Research Article

Impact of drought stress on biochemical responses, energy, and water productivity on maize forage (Zea mays L.)

Rouhollah Daneshvar Rad[1] · Hosein Heidari Sharifabad[1] · Masoud Torabi[2] · Reza Azizinejad[3] · Hamidreza Salemi[4] · Mohsen Heidari Soltanabadi[4]

Received: 1 July 2021 / Accepted: 20 September 2021
Published online: 09 October 2021

Abstract
Drought stress is the most important limiting factor in crop plants including maize (*Zea mays* L.), which is the third important world crop after wheat and rice. To examine the quantity and quality of forage as well as energy and water productivity of two maize varieties to drought stress, a field experiment was carried out as a split plot based on a completely randomized block design with three replications in Isfahan, Iran, during 2017 and 2018 growing seasons. The main and sub-plots were three irrigation regimes (100%, 80, and 60% full irrigation) and two maize varieties (704 and Maxima), respectively. Data analysis showed that drought stress harmed wet and dry forage yield and energy productivity, while its effect was positive on some forage quality such as ash, neutral detergent fiber (NDF), hemicellulose free cell wall (ADF), and lignin (ADL). Based on results, drought stress of 60% full irrigation resulted in reduced wet and dry forage maize yields. In addition, drought stress affected relationships among measured traits. According to increasing dried fodder and decreasing output energy under stress conditions, early mature variety Maxima is more proper to be used under drought stress. Besides, the Maxima variety was shown to be a suitable variety due to increasing dry matter and crude protein as well as decrease ADF and ADL than the 704 variety.
Article Highlights We submit an original research article entitled Effect of water stress on forage yield and quality and water and energy productivity in Maize (*Zea mays* L.). In this paper, we indicated regarding to impacts of climate change phenomenon throughout the world on crop production, especially in arid regions such as Iran, choosing proper variety can be one of the best candidates to provide for forage. The results of present paper have shown that the drought stress had no effect on water productivity of two maize varieties. The superiority of some forage quality traits in drought stress compared to the control in maize means that in drought conditions, maize forage can be used and increase the profitability of livestock products.

Keywords Crude protein · Input energy · Energy ratio · Forage yield · Correlation

Abbreviations
ADF Cell wall hemicellulose free
ADL Lignin
DM Dry matter
CP Crude protein
NDF Neutral detergent fiber

✉ Hosein Heidari Sharifabad, heidari_sharif_abad@yahoo.com | [1]Department of Horticultural Science, Faculty of Agricultural Sciences and Food Industries, Science and Research Branch, Islamic Azad University, Post box: 14515-775, Tehran, Iran. [2]Department of Crop science – Horticulture, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Post box: 817585-199, Isfahan, Iran. [3]Department of Horticultural Science, Faculty of Agricultural Sciences and Food Industries Science and Research Branch, Islamic Azad University, Post box: 817585-199, Tehran, Iran. [4]Agricultural Engineering Research Department, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran.

1 Introduction

Environmental stresses have been a destructive effect on various crops around the world. Drought is the greatest environmental stress in arid and semiarid regions which has restricted agricultural development [1, 2]. Among the grain, maize (*Zea mays* L.) is known due to multiple purposes as human food, animal feed, pharmaceutical, and bio-energy [3]. Maize is the source of income for majority of people in the world which is as human diet in developed countries and also used for industrial uses [4]. Maize is a major grain crops in Iran that it is grown almost all over the country [5]. According to the FAO, in Iran, the total area of maize production is 204305 hectares with a total production of 1.4 million tones, in 2019 [6].

Iran is a country with an arid climate where low annual precipitation falls from October through April. Moreover, in most of the country, the average annual precipitation is 250 mm or less [5]. On the other hand, drought stress has been reported to have had a negative effect on agricultural production, including maize [7, 8]. As a result, the yield decreases recorded close to 79–81% in maize due to drought stress [9]. Drought has disrupted the main components of photosynthesis and reduced biomass and crop yield [10]. It is also responsible for plant death by increasing the production of reactive oxygen species (ROS) [11]. However, alterations due to drought are highly complex and depend on stress intensity and the species studied [12]. Therefore, how plants respond to stress depends on their genetic heritage and environmental status [1].

Energy has played a key role in agriculture since its inception. Therefore, worldwide agricultural production has a positive relationship with energy input [13]. Agriculture is both a producer and consumer of energy. But, general energy consumption has always increased in agriculture in the world, including Iran, due to increasing population, limited supply of arable land, and improved standards of living. Energy productivity has been affected by the lack of efficient use of energy inputs. The efficient use of energy has increased output, productivity, and sustainable competition in rural areas [14]. Maize plays a major role in the agricultural economy when it comes to grain and feed production. At the same time, its production requires high energy inputs. Hence, research on the productivity of biomass production is required in terms of share in human energy production [15].

The quality of forage resources directly affects livestock production [16]. Therefore, a thorough understanding of productivity of important inputs such as water and energy is required for optimal management of forage systems regionally [17]. Thus, this study was conducted to evaluate important parameters about water and energy production and biochemical characteristics of maize forage under different irrigation managements.

2 Materials and methods

2.1 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. Some climatic parameters during this research are given in Table 1. The treatments consisted of irrigation managements with three levels (100% irrigation, 80 and 60% full irrigation) and maize variety 704 (late mature variety) and Maxima (early mature variety). The varieties were obtained from the Seed Breeding Research Center of Isfahan, Iran. Some climatic parameters during this research are given in Table 1. Soil moisture was determined by sampling of the soil surface daily in the laboratory basis on soil bulk density: 25%, the soil moisture content in the field capacity:14%, and permanent wilting point:1.35 kg.m^{-3}. These values were used to control the water requirement of two common cultivated maize 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 90 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 75 cm. Before planting, based on soil analysis (Table 2) ammonium phosphate and potassium sulfate fertilizers

Table 1 Monthly temperature and precipitation during the growing season in 2017–2018

	Temperature (°C)		Total precipitation (mm)
	Minimum	Maximum	
2017			
May	8	35	13.7
June	15	40.2	0
July	18	41.5	0.1
Aug	15	37	0.2
Sum	56	153.7	14
Average	14	38.5	3.5
2018			
May	10.4	38.6	16.8
June	19.2	41.6	8.4
July	21.3	42.5	0
Aug	20.9	41.5	0
Sum	71.8	164.2	25.2
Average	17.9	41	6.3

Table 2 Physical and chemical properties of the soil

Total nitrogen (%)	Absorbable phosphorus (ppm)	Absorbable potassium (ppm)	pH	Organic carbon (%)	Electrical conductivity (dSm-1)	Copper	Zinc	Manganese	Iron	Sand	Silt	Clay
					(ppm)			(%)				
0.1	40.5	700	7.2	0.9	1.2	0.3	1.04	1.1	0.6	70	12	18

ppm part per million, *dsm*$^{-1}$ deci siemens/meter

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. 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 18–20 irrigation in three treatments of 100%, 80, and 60% full irrigation, was 6449, 5676, and 4550 m3.ha^{-1} in 2017 and 7100, 5720, and 4710 m3.ha^{-1} in 2018, respectively. The total precipitation in the region was 14 mm and 25.2 mm for 2017 and 2018, respectively.

2.2 Measurement of traits

The total of energy required to produce maize forage was divided into the six main groups measured as input energy for instance: energy equivalent to machine, fuel consumption [18, 19], irrigation [20, 21], manpower [22, 23], seed [23, 24], pesticides and fertilizer [25]. We used these input energies to produce the system output energy, i.e., forage performance. Finally, energy intensity, energy productivity, net energy [21, 26], and energy ratio [27] were calculated with standard equations.

$$\text{Energy intensity} = \frac{\text{Total consumption energy }\left(\text{Mjha}^{-1}\right)}{\text{Maize yield }\left(\text{kg.ha}^{-1}\right)}$$

$$\text{Net energy} = \text{Output energy}\left(\text{Mjha}^{-1}\right) - \text{Input energy}\left(\text{Mjha}^{-1}\right)$$

$$\text{Energy ratio} = \frac{\text{Input energy }\left(\text{Mjha}^{-1}\right)}{\text{Total input energy}\left(\text{Mjha}^{-1}\right)}.$$

$$\text{Energy productivity} = \frac{\text{Maize yield }\left(\text{Kgha}^{-1}\right)}{\text{Input energy}\left(\text{Mjha}^{-1}\right)}.$$

Irrigation water productivity was determined by the following formula:

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

where IWP is the irrigation water productivity, D: mass of dry matter or yield, and W: the amount of water consumed by the plant (m^3).

To evaluate the biochemical properties of forage, 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 and applied for forage quality traits including ash and crude protein (CP) [28], neutral detergent fiber (NDF) and cell wall hemicellulose free (ADF) [29].

2.3 Statistical analysis

Data were subjected to analysis of variance; mean comparison, correlation coefficient, and principal component analysis (PCA) were conducted by Agricola library in R statistical software (4.3.19).

3 Results

The analysis of variance of related-yield traits (Table 3) indicated that irrigation levels significantly affected wet forage yield, dried fodder yield, input energy, output energy, energy ratio, energy intensity, net energy, and energy productivity of wet forage and dried fodder. There was no significant difference in water productivity of wet forage and dried fodder yields, while the results (Table 4) showed significant differences between varieties in all traits except input energy. The interaction between the stress and the variety was statistically significant for wet forage and dried fodder yields (Table 3). According to the results of the analysis of variance, experimental years affect significantly on all wet and dry forage yield traits and energy indices ($p < 0.01$), while the effect of year on all biochemical and

Table 3 Variance analysis of some yield and energy traits in maize varieties under irrigation levels

S.O.V	df	WFY	DFY	E.In	E.Out	E.ratio	E.I	E.N.G	E.P.W	E.P.D	W.P.W	W.P.D
Year	1	472.2**	63.8**	57,622,758,771**	147,096.5**	32.8**	0.01**	94,629,464,542**	0.1**	0.006**	20**	2.5**
Replication	2	129.7 ns	22.7 ns	11 ns	40,426.5 ns	4.53 ns	0. ns	40427390919 ns	0.01 ns	0.001 ns	4 ns	0.53 ns
Irrigation	2	2245**	279.7**	848,139,87**	699,407.2**	36.4**	0.86**	651,708,753,232**	0.11	0.01*	4.6 ns	1.08 ns
Irrigation × Year	2	2.4**	20.2*	55,136,242**	66,650.6**	4.7**	0.14**	64,404,516,179**	0.01**	0.001 ns	6.3**	0.8**
Error (a)	8	71	25.4	3	22,163.6	2.6	0.06	22,163,759,406	0.008	0.002	2.07	0.63
Variety	1	144.7**	122.3**	4 ns	45,094.6**	3.6*	0.13**	45,092,686,010**	0.01*	0.02*	4.3**	3.71**
Year × Variety	1	285.5**	15.5 ns	2 ns	12,109.6**	14.4**	0.41**	1,201,081,875,880**	0.04**	0.005**	11.6**	0.36 ns
Irrigation × Variety	2	11.4*	1.3*	1 ns	3567.6 ns	0.2 ns	0.01 ns	3567581261 ns	0.0007 ns	0.00003 ns	0.21 ns	0.006 ns
Year × Irrigation × Variety	2	17.7 ns	2.8 ns	0.001 ns	5542.2 ns	0.46 ns	0.01 ns	5542041413 ns	0.001 ns	0.0003 ns	0.31 ns	0.05 ns
Error (b)	12	11	5.8	6	3403.2	0.49	0.01	3,403,315,399	0.001	0.0006	0.35	0.14

**, *, ns, respectively, significant at level of 1 and 5% and no significant

SOV source of variance and *df* degree of freedom

water productivity traits did not show statistical significance except an amount of Ash and NDF (Tables 3 and 4).

The mean comparison for forage yield, energy, and water productivity of maize varieties under different water levels is represented in Table 3. Both varieties had the highest forage yield, input and output energy, energy ratio, net energy, and energy productivity of wet and dry forage under control conditions (no water stress). The different regime of irrigation was no difference one another for water productivity of wet forage and dried fodder yields. Energy productivity of dried fodder under 80% full irrigation was no different from 100% irrigation. However, the mean value of 80% was statistically similar to 60% irrigation. Water stress of 60% full irrigation showed the highest mean value for energy intensity than the two other irrigation treatments. The lowest mean values output energy, energy ratio, net energy, and energy productivity of wet and dry forage were recorded for 60% full irrigation. The variety Maxima had higher dried fodder yield, water, energy productivity of dried fodder, and energy intensity than the variety 704. However, the variety 704 had higher wet forage yield, output energy, energy ratio, water energy productivity of wet forage and net energy. Besides, both varieties of Maxima and 704 showed same mean values for input energy.

In general, in all three irrigation levels, the variety 704 had the higher wet forage yield than the Maxima variety; however, it was the opposite about dry forage yield (Figs. 1 and 2).

The results of statistical variance analysis of biochemical traits (Table 4) showed that the different levels of irrigation had a significant effect on all studied traits. Also, according to the results, the two varieties showed significant differences in terms of all biochemical traits, except lignin content. Similarly, there was a significant interaction between the irrigation levels and the variety for all biochemical traits except lignin (Table 5).

Based on the results of interaction between the water levels and the variety (Table 6) the highest mean values of CP, DM, and NDF of maize forage were observed in Maxima var. under 100% irrigation. The crude protein content of Maxima var. under 100% and 80% full irrigation was higher than 704 var, while the two varieties showed no significant differences under 60% full irrigation. Dry matter of Maxima var. had the highest value under control irrigation. However, decreasing water level led to reduction DM in Maxima var, but its mean value of dry matter was not different under 80% treatment from 60% full irrigation. In general, under all levels of irrigation, Maxima var. obtained more dry matter compared to 704 var. The lowest mean value of dry matter shared statistically equal under 80 and 60% full irrigation of 704 var.

Table 4 Variance analysis of some biochemical and water productivity traits in maize varieties under irrigation levels

S.O.V	Mean square						
	df	DM	CP	Ash	NDF	ADF	ADL
Year	1	2 ns	0.06 ns	0.56**	0.11**	0.29 ns	0.24 ns
Replication	2	3.4 ns	0.06 ns	0.35 ns	16.8 ns	0.19 ns	1.03 ns
Irrigation	2	30.2**	3.2**	5.08**	663.6**	177.5**	6.4**
Year × Irrigation	2	0.43 ns	0.29**	0.02 ns	5.5 ns	0.21 ns	1.3**
Error (a)	8	1.62	0.16	0.046	2	0.58	0.36
Variety	1	404.2**	0.77**	2**	356.8**	82*	0.06 ns
Year × Variety	1	0.68 ns	0.03 ns	0.63**	46.4**	0.14 ns	0.14 ns
Irrigation × Variety	2	1.75*	0.82*	0.35*	57.5**	35.6**	0.32 ns
Year × Irrigation × Variety	2	0.9 ns	0.012 ns	0.44**	29.3**	0.6 ns	0.06ns
Error (b)	12	1.41	0.02	0.045	3	0. 9	0.07

**, *, ns, respectively, significant at level of 1 and 5% and no significant. SOV: source of variance and df: degree of freedom. DM: dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: cell wall hemicellulose free, ADL: lignin, W.P.W: water productivity of wet forage yield, W.P.D: water productivity of dried fodder yield

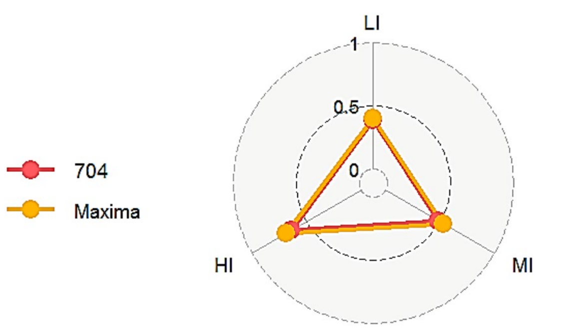

Fig. 1 Radar plot comparing wet forage yield of two maize varieties under different irrigation levels (LI: light irrigation (60% full irrigation), MI: moderate irrigation (80% full irrigation), and HI: high irrigation (100%))

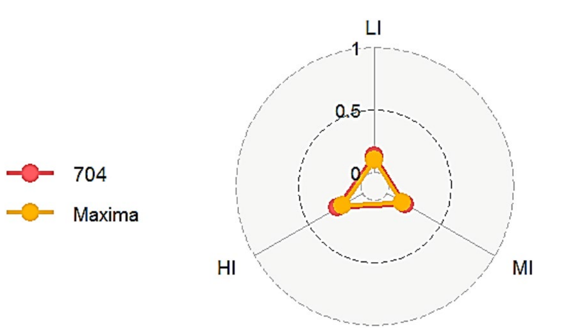

Fig. 2 Radar plot comparing dried fodder yield of two maize varieties under different irrigation levels (LI: light irrigation (60% full irrigation), MI: moderate irrigation (80% full irrigation), and HI: high irrigation (100%))

According to the results presented in Table 6, both varieties increased ash content with decreasing in water irrigation level. The highest and lowest mean value was recorded in the 704 variety under 60% full irrigation and control treatment, respectively. Comparing used varieties showed that drought stress led to a decrease in NDF, which under all three levels of irrigation regimes, NDF content of 704 variety was less than Maxima variety. However, no difference was detectable between 704 and Maxima variety regarding neutral detergent fiber under 60% full irrigation. Similarly, drought stress decreased ADF content among these two varieties. Although the highest mean value was related to the 704 variety under control irrigation, under 80% full irrigation no statistical difference was found among the two varieties. Under 60% full irrigation, ADF content in the Maxima variety was lower than the 704 variety. The 704 and Maxima varieties showed the highest value but no significantly different mean for lignin (ADL) under 100 irrigation levels, while no statistically significant difference between 704 and Maxima varieties was detectable for its lowest content under 60% full irrigation.

Due to the significant difference of some traits between control and stress treatments, evaluation of relationships related to measured traits was separately carried out for these three irrigation treatments.

Figures 3, 4, and 5 show the correlation plots among traits under control, 80%, and 60% of full irrigations, respectively. The correlation values between traits were observed differently, and in addition, in some cases, the sign of the correlation was changed.

There were completely different relationships in the correlation of research parameters with each other at different levels of irrigation. Wet forage yield was significantly positive with all measured parameters except energy intensity, water content, dry matter, NDF, and lignin at all irrigation levels in all three irrigation regimes. Yield of forage

Table 5 Mean comparison of irrigation levels and variety of maize for yield and energy traits

Factors	Treatment	WFY (kg ha^{-1})	DFY (kg ha^{-1})	E.In (Mj ha^{-1})	E.Out (Mj ha^{-1})	E.ratio (%)	E.I (Mj kg^{-1})	N.E.G (Mj ha^{-1})	E.P.W (kg Mj^{-1})	E.P.D (kg Mj^{-1})	W.P.W (kg m^{-3})	W.P.D (kg m^{-3})
Irrigation	100%	66.6^{a}	21^{a}	92,023.5^{a}	1176640^{a}	12.8^{a}	1.3^{c}	1084616^{a}	0.72a	0.23^{a}	9.7^{a}	3^{a}
	80%	51^{b}	15.4^{b}	83509^{b}	898980^{b}	11^{b}	1.6^{b}	815473^{b}	0.62^{b}	0.19^{ab}	9^{a}	2.7^{a}
	60%	34.4^{c}	11.5^{c}	75210^{c}	695710^{c}	9.3^{c}	2^{a}	620501^{c}	0.53^{c}	0.15^{b}	8.5^{a}	2.5^{a}
Variety	704	55.3^{a}	14b	83,580.5^{a}	95910^{a}	11.3^{a}	1.6^{b}	875588^{a}	0.64^{a}	0.16^{b}	9.7^{a}	2.4^{b}
	Maxima	54.3^{b}	17.8^{a}	83581^{a}	888390^{b}	10.7^{b}	1.7^{a}	804805^{b}	0.61^{b}	0.2^{a}	9.4^{b}	3^{a}
Year	2017	56^{a}	17.3^{a}	96233^{a}	987700^{a}	10^{b}	1.8^{a}	891466^{a}	0.75^{b}	0.17^{b}	9.8^{a}	3^{a}
	2018	48.7^{b}	14.7^{b}	70,928.7^{b}	859860^{b}	12^{a}	1.5^{b}	788926^{b}	0.68^{a}	0.2^{a}	8.3^{b}	2.5^{a}

Mean with the same letter(s) is not significantly different using Duncan's multiple range tests ($P \leq 0.05$)

WFY: wet forage yield, DFY: dried fodder yield, E.In: input energy, E. Out: output energy, E.ratio: energy ratio, E.I: energy intensity, E.N.G: net energy gain, E.P.W: energy productivity of wet forage yield, E.P.D: energy productivity of dried fodder yield, W.P.W: water productivity of wet forage yield, W.P.D: water productivity of dried fodder yield

Table 6 Mean comparison of interaction between irrigation levels and variety of maize for some biochemical traits

Biochemical traits	100%		80%		60%	
	704	Maxima	704	Maxima	704	Maxima
DM (%)	26.8^{c}	32.7^{a}	23.8^{d}	31^{b}	23.3^{d}	30^{b}
CP (%)	8.2^{c}	8.7^{a}	8.2^{c}	8.5^{b}	7.4^{d}	7.6^{d}
Ash (%)	6.4^{d}	5.6^{e}	7^{bc}	6.8^{c}	7.4^{a}	7^{b}
NDF (%)	63.5^{c}	72.6^{a}	58.4^{d}	67^{b}	52.7^{e}	54^{e}
ADF (%)	34^{a}	32.7b	31.3^{c}	30.7^{c}	29.4^{d}	22.4^{e}
ADL (%)	7.6^{a}	7.7^{a}	6.3^{bc}	6.7^{b}	6.4^{bc}	6^{c}

Mean with the same letter (s) is not significantly different using Duncan's multiple range tests ($P \leq 0.05$)

DM: dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: cell wall hemicellulose free, ADL: lignin

negatively correlated with energy intensity, water content, ash, ADF, lignin, and NDF under non-stress conditions.

The correlation of input and output energy with the amounts of lignin, dry matter, and crude protein at the level of 100% and 80% of complete irrigation negatively correlated with the application of 60% of irrigation stress, and it changed to positive. The correlation of energy ratio with NDF and crude protein also showed a similar relationship, while it was the opposite with ADL value. The energy intensity and lignin content positively correlated in 100% irrigation and 60% full irrigation stress and negatively in 80% full irrigation treatments. The relationship between energy intensity and crude protein in the control treatment was positive and positively correlated by changing the irrigation system to stress, which was completely reversed in the amount of NDF.

Under control conditions and 80% of full irrigation, the correlation of pure energy with crude protein and NDF was significantly negative, while their sign positively correlated in 60% of full irrigation.

Wet forage energy efficiency in all irrigation treatments had a positive correlation with other parameters except CP, ADF, and ADL with full irrigation regime.

Consumption of water with lignin and crude protein and productivity of fresh forage water with ash were negatively correlated in 60% of complete irrigation stress and positively correlated in two other irrigation administrations, while with crude protein showed the opposite correlation.

4 Discussion

According to the results, wet and dry forage yields of maize varieties were sensitive to drought stress, as the photosynthetic system is affected by water stress. Therefore, CO_2 assimilation is severely reduced, and leaf metabolism and crop growth are restricted [30–32]. So that, water stress of 60% full irrigation resulted in the greatest reduction in forage yield because of a decrease in plant growth. These results showed that water stress has a significant effect on the growth and yield component of maize forage;

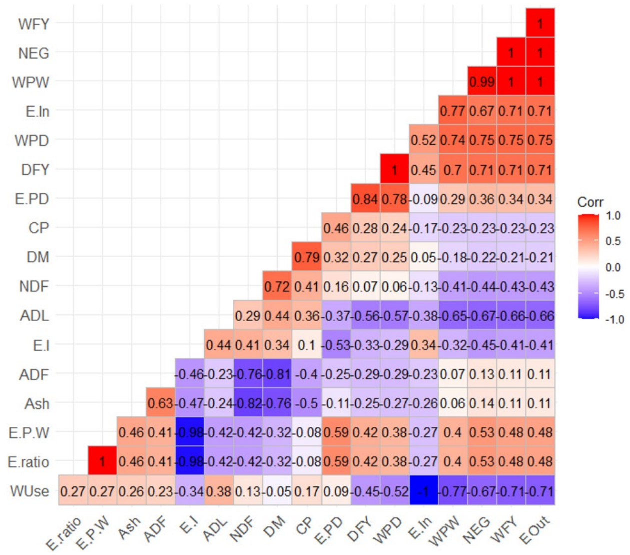

Fig. 3 Correlation plot for measuring association between measured traits of maize under full irrigation (100%). W Use: water use, E.ratio: energy ratio, E.P.W: energy productivity of wet forage yield, ADF: cell wall hemicellulose free, E.I: energy intensity, ADL: lignin, NDF: neutral detergent fiber, DM: dry matter, CP: crude protein, E.P.D: energy productivity of dried fodder yield, DFY: dried fodder yield, WPD: wet forage yield, E.In: input energy, WP.W: water productivity of wet forage, N.E.G: net energy gain, WFY: wet forage yield, E.Out: output energy

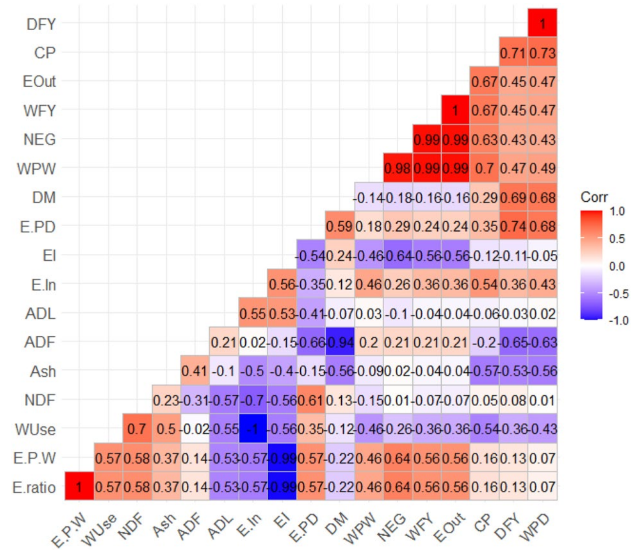

Fig. 5 Correlation plot for measuring association between measured traits of maize 60% under full irrigation. WUse: water use, E.ratio: energy ratio, E.PW.: energy productivity of wet forage yield, ADF: cell wall hemicellulose free, E.I: energy intensity, ADL: lignin, NDF: neutral detergent fiber, DM: dry matter, CP: crude protein, E.P.D: energy productivity of dried fodder yield, DFY: dried fodder yield, W.P.D: wet forage yield, E.In: input energy, WP.W: water productivity of wet forage, N.E.G: net energy gain, WFY: wet forage yield, E.Out: output energy

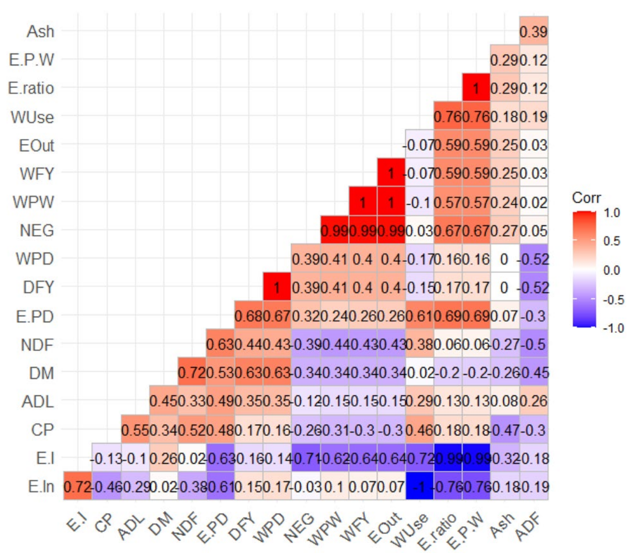

Fig. 4 Correlation plot for measuring association between measured traits of maize 80% under full irrigation. W Use: water use, E.ratio: energy ratio, E.PW.: energy productivity of wet forage yield, ADF: cell wall hemicellulose free, E.I: energy intensity, ADL: lignin, NDF: neutral detergent fiber, DM: dry matter, CP: crude protein, E.P.D: energy productivity of dried fodder yield, DFY: dried fodder yield, W.P.D: wet forage yield, E.In: input energy, WP.W: water productivity of wet forage, N.E.G: net energy gain, WFY: wet forage yield, E.Out: output energy

therefore, farmers should be able to manage water sources to achieve maximum yield.

The results showed that the highest output energy was related to control treatment. The lowest value was under 60% full irrigation treatment. The existence of a significant correlation between forage yield and output energy under full irrigation conditions confirms this relationship (Fig. 5). Similarly, the highest input energy was obtained under a 100% irrigation regime. The lowest average input energy value under 60% completes irrigation because of the increase in energy to pump water from the land. Energy ratio, energy productivity of wet forage and dried fodder, and net energy decreased with the decreasing irrigation water level. In contrast, the energy intensity increased under stress treatments than control. This indicates that by reducing water availability, energy consumption has increased in corn forage production, resulting in lower energy efficiency and productivity. Moreover, evaluating the influence of drought stress by examining of association between traits under different treatments showed that drought stress, in addition to reduction in yield and energy-related traits in maize, can change the relationship between these traits as well, and this issue was confirmed by correlation plots and principal component analysis.

In our study, the net irrigation requirement of maize was calculated as 608.21 mm in the area of the experiment. The volume of water consumption during the growing season, in three irrigation treatments and 18 to 20 irrigations, in the first year was 6449, 5676, and 4550 $m^3.ha^{-1}$ and in the second year 7100, 5720, and 4710 $m^3.ha^{-1}$, respectively. The mean comparison of treatments showed that there was no significant difference between the water productivity of wet and dry forage in all three irrigation treatments. Yazar et al. [32] showed that water management by changing water quantity during maize growth reduced evaporation and increased water productivity. Fung and Su [17] reported that different irrigation treatments have a slight effect on the water productivity of maize, and medium and low irrigation treatments had little effect on maize water productivity compared to full irrigation.

Based on the results, biochemical traits of forage maize were changed under stress treatments due to the plant response mechanism. For example, a change in crude protein production for cellular osmotic regulation and balance could be one of these mechanisms. In the current research, the highest mean value of DM was related to control treatment. The study by Mohammed and Mohammed [33] showed that DM of maize reduced under drought stress. One of the reasons for a decrease in CP under stress is their destruction by reactive oxygen species [34]. Antioxidant enzymatic activities increase under environmental stresses in plant cells and lead to reducing ROS damage. Among the antioxidant enzymatic, superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPX) are vital to preventing oxidative stress damage [35]. Under 60% full irrigation stress, ash content increased which indicates the physiological response of the plant to drought stress. So that, under stress accumulation of minerals in cells leads to concentration of its environment which there is a negative slope from roots to stem to continue absorption water [36]. In the present study, drought stress led to a decrease in NDF, ADF, and ADL. Crasta, Cox [37] documented the strong relationship between fiber contents in maize forage with water availability. Jiang, Yao [38] reported decline in hemicellulose concentrations, as a part of NDF, under drought. As well, some reports indicate decreased levels of ADF and ADL contents due to drought stress [39, 40]. One physiological reason for the reduction in cellulose during drought stress may be the formation of osmolytes (soluble sugars and proline). Osmolytes aid in the maintenance of osmotic equilibrium in the cell [41]. Since these traits lead to the reduction of forage quality, a decrease in these traits showed that forage intake could increase during drought years. Osmolytics contribute to maintaining osmotic balance in the cell [41]. As these characteristics lead to a reduction in feed quality, drought stress could increase feed quality by decrease these characteristics.

The variety 704 had higher wet forage yield compared to Maxima var, whereas Maxima var. showed higher dried fodder yield. But, decreasing water level led to decrease wet forage and dried fodder yields in both varieties. The early mature variety of Maxima had more dry matter yield than the late mature variety of 704 underwater stress, so varieties with shorter growth periods completed their growth cycle in a shorter time and provided high assimilation of dry matter under water stress conditions.

According to the results, a decrease in water level led decline in input and output energy for two varieties. The highest output energy was related to the variety 704 for fully plants irrigated, while input energy and energy ratio were not significantly different for the 704 and Maxima varieties. In all irrigation levels, the highest energy productivity of wet and dry forage was observed in 704 and Maxima, respectively. Water levels were not statistically different on energy intensity for the two varieties, but net energy of 704 var. was higher than Maxima var. under all levels of irrigation. The variety Maxima had a higher content of energy productivity than variety 704 although both varieties had equal mean value for input energy, due to reduction of the mean value of output energy. Therefore it seems the variety Maxima produces more forage and in terms of energy and environment is remarkably justified and sustainable. In evaluating water and energy productivity among barley varieties affected by drought stress, energy indices were different for different varieties [42].

The highest mean value of water productivity of wet forage was related to the variety 704 under full irrigation. In all irrigation levels, water productivity of wet forage of variety 704 increased compared to Maxima var. This issue could be because of higher wet forage in variety 704 than Maxima var. Conversely, in all three irrigation levels, water productivity of dried fodder increased in Maxima var. Thus, according to dried fodder yield and energy productivity of dried fodder Maxima might be more proper for forage production under water stress. Zwart and Bastiaansen [43] found that the range of water productivity of maize is 1.1–2.7 $kg.m^3$, which is close to the values of water productivity in the present study. Our study also showed that water wet and dry forage of productivity of maize under stress conditions were not different from the control treatment. The results of many researchers have shown that drought stress improves the water productivity index [32, 44, 45]. Drought stress improves water productivity by increasing stomatal resistance. Under these conditions, water losses due to transpiration reduced further photosynthesis and water productivity increased [46].

Two varieties showed different responses to different irrigation treatments in some measured traits related to maize forage quality consisting of dry matter, crude protein, ash, ADF, NDF, and ADL. Dry matter and crude protein were decreased as water irrigation levels were reduced in two varieties, which indicates that drought led to reduce production of these traits. However, in all irrigation regimes, both traits were higher in Maxima var. than variety 704. The increase of dry matter in Maxima var. under drought stress could be attributed to the lower sensitivity of this variety to drought. The reasons for the decrease in protein content under drought stress are related to inhibition of the activity of nitrate reductase, glutamine synthase, and glutamate synthetase enzymes under stress conditions in sensitive varieties [47]. Since the percentage of ash is the amount of minerals present in plant tissues, absorption of these substances by roots is reduced under drought stress; therefore, there is the possibility of reducing the percentage of ash in these conditions [48]. High concentrations of traits that led to reduced forage quality, such as NDF, ADF, and ADL, under drought stress have been reported [49]. In contrast, some studies reported a reduction in these traits under drought stress [50]. In the present study, in two varieties NDF, ADF, and ADL showed a decrease in stress conditions. Besides, the results of Weichenthal, Baltensperger [51] showed that ADF content in forage sorghum decreased under drought stress compared to normal irrigation. Hence, stress treatments of 80% and 60% full irrigation had no negative effect on the quality of the maize. However, crude protein content that increases forage quality also decreased under drought stress conditions. Since both quality and quantity of forage are important under drought conditions, maize varieties that tolerate not severe levels of drought stress show all characteristics. Therefore, based on the results of the current research, inducing mild drought stress could slightly decrease the yield of maize, which indicates the resistance of it to this level of stress. Under limited water conditions, this case could use for managing water consumption in maize. In addition, assessment of influences of severe drought stress (60% full irrigation) showed that affects the quantity and quality-related traits as well as the relationships among these traits. Xu, Zhou [12] reported increased antioxidant activity of maize under drought stress, which indicates that maize is suitable as a forage crop according to high antioxidant activity.

5 Conclusions

According to the market preferences such as grants and subsidies for agriculture production, the researches in the case of water and energy productivity have huge importance. Since production of forage maize requires a lot of energy, analysis about the reduced energy input is essential for sustainable development and reduces the negative impact on the environment. Overall results showed that drought stress negatively affected wet and dry forage yields and energy-related indices. But, its effect on some quality traits such as NDF, ADF, and ADL contents was positive, which led to an increase in forage quality under drought stress, while it did not affect water productivity of wet and dry forage. Also, considering forage yield and productivity energy-related traits, Maxima variety due to early maturity was able to more dried fodder yield with less output energy under water stress conditions and is introduced as more proper variety compared to 704 varieties. Additionally, the Maxima variety is suitable in terms of forage quality because of having increased DM and CP, as well as less ADF and ADL.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Sarshad A, Talei D, Torabi M, Rafiei F, Nejatkhah P (2021) Morphological and biochemical responses of *Sorghum bicolor* (L.) Moench under drought stress. SN Appl Sci 3:1–12
2. Kumar N, Poddar A, Shankar V, Shankhar Prasad Ojha Ch, Johnson A (2020) Crop water stress index for scheduling irrigation of Indian mustard (*Brassica juncea*) based on water use efficiency considerations. J Agron Crop Sci 206:148–159
3. Sah RP, Chakraborty M, Prasad K, Pandit MVK, Tudu MK, Chakravarty SC, Narayan M, Rana M, Moharana D (2020) Impact of water deficit stress in maize: phenology and yield components. Sci Rep 10:1–15
4. Courtial A, Solera M, Chateigner-Boutin AL, Rey-mond M, Méchin V, Wang H, Grima-Pettenati J, Barrière Y (2013) Breeding grasses for capacity to biofuel production or silage feeding value: an updated list of genes involved maize secondary cell wall biosynthesis and assembly. Maydica 58:67–102
5. Moradi H, Akbari GA, Khavari Khorasani S, Ramshini HA (2012) Evaluation of drought tolerance in corn (*Zea mays* L.) new hybrids with using stress tolerance indices. Eur J Sustain Dev 1:543–560
6. FAOSTAT-Agriculture database (2019) http://faostat.fao.org/en/#data/QCL

7. Song L, Jin J, He J (2019) Effect of severe water stress on maize growth processes in the field. Sustainability 11:1–18
8. He H, Hu Q, Li R, Pan X, Huang B, He Q (2020) Regional gap in maize production, climate and resource utilization in China. Field Crop Res 254:1–12
9. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra S (2009) Review article Plant drought stress: Effects, mechanisms and management. Agron Sustain Dev 29(185):212
10. Kappor D, Bhardwaj S, Landi M, Ramakrishnan M, Sharma A (2020) The impact of drought in plant metabolism: How to exploit tolerance mechanisms to increase crop production. Appl Sci 10:1–19
11. Sharma A, Wang J, Xu D, Tao S, Chong S, Yan D, Li Z, Yuan H, Zheng B (2020) Melatonin regulates the functional components of photosynthesis antioxidant system, gene expression and metabolic pathways to induced drought resistance in grafted *Carya cathayensis* plants. Sci Total Environ 713:2026–2032
12. Xu Z, Zhou G, Shimizu H (2009) Are plant growth and photosynthesis limited by pre-drought following rewatering in grass? J Exp Bot 60:3737–3749
13. Qasemipour E, Asbbasi A, Tarahomi F (2020) Water-saving scenarios based on input-output analysis and virtual water concept: Acase in Iran. Sustainability 12:1–16
14. Mubako S, Lahiri S, Lant C (2013) Input-output analysis of water transfers: case study of California and Illinois. Ecol Econ 93:230–3644
15. Rautaray SK, Pradhan S, Mohanty S, Dubey R, Raychaudhuri S, Mohanty RK, Mishra A, Ambast SK (2020) Energy efficiency, productivity and profitability of rice farming using *Sesbania* as green manure-cum-cover crop. Nutr Cycle Agroecosyst 116:83–101
16. Lopez-Malvar A, Ana Malvar R, Butron A, Revilla P, Pereira-Crespo S (2021) Genetic dissection for maize forage digestibility traits in a multi-parent advanced generation intercross. Agronomy 11:2–13
17. Fang J, Su Y (2019) Effects of soils and irrigation volume on maize yield, irrigation water productivity and nitrogen uptake. Sci Rep 9:1–11
18. Erdal G, Esengün K, Erdal H, Gündüz O (2007) Energy use and economic analysis of sugar beet production in Takat province of Turkey. Energy 32:35–41
19. Esengum K, Gunduz O, Erdal G (2007) Input-output energy analysis in dry apricot production of Turkey. Energy Convers Manage 48:592–598
20. Hartirli SA, Ozkan B, Fert C (2008) Energy inputs and crop yield relationship in greenhouse tomato production. Renew Energy 31:427–438
21. Yilmaz I, Akcaoz H, Ozkan B (2005) Analysis of energy use and input costs for cotton production in Turkey. Renew Energy 30:145–155
22. Ozkan B, Aqkcaoz H, Fert C (2004) Energy input output analysis in Turkish agriculture. Renew Energy 29:39–51
23. Mandal KG, Prasun Saha K, Ghosh PK, Hati K (2002) Biology and economic analysis of soybean-based crop production systems in central India. Biomass Bioenerg 23:337–345
24. Kitani O (1999) Agricultural engineering, Energy and biomass engineering. ASAE publication
25. López-Bellido L, Wery J, López-Bellido RJ (2014) Energy crops: prospects in context of sustainable agriculture. Eur J Agron 60:1–12
26. Khan S, Khan MA, Hanjra MA, Mu J (2009) Pathways to reduce the environmental footprints of water and energy inputs in food production. Food Policy 34:141–149
27. AOAC (1995) Official methods of analysis. In: Animal Feed. Chapter, 16th edition, AOAC International, Arlington, VI, USA. pp 30–40.
28. Van Soest PJ, Roberson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 74(3583):3597
29. Galeano E, Sales Vasconcelos T, Novais de Oliveira P, Carrer H (2019) Physiological and molecular responses to drought stress in teak (*Tectona grandis* L.f.). PLoS ONE 14:1–26
30. Moser SB, Feil B, Jampatong S, Stamp P (2006) Effect of pre-anthesis drought nitrogen fertilizer rate and variety on grain yield, yield components and harvest index of tropical maize. Agric Water Manag 81:41–58
31. Tani EG, Chronopoulou EE, Labrou N, Sarri E, Goufa M, Vaharidi X, Tornesaki A, Psvchogiou MJ, Bebeli P, Mabraham E (2019) Growth, physiological, biochemical, and transcriptional responses to drought stress in seedlings of Medicago sativa L. and their hybrid (Alborea). Agronomy 9:1–19
32. Yazar ATA, Howell D, Dusek A, Copeland KS (1999) Evaluation of crop water stress index for LEPA irrigated corn. Irrig Sci 18:171–180
33. Mohammed SH, Mohammed MI (2019) Impact of abiotic stress on quality traits of maize forage at two growth stage. J Hortic Plant Res 7:60–68
34. Wang C, Deng P, Wang X, Hu W, Li K, Chang J, Chen M, Wang Y, Yang G, He G (2013) A wheat WRKY transcription factor TaWRKY10 confers tolerance to multiple abiotic stresses in transgenic tobacco. PLoS ONE 8:65–120
35. Dixon DP, Cummins I, Cole DJ, Edwards R (1998) Glutathione-mediated detoxification systems in plants. Curr Opin Plant Biol 1:258–266
36. Assefa A, Bezabih A, Girmay G, Alemayehu T, Lakew A (2020) Evaluation of sorghum (*Sorghum bicolor* (L.) Moench) variety performance in the lowlands area of Wag Lasta, north eastern Ethiopia. Cogent Food Agric 6:1–12
37. Crasta OR, Cox WJ, Cherney JH (1997) Factors affecting maize forage quality development in the northwestern USA. Agron J 89:251–256
38. Jiang Y, Yao Y, Wang Y (2012) Physiological response, cell wall components, and gene expression of switchgrass under short-term drought stress and recovery. Crop Sci 52:2718–2727
39. Vincent D, Lapierre C, Pollet B, Cornic G, Negroni L, Zivy M (2005) Water deficits affect caffeate O-methyltransferase, lignification, and related enzymes in maize leaves. A Proteomic Investig Plant Physiol 137:949–960
40. Al-Hakimi AMA (2006) Counteraction of drought stress on soybean plants by seed soaking in salicylic acid. Int J Bot 2:421–426
41. Rogrs MJ, Lawson A, Kelly K (2017) Forage options for dairy with reduced water availability in the southern Murray Darling Basin of Australia. Sustainability 9:2–20
42. Hellal F, Mansour H, Abdel-Hady M, El-Sayed S, Abdelly Ch (2019) Assessment water productivity of barley varieties under water stress by AquaCrop model. AIMS Agric Food 4:501–517
43. Zwart SJ, Bastiaanssen WGM (2004) Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric Water Manage 69:115–133
44. Kang S, Shi W, Zhang J (2000) An improved water use efficiency for maize grown under regulated deficit irrigation. Field Crop Res 67:207–214
45. Oktem A, Simsek M, Oktem AG (2003) Deficit irrigation effects on sweet corn (*Zea mays* saccharataSturt) with drip irrigation in a semi-arid region. Agric Water Manage 61:63–74
46. Condon AG, Richard RA, Rebetzke GJ, Farquhar GD (2004) Breeding for high water use efficiency. J Exp Bot 55:2247–2459
47. Khan W, Prithiviraj B, Smith DL (2003) Photosynthetic responses of corn and soybean to foliar application of salicylates. J Plant Physiol 160:485–492
48. Kramer PJ (1983) Water relation of plants. United States, New York

49. Xu W, Lascano R (2007) New Stress Tolerant Corn Germplasm for Higher Water Use Efficiency and Water Conservation. The final report of the research project. Texas Water Development Board. http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/2005358021_germplasm.pdf accessed on 30 November 2007
50. Seguin P, Mustafa A, Sheaffer C (2002) Effects of soil moisture deficit on forage quality, digestibility, and protein fractionation of Kura clover. J Agron Crop Sci 188:260–266
51. Weichenthal BA, Baltensperger DD, Voge KP (2004) Feed values for annual forages in Western Nebraska. Animal Science Department. http://digitalcommons.unl.edu/animalscinbcr/21