14. Boutraa, T., Akhkha, A., Al-Shoaibi, A. A. and Alhejeli, A. M. 2010. Effect of Water Stress on Growth and Water Use Efficiency (WUE) of Some Wheat Cultivars (*Triticum durum*) Grown in Saudi Arabia. *J. Taibah Univ. Sci.,* **3(1):** 39-48.
15. Chaves, M. and Davies, B. 2010. Drought Effects and Water Use Efficiency: Improving Crop Production in Dry Environments. *Funct. Plant Biol.,* **37:** 3–6.
16. Creelman, R. A., Mason, H. S., Bensen, R.J., Boyer, J. S. and Mullet, J. E. 1990. Water Deficit and Abscisic Acid Cause Differential Inhibition of Shoot Versus Root Growth in Soybean Seedlings. Analysis of Growth Sugar Accumulation and Gene Expression. *Plant Physiol.,* **92:** 205-214.
17. Dahmardeh, K., Rad, M. R. P., Rad, M. R. N. and Hadizadeh, M. 2015. Effects of Potassium Rates and Irrigation Regimes on the Yield of Forage Sorghum in Arid Regions. *Int. J. Agron. Agric. Res.,* **6(4):** 207-212.
18. Doorenbos, J. and Kassam., A. H. 1979. *Yield Response to Water.* Irrigation and Drainage Paper No. 33, FAO, 193 PP.
19. Du, T., Kang, S., Sun, J., Zhang, X. and Zhang, J. 2010. An Improved Water Use Efficiency of Cereals under temporal and Spatial Deficit Irrigation in North China. *Agric. Water Manag.,* **97:** 66-74.

[ DOI: 10.52547/jast.24.6.1487 ]

20. El-Mageed, T.A.A., El- Samnoudi, I.M., Ibrahim, A. A. M. and. El Tawwab, A. R. A 2018. Compost and Mulching Modulates Morphological, Physiological Responses and Water Use Efficiency in Sorghum under Low Moisture Regime. *Agric. Water Manag.*, **208:** 431-439.
21. Howell, T. A., Cuenca, R. H. and Solomon, K. H. 1990. Crop Yield Response. "*Manegement of Farm Irrigation Systems*". Eds.: G. J. Hoffman., T. A. Howell., K. H. Solomon. 5 edition, An ASAE Monograph. Pp: 93- 116.
22. Garofalo, P. and Rinald, M. 2013. Water-Use Efficiency of Irrigated Biomass Sorghum in a Mediterranean Environment. *Span. J. Agric. Res.*, **11(4):** 1153-1169.
23. Gonulal, E., Soylu, S. and Sahin, M. 2021. Effects of Different Water Stress Levels on Biomass Yield and Agronomic Traits of Switchgrass (*Panicum virgatum* L.) Varieties under Semi-Arid Conditions. *Turk. J. Field Crops,* **26(1):** 25-34.
24. Haacker, E. M. K., Kendall, A. D. and Hyndman, D. W. 2016. Water Level Declines in the High Plains Aquifer: Predevelopment to Resource Senescence. *Groundwater,* **54:** 231–242.
25. Hao, B., Xue, Q., Bean, B.W., Rooney, W.L. and Becker, J.D. 2014. Biomass Production, Water and Nitrogen Use Efficiency in Photoperiod-Sensitive Sorghum in the Texas High Plains. Biomass Bioenerg., **62:** 108–116.
26. Harris, K., Subudhi, P. K., Borrell, A. K., Jordan, D. B., Rosenow, D., Nguyen, H., Klein, P., Klein, R. and Mullet, J. 2006. Sorghum Stay-Green QTL Individually Reduce Post– Flowering Drought-Induced Leaf Senescence. *J. Exp. Bot.,* **58:** 327–338.
27. Jahansouz, R. M., Afshar, R.K., Heidari, A. and Hashemi, M. 2014. Evaluation of Yield and Quality of Sorghum and Millet as Alternative Forage Crops to Corn under Normal and Deficit Irrigation Regimes. *Jordan J. Agric. Sci.,* **10(10):** 699-715.
28. Khodarahmpour, Z. 2011. Effect of Drought Stress Induced by Polyethylene Glycol (PEG) on Germination Indices in Corn (*Zea mays* L.) Hybrids. *Afr. J. Biotechnol.,* **10(79):** 18222-18227.
29. Keten, M. 2020. Determination of Water-Yield Relationships of Silage Maize and Sorghum Plants by Using Plant Stress Index (CWSI and WDI) under Deficit Irrigation Conditions. PhD Thesis, University of Kahramanmaras Graduate School of Natural and Applied Sciences. Kahramanmaraş, Turkey.
30. Kumar, D. D., Padma, V., Talwar, H. S. and Jabeen, F. 2013. Study on Association of Spad Chlorophyll Meter Reading (Scmr), Photosynthesis and Transpiration Rate with Grain Yield in Sorghum Genotypes Under Post Flowering Moisture Stress Conditions. *J. Res. Angrau.,* **41(4):** 73-77.
31. Kuscu, H., Turhan, A. and Demir, A. O. 2014. The Response Of Processing Tomato To Deficit Irrigation At Various Phenological Stages in A Sub-Humid Environment. *Agric. Water Manag.,* **133:** 92-103.
32. Lamm, F. R, Abou Kheira, A. A. and Trooien, T. P. 2010. Sunflower, Soybean, and Grain Sorghum Crop Production as Affected by Dripline Depth. *Appl. Eng. Agr.,* **26(5):** 873-882.
33. Li, R., Zhang, H., Zhou, X., Guan, Y., Yao, F., Song, G., Wang, J. and Zhang, C. 2010. Genetic Diversity in Chinese Sorghum and Races Revealed by Cloroplast Simple Sequence Repeats. *Genetic Resour. Crop Evol.,* **57:** 1–15.
34. Mastrorilli, M., Katerji, B. and Rana, G. 1999. Productivity and Water Use Efficiency of Sweet Sorghum as Affected by Soil Water Deficit Occurring at Different Vegetative Growth Stages. *Eur. J. Agron.,* **11:** 207–215.
35. Messina, C. D., Sinclair, T. R., Hammer, G. L., Curan, D. and Thompson, J. 2015. Limited-Transpiration Trait May Increase Maize Drought Tolerance in the US Corn Belt. *Agron. J.,* **107:** 1978–1986.
36. Munamava, M. and Riddoch, I. 2001. Responses of Three Sorghum (*Sorghum bicolor* (L.) Moench) Varieties to Soil Moisture Stress at Different Developmental Stages. *South Afr. J. Plant Soil.,* **18:** 75-79.
37. Nejad, M. M., Nejad, T. S. and Shokohfar, A. R. 2014. The Effects of Deficit Irrigation

[ DOI: 10.52547/jast.24.6.1487 ]

and Auxin on the Yield of Forage Sorghum. *Int. J. Biosci.,* **4(1):** 167-176.

38. Nour, A. M. and Weibel, D. E. 1978. Evaluation of Root Characteristics in Grain Sorghum. *Agron. J.,* **2:** 217-218.
39. Razmi, N. and Ghasemi, M. 2007. The Effect of Different Irrigation Regimes on Growth, Grain Yield and Yield Components of Grain Sorghum in Isfahan Climate. *Iran. J. Agron.,* **9:** 169-183.
40. Rostampour, M. F., Yarnia, M. and Khoee, F. R. 2012. Effect of Polymer and Irrigation Regimes on Dry Matter Yield and Several Physiological Traits of Forage Sorghum. *Afr. J. Biotechnol.,* **11(48):**10834-10840.
41. Saeed, M. A. I. and El-Nadi, H. A. 1998. Forage Sorghum Uield and Water Use Efficiency under Variable Irrigation. *Irrig. Sci.,* 1**8:** 67-71.
42. Saneoka, H., Ogata, S. and Agata, W. 1996. Cultivar Different in Dry Matter Production and Leaf Water Relations in Water-Stressed Maize (*Zea mays* L.). *Grassl. Sci.,* **41(4):** 294-301.
43. Steduto, P. and Albrizio, R. 2005. Resource Use Efficiency of Fieldgrown Sunflower, Sorghum, Wheat and Chickpea. II. Water Use Efficiency and Comparison with Radiation Use Efficiency. *Agric. For. Meteor.,* **130:** 269-281.
44. Takele, A. 2000. Seedling Emergence and Growth of Sorghum Genotypes under Variable Soil Moisture Deficit. *Acta Agronomica Hungarica,* **48(1):** 95–102.
45. Tariq, A. S., Akram, Z., Shabbir, G., Gulfraz, M., Khan, K. S., Iqbal, M. S. and Mahmoo, T. 2012. Character Association and Inheritance Studies of Different Sorghum Genotypes for Fodder Yield and Quality under Irrigated and Rainfed Conditions. *Afr. J. Biotechnol.,* **11(38):** 9189-9195.
46. Uzun, F., Garipoğlu, A. and Ocak, N. 2017. Water Use Efficiency, Yield, and Nutritional Quality of Maize and Sorghum Cultivars as Influenced by Irrigation in a Shallow Soil. *Anadolu J. Agric. Sci.,* **32(3):** 358-366.
47. Vasilakogloua, I., Dhimab, K., Karagiannidisb, N. and Gatsisb, T. 2011. Sweet Sorghum Productivity for Biofuels under Increased Soil Salinity and Reduced Irrigation. *Field Crops Res.,* **120(1):** 38-46.
48. Wagle, P., Kakani, V. G. and Huhnke, R. L. 2016. Evapotranspiration and Ecosystem Water Use Efficiency of Switchgrass and High Biomass Sorghum. *Agron. J.,* **108**: 1007– 1019.
49. Yan, W. and Tinker, N. A. 2006. Biplot Analysis of Multienvironment Trial Data: Principles and Applications. *Can. J. Plant Sci.,* **86:** 623–645.
50. Yin, L., Wang, S., Liu, P., Wang, W., Cao, D., Deng, X. and Zang, S. 2014. Silicon-Mediated Changes in Polyamine and 1-Aminocyclopropane-1- Carboxylic Acid are Involved in Silicon-Induced Drought Resistance in *Sorghum bicolor* L. *Plant Physiol. Biochem.,* **80**: 268–277.
51. Younis, M. E., EI-Shahaby, O. A., Abo-Hamed, S. A. and Ibrahim, A. H. 2000. Effect of Water Stress on Growth, Pigments and CO Assimilation in Three Aorghum Cultivars. *J. Agron. Crop Sci.,* **185**: 73-82.
52. Xiong, L., Wang, R., Mao, G. and Koczan, J. M. 2006. Identification of Drought Tolerance Determinants by Genetic Analysis of Root Response to Drought Stress and Abscisic Acid. *Plant Physiol.,* **142**:1065-1074.

[ DOI: 10.52547/jast.24.6.1487 ]

# اثرات سطوح مختلف تنش آبی بر زیست‌توده، عملکرد ریشه و برخی پارامترهای فیزیولوژیکی سورگوم

ا. گنلال

## چکیده

به منظور بررسی اثرات سطوح مختلف تنش آبی بر عملکرد زیست توده، عملکرد ریشه، نسبت ریشه به ساقه، برخی ویژگی‌های فیزیولوژیکی، راندمان کاربرد آب (WUE)، آب مصرفی فصلی، و تعیین نسبت کاهش عملکرد سورگوم سیلویی، این پژوهش در شرایط تنش آبی به مدت دو سال (۱۸-۲۰۱۷) روی سورگوم انجام شد. آزمایش ها در قالب طرح بلوک های تصادفی اجراشد. چهار تیمار آبیاری مختلف به کار رفت از جمله I1: آبیاری کامل، I1 %75 :I2 ، 50 :I3 ;٪ I1، و I1 25 :I4٪ . در سال ۲۰۱۷، بازده زیست توده خشک بین ۱۴.۱۱ (I4) و ۲۶.۰۲ تن در هکتار (I1)، هدایت روزنه ای بین ۷۲.۲ (I4) و ۱۴۷.۸ میلی مول در متر مربع درثانیه، محتوای کلروفیل بین ۳۷ (I4) و ۴۲.۱ (I1)، دمای تاج پوشش بین$^{o}$C ۲۷.۲ (I1) و$^{o}$C ۳۱.۳ (I4)، و WUE بین ۴.۵ (I1) و ۵.۵ کیلوگرم در متر مکعب (I3)بود. در سال ۲۰۱۸، بازده زیست توده خشک بین ۱۴.۵۱ (I4) و ۲۵.۹۲ تن در هکتار (I1)، هدایت روزنه ای بین ۶۹.۹ (I4) و ۱۲۹.۵ میلی مول در متر مربع درثانیه(I1) ، و محتوای کلروفیل بین ۳۹.۷ (I4) و ۴۳.۹ (I1)، دمای تاج پوشش بین$^{o}$C ۳۰.۰ (I1) و$^{o}$C ۳۴.۵ (I4)، و WUE بین ۴.۲ (I1) و ۴.۹ کیلوگرم در مترمکعب (I4) متغیر بود. بر اساس میانگین دو ساله، عملکرد ریشه خشک بین ۸.۱۵ (I4) و ۱۳.۲۷ تن در هکتار (I1)، نسبت ریشه به ساقه بین ۰.۵۱% (I1) تا ۰.۵۷% (I3-I4) و مصرف آب فصلی بین ۲۸۱ (I4) و ۵۹۸ میلی متر (I1) متغیر بود. تنش آب باعث کاهش عملکرد زیست توده، عملکرد ریشه، رسانایی روزنه ای، و محتوای کلروفیل شد و نسبت WUE و ریشه به ساقه را افزایش داد. عملکرد زیست توده با افزایش تنش آبی کاهش یافت، اما این کاهش در مقایسه با کاهش مقدار آب آبیاری داده شده کمتر بود.

[ DOI: 10.52547/jast.24.6.1487 ]