J. Agric. Sci. Technol. (2023) Vol. 25(6): 1403-1415

Comparison of Water-Yield Relations, Water Deficit Index, and Crop Water Stress Index in Silage Maize (*Zea mays* L.) and Sorghum (*Sorghum bicolor* L.)

M. Keten Gokkus[1*], and H. Degirmenci[2]

ABSTRACT

In this study, water-yield relations, Crop Water Stress Index (CWSI), which is one of the commonly used crops stress indicators, and the Water Deficit Index (WDI), which is a new approach, were compared by applying deficit irrigation in 2018-2019 growing period in Kahramanmaraş, Turkey. Five irrigation levels were applied to silage maize and sorghum plants. According to the results, yield was higher in silage maize than in silage sorghum both in full irrigation (100%) and in water-deficit irrigation (treatment where 80%, 60%, 40%, 20% meeting water requirement of plant). However, when average yield values of both years were examined, maize showed a decrease of 49 and 46%, respectively, while sorghum showed a decrease of 33%, compared to treatment with 40 and 20% irrigation, respectively. Similarly, there was a decrease of 66-54% in maize for 20% treatment, while there was a decrease of 45-46% in sorghum. This showed that sorghum maintained its yield potential better than maize in conditions of 60% or more water constraint. When the average CWSI and WDI indices were examined mutually, it was observed that rate of increase in stress and amount of decrease in productivity gave more consistent results in WDI than in CWSI. It has been understood that CWSI, one of crop stress determiners, is insufficient in determining stress compared to WDI, and WDI gives more accurate results. Accordingly, complete and accurate results of WDI have been obtained despite the shortcomings of CWSI method, which has been used in stress determination until now. It is suggested to use WDI for crop water stress index.

Keywords: Evapotranspiration, Irrigation, Crop canopy, Water scarcity.

INTRODUCTION

Water scarcity, which has increased in recent years, has become an important problem all over the world. Since agriculture is the main water user, it is necessary to consume water effectively to protect this restricted resource. Water use efficiency can be increased through different strategies (Farré and Faci, 2006). One of these strategies is to select plants with effective acceptable yields under deficit irrigation (Zwart and Bastiaanssen, 2004); another is to apply a deficit irrigation program.

Some crops use water more productively than other crops (Gurian-Sherman, 2012). For instance, sorghum consume less water than maize to catch up (Colaizzi *et al*., 2009). Silage maize is planted almost anywhere in Turkey and production amounts have doubled in the last decade (Tezel, 2018). However, maize is a water demanding plant and sensitive to water deficit (Farré and Faci, 2006). In those areas where rainfall or irrigation is limited for great silage yield, sorghum cultivation should replace maize (Bean and Marsails,

[1] Department of Biosystem Engineering, Faculty of Engineering and Architech, Nevşehir Hacı Bektaş Veli University, Nevşehir, Turkey.
[2] Department of Biosystem Engineering, Faculty of Agriculture, Kahramanmaraş Sütçü İmam University, Kahramanmaraş, Turkey.
*Corresponding author; e-mail: muallaketen34@gmail.com

[DOI: 10.22034/jast.25.6.1403]

2012).

Sorghum, as opposed to maize, is a drought-resistant crop (Camargo and Hubbard, 1999). Drought resistance of sorghum is because the stem, leaf sheath and leaf blade are generally covered with a wax layer, which minimizes amount of water to be lost from the plant (Acar *et al*., 2001). Sorghum species have great utilization potential both in arid areas and in terms of being an alternative to maize and other cultivated plants in periods when water is limited in irrigated farming areas (Yildiz *et al*., 2014; Yilmaz and Kokten, 2021). Silage sorghum has a potential yield similar to maize, making it a substitute for maize in fields where water supply is limited (Getachew *et al*., 2016).

Many researchers use CWSI to measure water stress and irrigation schedule (Tanriverdi *et al*., 2017; Zhou *et al*., 2021; Katimbo *et al*; 2022). However, CWSI has some trouble gauging plant surface Temperature (Ts). Whereas WDI is admitted to both soil and crop canopy temperatures as a Ts (El-Shirbeny *et al*., 2015), CWSI shows only canopy temperature as Ts. For this reason, some of datum are not beneficial to establish fundamentals of CWSI for early growing periods due to vegetation cover. The CWSI is only workable in situations of full vegetation cover, so Moran *et al*. (1994) build up WDI that let the index be forecasted for vegetation cover as well. Under these cases, WDI was thought to be a dependable index when compared with CWSI (Tanriverdi *et al*., 2017). However, the number of applied studies on this subject is very few. The fact that there are very limited studies on WDI will contribute to the next scientific studies and more precise determination of plant stress determiners will be provided.

The objectives of this study were:

1) To determine whether a silage sorghum plant grown under deficit irrigation conditions can be an alternative to maize for silage in a semi-arid climate zone,

2) To compare the plant stress treatments WDI and CWSI in both plants, to show missing side of CWSI with field application rather than theoretical,

3) To apply more appropriate measurement method such as WDI and to determine the differences between the two crops.

MATERIALS AND METHODS

Site, Soil, and Climate

This study was conducted in Kahramanmaras, East Mediterranean Turkey, in 2018 and 2019. While the texture class of the soil was clay loam in 2018, it was silty loam in 2019. Field capacity, wilting point and available water holding capacity were 288, 198, and 89 mm, respectively, in 2018. Field capacity is 327 mm and wilting point is 189 mm, available water holding capacity was 138 mm in 2019. pH and EC values were not a problem for plant growth. Average long annual temperature values in 2018 and 2019 were close to each other (Table 1). In case of growing plants as second crops in the region, plants need irrigation due to low amount of rainfall during the growing season.

Agronomic Studies

"Colonia" variety was used for silage maize (*Zea mays* L.) and "Es Foehn" variety was used for silage sorghum (*Sorghum bicolor* L.). Silage maize and silage sorghum were sown on 25 June 2018 and 22 June 2019. Sowing was 70 cm row spacing and 15 cm row top. 80 kg ha^{-1} P and 80 kg ha^{-1} N 20-20-0 compound fertilizer were given to the silage maize and sorghum during planting (Okursoy, 2009). When crops height were 40-50 cm, 100 kg ha^{-1} pure N was applied. Nitrogen fertilizer was applied

[DOI: 10.22034/jast.25.6.1403]

Table 1. Climatic data and long annual average values for the years.[a]

	Plant growing periods											
	June			July			August			September		
	1930 2019	2018	2019	1930 2019	2018	2019	1930 2019	2018	2019	1930 2019	2018	2019
T_{max} (°C)	31.9	38.6	43.4	35.6	41.6	39.4	36.0	41.1	42.8	32.5	40.5	39.1
T_{min} (°C)	18.7	13.6	11.4	22.2	17.8	16.7	22.2	19.0	17.2	18.3	14.4	9.0
T_{avg} (°C)	24.9	25.5	27.2	28.2	28.9	27.4	28.4	29.3	29.3	24.9	26.7	26.0
P_T (mm)	8.6	17.0	5.2	2.7	2.2	0.2	2.2	0.4	-	10.4	0.8	1.0
W_S (m s^{-1})	2.8	1.9	1.7	3.3	2.3	1.9	2.9	2.1	1.7	2.1	1.9	1.5

[a] T_{max}: Maximum Temperature, T_{min}: Minimum Temperature, T_{avg}: Average Temperature, Pt: Total precipitation, Ws: Wind speed.

by irrigation. Also, trial plots of 8.0 m in length and 3.5 m in width with 28 m^2 area were used. To prevent irrigation treatments from being affected by each other, the distance between parcels was 2 and 3 m distance between blocks. The total area of the experiment was1,590 m^2.

Irrigation and Crop Measurements

Drip irrigation system was used to irrigate the plants. Since the length of the plot was 8 m and 5 rows of plants were grown in each plot, a drip irrigation system was established with one lateral for each plant row. In the study, two different plants for silage Maize (M) and silage Sorghum (S) and 5 different irrigation levels (treatment where 100%, 80%, 60%, 40%, 20% meeting water requirement of plant) were applied. The control treatment was determined as 100% irrigated treatment. The trial treatments were arranged in a randomized complete block factorial design with three replications. Each of blocks had ten parcels, two plant types, five irrigation levels, and totally was carried out on 30 parcels. Irrigation levels depended on completion of 0.9 m deep root zone to field capacity when the soil moisture content that determined gravimetric methods decrease to 50% of available water holding capacity (Tanriverdi, 2003; Kiziloglu *et al*., 2009), this was defined as 100% irrigated treatment; others were 20% (M_{80} and S_{80}), 40% (M_{60} and S_{60}), 60% (M_{40} and S_{40}), 80% (M_{20} and S_{20}). Soil moisture was calculated in percent dry weight and then converted to depth. Irrigation started when the available water holding capacity of the 100% irrigated subject decreased to 50%. Irrigation was started with reference to 100% irrigation in other subjects (i.e., irrigation for 80, 60, 40, and 20% was started when the soil moisture of the 100% irrigated subject fell to 50% of the available water holding capacity). Irrigation started in 2018 when 50% of the 89 mm water holding capacity was subtracted from the field capacity, that is, when the soil moisture value reached 243 mm. In 2019, it was started with the same method when the soil moisture reached 258 mm. 20, 40, 60, and 80% less of 100% (M_{100} and S_{100}) was determined as M_{80} and S_{80}, M_{60} and S_{60}, M_{40} and S_{40}, M_{20} and S_{20}, respectively. Water budget equation was used in calculation of plant water consumption (Howell *et al*., 1986).

Crop Water Stress Index (CWSI)

Crop water stress index was determined according to the empirical method suggested by Idso *et al*. (1981).

$$CWSI = \frac{[(Tc-Ta)-LL]}{UL-} \quad (1)$$

Where, (Tc-Ta) is the differentiation among canopy Temperature (Tc, °C) and air Temperature (Ta, °C) for the actual case; LL: Lower boundary Line, no water stress treatment (the value of the transpiration limit at potential); UL: Upper limit boundary

[DOI: 10.22034/jast.25.6.1403]

Line, completely water stress (value of the non-transpiration limit). While CWSI value approaches 0 under full irrigation conditions, it approaches 1 under dry conditions. Canopy temperature was measured by infrared thermometer. Measurements were made in three repetitions from the four corners of each plot, and average was taken. Measurements were made between 11:00 and 14:00 hours.

Water Deficit Index (WDI)

When determining the WDI, a vegetation cover (vegetation index) trapezoid is drawn to represent the lower limit and upper limit, as in the CWSI. There are two important parameters in drawing this trapezoid. One of them is vegetation cover; the other is the temperature difference between Ts and Ta. Ts was measured by thermometer.

The measured Ts and the difference in air temperature (X-axis) (Ts-Ta) *versus* the vegetation cover (Y-axis) value is drawn. Thanks to these two parameters, vegetation trapezium is obtained (Figure 1).

There are three main methods of determining vegetation cover. These are, respectively, (i) Estimation, (ii) Measurement, and (iii) Theoretical methods. In this study, vegetation cover was determined by the measurement method. For this, Photosynthetic Active Radiation (PAR) meter instrument (Decagon Sunfleck Ceptometer, LP-80 PAR), with a probe length of 80 cm was used. PAR instrument measures light falling under plant (below canopy) and over plant (above canopy) to determine vegetation cover. By calculating these values, a coefficient representing the vegetation cover is determined for y-axis. PAR measurements under vegetation were made from the middle of a row of plants to middle of a neighboring row, and 10 readings were made in each plot. Also, PAR measurements above vegetation were made so that the sensor level was in the same direction as the lower readings (Neale, 1987). Then, the fraction (f) of the soil surface covered with vegetation was calculated according to Equation (2) (Tanriverdi, 2003).

$$f = \frac{(Va - Vb)}{Va} \qquad (2)$$

Where, Va: PAR value above Vegetation; Vb: PAR value below Vegetation. Ts and Ta values were measured with an infrared thermometer. The trapezoid VIT connecting the four lines point A of left line shows the lines defining the possible (Ts-Ta) range for full vegetation where water is not limited. Similarly, point B defines the possible (Ts-Ta) range for situations where there is no water available. The possible (Ts-Ta) range for complete vegetation is defined by the top line between vertices 1 and 2. The expressions shown in the form of a trapezoid are as follows: (l) The treatment with full vegetation irrigation, with the potential of full transpiration, (2) The treatment under water stress covered with full vegetation, where measurable treatment is insignificant, (3) Bare

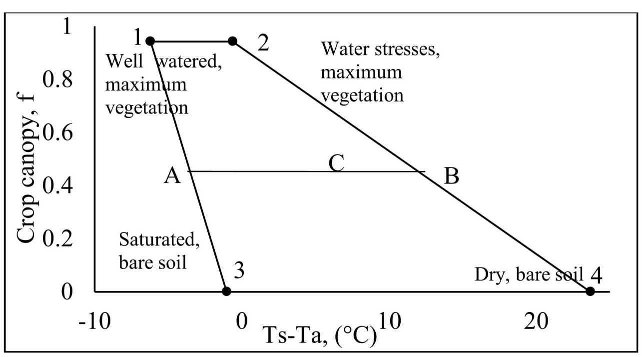

Figure 1. Vegetation index and Ts-Ta temperature differences.

[DOI: 10.22034/jast.25.6.1403]

and wet soil where evaporation is potential, and (4) Dry and bare treatment, no water for evaporation (Colaizzi *et al*., 2000). Moran *et al*. (1994) stated that the trapezoidal shape represents the actual (Ts-Ta) value and vegetation (C) point. Accordingly, points A and B can be linearly interpolated between vertices 1 and 3 with 2 and 4, respectively, while WDI is calculated. The energy balance between the surface and the atmospheric boundary layer (point C) is in equilibrium for each of the four trapezoidal. The lower limit of no water constraint (Ts-Ta) is at point A according to the given vegetation value, where there is water stress, and the upper limit is at point B. Using the VIT trapezoid, it is calculated according to WDI Equation (3).

$$\mathrm{WDI} = \frac{A-C}{A-B} \quad (3)$$

A treatment in non-limiting conditions for evaporation and transpiration (well irrigated, baseline), B is an upper limit where there is no water (fully exposed to water stress, baseline)

C is the actual measure of plant condition (Moran, 1994). The WDI range is similar to the CWSI, that is, a value of 0 indicates no water stress issue, while a value of 1 indicates an issue with water stress.

Statistical Analysis

Variance analysis was conducted to determine the level of differences between the obtained data. Duncan's test was used to classify the differences seen as a result of variance analysis. SAS program was used for statistical analysis.

RESULTS AND DISCUSSION

Irrigation-Crop Yield Relations

Parameter of irrigation water and Evapotranspiration (ET) for all treatments in the experimental years are given in Table 4. During growing season of 2018, maize from M_{100} to M_{20} was 848.64 and 530.57 mm, respectively. In 2019, applied water was between 935.87 and 502.49 mm. During growing season of 2018, applied water to sorghum was between 774.03 and 515.64 mm for the highest S_{100} treatment and lowest S_{20} treatment, respectively. In 2019, lowest S_{20} irrigation water, which gave highest S_{100}, was applied as 882.65 and 491.85 mm, respectively. Yolcu (2014) was applied 529 mm water to corn. Silage sorghum was found 391.5 and 778.00 mm by Kaplan et al. (2019).

Evapotranspiration (ET) of silage maize varied from 859 mm in M_{20} to 1,092 mm in M_{100} treatment in 2018 growing season; and 667 mm in M_{20} to 928 mm in M_{100} treatment in 2019 growing season. These values in silage sorghum varied from 856 mm in S_{20} to 1,017 mm in S_{100} treatment in 2018 growing season; and 658 mm in S_{20} to 875 mm in S_{100} treatment in 2019 growing season (Table 2). For silage maize, the amount was 578 mm (Farré and Faci, 2006), and for silage sorghum it was 890.5 mm (Kaplan *et al*., 2019). ET decreased with the response of environment to climatic conditions such as temperature and humidity, as plants could not get enough water from soil in deficit treatments. In both years, plant water consumption was lower in silage sorghum compared to silage maize, as sorghum requires less water than maize.

Three groups were formed according to two-year average results of different irrigation treatments. While the highest silage yield was determined as 67.03 t ha^{-1} in 100% irrigated treatments, the lowest yield was determined as 33.02 t ha^{-1} in 20% irrigated treatments (Table 3).

In both years and the average of the years, maize was higher than sorghum. Considering these two-year average values, yield value of 53.89 t ha^{-1} in maize was 46.21 t ha^{-1} in sorghum (Table 3). In this case, it was observed that more yield was obtained from silage maize compared to sorghum. However, when average yield values of 2019 and both years were examined, maize decreased by 49 and 46%, respectively, in treatment with 40% and 20% irrigation, while sorghum decreased by 33%.

[DOI: 10.22034/jast.25.6.1403]

Similarly, while maize decreased by 66% to 54% in 20% irrigated treatment, there was a 45% to 46% decrease in sorghum. This situation showed that sorghum preserves its yield potential better than maize when there is 60% or more water deficit. In previous studies for silage maize, yield values were found between 9.30 t ha^{-1} and 75.20 t ha^{-1} (Mostafa and Derbala, 2013; Kaplan *et al*., 2016). Previous studies on sorghum found yield between 23.96 and 94.70 t ha^{-1} (Saghafi *et al*., 2013; Hussein and Alva., 2014).

Crop Water Stress Index (CWSI)

In 2018 and 2019, the upper limit value varied between -0.16 and 0.99°C (Figure 2). This value Orta *et al*. (2003) found that -1.0°C, Payero and Irmak (2006) 1.61°C, In the study, lower limit value (assumed lower limit without water stress) equations of maize for silage were determined as Tc-Ta= -1.0376VPD-0.2189 in 2018, and Tc-Ta= -1.9761VPD-0.365 in 2019. The upper limit value for silage sorghum varied between 0.34-1.13°C in 2018 and 2019 (Figure 2). In the study, lower limit value (assumed lower limit of water stress) equations for silage sorghum was determined as Tc-Ta= -1.44VPD+0.4095 in 2018, and Tc-Ta= -1.51VPD-1.18 in 2019.

In both years, silage maize and sorghum CWSI values were the lowest for M_{100} and S_{100}, and the highest for M_{20} and S_{20} (Figure 2). As Idso *et al*. (1981) stated, theoretically, CWSI values range from 0 to 1. However, in the study, it is seen that the treatments other than the M_{100} and S_{100} have exceeded 1 in some measurements during plant growth period. It was thought that this value may cause stress in the plant depending on soil moisture and the air temperature of that day. Alderfasi and Nielsen (2001) stated that, in CWSI measurements, many observed values

Table 2. Irrigation and Evapotranspiration (ET) of silage maize and sorghum.

Years	Maize			Sorghum		
	Treatment	Irrigation (mm)	ET (mm)	Treatment	Irrigation (mm)	ET (mm)
2018	M_{100}	848.64	1092	S_{100}	774.03	1017
	M_{80}	769.13	1035	S_{80}	709.41	982
	M_{60}	689.61	975	S_{60}	644.82	937
	M_{40}	610.9	918	S_{40}	580.23	835
	M_{20}	530.57	859	S_{20}	515.64	856
2019	M_{100}	935.87	928	S_{100}	882.65	875
	M_{80}	827.53	879	S_{80}	784.95	825
	M_{60}	719.18	813	S_{60}	687.25	767
	M_{40}	610.84	739	S_{40}	589.55	720
	M_{20}	502.49	667	S_{20}	491.85	658

Table 3. Yield (t ha^{-1}) of silage maize and sorghum in different treatments.

Irrigation	2018			2019			Mean of 2 years		
	Maize	Sorghum	Mean	Maize	Sorghum	Mean	Maize	Sorghum	Mean
%100	84.32	70.37	77.34^{a}	63.01	50.41	56.71^{a}	73.66	60.39	67.03^{a}
%80	70.83	60.23	65.53^{b}	56.48	43.80	50.14^{ab}	63.66	52.02	57.84^{b}
%60	68.10	56.16	62.13^{b}	49.31	36.14	42.72^{bc}	587.1	46.15	52.43^{b}
%40	47.23	46.84	47.03^{c}	32.14	33.59	32.87^{cd}	39.68	40.22	39.95^{c}
%20	46.65	37.27	41.96^{c}	20.83	27.31	24.07^{d}	33.74	32.29	33.02^{c}
Mean	63.43^{a}	54.18^{b}	58.80^{a}	44.36^{a}	38.25^{b}	41.30^{b}	53.89^{a}	46.21^{b}	

[DOI: 10.22034/jast.25.6.1403]

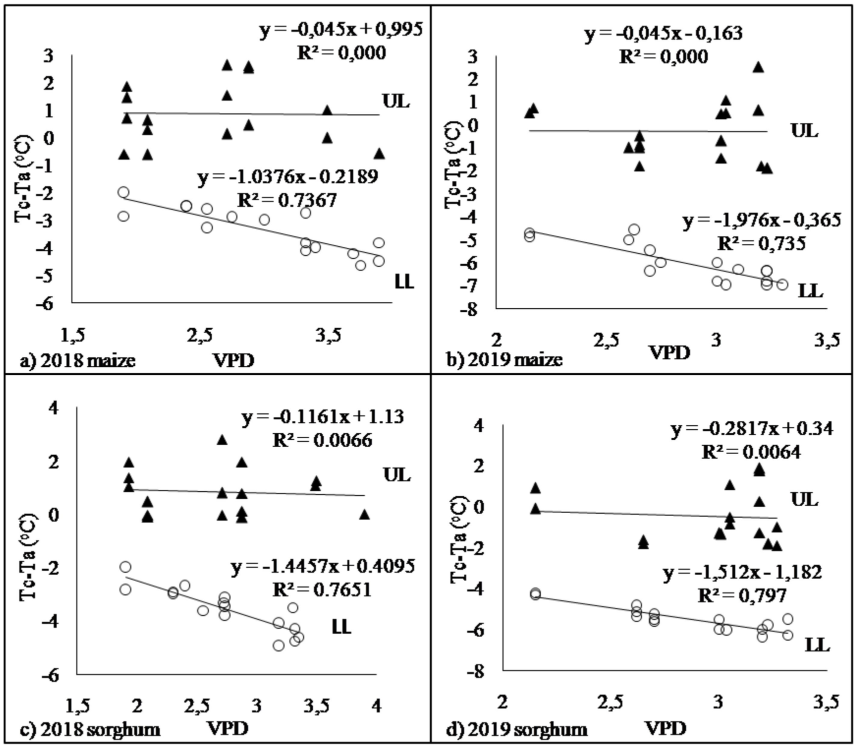

Figure 2. Upper and lower limit of silage maize and sorghum.

could be found outside this range.

In Figure 3 and from M_{100} to M_{20}, the average CWSI values for silage maize varied between 0.14 and 0.73 in 2018, respectively, but it varied between 0.39 and 0.82 in 2019. For silage sorghum, average CWSI values in 2018 varied from S_{100} to S_{20}, respectively, between 0.27 and 0.67, while in 2019 it varied between 0.32 and 0.72 (Figure 3). As can be seen from the figures, CWSI values differed according to irrigation treatments. In 2018 and 2019, M_{100} and S_{100} treatments were calculated as very small values such as 0.14 and 0.39, 0.27, and 0.32, respectively; M_{20} and S_{20} threads were calculated at very large values such as 0.73 and 0.82, 0.67 and 0.72, respectively. Approximately 38 to 47% decrease in irrigation amount of silage maize caused an increase of 2 to 5 times in plant water stress index. A reduction of 34 to 45% applied to silage sorghum irrigation resulted in a 2.5 fold increase in crop water stress index. The 2 to 5 fold increase in CWSI in silage maize resulted in an approximately 3- fold decrease in yield, while this resulted in a 2-fold decrease in yield in silage sorghum. In both plants, CWSI values before irrigation increased with the decrease in soil moisture. Generally, silage maize CWSI value was higher than sorghum. This situation showed that maize silage plant was more sensitive to water stress than silage sorghum. Fattahi *et al*. (2018) found CWSI values between 0.12 and 0.46. In the sorghum, O'Shaughnessy *et al*. (2012) found it to be 0.45.

Water Deficit Index (WDI)

In 2018 and 2019, as irrigation level increased, the fraction (f) of the soil surface covered with vegetation value increased to higher values, while Ts-Ta value decreased, as irrigation level decreased, the vegetation decreased and the Ts-Ta value increased. In both years, vegetation value changed between 0 and 1. While the highest vegetation value was 0.94 in 2018, this value was 0.90 in 2019. As intersection point

[DOI: 10.22034/jast.25.6.1403]

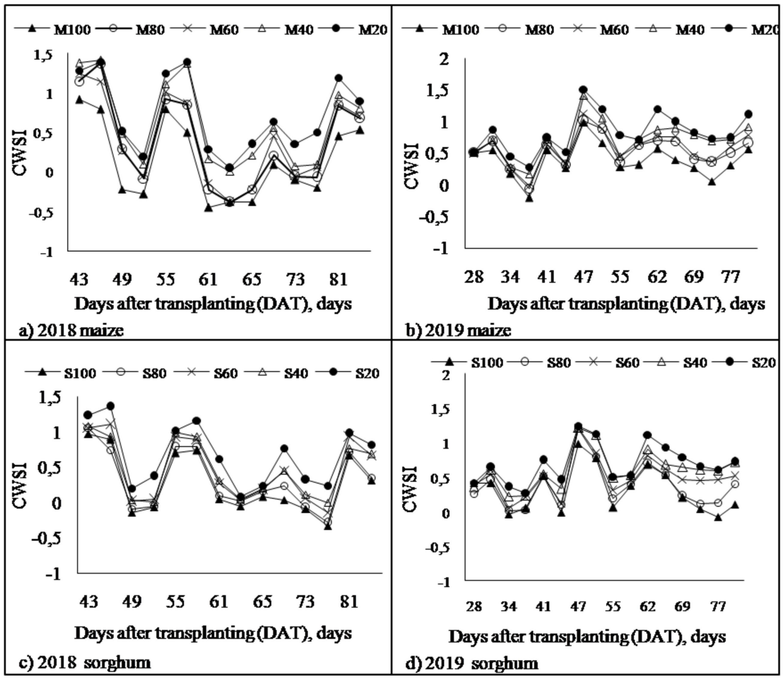

Figure 3. CWSI of silage maize and sorghum.

(point C) of vegetation cover and temperature difference values in the trapezoid gets closer to maximum vegetation value, the Ts-Ta (distance A-B) interval has decreased (Figure 4). This situation showed that points close to dry bare soil conditions also have a wider Ts-Ta interval. Increasing AB distance causes a decrease in WDI. Therefore, if vegetation is dense and there is no water stress, there is a narrow Ts-Ta range, and if vegetation is sparse and water stress is high, there is a wider Tc-Ta range. When distribution of points is examined, it is understood that M_{100} has a narrower AB distance compared to other treatments, AB range increases with decrease in irrigation level and the range is mostly seen in M_{20}. Similar results are reported by Tanriverdi (2003) in maize.

In 2018 and 2019, as irrigation level increased, vegetation (f) value increased to higher values, while Ts-Ta value decreased; and as irrigation level decreased, vegetation decreased and Ts-Ta value increased. In both years, vegetation value changed between 0 and 1. While the highest vegetation value was 0.92 in 2018, it was 0.90 in 2019. Results similar to silage maize were also seen in sorghum. It is understood that S_{100} has a narrower AB distance compared to other treatments, AB range increases with decrease in irrigation level and range is mostly seen in S_{20} range. When both plants were evaluated together, it was concluded that maize had a higher vegetation value. Comparison of vegetation cover values for 2018 and 2019 revealed that values for 2019 were low in both maize and sorghum. This situation coincides with the fact that green grass yield was lower in 2019 compared to 2018 (Figure 5).

The WDI values obtained by using the slopes of equations of lines 1-2 and 2-4 of the trapezoid are given in Figure 6. In 2018 and 2019, silage maize and sorghum WDI values were lowest for M_{100} and S_{100}, and highest for M_{20} and S_{20}. WDI increased as irrigation decreased. Although the WDI values were very close to each other, they had different sensitivity levels to water stress (Figure 5).

WDI values for silage maize in 2018 varied between 0.18 and 0.45 for, respectively, M_{20} and M_{100}, while it varied between 0.21 and 0.47 in 2019. The average WDI values for silage sorghum ranged

[DOI: 10.22034/jast.25.6.1403]

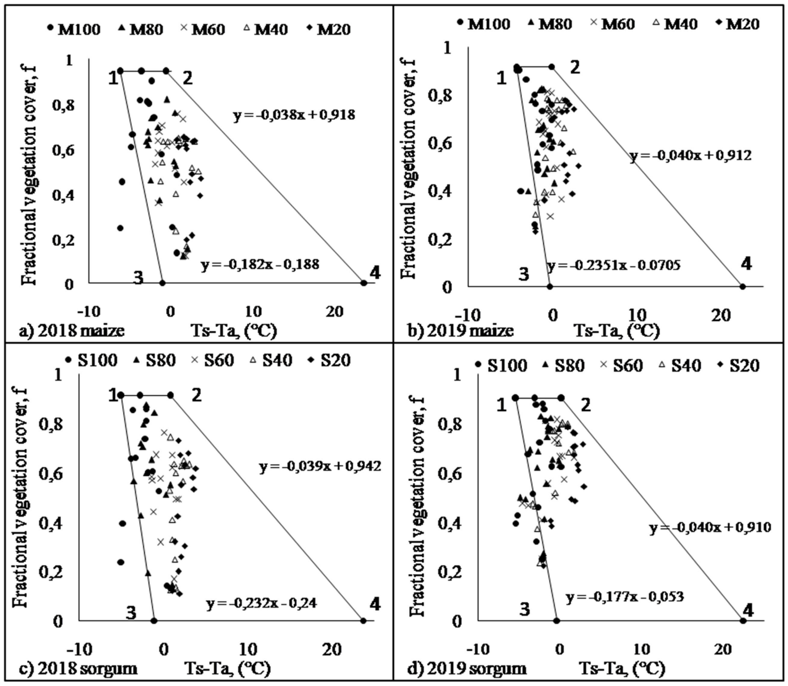

Figure 4. Trapezoid of silage maize and sorghum.

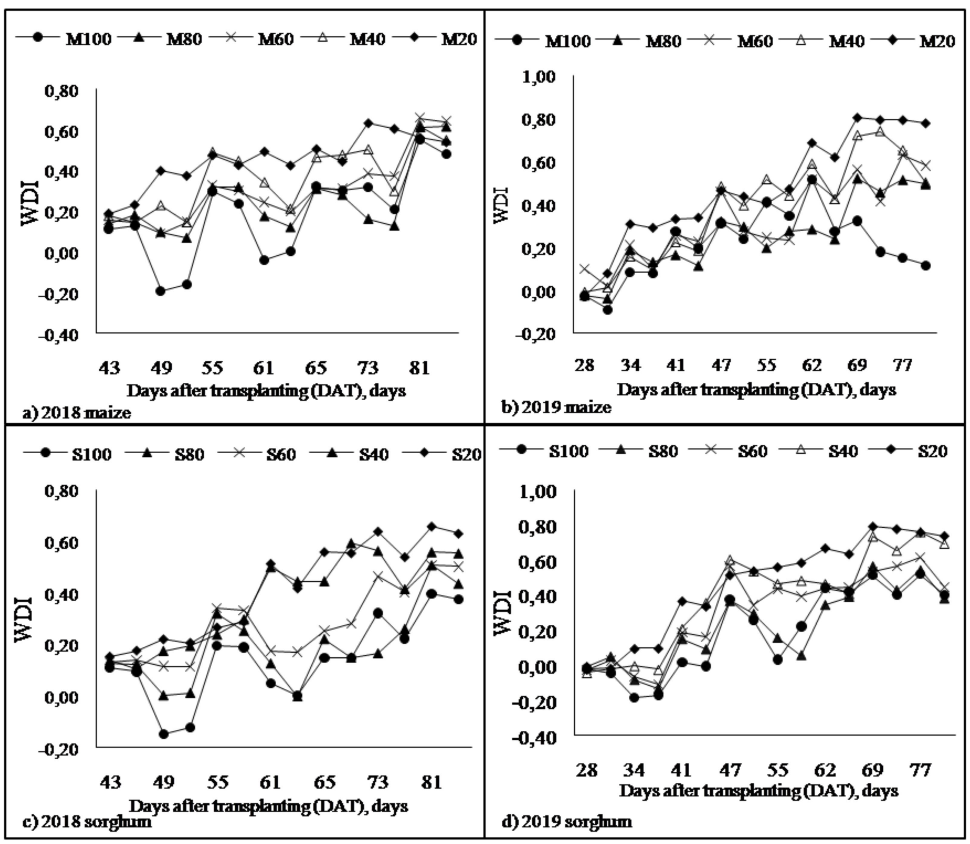

Figure 5. WDI of silage maize and sorghum.

[DOI: 10.22034/jast.25.6.1403]

between 0.14 and 0.42 between S100 and S20 in 2018, while they ranged between 0.20 and 0.46 in 2019. In 2018 and 2019, M_{100} and S_{100} treatments were calculated as very small values such as 0.18 and 0.21, 0.14 and 0.20, respectively; M_{20} and S_{20} treatments were calculated with higher values such as 0.45 and 0 0.47, 0.42 and 0.46, respectively (Figure 5). Approximately 38 to 47% decrease in irrigation amount of maize for silage resulted in a 2.5- to 3-fold increase in water deficit index. The 34 to 45% reduction applied to silage sorghum irrigation resulted in an approximately 2.5- to 3-fold increase in crop water stress index. While 2.5- to 3-fold increase in CWSI in silage maize caused a 3-fold decrease in yield, this resulted in a 2-fold decrease in silage sorghum. As can be seen from tables and figures, WDI values differed according to irrigation treatments. Generally, silage maize WDI value was higher than sorghum. This situation showed that silage maize was more sensitive to water stress than silage sorghum.

When CWSI and WDI indexes were examined mutually, it was seen that increase in stress and amount of decrease in efficiency gave more consistent results in WDI compared to CWSI. CWSI, which gives results about crop stress situation based on crop temperature only, is insufficient, it is necessary to evaluate crop, soil and so on. As a result of this study, it was understood that temperature data such as (surface) representing whole environment give more accurate results in evaluating stress.

CONCLUSIONS

In this study, in fully (100%) irrigated conditions, silage maize yield was higher than sorghum yield. Maize and sorghum responded differently to deficit irrigation. Previous studies have mentioned physical similarities and differences between the two crops, but no one has studied WDI, CWSI in both plants. WDI, which was generally mentioned theoretically in previous studies, has been shown practically in this study. It has been shown that the rate of increase in stress and the amount of decrease in yield give more consistent results in WDI than in CWSI.

While 100% irrigation is recommended to ensure high efficiency for both plants, it is recommended to use limited irrigation in places where water supply is insufficient. While maize decreased by 49 and 46%, respectively, in 40% treatment, sorghum decreased by 33% compared to 100% irrigated area. Similarly, a decrease of 66 to 54% was observed in maize in 20% irrigated area, while there was a decrease of 45-46% in sorghum. This showed that sorghum maintained its yield potential better than maize in conditions of 60% or more water shortage. It is suggested to grow sorghum in places where there is a water deficit of 60% or more.

Water stress and decrease in yield are directly related to decrease in irrigation water given to treatments . This is confirmed by the high yield, low CWSI and WDI in 100% irrigated treatments and the low yield, high CWSI and WDI in 20% irrigated treatments. Water stress and yield reduction were directly related. Relatively more accurate results were obtained from the WDI than from the CWSI, as a result of associations based on the decrease or increase of stress indices as a result of proportional increase or decrease in yield. Especially maize shows this situation better, because 42.5% less water to maize made CWSI value 3.5 while WDI value was 2.35. An increase of 2.35 in WDI caused a 2.4 fold decrease in yield. Consistency of WDI and yield increase and decrease rates showed that WDI gave more consistent results than CWSI. It was understood that CWSI, one of crop stress determiners, was insufficient in determining stress compared to WDI, and WDI gave more accurate results. It is suggested to use WDI in determining crop stress. In addition, this study will contribute to future researchers and producers due to its positive effect on

[DOI: 10.22034/jast.25.6.1403]

sustainable use of water resources with deficit irrigation application of crops (such as maize and sorghum) grown in the face of rapidly changing climatic conditions.

ACKNOWLEDGEMENTS

This study was supported by Kahramanmaraş Sütçü İmam University Scientific Research and Projects Coordinatorship (Project no: 2017/6-33 M). This study was extracted from a doctoral thesis.

REFERENCES

1. Acar, R., Akbudak, M. A. and Sade, B. 2001. Sorgum-Sudanotu Melezi (silaj amaçlı). *Konya Ticaret Borsası Dergisi*, **4(9):** 18-23.
2. Alderfasi, A. A. and Nielsen, D. C. 2001. Use of Crop Water Stress Index for Monitoring Water Status and Scheduling Irrigation in Wheat. *Agric. Water Manag.,* **47:** 69-75.
3. Bean. B. and Marsalis. M. 2012. Maize and Sorghum Silage Production Considerations. *The High Plains Dairy Conference*.
4. Camargo, M. B. P. and Hubbard. K. G. 1999. Drought Sensitivity Indices for Sorghum Crop. *J. Prod. Agric*., **12:** 312–316.
5. Colaizzi, P. D., Choi, C. Y., Waller, P. M., Barnes, E. M. and Clarke, T. R. 2000. Determining Irrigation Management Zones in Precision Agriculture Using the Water Deficit Index at High Spatial Resolutions. *ASAE Annual International Meeting*, PP. 1-19.
6. Colaizzi, P. D., Gowda, P. H., Marek, T. H. and Porter, D. O. 2009. Irrigation in the Texas High Plains: A Brief History and Potential Reductions in Demand. *Irrig. Drain*., **58:** 257–274.
7. El-Shirbeny, M. A., Ali, A. M., Rashash, A. and Badr, M. A. 2015. Wheat Yield Response to Water Deficit under Central Pivot Irrigation System Using Remote Sensing Techniques. *World J. Eng. Technol.*, **3:** 65-72.
8. Farré, I. and Faci, J. M. 2006. Comparative Response of Maize (*Zea mays* L.) and Sorghum (*Sorghum bicolor* L. Moench) to Deficit Irrigation in a Mediterranean Environment. *Agric. Water Manag.,* **83(1-2):** 135-143.
9. Fattahi, K., Babazadeh, H., Najafi, P. and Sedghi, H. 2018. Scheduling Maize Irrigation Based on Crop Water Index (CWSI). *Appl. Ecol. Environ. Res.,* **16(6):** 7535-7549.
10. Getachew, G., Putnam, D. H., Ben, C. M. D. and Peters, E. J. D. 2016. Potential of Sorghum as an Alternative to Maize Silage. *Am. J. Plant Sci.,* **7:** 1106-1121.
11. Gurian-Sherman, D. 2012. High and Dry: Why Genetic Engineering Is Not Solving Agriculture's Drought Problem in a Thirsty World. UCS: Union of Concerned Scientists, United States of America.
12. Howell, T. A., Musick, J. T. and Tolk, J. A. 1986. Canopy Temperature of Irrigated Winter Wheat. *Trans. ASAE,* **29(6):** 1692–1699.
13. Hussein, M., Alva, K. 2014. Growth, Yield and Water Use Effeciency of Forage Sorghum as Affected by Npk Fertilizer and Deficit Irrigation Sorghum-Forage-Omitting of Irrigation-NPK Fertilizer-Growth, Yield-Water Use Efficiency. 5. 2134-2140. 10.13140/2.1.3557.0881.
14. Idso, S. B., Jackson, R. D., Pinter, P. J. and Hatfield, J. L. 1981. Normalizing the Stress–Degree–Day Parameter for Environmental Variability. *Agric. Meteorol.,* **24:** 45-55.
15. Kaplan, M., Arslan, M., Kale, H., Kara, K. and Kokten, K. 2016. GT Biplot Analysis for Silage Potential. Nutritive Value. Gas and Methane Production of Stay-Green Grain Sorghum Shoots. *Cien. Inv. Agr*., **44(3):** 230-238.
16. Kaplan, M., Kara, K., Unlukara, A., Kale, H., Beyzi Buyukkilic, S., Varol, I. S., Kizilsimsek, M. and Kamalak, A. 2019. Water Deficit and Nitrogen Affects Yield and Feed Value of Sorghum Sudangrass Silage. *Agric. Water Manag.,* **218:** 30-36.
17. Katimbo, A., Rudnick, D. R., DeJonge, K. C., Lo, T. H., Qiao, X., Franz, T. E., Nakabuye, H. N. and Duan, J. 2022. Crop Water Stress Index Computation Approaches and Their Sensitivity to Soil Water Dynamics. *Agric. Water Manag.,* **266:** 1-16.

[DOI: 10.22034/jast.25.6.1403]

18. Kiziloglu, F.M., Sahin, U., Kuslu, Y. and Tunc, T. 2009. Determining Water–Yield Relationship, Water Use Efficiency, Crop and Pan Coefficients for Silage Maize in A Semiarid Region. *Irrig. Sci.,* **27**: 129–137.
19. Moran, M. S., Clarke, T. R., Inoue, Y. and Vidal, A. 1994. Estimating Crop Water Deficit Using the Relation between Surface-Air Temperature and Spectral Vegetation Index. *Remote Sens. Environ.,* **49:** 246–263.
20. Mostafa, H. and Derbala, A. 2013. Performance of Maize Crop for Silage Production Using Three Different Irrigation Systems. Scientific Papers Series Management. *Econ. Eng. Agric. Rural Dev.,* **13(2):** 261-268.
21. Neale, C. M. U. 1987. Development of Reflectance-Based Crop Coefficients for Maize. Ph. D. Dissertation, Department of Agricultural and Chemical Engineering, Colorado State University, Ft. Collins, CO, 170 PP.
22. Okursoy, H. 2009. Trakya Koşullarında Farklı Sulama Yöntemleri Altında İkinci Ürün Silajlık Mısırın Su Üretim Fonksiyonlarının Belirlenmesi. *Doktora Tezi*, *Fen Bilimleri Enstitüsü, Namık Kemal Üniversitesi,* 160 PP.
23. Orta, A.H., Erdem, Y. and Erdem, T. 2003. Crop Water Stress Index for Watermelon. *Sci. Hortic.,* **98(2):** 121-130.
24. O'Shaughnessy, S. A., Evett, S. R., Colaizzi, P. D. and Howell, T. A. 2012. A Crop Water Stress Index and Time Threshold for Automatic A Crop Water Stress Index and Time Threshold for Automatic Irrigation Scheduling of Grain Sorghum. *Agric. Water Manag.,* **107:** 122-132.
25. Payero, J. O. and Irmak, S. 2008. Construction, Installation, and Performance of Two Repacked Weighing Lysimeters. *Irrigation Science*, **26**: 191-202.
26. Saghafi, A. A., Zand, B., Nasri, M. and Jaberiaghdam, M. 2013. Study of Water Use Efficiency on Yield and Yield Components on Cultivars of Corn, Sorghum and Millet in Varamin Region. *Tech. J. Eng. Appl. Sci.*, **3(23):** 3395-3398.
27. Tanriverdi, C. 2003. Available Water Effects on Water Stress Indices for Irrigated Maize Grown in Sandy Soils. Bioresource and Agricultural Engineering Program, Department of Civil Engineering, Colorado State University, Fort Collins, CO, 110 PP.
28. Tanriverdi, Ç., Atilgan, A., Degirmenci, H. and Akyuz, A. 2017. Comparison of Crop Water Stress Index (CWSI) and Water Deficit Index (WDI) by Using Remote Sensing (RS). Commission of Technical Rural Infrastructure, Nr III/1/2017, Polish Academy of Sciences, Cracow Branch, PP. 879-894.
29. Tezel, M. 2018. Türkiye'de Silajlık Mısır Üretimi Ve Hayvan Beslemede Yeri. *Türktob Dergisi,* Sayı: 25 Sayfa: 17-19.
30. Yildiz, M., Tansı, S. and Sezen, S. M. 2014. Tuz ve Kuraklık Stresine Dayanıklı Ekonomik Öneme Sahip Yeni Bitkiler: Quinoa, Sorghum, Crambe, Kapari. *2nd International Drought and Desertification Symposium,* 16-18 September, Konya.
31. Yilmaz, H. S. and Kokten, K. 2021. Determination of Cadmium Accumulation in Grains and Other Plant Organs of Sorghum Varieties. *Int. J. Phytoremediation,* **23(14):** 1457-1465.
32. Yolcu, R. 2014. The Effect of Different Irrigation Levels and Nitrogenous Fertilizer Applied in Different Periods on Yield and Yield Characteristics of Silage Corn Irrigated with Drip Irrigation in Diyarbakır Conditions. Cukurova University, Institute of Science and Technology, Doctoral Thesis. p:147.
33. Zhou, Z., Majeed, Y., Naranjo, G. D. and Gambacorta, E. M. 2021. Assessment for Crop Water Stress with Infrared Thermal Imagery in Precision Agriculture: A Review and Future Prospects for Deep Learning Applications. *Comput. Electron. Agric.,* **182:** 106019.
34. Zwart, S. J. and Bastiaanssen, W. G. M. 2004. Review of Measured Crop Water Productivity Values for Irrigated Wheat, Rice, Cotton and Maize. *Agric. Water Manag.,* **69(2):**115-133.

[DOI: 10.22034/jast.25.6.1403]

مقایسه روابط عملکرد-آب، شاخص کمبود آب، و شاخص تنش آبی گیاه در ذرت (*Zea mays* L.) و سورگوم (*Sorghum bicolor* L.) سیلویی

م. کیتن گوکوس، و ح. دیگیرمنسی

چکیده

در این پژوهش، روابط عملکرد-آب، شاخص تنش آبی گیاه (CWSI) که یکی از تعیین کننده‌های متداول تنش گیاهان است، و شاخص کمبود آب (WDI) که رویکردی جدید است، با اعمال کم‌آبیاری در منطقه Kahramanmaraş در ترکیه در دوره رشد ۲۰۱۸-۲۰۱۹ مورد مقایسه قرار گرفت. پنج سطح آبیاری برای گیاهان ذرت و سورگوم سیلویی اعمال شد. بر اساس نتایج، عملکرد ذرت سیلویی نسبت به سورگوم سیلویی هم در آبیاری کامل (۱۰۰ درصد) و هم در کم‌آبیاری (۸۰%، ۶۰%، ۴۰%، و ۲۰%) بیشتر بود. با این حال، زمانی که میانگین عملکرد هر دو سال بررسی شد، ذرت به ترتیب ۴۹% و ۴۶% کاهش نشان داد، در حالی که سورگوم نسبت به تیمار با آبیاری ۴۰% و ۲۰% کاهش ۳۳% را نشان داد. همچنین، تیمار ۲۰% در ذرت ۶۶% تا ۵۴% کاهش و در سورگوم ۴۵% تا ۴۶% کاهش داشت. این نتیجه نشان داد که در شرایط محدودیت آب، سورگوم پتانسیل عملکرد خود را ۶۰ درصد یا بیشتر بهتر از ذرت حفظ می کند. هنگامی که میانگین شاخص‌های CWSI و WDI به طور متقابل مورد بررسی قرار گرفت، مشاهده شد که میزان افزایش تنش و میزان کاهش بهره‌وری نتایج پایدارتری در WDI نسبت به CWSI داد. مشخص شده است که CWSI، یکی از تعیین کننده های تنش محصول، در تعیین تنش در مقایسه با WDI ناکافی است و WDI نتایج دقیق تری می دهد. بنا بر این، با کاستی هایی که روش CWSI تاکنون در تعیین تنش داشته است، نتایج کامل و دقیق در WDI به دست آمد. پیشنهاد می شود از WDI به عنوان یکی از تعیین کننده های تنش آبی محصول استفاده شود.

[DOI: 10.22034/jast.25.6.1403]