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Original article

Evaluation of forage yield and quality, and water use efficiency of forage sorghum (*Sorghum bicolor* L. Moench) in response to different levels of drought stress and nitrogen

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Extended abstract

Introduction

Lack of irrigation water resources has been identified as the most important problem in forage production. Therefore, to increase the productivity of crop production using limited water resources, it is necessary to pay attention to the cultivation of drought-tolerant crops. Sorghum has a high resistance to abiotic stresses and can perform well in comparison with other summer crops. Irrigation and fertilization are not only costly but also are of the most important factors affecting the quantity and quality of forage crops. Therefore, the present study was conducted to evaluate the effects of different levels of drought stress and nitrogen fertilizer on the sorghum forage yield and quality, and water use efficiency.

Materials and methods

This study was conducted as split-plots based on a randomized complete block design with three replications in Karaj, Iran, during the 2018 growing season. Drought stress at three levels (no-stress, moderate and severe stress; including the supply of 100, 75, and 50% soil moisture deficit, respectively) as the main factor and nitrogen fertilizer application from urea source at four levels (0, 150, 300, and 450 kg ha^{-1}) as the sub-factor were evaluated. In all experimental treatments, nitrogen fertilizer was applied in two equal parts, at planting and 5-6 leaf stage. In the present study, drip tape irrigation approach was applied (with a diameter of 16 mm and drip distance of 10 cm). Irrigation cycle was considered constant for all plots and different levels of irrigation water were applied. In order to properly establish the sorghum crops, deficit irrigation regimes were started after 2-4 leaf stage. Sorghum forage was harvested at the milky-dough stage. Data were subjected to two-way analysis of variance (ANOVA) and the difference between treatment means was separated using LSD test. A significance level of 95% was applied by GLM procedure of SAS 9.1 .

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Results and discussion

The results of ANOVA showed that the main effect of drought stress and nitrogen fertilizer on the forage yield, irrigation water use efficiency (IWUE), plant height, and quality characteristics of sorghum forage (except hemicellulose) was significant ($p \leq 0.01$). Also, the interaction effect of drought stress × nitrogen fertilizer on the forage yield, IWUE, plant height, and crude protein content at the probability level of 1%, and on other quality characteristics of sorghum forage (except hemicellulose) at the probability level of 5% was significant. The highest dry-matter and protein yield (40.03 and 3.48 t ha-1, respectively) and the maximum plant height (224 cm) were obtained with full irrigation and application of 450 kg nitrogen ha-1, whereas the maximum IWUE for dry matter and protein production (6.793 and 0.672 kg m-3, respectively) was obtained under moderate stress and with the application of 450 kg nitrogen ha-1. By increasing the nitrogen fertilizer application from 0 to 450 kg ha-1 under full irrigation, moderate stress, and severe stress conditions, the dry matter yield increased by 167, 181 and 101%, respectively, protein yield increased by 238, 284 and 174%, respectively, forage protein content increased by 27, 36 and 39%, respectively, and relative feed value increased by 8, 6 and -2%, respectively. Overall, in order to achieve the maximum quantity and quality of forage and the highest water use efficiency in full irrigation and moderate drought stress conditions, application of 450 kg nitrogen ha-1, and in severe stress conditions, application of 300 kg nitrogen ha-1 can be recommended.

Conclusion

Generally, the results illustrated that the treatment of moderate drought stress (supply of 75% soil moisture deficit) with the application of 450 kg nitrogen ha-1, along with saving water and producing high forage yield, among the studied treatments resulted in the highest water use efficiency, DMD, NEL, and RFV, and the minimum ADF and NDF, can be recommended as the superior treatment for sorghum forage. In case of severe limitation of irrigation water resources, supply of 50% soil moisture deficit (severe drought stress) along with application of 300 kg nitrogen ha-1 can be recommended.

***Keywords*:** Energy, Deficit irrigation, Digestibility, Protein, Water productivity

Table 1. Some meteorological data of the experimental site

Month	T_{mean}[a]	T_{min}	T_{max}	Evap.	Prec.
	---------- °C ----------			---------- mm ----------	
June	33.8	17.4	25.6	334.3	7.23
July	37.9	23.3	31.9	471.8	0.0
August	36.2	20.1	28.4	425.6	0.0
September	31.6	16.8	24.0	266.1	0.81

[a] T_{mean}, mean temperature; T_{min}, minimum temperature; T_{max}, maximum temperature; Evap., evaporation; Prec., precipitation.

Table 2. Physical and chemical properties of the experimental field soil

Clay	Silt	Sand	Texture	pH	OM[a]	N	P	K	EC
----------%----------					----------%--------		---------mg kg^{-1}----------		dS m^{-1}
24	39	37	Loam	7.3	0.44	0.04	6.3	255	1.39

[a] OM, organic matter; EC, electrical conductivity

Table 3. ANOVA results of forage yield, water use efficiency, and plant height of sorghum as affected by drought stress and nitrogen fertilizer

S.O.V	d.f	Forage yield		Water use efficiency		Plant height
		Dry matter	Protein	Dry matter	Protein	
Replication	2	1.10^{ns}	0.01^{ns}	0.04^{ns}	0.0005^{ns}	23^{ns}
Drought (D)	2	448.14^{**}	1.97^{**}	1.86^{**}	0.0388^{**}	6138^{**}
Error a	4	0.49	0.01	0.02	0.0001	37
Nitrogen (N)	3	676.85^{**}	7.34^{**}	25.96^{**}	0.2891^{**}	2215^{**}
D × N	6	45.11^{**}	0.34^{**}	1.15^{**}	0.0096^{**}	385^{**}
Error b	2	1.72	0.01	0.06	0.0005	25
C.V. (%)	-	5.23	5.59	4.96	5.47	2.73

* and ** significant at P≤0.05 and P≤0.01, respectively. ns: not significant.

Table 4. The interaction effects of drought stress × nitrogen fertilizer on the forage yield, water use efficiency, and plant height of sorghum

Treatment		Forage yield		Water use efficiency		Plant height
Drought stress	Nitrogen rate	Dry matter	Protein	Dry matter	Protein	
	kg. ha^{-1}	----------ton ha^{-1}----------		----------kg m^{-3}----------		cm
No stress	**0**	14.97^{c}	1.03^{d}	2.232^{c}	0.153^{d}	175^{c}
	150	30.51^{b}	2.24^{c}	4.550^{b}	0.333^{c}	190^{b}
	300	37.93^{a}	3.06^{b}	5.656^{a}	0.455^{b}	222^{a}
	450	40.03^{a}	3.48^{a}	5.968^{a}	0.519^{a}	224^{a}
$LSD_{0.05}$		3.50	0.29	0.522	0.044	11
Moderate stress	**0**	12.32^{c}	0.89^{d}	2.422^{c}	0.176^{d}	166^{c}
	150	27.10^{b}	2.07^{c}	5.326^{b}	0.406^{c}	183^{b}
	300	28.64^{b}	2.44^{b}	5.630^{b}	0.479^{b}	204^{a}
	450	34.56^{a}	3.42^{a}	6.793^{a}	0.672^{a}	208^{a}
$LSD_{0.05}$		2.25	0.22	0.442	0.042	10
Severe stress	**0**	9.78^{c}	0.72^{c}	2.822^{c}	0.207^{c}	153^{a}
	150	23.10^{a}	1.76^{b}	6.659^{a}	0.508^{b}	160^{a}
	300	22.23^{a}	2.16^{a}	6.408^{a}	0.622^{a}	160^{a}
	450	19.62^{b}	2.00^{a}	5.656^{b}	0.575^{a}	161^{a}
$LSD_{0.05}$		1.80	0.18	0.520	0.053	9
$LSD_{0.05}$ (Drought×Nitrogen)		2.25	0.20	0.426	0.040	9

Means with similar letters in each column, show non-significant difference according to LSD tests at 5% level

Table 5. ANOVA results of qualitative characteristics of sorghum forage as affected by drought stress and nitrogen fertilizer

S.O.V	d.f.	Mean square						
		CP[a]	ADF	NDF	HEM	DMD	NEL	RFV
Replication	2	0.03^{ns}	0.88^{ns}	4.17^{*}	1.48^{ns}	0.53^{ns}	602^{ns}	15.45^{*}
Drought (D)	2	2.88^{**}	8.60^{**}	8.75^{**}	0.16^{ns}	5.21^{**}	5916^{**}	57.87^{**}
Error a	4	0.05	0.04	0.54	0.68	0.03	29	1.07
Nitrogen (N)	3	11.37^{**}	1.49^{**}	5.34^{**}	1.40^{ns}	0.91^{**}	1022^{**}	21.20^{**}
D × N	6	0.48^{**}	1.02^{*}	3.18^{*}	0.66^{ns}	0.62^{*}	696^{*}	13.52^{*}
Error b	2	0.02	0.28	0.98	0.57	0.17	191	3.60
CV %	-	4.51	4.49	4.58	6.75	4.76	4.01	5.08

[a] CP: crude protein content; ADF: acid detergent fiber; NDF: neutral detergent fiber; HEM: hemicellulose; DMD: dry matter digestibility; NEL: net energy for lactation; RFV: relative feed value; * and ** significant at P≤0.05 and P≤0.01, respectively. ns: not significant.

Table 6. The interaction effects of drought stress × nitrogen fertilizer on the qualitative characteristics of sorghum forage

Drought stress	Nitrogen rate	CP[a]	ADF	NDF	HEM	DMD	NE_L	RFV
	$Kg.ha^{-1}$	----------%----------					$Mcal.\ kg^{-1}$	
No stress	**0**	6.85^{d}	37.12^{a}	65.49^{a}	28.37^{a}	59.98^{b}	1.328^{b}	85.2^{c}
	150	7.33^{c}	36.14^{b}	64.29^{ab}	28.15^{a}	60.75^{a}	1.354^{b}	87.9^{bc}
	300	8.05^{b}	35.70^{b}	63.06^{bc}	27.35^{a}	61.09^{a}	1.365^{b}	90.1^{ab}
	450	8.69^{a}	35.23^{b}	61.89^{c}	26.65^{a}	61.45^{a}	1.377^{a}	92.4^{a}
$LSD_{0.05}$		0.22	0.95	1.92	1.74	0.73	0.025	3.4
Moderate stress	**0**	7.25^{d}	36.06^{a}	63.87^{a}	27.81^{a}	60.81^{d}	1.356^{d}	88.5^{c}
	150	7.62^{c}	35.63^{b}	63.29^{ab}	27.66^{a}	61.14^{c}	1.367^{c}	89.9^{bc}
	300	8.50^{b}	35.21^{c}	62.74^{b}	27.53^{a}	61.47^{b}	1.378^{b}	91.1^{b}
	450	9.89^{a}	34.63^{d}	61.31^{c}	26.67^{a}	61.92^{a}	1.393^{a}	93.9^{a}
$LSD_{0.05}$		0.28	0.28	1.10	1.17	0.22	0.008	1.5
Severe stress	**0**	7.33^{d}	34.35^{a}	61.98^{a}	27.63^{a}	62.15^{a}	1.401^{a}	93.3^{a}
	150	7.62^{c}	34.02^{a}	61.37^{a}	27.35^{a}	62.40^{a}	1.409^{a}	94.6^{a}
	300	9.70^{b}	34.18^{a}	61.90^{a}	27.72^{a}	62.27^{a}	1.405^{a}	93.6^{a}
	450	10.17^{a}	34.93^{a}	62.65^{a}	27.72^{a}	61.69^{a}	1.385^{a}	91.6^{a}
$LSD_{0.05}$		0.24	1.54	2.62	1.86	1.20	0.040	5.4
$LSD_{0.05}$ (Drought×Nitrogen)		0.21	0.91	1.70	1.75	0.71	0.024	3.3

[a] CP: crude protein content; ADF: acid detergent fiber; NDF: neutral detergent fiber; HEM: hemicellulose; DMD: dry matter digestibility; NE_L: net energy for lactation; RFV: relative feed value.

Means with similar letters in each column, show non-significant difference according to LSD tests at 5% level