Water productivity, morphological and biochemical responses of *Sorghum bicolor* (L.) under various levels of drought stress

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Abstract

Sorghum is a potential fodder crop that has high yielding and superior quantity to feed of livestock. In arid and semi-arid areas, both quantity and quality are susceptible to drought. This study assesses the impact of drought stress on morphological characteristics, forage quantity and quality, and water productivity on two sorghum varieties. The experiment was carried out in a split-plot, based on the completely randomized design with three replications in Isfahan, Iran, in 2017, and 2018 crop years. The treatments consisted of irrigation treatments with three levels (control, 80, and 60% full irrigation) and two varieties of sorghum (Speedfeed and Pegah). The results showed that drought stress had no adverse effect on the vegetative traits and forage yield of sorghum, while it improved some traits related to animal nutrition. The results indicate that drought stress up to 60% full irrigation had no significant effect on the qualitative and quantitative yield of sorghum forage and water productivity. Besides, according to Stress Susceptibility Index and Stress Tolerance Index, Also increase wet and dry forage water productivity in 60% irrigation compared to 100%, the Pegah variety is more adapted to water stress conditions. The Speedfeed variety is appropriate as a result of animal nutrition, but depending on the reduction in Neutral detergent fiber and Lignin, the Pegah variety may be more appropriate for forage quality.

Abbreviations

ADF- cell wall—hemicellulose free
ADL- lignin
CP- crude protein
DDM- digestible dry matter
D.F.Y- dried fodder yield
DM- dry matter
DMI- dry matter intake
ME- metabolizable energy
N- nitrogen percentage
NDF- neutral detergent fiber
No. L- Leave number
P.H- plant height
P.W- panicle weight
S.D- stem diameter
SSI- stress susceptibility
STI- stress tolerance index
TDN- total digestible nutrients
W.P.W- water productivity of wet forage
W.P.D- water productivity of dried fodder
W.F.Y- wet forage yield

Introduction

Drought stress induces morphological, physiological and biochemical changes in plants. Abiotic plant stress has been adversely affected by stability in global food availability (Takahashi *et al.*, 2020; Qadir *et al.*, 2015). Drought stress is the most important abiotic stress which has reduced yield and crop growth in the arid and semiarid area (Sarshad *et al.*, 2021). Sorghum (*Sorghum bicolor* L.) is a crop of cereal family with multiple uses for food, forage crop, and energy. Sorghum is highly tolerant to drought, flooding, and salinity than other cereal crops (Sarshad *et al.*, 2021; Qadir *et al.*, 2015). As a result, this crop is the fifth most cultivated cereal by humans, after wheat, rice, maize, and barley (Assefa *et al.*, 2020). The forage quality and energy value of sorghum are similar to maize. However, their use is considerably different. Sorghum is used as silage, wet forage, dried fodder, and direct grazing. While, maize's silage is the most commonly used type of livestock feed (Vadakekara Joseph, 2016). Moreover, the good resprouting ability after harvest led to a more appropriate economic value than maize (Oliveira *et al.*, 2020).

The response of plants to abiotic stresses depends on their genetic backgrounds and environmental status (Sarshad *et al.*, 2021). Sorghum has high genetic variability and germplasm resources to adopt new varieties to various ecological regions (Bibi *et al.*, 2016). The primary purpose of plant breeders is to identify and understand the mechanism of stress tolerance in sorghum (Ranjendran *et al.*, 2011). As a result, sorghum is expected to be more added soon, crop improvement program to meet the demand for energy and food (Qadir *et al.*, 2015).

The consequences of droughts for vegetation are especially severe in regions, where water deficiency already limits plant productivity, such as in Iran that has an average rainfall of 240 mm. On the other hand, agriculture leads to decreasing of freshwater by 91% annually in Iran (Hidari Sharif Abad, 2019). Presently and future, agriculture faces water scarcity, hence the need for irrigation management from emphasizing water productivity increasing.

Sorghum has been introduced as a drought-tolerant crop because of various morphological and physiological characteristics (Achakzai, 2011). As it is adaptable to Iran's climatic conditions, it can be considered to provide high-quality forage under dry conditions. Therefore, the objective of this research was an evaluation of drought stress on quantity trait, water productivity, and quality forage of two varieties of sorghum with different genetic backgrounds.

Material and methods

Field experiment

A spit-plot experiment was carried out in a randomized block design with three replicates in Isfahan, Iran, during the 2017 and 2018 crop seasons. The treatments consisted of irrigation managements with three levels (100% irrigation, 80 and 60% full irrigation) and sorghum varieties Speedfeed (early mature) and Pegah (late mature). The varieties belonging to the Iranian forage sorghum cultivars, which were obtained from the Seed Breeding Research Center of Isfahan, Iran. To manage irrigation, soil bulk density and the soil moisture content in the field capacity (FC) and permanent wilting point (PWP) were determined by sampling the soil surface in the laboratory, 25%, 14%, and 1.35 kg.m3 respectively. These values were used to control the pure water requirement of two common cultivated sorghum varieties in Iran. Irrigation treatments are arranged in the main plot and varieties in the sub-plot.

After a tillage and disk lever in the field, seeds were sown on the ridge with a density of 250 thousand plants per hectare in early June (based on the common planting date of the region) for both years. In each plot, the length of every ridge was 12 m and the distance between the ridges was 60 cm. Consequently, the distance between the seedlings on the row was 60 cm. Before planting, ammonium phosphate and potassium sulfate fertilizers were applied at 250 and 150 kg.ha-1 respectively. Urea fertilizer was applied as a dressing when the plants were 40 cm in height with an irrigation system. Irrigation was done by drip-strip and the irrigation cycle was based on the constant cycle and water net requirement of the plant (evaporation pan class A). The water requirement was calculated based on the daily evapotranspiration values of the reference plant (ET0) and the plant coefficient (KC) from the combined model of Penman- Montes-FAO (Allen *et al.*, 2009). Irrigation water depth was calculated with 85% application efficiency, due to the requirement of three irrigation treatments (100, 80, and 60% full irrigation) in the irrigation system. The volume of water consumed was also measured with a calibrated meter. The amount of water consumption during the growing season, in 18 to 20 irrigation in three treatments of 100%, 80, and 60% full irrigation was 5038, 42250, and 3350 m3.ha-1 in 2017 and 4400, 5445, and 3225 in 2018 respectively. The total precipitation in the region was 14 mm and 25.2 mm for 2017 and 2018 respectively.

Measurement of traits

Morphological characteristics such as plant height, leaf number, panicle length, panicle weight, wet forage, and dried fodder yield were evaluated after harvest.

Samples of plants were harvested and after drying in the oven at 75°C for 24 h, grounded and passed through a 2-mm sieve then biochemical traits were determined. Biochemical traits including Ash and Crude Protein (CP) were calculated by AOAC (1995) method, Neutral Detergent Fiber (NDF) and Cell wall-hemicellulose free (ADF) were calculated by Van Soest (1991) method. Moreover, Dry Matter Digestibility (DMD) (Oddy *et al.*, 1983), Metabolizable Energy (ME) (SCA, 1990), Total Digestible Nutrients (TDN), and Dry Matter Intake (DMI) (Lithourgidis *et al.*, 2006) obtained using the following formulas:

$$\%DMD = 83.58 - 0.824\ \%ADF - 2.262\ \%N$$

$$ME\ (Mj.kg^{-1}) = 0.17\ \%DDM - 2$$

$$TDN = (-1.29 \times ADF) + 101.35$$

$$DMI = 120 \div \%\ NDF$$

Irrigation water productivity was determined by the fol-

Fig. 1 -

Table 1 - Variance analysis of some agronomical traits, forage yield, biochemical and water productivity in two varieties of sorghum under different irrigation levels

S.O.V	M.S																				
	df	W.F.Y	D.F.Y	P.H	No. L.	P.L	P.W	S.D	W.P.W	W.P.D	DM	CP	Ash	NDF	ADF	ADL	N	DDM	ME	TDN	DMI
R	2	493	43	151	0.22	0.56	17.8	7.5	26.4^{ns}	2.3^{ns}	0.71	0.05	2.6	3	9	0.05	0.005	24.8	0.7	59.3	0.01
Irri	2	1809.5**	131.5**	1112**	0.18^{ns}	19.6**	193**	21.5**	35.2**	4.9*	25**	4.6**	3.7 ^{ns}	43.2**	21**	8.5**	0.24**	18*	0.5*	70**	0. 1**
Error a	8	31.3	13.7	436.4	0.57	2.2	39.6	0.1	1.6	0.9	0.35	0.11	2.2	2	1	0.23	0.02	5.3	0.1	13.3	0.02
V	1	3006.6**	44.7^{ns}	76^{ns}	32**	7.6^{ns}	132.4**	499.5**	160.9**	3.9*	404.2**	4.8**	3.7^{ns}	498**	176.7**	24.2**	0. 1**	138**	4**	294**	0.6**
I×V	2	158.5^{ns}	61 ^{ns}	569*	1.4^{ns}	0.9 ns	142.8*	2.4^{ns}	4.1^{ns}	3.3^{ns}	6**	0.3^{ns}	3^{ns}	11.8*	3.3 ^{ns}	0.2 ^{ns}	0.01^{ns}	3.6^{ns}	0.1^{ns}	11^{ns}	0.02 ^{ns}
Error b	12	53.6	17	143.6	0.77	2	27.6	0.1	2.8	1	1	0.1	2.3	1.7	2	0.46	0.01	6.2	0.1	16.4	0.009
CV (%)	-	6	19	3.7	5.3	7.3	13	2	8	17.4	4	3.4	17.7	2.3	3.6	6.7	3.4	1.8	2.3	3	2.4

**,*, ns: respectively, significant at the level of 1, 5%, and no-significant, SOV: source of variance, df: degree of freedom, and CV: coefficient of variation (R: replication, Irri: irrigation, V: variety, W.F.Y: wet forage yield, D.F.Y: dried fodder yield, P.H: plant height, No. L: leave number, P.W: panicle weight, S.D: stem diameter, W.P.W: water productivity of wet forage, W.P.D: water productivity of dried fodder, DM: dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: cell wall—hemicellulose free, ADL: lignin, N: nitrogen percentage, DDM: digestible dry matter, ME: metabolizable energy, TDN: total digestible nutrients, DMI: dry matter intake)

Table 2 - Mean comparison of irrigation levels and variety of sorghum for morphological and biochemical trais, forage yield and water productivity

Factors	treatment	W.F.Y (kg.ha^{-1})	W.F.D (kg.ha^{-1})	P.L (cm)	No.L	P.L (cm)	P.W (gr)	S.T (cm)	W.P.W (m3.ha^{-1})	W.P.D (m3.ha^{-1})	DM (%)	CP (%)	Ash (%)	NDF (%)	ADF (%)	ADL (%)	N (%)	DDM (%)	ME (Mj.kg^{-1})	TDN (%)	DMI (%)
Irri	100%	103.8a	29.8a	192.2a	13a	21.2b	27.5ab	20a	19.8b	5.7b	27.4a	9a	9a	58.7a	36.5a	8.7c	1.4a	57b	7.6b	54.2b	2 b
	80%	89.3b	25b	186.8b	12.6a	22.7a	33.2a	17.3b	20.6b	5.7b	25.8b	8.3b	8.5a	57.7a	34.6b	9.6b	1.3b	58a	7.8a	56.6a	2b
	60%	79.4c	23.5b	173.5c	12.8a	20.2b	25.5b	12.2c	23a	6.8a	24.5c	7.8c	9.6a	55b	34b	10.3a	1.2c	58a	8a	57.5a	2a
V	Speedfeed	81.7b	25a	182.7a	11.8b	21.8a	30.6a	22.2a	19b	23.3a	29.2a	8.7a	9.4a	60.8a	32.8b	10.3a	1.2a	60a	8a	53.2b	2b
	Pegah	100a	27.2a	185.6a	13.7a	21a	26.8b	14.7b	5.7b	6.4a	22.5b	8b	8.7a	53.4b	37.2a	8.7b	1.4a	56b	7.4b	59a	2.2a

Mean with the same letter(s) is not significantly different using Duncan,s multiple range tests (p≤0.05)(R: replication, Irri: irrigation, V: variety, W.F.Y: wet forage yield, D.F.Y: dried fodder yield, P.H: plant height, No. L: leave number, P.W: panicle weight, S.D: stem diameter, W.P.W: water productivity of wet forage, W.P.D: water productivity of dried fodder, DM: dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: cell wall—hemicellulose free, ADL: lignin, N: nitrogen percentage, DDM: digestible dry matter, ME: metabolizable energy, TDN: total digestible nutrients, DMI: dry matter intake lowing formula:

$$IWP = \frac{D}{W}$$

Where IWP is the irrigation water productivity, D mass of dry matter or yield, and W amount of water consumed by the plant (m3).

To measure susceptibility and tolerance of sorghum varieties, stress susceptibility index (SSI) and stress tolerance index (STI) were measured according to Fischer &Maurer (1978) and Fernandez (1992) respectively, using the following formula:

$$SSI = \frac{1-\frac{Y_s}{Y_p}}{1-\frac{\bar{Y}_s}{\bar{Y}_p}}$$

$$STI = \left(\frac{Y_p}{\bar{Y}_p}\right)\left(\frac{Y_s}{\bar{Y}_s}\right)\left(\frac{\bar{Y}_s}{\bar{Y}_p}\right) = \frac{(Y_p)(Y_s)}{(\bar{Y}_p)^2}$$

Where Ys, Yp, Ȳp, and Ȳs are forage yield under stress conditions, under normal conditions, and the average yield of two varieties under normal and stress conditions respectively.

Statistical analysis

All parameters were analyzed using the analysis of variance (ANOVA). Two-way ANOVA was applied to specify the effect of two varieties of sorghum and different irrigation levels (three levels). Additionally, correlation analyses between parameters were carried out using a linear regression model. Some of the data sets were changed in terms of logarithm to meet the requirement of ANOVA in terms of normality and homogeneity of variance. Several comparisons have been performed on partial data sets by applying Duncan's test. To assess the effect all properties under different irrigation levels and varieties of sorghum principal component analysis (PCA) was employed. All statistical analyses were carried out in R software (4.3.19).

Results

Plant responses to drought

Results indicated that (Table 1) irrigation levels significantly affected wet forage and dried fodder yield, plant height, panicle length, panicle weight, stem diameter, and water productivity of wet, and dry forage. The analysis of variance showed that cultivars in terms of wet forage yield, number of leaves, panicle weight, stem diameter, and water productivity of wet and dry forage had significantly different. There was a significant interaction between the water regime and the variety for plant height and panicle weight.

Table 2 shows the mean morphological comparison characteristics, yield, and water productivity of forage related to irrigation levels and varieties of sorghum. The control condition (100% irrigation) had the highest wet forage and dried fodder yield and stem diameter. There was no difference between 100% irrigation and two levels of water stress (80 and 60% full irrigation) for plant height and number of leaves. The highest mean value for the length and weight of the panicles was observed for 80% full irrigation. The water stress of 60% full irrigation had the lowest mean values for wet forage yield and stem diameter. The lowest mean values for panicle length and panicle weight were recorded for 60% full irrigation; however, the difference between 100% and 60% full irrigation was not significant. Also, the highest wet and dry forage water productivity was related to 60% full irrigation treatment. However, 100% treatment was not significantly different from 80% full irrigation. The net irrigation requirements of sorghum in the area of the research were 501 mm. Volumes of water consumption during the growing season (late June - early October) in triple treatments, during 18 to 20 irrigations of sorghum in the first year, 5038, 4250, 3350 and in the second year 5445, 4400, 3525 m3.ha-1, respectively.

Among the two varieties, the Pegah variety showed the highest mean values for wet forage yield and number of leaves, while the lowest mean values for panicle weight and stem diameter. Speedfeed and Pegah varieties had no significant difference in dried fodder yield, plant height, and panicle length. In addition, the Pegah variety had the highest wet and dry forage water productivity.

Pegah variety showed the highest wet forage yield under three irrigations compared to the Speedfeed variety. For two varieties with decreasing water levels, wet forage yield also decreased. Because the reduction of the wet forage yield from 100% irrigation to 60% full irrigation was highly different, stress susceptibility index (SSI) and stress tolerance index (STI) were measured according to the wet forage yield of these two water stress treatments (Table 3). Although SST was reduced for two varieties with the decrease water level, the highest SST under both water stresses was recorded for the Pegah variety. Therefore, SSI for the Pegah variety whose irrigation was decreasing was below the Speedfeed.

Statistical analysis related to biochemical traits is presented in Table 3. The results showed that irrigation regimes and cultivars have significantly different biochemical traits, with the exception of ashes. Interaction

Table 3 - Stress susceptibility and tolerance indices of sorghum varieties

Variety	Yield			SSI		STI	
	100%	80%	60%	80%	60%	80%	60%
Pegah	117a	95.5a	87.3a	1.03	0.93	0.97	0.86
Speedfeed	90.6b	83b	71.4b	0.96	1.07	0.75	0.63

Mean with the same letter(s) is not significantly different using Duncan's multiple range tests (p≤0.05). SSI: stress susceptibility, STI: stress tolerance index

between the water management and the cultivars was significant for NDF.

Mean comparison of some sorghum quality characteristics (Table 2) showed that the highest crude protein content, nitrogen, and dry matter percentage were observed under full irrigation. The reduction of water level to 80 and 60% full irrigation has significantly reduced the amount of these traits. Irrigation regimes of 80 and 60%was recorded as the highest mean values for DMD, ME, and TDN. Whereas the lowest content of these traits was related to 100% treatment. The highest content of NDF was shared between 100% irrigation and 80% full irrigation. The highest ADF was obtained under full irrigation and with decreasing access to water (80 and 60% full irrigation), its value decreased. In contrast, water stress resulted in a significant increase in ADL and DMI content of the forage. Comparison of two varieties revealed that the means of dry matter, crude protein, lignin, NDF, and dry matter intake were the highest in Speedfeed Var. while, Pegah Var. had the highest content of ADF, nitrogen, ME, DMD, and TDN

Relationships among parameters

The relationships between traits were separately investigated for these three irrigation treatments. The correlation plots under full irrigation and severe stress (60% full irrigation) represent in figures 1 and 2 respectively. There were differences in the relationships between traits and in some traits the sign of the correlation was altered. Correlation of plant height with TDN, ME, DMD, number of leaves, and panicle weight was negative under full irrigation and water stress treatments, which correlation values with ME, DMD, TDN, and number of leaves changed under water stress treatments. Besides, plant height had a negative correlation with the dry matter, NDF, and lignin content under control irrigation and 60% full irrigation which the correlation values of dry matter and lignin changed under 60% full irrigation. Dry matter was negatively correlated with ADF, DMI, number of leaves, wet forage yield, water productivity of wet forage yield, and stem diameter under all three irrigation levels. Except for the correlation of DMI in stress treatment of 60% full irrigation that there was no change in the other trait correlation values in the three irrigation managements.

In three irrigation treatments, the correlation between panicle length and ADF, DMI, number of leaves and wet forage yield was negative. The correlation between panicle length, and ADF and DMI has been altered under water stress of 80% full irrigation. While underwater stress of 60% full irrigation was similar to control treatment. Its correlation value with the number of leaves under 80% full irrigation had not only different but also it's a sign changed. Moreover, the correlation between panicle length and wet forage yield was different underwater stress treatments and the sign of the correlation was changed. Under three irrigation, the correlation value panicle weight with yield and water productivity of wet forage, stem diameter, DMI, and ADF was negative. Correlations of panicle weight with yield and water productivity of wet forage were different under water stress and no water stress. Also, its correlations with stem diameter, number of leaves, and dry fodder yield under 80% full irrigation were similar to full irrigation, but under 60% irrigation was different. Also, the correlation values of panicle weight with DMI and ADF showed differently and their sign was changed. Correlation of the number of leaves and stem diameter with crude protein, lignin, NDF, nitrogen percentage, DMD, ME, and TDN were negative under three irrigation levels. Under 80% full irrigation, the correlation of the number of leaves with NDF was different and its sign was also changed. While, its correlation signs changed with nitrogen percentage, DMD, ME, and TDN in response to 60% full irrigation.

Under all three irrigation treatments, the correlation of yield and water productivity of wet forage with crude protein, NDF, lignin content, nitrogen percentage, ME, DMD, and TDN were negative. The correlation values of wet forage yield and its water productivity with NDF, lignin content, nitrogen percentage, ME, DMD, and TDN were different under 80% full irrigation compared to control treatment. While under 60% full irrigation was similar to 100%. Also, lignin content, nitrogen percentage, ME, DMD, and TDN showed negative correlations with dry fodder yield and its water productivity under two water stress treatments. Except for ash, which had a different correlation trend with yield and water productivity of dry fodder, other traits were not different under 80 and 60% full irrigation.

So that more accurately evaluate the relationships between traits under control irrigation and stress treatments, principal components analysis was conducted (Figure 3). As shown in the figure, the first and second components accounted for about 48.9% and 23% respectively. Approximately, all associations between traits were affected by years of experiments, irrigation regimes, and varieties. Furthermore, these results were somewhat consistent with the results of correlation which different irrigation levels followed changes in the relationships between traits of sorghum varieties.

Discussion

Among the morphological traits and forage yield of sorghum varieties, plant height, stem diameter, and wet forage yield, are more sensitive to reduction of irrigation level, because the main damage of water stress in plants is growth reduction, which is caused by reduced cell inflammation. Ultimately, reduced growth leads to a decrease in the photosynthetic level and biomass production of the plant (He &Dijkstra, 2014). Thus, water stress of 60% full irrigation caused the highest decrease in wet forage yield of sorghum plants due to the reduction of vegetative traits. This relationship is confirmed by the positive correlation between wet forage yield and plant height and stem diameter in the three irrigation levels. (Figure 3). Since sorghum is relatively resistant to environmental stresses (A.Jabereldar *et al.*, 2017), dry fodder yield, length, and weight of panicle no statistical differences between water stress treatments and control irrigation were detectable. Also, water productivity in sorghum increasing with decreasing water supply. This is consistent with the results of previous studies on the resistance of sorghum cultivars to water stress (Khatab *et al.*, 2017; Jabereldar *et al.*, 2017). These findings showed that reduction of irrigation level to 60% full irrigation in sorghum might have no significant negative impact on morphological traits, yield component, and fodder yield. Therefore, farmers could be able to manage water sources, without reducing yield, increase water productivity.

The result of the correlation plot and principal com-

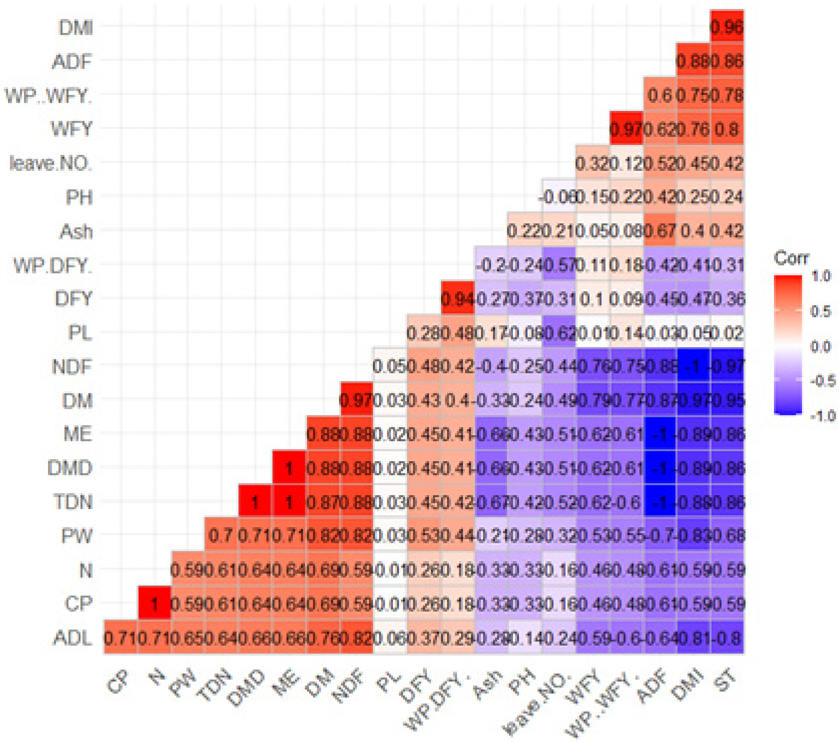

Fig. 1 - Correlation plot of traits of sorghum under full irrigation

(DM: dry matter, CP: crude protein, NDF: Neutral Detergent Fiber, ADF: Cell wall—hemicellulose Free, ADL: lignin, N: nitrogen percentage, DMD: Dry Matter Digestibility, ME: Metabolizable Energy, TDN: Total Digestible Nutrients, DMI: Dry Matter Intake, PW: Panicle Weight, PL: Panicle Length, DFY: Dry Fodder Yield, WP.DFY: Water productivity of Dry Fodder Yield, PH: Plant Height, Leave No.: Leave Number, WFY: Wet Forage Yield, WP.WFY: Water productivity of Wet Forage Yield, ST: Stem Diameter) ponent analysis verified that water stress led to a reduction in morphological traits and dry fodder yield of sorghum and change the relationship between these traits. Moreover, the change in the relationship between chemical traits and fodder yield under reduction irrigation level is due to plant response mechanisms. For instance, shifting protein production for osmotic regulation can be one of these mechanisms (Allahdadi and Bahreininejad, 2019).

Klock *et al.* (2012) showed that the yield of sorghum was affected by the amount of irrigation. Also, the results of this study showed that a slight decline in water level has no significant effect on most growth and reproductive traits. However, Perrier *et al.* (2017) demonstrated that water stress has resulted in reduced fodder yield and growth parameters in sorghum. According to our findings, Khalil *et al.* (2015) depicted that drought stress led to a decrease in nutrients in forage such as nitrogen. In addition, Nouri *et al.* (2020) showed that decreasing in soil moisture level in field led to reduction vegetative traits. While, plant inoculated with Arbuscular Mycorrhizal fungal species increased drought tolerance of plant.

The Speedfeed variety had the highest mean values for the weight of the panicles and the diameter of the stems. However, both varieties did not differ significantly for dry forage, plant height, and panicle length. The interaction effect of water stress and varieties also showed that the best variety according to wet forage and dry fodder yields under stress treatments was Pegah var. on the other hand, the highest difference of wet forage and dry fodder yields among varieties was related to 60% full irrigation, which the highest forage yield was observed for Pegah var. Accordingly, SSI and STI indices were evaluated to the forage yield of varieties under drought stress. As a result, the highest STI and lowest SSI were recorded for Pegah var. Based on morphological and traits and forage yield, Pegah var. could be suggested as a more suitable variety under water stress. The response of different hybrids of sorghum was evaluated under drought stress by Assefa *et al.* (2010). Their results showed that there are genotype variation to drought tolerance among sorghum varieties.

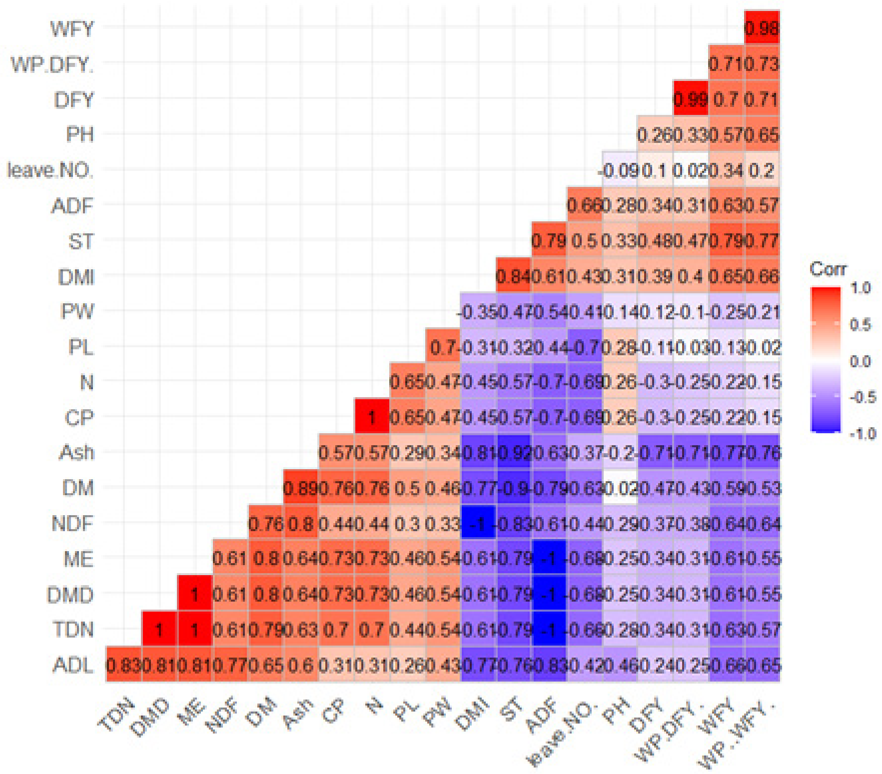

Fig. 2 - Correlation plot of traits of sorghum under 60% full irrigation

(DM: dry matter, CP: crude protein, NDF: Neutral Detergent Fiber, ADF: Cell wall—hemicellulose Free, ADL: lignin, N: nitrogen percentage, DMD: Dry Matter Digestibility, ME: Metabolizable Energy, TDN: Total Digestible Nutrients, DMI: Dry Matter Intake, PW: Panicle Weight, PL: Panicle Length, DFY: Dry Fodder Yield, WP.DFY: Water productivity of Dry Fodder Yield, PH: Plant Height, Leave No.: Leave Number, WFY: Wet Forage Yield, WP.WFY: Water productivity of Wet Forage Yield, ST: Stem Diameter)

The highest mean values of some biochemical traits of sorghum including ADL, DDM, ME, TDN, and DMI was observed in stress treatments. According to the lowest mean values of these traits under control irrigation, therefore water level reduced led to increased production of these traits in the plant. Environmental stresses such as drought stress, increase the cell wall lignification which is due to reduction in nutrient availability, translocation in plant and plant growth (Lisar *et al.*, 2012). On the other hand, since feed-related traits are associated with the Cell wall—hemicellulose Free (Newman *et al.*, 2006), decrease ADF led to an increase in the percentage of nutrients. Reported that high lignin content has a role in reducing water potential, prevents oxidative destruction, and helps in keeping the structure of proteins and membrane under drought stress (Sarshad *et al.*, 2021). Conversely, the maximum percentage of dry matter, crude protein, and nitrogen were in the control treatment. As a low amount of fiber of forage led to increasing its quality (Abdi & Habibi, 2017), high forage quality was obtained under water stress treatments. Hence, mild water stress, in addition to saving water resources, could be able to increase the quality of the sorghum.

However, crude protein traits, which are an important factor for forage quality (Allahdadi and Bahreininejad, 2019), decreased under stress conditions. Due to the importance of quality and quantity of forage, sorghum varieties of this study were able to keep both characteristics for mild stress levels. Therefore, reducing the water level to 60% full irrigation could not decrease the quality and quantity yield of sorghum, which is due to resistance to environmental stresses. These results showed that water consumption management in this plant is possible under limited water conditions. It has been reported that the high antioxidant capability of sorghum under stress conditions leads to its suitability as a forage crop (Zhang & Kirkham, 1996). In plants, water deficit leads to increased production of reactive oxygen species (ROS), which rapidly injury living tissues and macromolecules (Khaleghi *et al.*, 2019). Antioxidants eliminate this type of oxygen, which is a stress tolerance mechanism in plants. According to our results, showed that drought stress reduced protein production compared to control irrigation (Allahdadi and Bahreininejad, 2019).

Comparing two varieties showed that there was no difference in ash and nitrogen percentage. The highest percentage of dry matter, crude protein, ADF, ADL, DDM, and ME was observed in Speedfeed var. Speedfeed var. be proper variety according to animal nutrition-related traits but because of reduction NDF and ADL, Pegah var. might be more proper. Based on these results, reported that depending on plant variety, the quality of forage was different (Allahdadi and Bahreininejad, 2019). In another research, the interaction between water stress and variety led to a different response in varieties of sorghum (Masojídek *et al.*, 1991). Therefore, due to the high genetic diversity and germplasm resources of sorghum, this plant has the ability to achieving high tolerant genotypes (Qadir & Bibi, 2019).

Conclusions

Overall, results showed that except for wet forage yield, drought stress had no adverse effect on other morphological traits. Furthermore, the effect of the reduction in the level of irrigation was positive on panicle length and weight and feed animal-related traits. Therefore, these factors in addition to saving water consumption, increase the quality of forage. Hence, according to the present results, reducing water to 60% full irrigation could be suitable for sorghum production. Furthermore, results of susceptibility (SSI) and tolerance (STI) indices introduced that Pegah as the more suitable variety for stress conditions. Additionally, Speedfeed variety is suitable due to animal nutrition, but according to the reduction of NDF and ADL, Pegah variety might be more suitable related to forage quality.

Author contribution

All authors contributed to the design of the study and proposal writing. Material preparation, data collection and analysis were performed by RD. The data was analyzed by RD and HH. The manuscript was written by RD, HH and MT. RA, HS and MH read and approved the final manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

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