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Research Article

Different Efficient Responses of Sorghum and Maize Varieties to Different Irrigation Systems

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Abstract: Drought is one of the most common abiotic stressors in the agricultural community. The purpose of this study was to assess the effects of drought on sorghum and maize seedlings. The experiment was conducted as a randomized complete block design (RCBD) in a split plot arrangement with three replicates over two years in Isfahan, Iran. Investigational treatments include three-tier drought stress for two varieties of each plant species. The results demonstrate that the highest energy productivity of fresh forage was obtained in the Pegah variety of sorghum (1.49 kg Mj^{-1}) and the lowest was obtained in the Maxima variety of maize (0.52 kg Mj^{-1}).With 60% irrigation, the lowest water productivity of fresh and dry fodder in maize was found in the Maxima variety (8.32 kg m^{-3}) and the 704 variety (2.15 kg m^{-3}). However, sorghum in the Pegah cultivar at 60% irrigation had the highest water productivity when it came to wet and dry fodder, with an average of 25.45 kg m^{-3} and 7.57 kg m^{-3}, respectively. These results clearly show that in the aspect of energy consumption and production, sorghum was able to optimally convert the consumed energy into more fodder. On the other hand, the Pegah variety in sorghum, having the highest energy efficiency of dry fodder regardless of the amount of water used, was a more suitable plant to choose for planting in areas with water shortage.

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1. Introduction

Water as a limited resource has been affected worldwide by climate change and population growth, which has led to an increase in per capita water consumption in households, industry, and agriculture (Van et al., 1991; Admasu et al., 2019; Dirwai et al., 2021). Agricultural food production represents 70% of global fresh water (Mustafa et al., 2021) and this amount is over 94% in Iran as only 7.7 million hectares (21% of agricultural land) are covered by irrigation (FAO, 2019). The results of droughts are particularly severe in areas where water scarcity is already limiting plant yield, as is the case in Iran (Nouri et al., 2020) it is therefore more necessary than ever to identify solutions to reduce water use and increase productivity. Water productivity is an index that shows the amount of product obtained from the consumed water. This index is a key basis for studying the production of agricultural products and the efficiency of water resources. In addition to water productivity, the amount of energy needed to produce agricultural products is also very important. Considering the energy crisis and the emission of greenhouse gases, all efforts are aimed at reducing energy consumption as much as possible. Most advanced and even developing countries have tried to optimize their agricultural systems in terms of energy consumption by examining the energy input for the production of various agricultural products and by calculating the energy efficiency index (Tarjuelo et al., 2015).

One way to reduce water consumption is to control irrigation stages and eliminate irrigations that have little effect on crop yield (Karam et al., 2007) and enhance water productivity (Bekele and Tilahun 2007). The water productivity index is a key foundation for the study of agricultural output and water resource efficiency (Passioura, 2006). A number of works on irrigation system performance assessment have been published, presenting the methodology, modeling, and case studies that help to improve the water and energy efficiency of irrigation systems (Khadra and Lamaddalena, 2006; Lamaddalena and Pereira, 2007; Abadia et al., 2008; Calejo et al., 2008). On the other hand, drought-induced stress is defined as the lack of moisture required for normal plant growth and life cycle completion (Mousavi-Avval et al., 2011), which causes 55% of crop losses in the entire of world (Bray et al., 2000) and affects nearly every aspect of the plant such as morphology, physiology and metabolism (Jabereldar et al., 2017; FAO, 2019). Therefore, it is important to choose an alternative crop in place of plants with high water needs and compatible with the stress of drought (Yolci and Tunçtürk, 2022).

Maize (*Zea mays* L.) is the world's third largest cereal crop after wheat and rice, grown mainly for cereal consumption and secondarily for forage (FAO, 2019). It can be cultivated under a wide variety of climatic conditions (Saad-Allah et al., 2021). In a study on maize that was conducted between two treatments of strip drip irrigation system and furrow irrigation system, the superior treatment in strip drip irrigation system (85% irrigation level) compared to the full irrigation treatment in the furrow irrigation system, the seed yield and water productivity was increased by 38% and 171%, respectively (Shahsavari et al., 2018). However, their production and productivity are seriously threatened by the scarcity of water resources (Admasu et al., 2019). Despite its high yield, maize also needs high water content. This has encouraged farmers to seek replacement crops in recent years. In recent years, *Sorghum bicolor* L. was identified as an appropriate option due to its tolerance to drought (Smith and Frederiksen, 2000). Sorghum is a C4 grain that has successfully adapted to semi-arid and arid areas. It can grow in environments with low rainfall and production yield Sorghum can stop its growth in the face of water shortage and continue to grow again with rain or irrigation. The results of Javadi and Esfahani (2023) showed that the input energy of maize is more than its output energy, as a result, it has a negative energy balance, while sorghum has a positive energy balance. Sorghum had a higher output energy (391920 MJ kg^{-1}) and efficiency of energy consumption (2.72) than maize.

Considering the importance of agricultural products such as maize and sorghum under the conditions of lack of water resources in the agricultural sector in Iran, particularly in recent years, it is necessary to be able to use appropriate irrigation methods and also to select suitable crop species and the alternative produced with the highest performance and efficiency of water and energy consumption with a lower volume of water consumption. Hence, the aims of this study were to evaluate the effects of drought on the nutritional compositions of Sorghum and Maize and Comparison of traits of the two plants including water productivity, energy, and drought tolerance indices that were dimensionless.

2. Material and Methods

2.1. Description of where and how to plant

Randomized complete block design (RCBD) in split plot arrangement was employed with three replicates at Isfahan(Latitude 38.5 to 50.5 degrees, Longitude 45 to 32.5 degrees, and height above sea level is 1595 meters), Iran, during the 2017 and 2018 seasons (Table 1). According to the plan, the main plots include three different levels of irrigation (100% (HI), 80% (MI), and 60%(LI) of full irrigation), and the subplots include two varieties of sorghum (Speedfeed (early mature) and Pegah (late mature)) and two varieties of maize (704 (late mature variety) and Maxima (early mature variety)). Varieties belonging to Iranian forage cultivars were obtained from the Isfahan Seed Improvement Research Centre in Iran.

First of executive operation, a plot of land with an area of approximately 2500 m^2 was deeply plowed. Then ammonium phosphate and potassium sulfate fertilizers were added before planting according to the soil test and at the rate of 250 and 150 kilograms per hectare, respectively, and were placed under the soil using a disc. Other seed bed preparation operations were done in spring when the weather was favorable. In this way, stacks with a distance of 60 cm for sorghum and 75 cm for fodder maize were created as crop rows. When the soil temperature reached 12 degrees Celsius, the plants were planted in the field. The planting date for both was mid-June.

The planting density for sorghum and fodder maize was considered to be 250 and 90 thousand plants per hectare, respectively. Each plot included four planting lines with a length of 12 meters and the distance between the plants on the row was 60 cm (for sorghum) and 75 cm (for maize). Weed control, operations, and harvesting with choppers and machines available in the country for planting, and harvesting sorghum and maize were essential factors for selecting distances. After vegetation and in the stage of four to six leaves, the plants were thinned so that the distance between the plants on the row reached the desired density. The harvest timing of sorghum and corn was set at the beginning of the phase of conversion of seeds from soft pulp to hard pulp, which was the case for sorghum in the first harvest after 90 days for Speedfeed and for Pegah after 112 days after planting. The second harvest occurred 45 days after the first harvest. Varieties 704 and Maxima were also harvested 110 and 95 days after planting, respectively.

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. Moisture values around FC, PWP, and bulk density were 25%, 14%, and 1.35 kg m^{-3} respectively. These values were used to control the pure water requirement of two commonly cultivated maize varieties in Iran. Irrigation was done in the form of a drip-strip and the irrigation cycle was determined based on a fixed cycle and according to the pure water requirement of the plant (class A evaporation pan). Irrigation was done by the irrigation cycle. The drip irrigation system consisted of a control unit and distribution lines. Drip laterals of 16mm in diameter had in-line emitters spaced 0.50 m apart, each delivering 4l h^{-1} at the pressure of 100 kPa.

Water requirement was estimated according to daily evapotranspiration values of the reference plant (ET0) and crop-specific coefficient (KC) of the combined Penman-Montes-FAO model (Allen et al., 1998). Crop water use (ET) was estimated based on an onedimensional water balance equation using soil water measured by the neutron and gravimetric sampling methods. Water use was the total of seasonal water depletion (planting to harvest) plus rainfall and irrigations during the same period.

The water balance equation is as follows:

$$ET = I + P \pm DS - D \qquad (1)$$

where ET is evapotranspiration (mm), I the irrigation (mm), P the precipitation (mm), D the deep percolation (i.e., drainage, mm), and DS is change of soil water storage in a given time period Dt (days) within plant rooting zone. Water use efficiency was computed as the ratio of crop grain yield to seasonal water use. (Howell et al., 1995).

The irrigation water quality included EC: 1.9 dS/m, pH: 7.2, anion including HCO3: 4.6 meq/L, Cl: 9.2 meq/L, $SO4^{-2}$: 6.5 meq/L, cation including Ca^{2+}: 6.6 meq/L, Mg^{2+}: 3 meq/L, and Na^{+}:10.3 meq/L. Water consumption was also measured by a calibrated meter. The amount of water consumption during the growing season, in 18 to 20 times irrigation in three treatments of 100%, 80, and 60% full irrigation was 5038, 4225, and 3350 m^3 ha^{-1} in 2017 and 4400, 5445, and 3225 m^3 ha^{-1} in 2018 respectively for sorghum and 6449, 5676, and 4550 m^3 ha^{-1} in 2017 and 7100, 5720, and 4710 m^3 ha^{-1} in 2018 respectively for maize.

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

2017	Temperature (ºC) Min.	Max.	Total precipitation (mm)
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

2.2. Laboratory analyses

2.2.1. Irrigation water and energy efficiency

Irrigation efficiency refers to the mass of dry matter or the output per unit (m^3) of water consumed by the plant. The total energy required for the production of the two plant species studied in the six major groups, including machine equivalent energy, fuel consumption (Erdal et al., 2007), irrigation (Hatirli et al., 2006), manpower (Ozkan et al., 2004), seed (Mokhtarpour et al., 2000), Pesticides and fertilizer (Lopez-Malvar et al., 2021). For this purpose, all inputs and outputs were converted into equivalent energy using standard conversion coefficients as shown in Table 2. Finally, some energy parameters were calculated according to the following formulas (AOAC, 1995):

$$\text{Energy intensity} = (\text{total consumption energy (Mj ha}^{-1})/\text{plant yield (kg ha}^{-1}) \quad (2)$$

$$\text{Energy productivity} = (\text{plant yield (Kg ha}^{-1)}/\text{input energy (Mj ha}^{-1)}) \quad (3)$$

$$\text{Energy ratio} = (\text{input energy (Mj ha}^{-1})/\text{total input energy (Mj ha}^{-1}) \quad (4)$$

Table 2. Energy equivalents of input and output in maize and sorghum production systems

Energy flow	Unit	Energy coefficients(MJ Unit^{-1})
A. Inputs		
Diesel fuel	L	47.8
Human labor	h	1.96
Machinery	kg	62.7
Nitrogen	kg	47.1
Phosphate(P_2O_5)	kg	15.8
Potassium(K_2O)	kg	9.28
Herbicide	kg	101.2
Insecticide	kg	238
Other fertilizer	kg	0.3
Irrigation water	m3	0.63
Seed	kg	14.7
B. Output		
Maize yield	kg	14.7
Sorghum yield	kg	14.7

2.2.2.Nutritional traits

To evaluate the biochemical characteristics of forage, samples were dried in the oven at 75 °C for 24 h, then passed through a 2 mm sieve and applied for measuring Ash and Crude Protein (CP) (Taize and Zeiger, 1998) Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) (Galeano et al., 1998). In order to determine the total Nitrogen Kjeldahl method was used (Bremner and Mulvaney, 1982)

Traits related to animal nutrition for each plant studied include total digestible nutrient (TDN) and dry matter Intake (DMI) (Lithourgidis et al., 2006), which was calculated according to the following formulas:

$$DMI = 120 \div \% \ NDF \tag{5}$$

$$TDN = (-1.29 \times ADF) + 101.35 \tag{6}$$

2.2.3.Statistical analysis

The collected data were analyzed through variance analysis using SAS (v. 9.3) to determine the statistical significance of the treatment effects. Additionally, correlation analyses between parameters were carried out using a linear regression model. Treatments were compared using the Duncan test at the 1% and 5% level of probability. The statistical analysis was applied on the data using R software(4.3.19).

3. Results and Discussion

The analysis of variance of related-yield traits indicated that year and plant factors significantly affected all parameters (Table 3) but irrigation and variety did not significantly affect the Water productivity of dried forage. The interaction among traits was not significant for most parameters (Table 3).

Table 3. Analysis of variance of experimental treatments on the measured indices of maize and sorghum forage in 2017-2018

S.O.V	d.f	Energy Ratio	Energy Productivity of Fresh Forage	Energy Productivity of Dried Forage	Energy Intensity	Water Productivity of Fresh Forage	Water Productivity of Dried Forage
Year	1	387**	0.65**	0.05**	1.24**	46**	4.8**
Year*Replication	4	14.36	0.02	0.004	0.06	11.94	1.2
Plant	1	1889**	7.45**	0.54**	13.01**	2653**	200.96**
Plant*Year	1	133.7**	0.1**	0.01*	0.09*	0.22^{ns}	0.01^{ns}
Error a	4	42.4	0.1	0.01	0.19	34.5	3.5
Irrigation	2	45.63**	0.17**	0.01**	0.52**	8.5**	1.17^{ns}
Irrigation*Year	2	4.6^{ns}	0.015^{ns}	0.001^{ns}	0.065^{ns}	5^{ns}	0.5^{ns}
Irrigation*Plant	2	3.47^{ns}	0.006^{ns}	0.004^{ns}	0.35**	31.39**	0.03**
Irrigation*Plant*Year	2	5.84^{ns}	0.18^{ns}	0.002^{ns}	0.83^{ns}	3.2^{ns}	0.41^{ns}
Error b	16	2.2	0.01	0.004	0.34	1.85	1.3
Variety	1	97.16**	0.34**	0.001^{ns}	0.37**	109.1**	0.0004^{ns}
Variety*Year	1	13.5*	0.04*	0.006^{ns}	0.32**	26.42*	1.23^{ns}
Variety*Plant	1	53.3**	0.19**	0.02**	0.008^{ns}	56.18**	8**
Variety*Plant*Year	1	2.88^{ns}	0.004^{ns}	0.0001^{ns}	0.11*	0.1^{ns}	0.06^{ns}
Variety*Irrigation	2	2.06^{ns}	0.002^{ns}	0.007*	0.003^{ns}	1.7^{ns}	1.64^{ns}
Variety*Irrigation*Year	2	2.05^{ns}	0.008^{ns}	0.002^{ns}	0.003^{ns}	2.11^{ns}	0.16^{ns}
Variety*Plant*Irrigation	2	2.21^{ns}	0.008^{ns}	0.006^{ns}	0.02^{ns}	2.7^{ns}	1.72^{ns}
Variety*Plant*Irrigation*Year	2	1.72^{ns}	0.007^{ns}	0.001^{ns}	0.021^{ns}	2.45^{ns}	0.07^{ns}
Error c	24	2	0.01	0.0002	0.01	2.62	0.08

ns, * and ** are no-significant and significant at the five and one percent levels, respectively.

Table 4. Analysis of variance of experimental treatments on forage quality and nutrition of maize in 2017-2018

S.O.V	d.f	Crude Protein	Nitrogen content	Ash Content	Neutral Detergent Fiber	Acid Detergent Fiber	Total Digestible Nutrients	Dry Matter Intake
Year	1	0.65^{ns}	0.001^{ns}	0.56**	81.06**	0.29^{ns}	0.49^{ns}	0.1^{ns}
Year(Replication)	4	0.29	0.007	0.35	16.88	0.19	0.32	0.1
Irrigation	2	3.21**	0.08**	5.08**	663.61**	177.51**	295.4**	107**
Irrigation*Year	2	0.29**	0.007**	0.028^{ns}	5.5^{ns}	0.21^{ns}	0.36^{ns}	0.05^{ns}
Error a	8	0.16	0.004	0.046	1.98	0.58	0.96	0.4
Variety	1	0.77**	0.01**	1.92**	356.83**	81.93**	136.3**	60.4**
Irrigation*Variety	2	0.082*	0.002**	0.35**	57.54**	35.65**	59.3**	23.3**
Variety*Year	1	0.37^{ns}	0.0009^{ns}	0.63**	46.46**	0.14^{ns}	0.23^{ns}	0.05^{ns}
Irrigation*Variety*Year	2	0.012^{ns}	0.0003^{ns}	0.44**	29.36**	0.6^{ns}	0.99^{ns}	0.4^{ns}
Error b	12	0.021	0.0008	0.045	2.92	0.99	0.48	0.1

ns, * and ** are no-significant and significant at the five and one percent levels, respectively.

According to the two-way ANOVA, changes in Irrigation and Variety of maize significantly affect all the nutrition properties. Furthermore, the year factor and the joint effect of the factors significantly changed Ash content and NDF variables (Table 4).

Changes in the factor of the year did not significantly impact all parameters of forage quality and sorghum nutrition. In addition, irrigation and variety had an important effect on all variables except ash content. Nevertheless, the combined effect of the factors has not changed substantially (Table 5).

Table 5. Analysis of variance of experimental treatments on forage quality and nutrition of sorghum in 2017-2018

S.O.V	d.f	Crude Protein	Ash Content	Neutral Detergent Fiber	Acid Detergent Fiber	Total Digestible Nutrients	Dry Matter Intake
Year	1	0.01^{ns}	1.88^{ns}	7.55^{ns}	0.76^{ns}	1.2^{ns}	0.01^{ns}
Year(Replication)	4	0.05	2.67	2.9	8.91	14.8	0.004
Irrigation	2	4.69^{**}	3.73^{ns}	43.21^{**}	21.02^{**}	35^{**}	0.05^{**}
Irrigation*Year	2	0.2^{ns}	1.97^{ns}	0.34^{ns}	0.51^{ns}	0.8^{ns}	0.009^{ns}
Error a	8	0.11	2.25	2.04	1	1.6	0.002
Variety	1	4.89^{**}	3.75^{ns}	498.1^{**}	176.71^{**}	294^{**}	0.67^{**}
Irrigation*Variety	2	0.3^{ns}	3^{ns}	11.87^{*}	3.35^{ns}	5.5^{ns}	0.01^{*}
Variety*Year	1	0.13^{ns}	1.69^{ns}	1.88^{ns}	0.00001^{ns}	0.00001^{ns}	0.004^{ns}
Irrigation*Variety*Year	2	0.28^{ns}	2.59^{ns}	2.09^{ns}	0.22^{ns}	0.3^{ns}	0.003^{ns}
Error b	12	0.1	2.36	1.76	1.91	4	0.002

ns, * and ** are no-significant and significant at the five and one percent levels, respectively.

For all irrigation levels, the energy ratio and energy productivity of fresh and dried forages of both sorghum varieties were significantly higher than those of maize (Table 6). These parameters were significantly higher under Pegah, Speedfed, and Maxima 704, respectively, and were reduced by drought stress (Table 6). Regardless of energy intensity, drought stress has dramatically increased energy intensity for both plant species. Energy intensity was highest in 704 compared to other Maxima, Speedfed, and Pegah plantings, respectively (Table 6). Under drought stress, water productivity for fresh and dried forage was significantly higher under sorghum than under maize. However, the impact of irrigation levels was different among sorghum varieties, maize varieties showed no significant content. There was no difference in water productivity for fresh and dried forage between Pegah and Speedfed when we did not experience drought stress. Pegah, on the other hand, was above Speedfed when drought conditions were high (Table 6).

Table 6. Average comparison of the effects of interaction between varieties of maize and sorghum under drought stress

	Irrigation Levels											
	HI				MI				LI			
	Sorghum		Maize		Sorghum		Maize		Sorghum		Maize	
	Speedfed	Pegah	704	Maxima	Speedfed	Pegah	704	Maxima	Speedfed	Pegah	704	Maxima
Energy Ratio (%)	18.48^{c}	23.47^{a}	12.46^{de}	13.23^{d}	18.34^{c}	21.04^{b}	10.60^{fg}	11.44^{e}	17.28^{c}	21.05^{b}	9.21^{g}	9.51^{g}
Energy Productivity of Fresh Forage (kg Mj^{-1})	1.17^{c}	1.49^{a}	0.7^{de}	0.75^{d}	1.16^{c}	1.34^{b}	0.60^{fg}	0.64^{ef}	1.1^{c}	1.34^{b}	0.52^{g}	0.54^{g}
Energy Productivity of Dried Forage (kg Mj^{-1})	0.41^{a}	0.36^{ab}	0.25^{c}	0.20^{cd}	0.32^{b}	0.38^{a}	0.21^{cd}	0.16^{de}	0.32^{b}	0.4^{a}	0.17^{de}	0.13^{e}
Energy Intensity (Mj kg^{-1})	0.89^{e}	0.67^{f}	1.44^{d}	1.34^{d}	0.88^{e}	0.76^{f}	1.78^{b}	1.57^{c}	0.92^{e}	0.75^{f}	1.96^{a}	1.89^{ab}
Water Productivity of Fresh Forage (kg m^{-3})	17.26^{e}	22.41^{b}	9.35^{fg}	10.14^{cf}	19.21^{d}	17.26^{e}	8.48^{fg}	9.39^{fg}	20.81^{c}	25.45^{a}	8.32^{g}	8.72^{fg}
Water Productivity of Dried Forage (kg m^{-3})	5.97^{bc}	5.42^{bc}	3.41^{d}	2.77^{de}	5.22^{c}	6.32^{b}	3^{de}	2.40^{de}	6.13^{bc}	7.57^{a}	2.84^{de}	2.15^{e}

The numbers in each column that have at least one letter in common are in a statistical group. LI: light Irrigation (60% full irrigation), MI: Moderate Irrigation (80% full irrigation) and HI: High Irrigation (100%).

To evaluate the relationships between traits under drought stress treatments, principal components analysis was conducted (Figure 1). As illustrated in the figure, the first and second components accounted for approximately 59% and 25.1% respectively. Approximately, all associations between characters have been affected by irrigation levels. Furthermore, Ash, WPFF, WPDF, EPFF, and EPDF were integrally occupied with high correlation with the Low irrigation in Pegah and Speedfed variety while ADF, NDF, and DMI were associated with the application high irrigation. Moreover, the abundance of TDN and EI can be more attributed to the moderate and low irrigation in Maxima and 704 varieties (Figure 1).

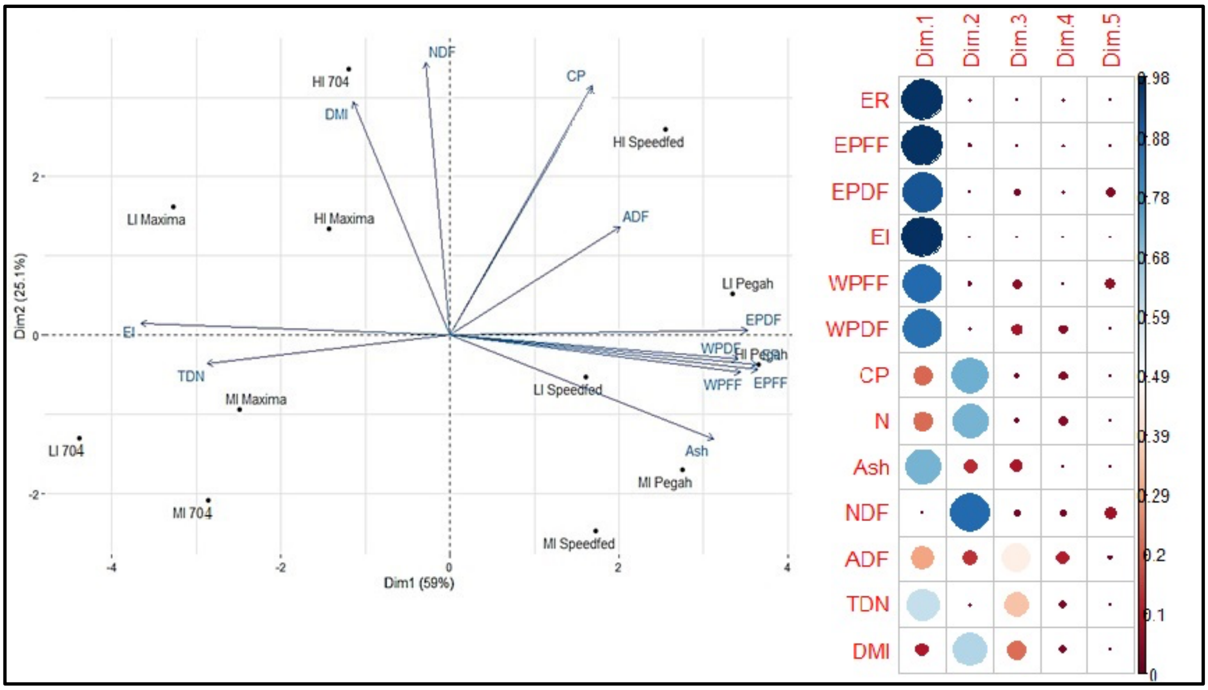

Figure1. Principal Component Analysis (PCA) of data for all characteristics of plants under the different Irrigation. ER: Energy Ratio, EPFF: Energy Productivity of Fresh Forage, EPDF: Energy Productivity of Dried Forage, EI: Energy Intensity, WPFF: Water Productivity of Fresh Forage, WPDF: Water Productivity of Dried Forage, CP: Crude Protein, Ash: Ash Content, NDF: Neutral Detergent Fiber, ADF: Acid Detergent Fiber, TDN: Total Digestible Nutrients, DMI: Dry Matter Intake. LI: light Irrigation (60% full irrigation), MI: Moderate Irrigation (80% full irrigation,) and HI: High Irrigation (100%).

In all three irrigation regimes, the EI of Maze varieties was higher than the Sorghum varieties significantly. While this value was quite the opposite for the other parameters (Figure 2). The highest ER, energy productivity, and water productivity were obtained in MI of Speedfeed variety. In the Maxima variety similar to the 704 variety, with decreasing water availability, energy and water parameters were decreased (Figure 2).

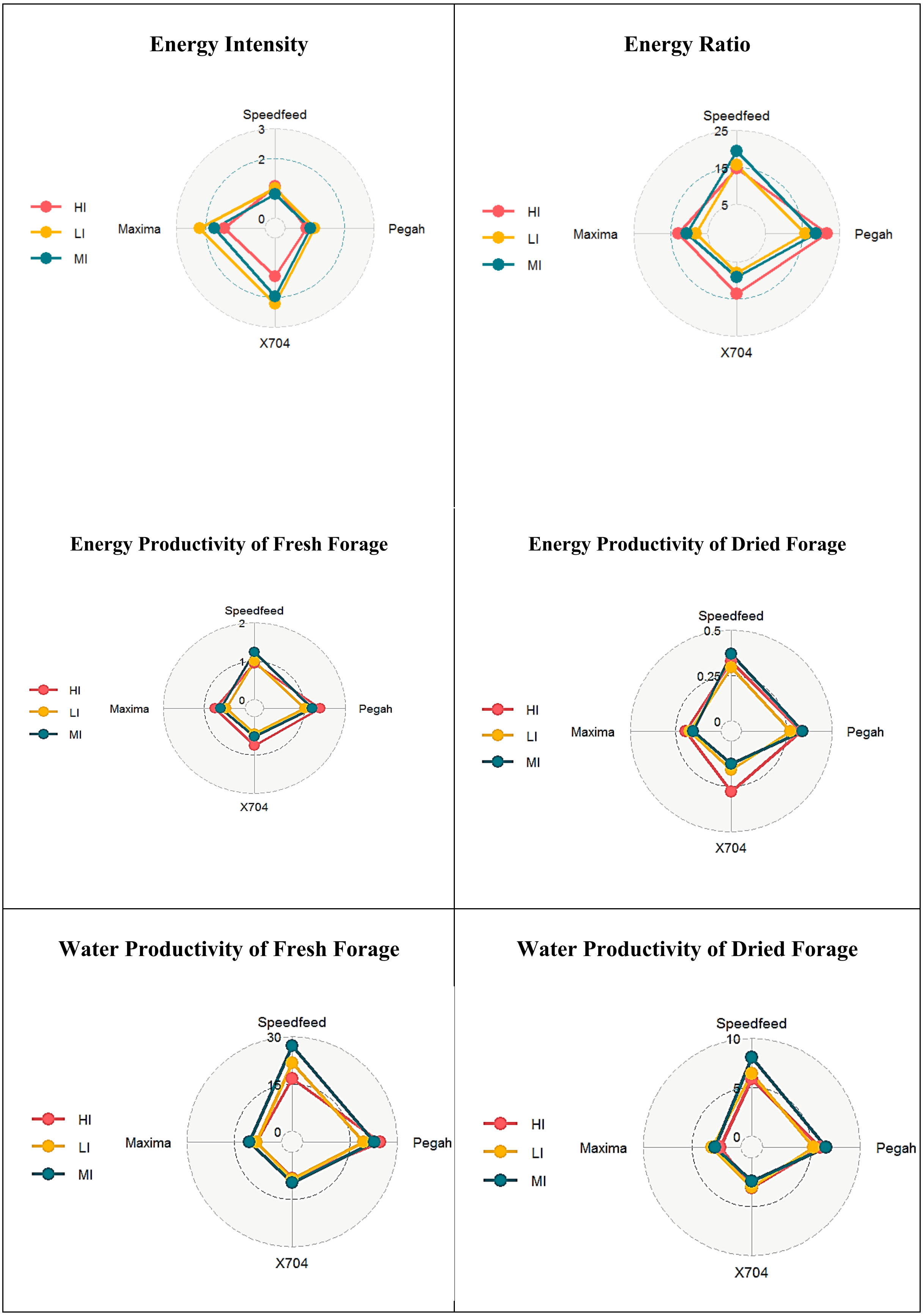

Figure 2. Radar plot comparing energy and water parameters of two Maize and Sorghum varieties under different irrigation levels (LI: light Irrigation (60% full irrigation), MI: Moderate Irrigation (80% full irrigation) and HI: High Irrigation (100%).

4. Discussion

As indicated in the results, most of the measured factors were modified considerably depending on irrigation and the year. Our finding indicated that energy ratio, fresh and dry forage energy productivity significantly increased up to 34% while the rate of energy intensity, fresh and dry forage water productivity reduced up to 25% during 2 years. The assumption is that the primary objective of agricultural production should be to reduce inputs and increase energy production. It seems that by increasing water stress during the year, growth and water-related indicators, especially productivity reduced that this result was also supported by Gomaa et al., (2021).

In general, we observed that the lowest energy intensity was associated with sorghum varieties, which did not differ significantly depending on irrigation levels. These results clearly show that in terms of energy consumption and production of two plants sorghum was able to optimally convert the energy consumption into a larger amount of forage than Maize. On the other hand, the Pegah variety, with the highest energy efficiency of dry forage, regardless of the amount of water consumed, was a more suitable plant to be selected for planting in areas with water shortage. Because under water stress conditions can play a significant role in converting energy use to production. Speedfed hybrid variety has a shorter growth period due to its multiplicity and, except for the amount of soluble sugar, has a preference over the Pegah variety in relation to some qualitative parameters. Its dry matter, protein, and minerals (ash) are higher than the Pegah variety. Although soluble fibre and lignin, in other words, it has lower digestibility than Pegah (Mokhtarpour et al., 2000).

The findings showed that the sorghum variety Pegah in low irrigation has the highest freshwater productivity. This product is well-suited for drought, elevated temperatures, and soil salinity (Bazaluket al., 2021). Farre and Faci (2006) reported that by reducing irrigation water to 50% of full irrigation, Maize yield is reduced by 20%. While grain sorghum yield decreased by only 8% in the 72% reduction of irrigation water (Klocke and Currie, 2009) that we observed the same trend in our study. Unlike other plants, sorghum requires less water and fertilizer per unit of biomass, which is a significant factor leading to a positive energy balance (Bonin et al., 2016) In Italy, the energy efficiency of sorghum is between 1.4-3.9 and 7.5-15 (kg Mj^{-1}) (Garofalo et al., 2016) In Asia (north-eastern China), the energy efficiency of their forages is between 9.3 and 12.4 (kg Mj^{-1}) (Renet al., 2012).

In maize and sorghum plants, the amount of crude protein decreased by about 11% and 7.8%, respectively, by reducing the irrigation level. Crude protein content is one of the most important factors in fodder quality (Wang, 2010). Some studies have reported an increase in the crude protein of fodder plants in the face of drought stress (Jensen et al., 2007; Allahdadi and Bahraini Nejad, 2019; Hatipoğlu et al., 2022), which is probably due to an increase in nitrogen concentration in dry soil. (Jensen et al., 2007). While other researchers have stated the reduction of protein amount in drought stress (Khalil et al., 2015). One of the reasons for protein reduction is their destruction during stress. In such a way that oxygen free radicals cause oxidative degradation of proteins, which occurs in a specific position of amino acids (Wang et al., 2013).

Increasing the water level led to a decrease in the percentage of maize fodder ash, but it did not have a significant effect on sorghum. Among the quality characteristics of fodder, the percentage of ash is a positive indicator of the content of mineral elements in fodder (Daddersan et al., 2016). The increase of ash, or in other words, mineral salts in fodder with the increase of stress, indicates the physiological reaction that the plant shows in dealing with the phenomenon of drought stress. So that the accumulation of mineral salts in the cell sap causes the concentration of the cell sap, and as a result, the negative slope from the root side to the aerial part provides the continuation of water absorption and prevention of the destructive effect of water stress (Abbas et al., 2021), which is in accordance with the findings of the present study.

In maize and sorghum, facing drought stress led to a decrease in the reducing traits of fodder quality, including insoluble fibers in neutral and acidic detergents. Insoluble fibers in acidic detergent and neutral detergent are considered two important features in fodder quality, and high-quality fodder has a low concentration of these two (Caballero et al., 1995).

A good fodder plant should have high dry matter and energy performance (high digestibility) and low fiber for optimal fermentation in silos and storage. These features, except for the amount of protein in maize, are more than other fodder plants (Curran and Posch, 2000). Many studies have shown that the grain and fodder yield of maize decreases under drought stress conditions (Hajibabaei and Azizi, 2014; Farahmandfar et al., 2018). Cakir (2004) evaluated the effect of water stress in maize and reported that water deficiency during the rapid vegetative growth stage reduces dry matter yield by 28-32%. Jama and Otman (1993) investigated the effect of moisture stress in the early stage of maize growth and found that delay in irrigation in this stage reduces the dry weight of the plant. Today, it is well known that the dry matter yield of forage decreases with drought stress (Marsalis et al., 2009; Rostamza et al., 2011; Jahanzad et al., 2013). While no significance was observed in the amount of dry matter in water stress levels with the control treatment in sorghum, it has been reported that sorghum can drain more moisture from the soil in water-deficient conditions (Jose et al., 1990).

Conclusion

The lowest energy intensity was associated with the sorghum Pegah variety, which did not differ significantly in the different irrigation levels. These results clearly demonstrate that in terms of energy consumption and production of maize and sorghum, sorghum has been able to optimally convert energy consumption into fodder. On the other side of the coin, the Pegah variety with the highest energy efficiency of dry forage, regardless of the amount of water consumed, was a more suitable plant to be selected for planting in areas with water shortage. Because under water stress conditions can play an important role in the conversion of energy use to production. Sorghum is more economically preferable to maize in the event of drought. As a result of its morphological characteristics, sorghum has a higher tolerance to drought.

Conflict of interest

The authors declare that they have no conflict of interest.

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