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Water use efficiency, yield, and nutritive value of maize and sorghum cultivars irrigated in a shallow soil

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ABSTRACT
To investigate the changes in irrigation water use efficiency (IWUE) and some agronomic and nutritional characteristics of forage maize and sorghum cultivars (cvs) irrigated in a shallow soil, two maize and seven sorghum cvs were evaluated in rain-fed (NIR) and irrigated (IR) field conditions for a 3-year period. The experimental design was a randomized complete block in a split-plot arrangement. The irrigation increased plant height of forages whereas decreased metabolizable energy and relative feed values. There was an advantage for sorghum cvs over maize cvs regarding to agronomic and nutritional traits in a shallow soil, irrespective of irrigation. The IR-cvs had higher yield and nutritional quality compared to the NIR-cvs. The IWUE values of Jumbo, Grazer, Hayday, El Rey and Gozde cvs were higher than those of other sorghum cvs. The studied cvs, except for El Rey (the highest) and Rox (the lowest) had similar IWUE values. The plant heights and dry matter (DM), digestible DM (DDM) and crude protein (CP) yields of sorghum cvs were greater than those of maize cvs, except for Rox and Early sumac. When cvs classes were compared for the yields of DM, DDM and CP, the classes ranked in the following order: Rx-893 = Karadeniz Yildizi = Rox = Early Sumac ≤ Gözde = Grazer = Hayday = Jumbo = El Rey.

Keywords:
Chemical composition
Feed value
Forage
Plant morphology
Water stress

Sığ toprakta sulamadan etkilenen mısır ve sorgum çeşitlerinin su kullanım etkinliği, verimi ve besin değeri

ÖZET
Sığ toprakta, sulanan yemlik mısır ve sorgum çeşitlerinin sulama suyu kullanım etkinliği (SSKE) ve bazı tarımsal ve besin değeri özellikleri için; iki mısır ve yedi sorgum çeşidi, doğal yağış alan (YA) ve doğal yağış artı sulama yapılan (SU) tarla koşullarında 3 yıllık bir sürede değerlendirilmiştir. Deneme, tesadüf bloklarında bölünen bölünmüş parseller deneme desenine göre yürütülmüştür Sulama, yem bitkilerinin bitki yüksekliğini artırırken, metabolik enerji ve nispi yem değerlerini düşürmüştür. Sulamadan bağımsız olarak, sığ toprakta agronomik ve besleme özellikleri bakımından sorgum çeşitleri mısır çeşitlerinden daha avantajlı bulunmuştur. Sulanan yemlik çeşitler, sulanmayan çeşitlere göre daha yüksek verim ve besleme kalitesine sahip olmuşlardır. Jumbo, Grazer, Hayday, El Rey ve Gözde çeşitlerinin SSKE değerleri diğer sorgum çeşitlerinden daha yüksek bulunmuştur. El Rey (en yüksek) ve Rox (en düşük) hariç, diğer tüm çeşitlerin SSKE değerleri benzer bulunmuştur. Rox ve Early Sumak hariç, sorgum çeşitlerinin bitki yükseklikleri ve kuru madde (KM), sindirilebilir KM (SKM) ve ham protein (HP) verimleri, mısır çeşitlerinden daha yüksek olmuştur. KM, SKM ve HP bakımından çeşitler karşılaştırıldığında sıralama şu şekilde olmuştur: Rx-893 = Karadeniz Yildizi = Rox = Early Sumak ≤ Gözde = Grazer = Hayday = Jumbo = El Rey.

Anahtar Sözcükler:
Besleme değeri
Bitki morfolojisi
Kimyasal kompozisyon
Su stresi
Yem bitkisi

1. Introduction

In the Mediterranean region, including Turkey, the main factor restricting productivity of summer forage crops are high temperatures, inadequacy of precipitation and irrigation possibilities during summer period (Carmi et al., 2006). Therefore, maize and sorghum forage producers need new hybrids or cultivars with high quality that require less water (Kiziloglu et al., 2009; Jahansouz et al., 2014). Cultivar choice is one of the most important management decisions for forage production and animal operations. In this perspective, sorghum is an important forage (Bean et al., 2013) and staple food crop (Badigannavar et al., 2016) in many regions of the world, because this forage has higher water use efficiency (WUE) and production capacity, and also, is more tolerant to drought, high temperatures, diseases, pests, unfavorable soil conditions (Farré and Faci, 2006; Jahansouz et al., 2014). However, there are contrasting results with respect irrigation WUE (IWUE) of sorghum cultivars (cvs) under irrigated conditions compared to that under rain-fed conditions (Garofalo and Rinaldi, 2013)

The need for irrigation may differ in fields with different soil characteristics such as deep and shallow, since water storage in soil or soil moisture varies depending on physical and chemical properties of field soil (Cichota et al., 2016). Previous studies (Farré and Faci, 2006; Kiziloglu et al., 2009; Islam and Horadagoda, 2012; Jahansouz et al., 2014; Xin et al., 2015) have highlighted responses of the maize and sorghum plants in terms of agronomic and physiological traits such as biomass, water extraction and canopy dynamics under non-irrigated (NIR)- and irrigated (IR)-field conditions. These studies have focused on crude protein (CP), digestible dry matter (DDM), acid detergent fiber (ADF), neutral detergent fiber (NDF) and some mineral contents as well as dry matter yield (DMY), plant height and numbers of leaf and tiller at normal soil condition. Agronomic and nutritional characteristics as well as IWUE of maize and sorghum cvs may change in response to irrigation management, especially in shallow soils with limited moisture retention capacity.

There has been insufficient information on some maize and sorghum cvs regarding to IWUE, agronomic and nutritional traits under rain-fed and irrigated conditions in a shallow soil. Therefore, the objective of this study was to evaluate some agronomic (plant height, the number of leaf and tiller, and DMY) and nutritional (DDM, CP, NDF, ADF and mineral content) responses to irrigation in two maize and seven sorghum cvs and to determine the IWUE of irrigated-cvs for a 3-year period, and thus, to select the water-efficient maize and sorghum cvs in the shallow soil (<30 cm).

2. Material and Methods

This study was conducted at the Experimental Field of the Agricultural Faculty, Ondokuz Mayis University, Samsun-Turkey located in the northern part of Turkey (41°21´ N, 36°15´ E, elevation 140 m a.s.l.) in a period of three years. The climate of experimental field represents a range of Mediterranean climates that differ only in regards to the extent of summer drought. Long-term (from 1950 to 2015) mean annual precipitation and temperature were 706.3 kg m^2 and 14.5 °C, respectively. Some weather data such as temperature, humidity, wind speed and sunshine during the growing seasons (May to September) of each experimental year are presented in Table 1. This trial was conducted in soil conditions (shallow soil) with about 20 cm profile depth (Table 2).

Table 1. Some weather data such as temperature (T), relative humidity (RH), wind speed and sunshine during the growing

	Year	May	June	July	August	September
Daily T_{max} (°C)	1st	26.3	27.2	29.7	31.2	28.6
	2nd	26.6	29.1	30.3	32.4	30.2
	3rd	29.4	33.8	29.7	30.3	29.6
Daily T_{min} (°C)	1st	7.5	10.0	16.3	17.5	13.7
	2nd	5.6	14.0	16.4	18.2	14.0
	3rd	7.8	15.0	16.4	18.5	13.6
Daily RH_{max} (%)	1st	96.0	96.0	95.0	94.0	95.0
	2nd	96.0	95.0	90.0	96.0	96.0
	3rd	96.0	95.0	94.0	95.0	96.0
Daily RH_{min} (%)	1st	47.0	48.0	50.0	54.0	51.0
	2nd	55.0	52.0	48.0	41.0	44.0
	3rd	55.0	41.0	48.0	43.0	44.0
Precipitation (mm $month^{-1}$)	1st	34.7	51.1	5.9	114.2	69.7
	2nd	69.0	36.3	9.0	0.0	66.2
	3rd	67.0	38.0	31.4	111.8	28.7
ET_0 (mm d^{-1})	1st	2.1	4.1	4.2	4.7	3.2
	2nd	2.4	4.4	5.0	5.3	3.1
	3rd	3.1	4.7	4.7	4.4	3.2
Wind speed (m s^{-1})	1st	1.6	2.0	2.0	2.3	2.0
	2nd	1.3	2.0	2.5	2.3	1.9
	3rd	1.5	1.9	2.1	1.7	1.9
Daily sunshine (h)	1st	6.4	9.7	9.7	9.7	7.2
	2nd	5.6	8.7	9.0	9.5	7.2
	3rd	8.1	10.1	10.5	9.4	7.3

Table 2. Some physical and chemical properties of the experimental field soil and irrigation water

Properties	Field soil	Properties	Irrigation water
Effective soil depth (cm)	20	Quality	C_2S_1
Texture	Clay	pH	7.55
Field capacity (P_w)	45.0	SAR	0.41
Wilting point (P_w)	24.0	EC (dS m^{-1})	0.29
Bulk density (g cm^{-3})	1.24		
pH (1:2.5 s w^{-1})	6.25		
Electrical conductivity (EC, dS m^{-1})	2.25		
Organic matter (mg kg^{-1})	2.30		
Extractable P (mg kg^{-1})	1.22		
Exchangeable K (mg kg^{-1})	109.2		

In this study, composite maize cvs (Rx-893 and Karadeniz Yildizi) and sorghum cvs (Rox and Early Sumac), sudangrass (Gozde), sorghum × sudangrass hybrids (Jumbo, Grazer, Hayday and El Rey) were evaluated in two water treatments (non-irrigated or rain-fed, NIR and irrigated, IR) for three consecutive years (2006, 2007 and 2008). In each year, the experimental design was a randomized complete block in a split-plot arrangement. Water treatment (NIR and IR) was assigned to the main plots. Each plot was 5 × 39.5 m with a distance of 4 m between each plot. Each sub-plot was 5 × 3.5 m with a distance of 1 m between each sub-plot and had five rows with a distance of 70 cm between rows. The plots assigned to water treatments were not changed throughout the experiment. Sub-plots were randomly allocated to nine forage cvs.

Experimental field was tilled to a depth of 15 cm and then seed bed was prepared by raking. Furrows were made in the soil with a hoe and then seeds were sown manually in to a 4-5 cm depth of the soil in May of each year. Sorghum and maize cvs were sown at a density of 25 and 10 seeds per m^2 (Adelana and Milbourn, 2009). Nitrogen (Calcium ammonium nitrate, 180 kg ha^{-1}) and phosphorus (diammonium phosphate, 100 kg ha^{-1}) fertilizer were based on soil analysis. All of the P and half of the N were applied manually during sowing. The experimental area was hoed during 4-5 leaf growth stage. The other half part of N was applied when the plants reached to a height of 40 cm and the experimental area was hoed again.

The experiment was started with the soil moisture content of all plots at field capacity. To estimate irrigation timing, the plant observation method was used, which is normally used by farmers in the field. As known, this method is based on observing changes in plant characteristics, such as changes in colour of the plants, curling of the leaves and ultimately plant wilting. Therefore, when a few leaves have turned yellow and are rolled but the majority of leaves are still green and relatively turgid (Zhang et al., 2011), irrigation was implemented. In the IR treatment, water was applied to a leveled basin and provided directly from the field channel into the basin through bundbreaks. Soil samples were collected before and two days after each irrigation from two layers (0-10 and 10-20 cm) to determine soil moisture content and field capacity, as described previously (Carmi et al., 2006). In the study, the topsoil, the slope of land, soil types and available stream size were shallow, gentle (flood plain < 0.3%), clay and 15 l sec^{-1}, respectively. Therefore, the width and length of basins were calculated as approximately 15 m and 17.5 m in order not to expose the infertile subsoil, to be irrigated efficiently and to avoid a water movement belowground from the basins of IR-field once basins are irrigated. Thus, the dimensions of basins were equated to those of sub-plots to ensure the amount of irrigation water supplied (Table 3) and to obtain good water distribution. If rainfall was sufficient to fill the soil profile or the basins to field capacity, irrigation was not applied. Therefore, irrigation interval was irregular in the study.

All cultivars, except for Jumbo were harvested when they reached milk dough stage (during 15 to 22 September). Jumbo, late maturing cultivar was harvested prior to clustering stage. All cultivars re-grown after harvest were harvested second time in the end of October.

At the first harvest, the plant height, leaf and tiller numbers (Kim et al., 2010a,b) per plant were measured and counted. The rest of the parcel discarded the edge effect was completely harvested and weighed. Thus, measurements and observations were made in parcels of 8.4 m^2. Initially, 2 kg of fresh plant tissue from each parcel was separated. Bulk sample was mixed thoroughly and only 0.5 kg was finally dried at 60 °C for 72 h to determine the dry matter (DM) content. Samples were then finely ground and used for chemical analysis at the Analytical Laboratory of Departments of Field Crops (Faculty of Agriculture, Ondokuz Mayis University). The contents of acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP) and some minerals (Ca, P, Mg and K) contents of all cultivars were determined by using near-infrared reflectance spectroscopy (NIRS). The near-infrared spectra were collected with a monochromator (FOSS NIR Systems 6500, Silver Spring, MD, USA), by scanning the 400-2500 nm spectral range. All spectra and reference data were recorded and managed with the WINISI version 1.6 software (Infrasoft International, Port Matilda, PA, USA). The IWUE of forages was calculated using the following equations (Howell, 2011); IWUE (kg m^{-3}) = (irrigated forage yield–non-irrigated forage yield)/irrigation water amount.

As described previously (Moore and Undersander, 2002), DDM and DM intake (DMI) was calculated from percentage of ADF and NDF values using the following equations; DDM (%)=88.9–(0.779 × % ADF) and DMI (% of body weight, BW)=120/(% NDF). Metabolizable energy (ME) was estimated using the following equation; ME (MJ kg^{-1} DM)=0.17% DDM–2.0. Relative feed value (RFV) was estimated from DDM and DMI using the following equation; RFV (g kg^{-1} DM) = (DDM×DMI)/1.29. The tetany ratio is calculated on an equivalent weight basis using a so-called tetany ratio [K/(Ca + Mg)].

An ANOVA technique for split-plot design was performed using the GLM MULT procedure of SPSS 21.0. However, one way ANOVA (Compare Means procedure of SPSS) was conducted to evaluate the effects of the forage cultivar on the IWUE. The assumption of homogeneity of variance was tested using Levene's Test of equality of variances, which is produced in SPSS. Thus, all data were pooled across three years, because error variance was homogeneous. Results are presented as a mean of the three experimental years and a pooled standard error of the mean (SEM). Tukey’s range test at a significance level of $P < 0.05$ was applied for mean separation when the F-test was significant.

Table 3. Number (no) of irrigation and amount of irrigation water for maize and sorghum cultivars during the growing periods of three consecutive years

	Years		
Trait	2006	2007	2008
No of irrigation	10	14	12
Amount of irrigation water (mm)			
For maize	390.3	545.7	468.1
For sorghum	304.8	442.7	312.2
Water saving (%)	22.0	18.9	33.3

3. Results and Discussion

The IR treatment increased the plant height, the total DM (14132 vs. 7915 kg h^{-1}), DDM (8957 vs. 5843 kg h^{-1}) and CP (1184.7 vs. 766.6 kg h^{-1}) yields and the ADF (396.98 vs. 379.40 g kg^{-1} DM) content, whereas it decreased the tiller number, RFV (82.56 vs. 85.70) and the DDM (579.76 vs 593.45 g kg^{-1} DM), ME (8.09 vs. 7.86 g kg^{-1} DM) contents (Table 4 and Table 5) compared to the NIR treatment. The sorghum cvs in the IR-field had lower ($P < 0.05$) DMY at second harvest compared to those in the NIR-field. The IR treatment decreased Mg content (1.89 vs. 2.13 g kg^{-1} DM), but increased K content (11.46 vs. 10.48 g kg^{-1} DM) of crops in soil.

The total DMY of Rx-893 (7639 kg/h) was lower ($P < 0.05$) than those of all sorghum cvs (to 11425 kg h^{-1}), whereas those of Karadeniz Yildizi (8511 kg h^{-1}) was similar to those of Rox and Early Sumac (11425 and 11535 kg h^{-1}). El Rey, Jumbo, Hayday, Grazer, and Gözde (16030, 15914, 14881, 14714, and 14323 kg h^{-1}) had a similar total DMY, but those of Rox and Early Sumac were lower ($P < 0.05$) than those of other sorghum cvs (Table 6). Table 6 shows that Jumbo and Grazer had higher ADF and NDF values and lower DDM, DMI, ME and RFV compared to the other sorghum cvs ($P < 0.05$). In general, Rx-893, Karadeniz Yildizi, Rox and Early Sumac had higher values in terms of DMI and ME contents compared to other cvs ($P < 0.05$). Jumbo and Gözde had the highest ADF values whereas Rx-893, Karadeniz Yildizi, Rox and Early Sumac had the lowest values ($P < 0.05$). The NDF values of sorghum cvs were higher ($P < 0.05$) than those of maize cvs. Jumbo, El Rey and Gözde had the lowest CP and Ca contents compared to maize and other sorghum cvs ($P < 0.05$). The P contents of Grazer and Gözde were lower ($P < 0.05$) than those of Rx-893, Karadeniz Yildizi and Jumbo cvs. The K contents of Jumbo and Hayday were higher than those of Rx-893 and Rox. In terms of the Mg content and K/(Ca+Mg) ratio, Jumbo, El Rey and Gözde had lower and higher values ($P < 0.05$), respectively compared to Rx-893, Karadeniz Yildizi and Rox (Table 7).

Although sorghum cvs resulted in an average 24.7% saving (Table 3) in irrigation water compared maize cvs, the studied cvs, except for El Rey and Rox had similar IWUE values (Table 8). The IWUE for El Rey (2.65 kg m^{-3}) was higher ($P < 0.05$) than those for other cvs (0.71 to 1.68 kg m^{-3}). The IWUE values of Jumbo (1.68 kg m^{-3}), Karadeniz Yildizi (1.57 kg m^{-3}), Gozde (1.58 kg m^{-3}), and Hayday (1.54 kg m^{-3}) were higher ($P < 0.05$) than those of Rox (0.71 kg m^{-3}).

When the interaction effects of factors on any of the studied parameters were significant (Table 4), these are presented in Table 5. Table 4 and Table 5 show that a water treatment × forage cultivar interaction was observed for the yields of total DM ($P = 0.050$), DDM ($P < 0.046$), and CP ($P < 0.001$). Similarly, an effect of interaction was observed for the Ca/P ratio ($P < 0.024$) and the contents of CP ($P < 0.017$), Ca ($P < 0.046$) and K ($P < 0.012$). The rain-fed Jumbo, El Rey and Rx-893 had higher, similar and lower in terms of the total DM, DDM, and CP yields compared to IR-treated counterparts, respectively.

The results of the present study indicate that while yields of studied forages were related to irrigation and cvs, the nutritional quality were related only to cvs, and there was an advantage for sorghum cvs over maize cvs regarding to agronomic and nutritional traits in a shallow soil, irrespective of irrigation. In addition, Grazer, Hayday, Jumbo and El Rey cvs might have an advantage over the other sorghum cvs.

Table 4. Level of significance (P-values) and standard error of the mean (SEM) for water treatment (WT) and forage cultivar (FC) effects on some agronomic and nutritional traits of forage maize and sorghum cultivars as influenced by irrigation in a shallow soil

Item[1]	WT	FC	WT × FC	SEM
Agronomic traits				
Yield (kg ha^{-1}) of				
Total dry matter (DM)	<0.001	<0.001	0.050	250.0
DM at second harvest	<0.001	0.492	0.196	5.180
Digestible DM (DDM)	<0.001	<0.001	0.046	140.5
Crude protein (CP)	<0.001	<0.001	<0.001	21.15
Plant height (cm)	<0.001	<0.001	0.966	3.595
Number of				
Leaves per plant	0.233	<0.001	0.859	0.117
Tiller per plant	0.002	<0.001	0.205	0.076
Nutritional traits				
DDM (g kg^{-1} DM)	0.001	<0.001	0.255	2.049
Dry matter intake (DMI, % of BW)	0.238	<0.001	0.991	0.011
Metabolizable energy (ME, MJ kg^{-1} DM)	0.001	<0.001	0.255	0.035
Relative feed value (RFV)	0.046	<0.001	0.885	0.781
Acid detergent fiber (ADF, g kg^{-1} DM)	0.001	<0.001	0.255	2.631
Neutral detergent fiber (NDF, g kg^{-1} DM)	0.261	<0.001	0.964	3.716
CP (g kg^{-1} DM)	0.815	<0.001	0.017	1.153
Ca (g kg^{-1} DM)	0.538	0.009	0.046	0.117
P (g kg^{-1} DM)	0.100	<0.001	0.058	0.025
K (g kg^{-1} DM)	0.052	<0.001	0.012	0.260
Mg (g kg^{-1} DM)	0.016	<0.001	0.157	0.049
Ca/P	0.199	0.414	0.024	0.065
K/(Ca+Mg)	0.267	<0.001	0.064	0.030

[1]Data are averages observed for the three experimental years (2006, 2007 and 2008)

The results on the IWUE values were in unison with the previous studies on sorghum (Farré and Faci, 2006) and maize (Carmi et al., 2006; Ors et al., 2015). These resul ts indicate that the irrigation may be needed and is generally quite beneficial on soils with low available water capacity (Farré and Faci, 2006; Cichota et al., 2016). Enciso et al. (2015), reported that a dry-land treatment resulted in higher average WUE than water limiting and full irrigation treatments. Under the weather conditions of the present study (Table 1), the yield of all sorghum cvs responded positively to irrigation. However, IWUE of the sorghum cvs, except for El Rey was similar those of maize cvs. Therefore, sorghum did not have advantage of irrigation, as reported by Jahansouz et al. (2014) and Afshar et al. (2014) in a well-watered environment. Afshar et al. (2014), noted that irrigation increased grain yield ofsome sorghum cvs (Kimia and Speedeh), while improving their IWUE. Inconclusive outcomes among the previously published studies and the present study results may be due to the fact that the studies differed not only in the sorghum and maize cvs used (Afshar et al., 2014; Jahansouz et al., 2014), but also in the environmental and soil conditions as well as different in the calculation method of IWUE, the water uptake pattern of both forage cvs and the irrigation system (Carmi et al., 2006; Garofalo and Rinaldi, 2013; Jahansouz et al., 2014; Ors et al., 2015; Cichota et al., 2016). Indeed, some sorghum cvs such as Jumbo, Grazer, Hayday and Gözde did not take advantage of irrigation because there were not different among these cvs. Our results are in agreement with previous studies (Farré and Faci, 2006; Kiziloglu et al., 2009; Jahansouz et al., 2014) which reported that IWUE was higher in sorghum than in maize under rain-fed field conditions.

In the present study, for each two forage species, the DMY under irrigation was greater than rain-fed conditions, as reported in previous studies (Carmi et al., 2006; Enciso et al., 2015). The decreases in the plant height and total DMY under dry land conditions may be resulted from soil depth (Rostamza et al., 2013). The DMY of sorghum cvs at second harvest may be related to the well-developed root system of rain-fed cvs during drought stress (Afshar et al., 2014; Rostamza et al., 2011) Our results are disagreement with previous studies (Kiziloglu et al., 2009; Jahansouz et al., 2014) indicating that deficit irrigation led to a rise in ADF, and caused significant reductions in digestibility and RFV in maize and sorghum cvs. Forages with low ADF and NDF had higher DDM and DMI values, which result in higher ME and RFV (Kiziloglu et al., 2009), because the levels of ADF and NDF negatively affect the digestibility and intake of forages. Therefore, the IR treatment may be reduced the DDM, ME and RFV of crops due to increase in the ADF contents. An increase in the studied traits of IR-treated both plant cvs compared to that of NIR-counterparts indicate that the erratic rainfall patterns may not meet water needs of these plants in the condition of the present study. Indeed, when the storage capacity of the soil is limited or the water flow rate is high, nutrients will be transported faster down the profile, limiting the opportunity for plant uptake (Cichota, 2016).

Tiller appearance was highly synchronized with main shoot leaf appearance, with a consistent hierarchy for tillering across environments (Kim et al., 2010b). A significant yield advantage of high-tillering types indicate in high-yielding seasons when water was plentiful, whereas such types incurred a significant disadvantage in water-limited circumstances (Kim et al 2010a,b) as in the present study. This may explain why the tiller numbers per plant decreased whereas the yields of DM, DDM and CP increased in the IR-treated sorghum cvs compared to the NIR-treated sorghum cvs. A reduction in leaf number per plant is one of the first impacts of drought stress on plants (Rostamza et al., 2011). However, the result that the effect of water treatment was not reflected on leaf number of studied crops is in accordance with the results reported by Carmi et al (2006). The results on the leaf and tiller numbers are in accordance with the previous results indicating there is a wide range in tiller number depending on genotype and growing conditions (Kim et al., 2010a,b).

The CP contents of crops is conflict with results of previous studies noting that reduced irrigation led to a decrease (Yosef et al., 2009) or an increase (Jahansouz et al., 2014) in the CP content of forages. Indeed, our data did not indicate any effect of irrigation on CP content, as reported for maize (Islam et al., 2012). The results on the CP content may be related to the fact that the water-stressed plants had similar or higher nitrogen content compared with IR-treated plants (Grzesiak, 2001). Increasing of insoluble fibres in water-stressed plants is one of the physiological responses of plants to prevent moisture loss (Kiziloglu et al., 2009; Jahansouz et al., 2014). Based on these information and our results on leaf number and ADF, NDF and CP contents, either the stress due to the lack of irrigation in the present study has no enough adverse effect on ADF and NDF contents or it was not such a level that would cause an effect on these variables.

Interaction effects observed on yields of DM, DDM and CP may be resulted in genetic makeup of both maize and sorghum cvs, because there is genotypic variation between maize cross hybrids in response to drought stress (Farré and Faci, 2006; Payero et al., 2006; Xin et al., 2015). These researchers reported that irrigation and maize variety had interaction effects on agronomic, chemical, nutritional, and structural features, as found in the present study. The well-watered field conditions led to almost 2.6 and 1.9 times increase in the DMY of Karadeniz Yildizi and El Rey compared to the drought stress. These results support the ideas that maize produces the maximum yield as compared to sorghum when rainfall is applied in excess quantity and soil is fertile enough (Muchow, 1989), that there are higher yield and vegetative growth in sorghum than in maize under water stress (Jahansouz et al., 2014), and that both maize and sorghum cvs are widely grown under rain-fed conditions (Farré and Faci, 2006).

The maize cvs had lower yields compared to sorghum cvs, except for Rox and Early Sumac in the well-watered field condition. This result may be related to the fact that soil is not fertile enough due to shallow. However, not only relative yields but also prices and labour costs should be taken into consideration in comparison of maize with sorghum. On the other hand, the Karadeniz Yildizi and Gözde cvs breed in Turkey were found to be comparable to other maize and sorghum cvs in the present and previous studies (Payero et al., 2006; Jahansouz et al., 2014; Xin et al., 2015). The fact that used sorghum cvs had similar or better feed value as maize indicate that the forage sorghum cvs had very high yield and in rain-fed fields with the shallow soil as in the present study can out yield maize.

Table 5. The effect of water treatment (non-irrigated, NIR and irrigated, IR) on some agronomic and nutritional traits of forage maize and sorghum cultivars in a shallow soil, irrespective of cultivars

Item[1]	NIR	IR
Agronomic traits		
Yield (kg ha^{-1}) of		
Total DM	7915b	14132a
DM at second harvest	274.5a	142.7b
DDM	5843.0b	8957a
CP	766.6b	1184.7a
Plant height (cm)	200.52b	275.52a
Number of		
Leaves per plant	11.74	12.03
Tiller per plant	2.28a	1.75b
Nutritional traits		
DDM (g kg^{-1} DM)	593.45a	579.76b
DMI (% of BW)	1.85	1.83
ME (MJ kg^{-1} DM)	8.09a	7.86b
RFV	85.70a	82.56b
ADF (g kg^{-1} DM)	379.40b	396.98a
NDF(g kg^{-1} DM)	653.03	661.42
CP (g kg^{-1} DM)	78.47b	79.00a
Ca (g kg^{-1} DM)	5.52b	5.67a
P (g kg^{-1} DM)	2.53	2.45
K (g kg^{-1} DM)	10.48b	11.46a
Mg (g kg^{-1} DM)	2.13a	1.89b
Ca/P	2.25a	2.41b
K/(Ca+Mg)	0.59	0.67

[1]Data are averages observed for three experimental years (see Table 4 for statistical analysis, the abbreviation and SEM of each item); a,b Means with different letters in the same row are different ($P < 0.05$).

Table 6. The effect of cultivars on some agronomic and nutritional traits of forage maize and sorghum cultivars in a shallow soil, irrespective of water treatment

	Maize cultivars		Sorghum cultivars						
Item[1]	Rx-893	K. Yildizi	Jumbo	Grazer	Hayday	El Rey	Gozde	Rox	E. Sumac
Agronomic traits									
Yield (kg ha^{-1}) of									
Total DM	7639d	8511cd	15914a	14714ab	14881a	16030a	14323ab	11425bc	11535bc
DM at 2^{nd} harvest				206.8	225.1	212.2	190.6	201.3	215.6
DDM	4611c	5195c	8621a	8402a	8556a	9222a	8090ab	6921b	6984b
CP	679.7bc	779.3c	1059.2a	1119.4a	1163.3a	1124.9a	984.6ab	919.9abc	950.3abc
Plant height (cm)	191.2cd	197.3cd	330.7a	255.7b	266.7b	241.3bc	276.0b	194.3cd	189.0c
Number of									
Leaves per plant	13.7a	11.5bcd	10.9cd	11.7bcd	10.3d	12.1abc	11.4bcd	12.7ab	12.7ab
Tiller per plant				2.5ab	3.1a	2.6ab	1.8bc	1.3c	1.9bc
Nutritional traits									
DDM (g/kg DM)	614.38a	616.87a	539.87d	574.92c	576.40c	578.99bc	565.40cd	606.66a	605.93ab
DMI (% of BW)	2.03a	1.96a	1.71c	1.77bc	1.78bc	1.79bc	1.72c	1.91ab	1.90ab
ME (MJ kg^{-1} DM)	8.44a	8.49a	7.18d	7.77c	7.80c	7.84bc	7.61cd	8.31ab	8.30ab
RFV	97.25b	93.92b	71.73c	78.95c	79.74bc	80.44bc	75.47c	90.13ab	89.52ab
ADF (g kg^{-1} DM)	352.53d	349.33d	448.18a	403.18b	401.27b	397.96bc	415.40ab	362.44d	363.38cd
NDF (g kg^{-1} DM)	599.39d	614.03d	706.54a	679.83ab	679.35ab	675.01ab	701.25a	628.17bc	631.44bcd
CP (g kg^{-1} DM)	90.15a	91.24a	70.34b	77.37ab	76.81ab	71.01b	68.39b	81.33ab	81.97ab
Ca (g kg^{-1} DM)	6.16a	6.23a	5.02b	5.70ab	5.88a	4.83b	4.76b	6.03a	5.73ab
P (g kg^{-1} DM)	2.75a	2.67ab	2.70ab	2.26c	2.42abc	2.38bc	2.22c	2.54abc	2.46abc
K (g kg^{-1} DM)	8.66b	10.23ab	13.15a	11.76ab	12.80a	11.61ab	11.14ab	8.62b	10.73ab
Mg (g kg^{-1} DM)	2.42ab	2.43ab	1.61d	1.82bcd	1.72cd	1.68d	1.51d	2.49a	2.37abc
Ca/P	2.36ab	2.39ab	1.96c	2.57a	2.49a	2.08bc	2.26b	2.41ab	2.44ab
K/(Ca+Mg)	0.44b	0.51b	0.88a	0.69ab	0.75ab	0.78a	0.79a	0.44b	0.57ab

[1]Data are averages observed for the three experimental years (see Table 4 for statistical analysis, the abbreviation and SEM of each item). a,b,c,d Means with different letters in the same row are different ($P < 0.05$). K. Yildizi: Karadeniz Yildizi, E. Sumac: Early Sumac.

Table 7. The effect of water treatment × forage cultivar interaction on agronomic traits (yields of total DM, DDM and CP) and nutritional (CP, Ca and K contents and Ca/P ratio) of forage maize and sorghum cultivars in shallow soil[1]

Treat	Cultivars	Yield (kg ha^{-1}) of			Contents (g kg^{-1} DM) of			
		Total	DDM	CP	CP	Ca	K	Ca/P
NIR	Maize							
	Rx-893	4923d	3021f	393.9e	82.40bc	5.92abc	7.08bc	2.18abc
	Karadeniz Yildizi	4724d	2902f	403.1e	87.88ab	5.81ab	10.49abc	2.13abc
	Sorghum							
	Jumbo	12854c	7282de	1033.0bcd	79.26bc	4.64c	14.21a	1.66c
	Grazer	12079c	7180de	997.4bcd	82.96bc	5.82ab	11.14abc	2.50abc
	Hayday	11892c	6916de	856.4cd	71.17cd	5.19abc	11.76abc	2.14abc
	El Rey	11197c	6612de	800.0cd	71.31cd	4.66c	11.53abc	1.95bc
	Gözde	11440c	6452de	759.2d	65.27d	4.43c	12.59bc	2.00bc
	Rox	10149c	6235de	847.0cd	84.32ab	6.77a	6.72c	2.71ab
	Early sumac	9862c	5989e	809.1cd	81.63bc	6.44ab	8.78abc	2.95a
IR	Maize							
	Rx-893	10355c	6200de	965.5bcd	97.90a	6.39ab	10.23abc	2.55abc
	Karadeniz Yildizi	12298c	7488de	1155.6b	94.61ab	6.66ab	9.97abc	2.64ab
	Sorghum							
	Jumbo	18975ab	9960b	1085.4bc	61.43d	5.40abc	12.09abc	2.26abc
	Grazer	17348ab	9621bc	1241.4ab	71.78cd	5.58abc	12.37ab	2.65ab
	Hayday	17869ab	10197ab	1470.1a	82.44bc	6.58ab	13.84a	2.84ab
	El Rey	20862a	11832a	1449.9a	70.71cd	5.00bc	11.69abc	2.22abc
	Gözde	17206b	9728bc	1210.0ab	71.51c	5.08bc	9.70abc	2.51abc
	Rox	12701c	7606de	992.9bcd	78.34b	5.29bc	10.52abc	2.11abc
	Early Sumac	13208c	7979cd	1091.5bc	82.31bc	5.02bc	12.69a	1.93bc

[1]Data are averages observed for the three experimental years (see Table 4 for statistical analysis, the abbreviation and SEM of each item). a,b,c,d Means with different letters in the same column are different ($P < 0.05$).

Table 8. Relative dry matter yields (DMY, %) of forage cultivars under non-irrigated (NIR) and irrigated (IR) field conditions and irrigation water use efficiency (IWUE, kg ha^{-1} mm^{-1}) values of forage cultivars in the growing periods under IR-field conditions

Treat	Forage cultivar	DMY[1]	DMY[2]	IWUE[3]
NIR	Maize			
	Rx-893	47.5	40.0	
	Karadeniz Yildizi	38.4	38.4	
	Sorghum			
	Jumbo	67.7	61.6	
	Grazer	69.6	57.9	
	Hayday	66.5	57.0	
	El Rey	53.7	53.7	
	Gözde	66.5	54.8	
	Rox	79.9	48.6	
	Early Sumac	74.7	47.3	
IR	Maize			
	Rx-893	100.0	84.2	1.15bc
	Karadeniz Yildizi	100.0	100.0	1.57b
	Sorghum			
	Jumbo	100.0	91.0	1.68b
	Grazer	100.0	83.2	1.46bc
	Hayday	100.0	85.7	1.54b
	El Rey	100.0	100.0	2.65a
	Gözde	100.0	82.5	1.58b
	Rox	100.0	60.9	0.71c
	Early Sumac	100.0	63.3	1.04bc

[1]Expressed as a percentage of the yield of each cultivar from IR-field.
[2]Expressed as a percentage of the yield of maize or sorghum cultivars with the highest yield from IR-field.
[3]Data are averages observed for the three experimental years. Standard error of the mean = 0.018; [a,b]Means with different letters in the same column are different ($P < 0.05$).

In general, the research data show that sorghum cvs, except Rox and Early Sumac appear to be inferior to maize in DDM and DMI. Rox and Early Sumac in sorghum cvs, characterized by reduced ADF, had the digestibility, ME and RFV to a level close to that of maize cvs. In addition, these cvs had higher yields of DM, DDM and CP compared to maize cvs under rain-fed conditions in the shallow soil. Therefore, the DDM, DMI, ME, CP and RFV of maize and sorghum cvs reconfirm high forage quality of maize cvs, as reported by Jahansouz et al. (2014). Nutrient contents of studied cultivars were within the ranges reported for different maize and sorghum cvs (Payero et al., 2006). The RFV, ME and CP are the major limiting nutritive properties in roughages for livestock, since forages with higher RFV are more digestible and palatable (Jahansouz et al., 2014). Therefore, the tested sorghum cvs, especially Hayday, Grazer and El Rey may be more suitable for sustainable forage production under rainfall-limited conditions in the shallow soil.

An imbalance of K, Ca and Mg in the forage crops may cause grass or hypomagnesemic tetany in livestock (Jefferson et al., 2001). However, the change in the Mg and K contents as influenced by irrigation in a shallow soil did not cause tetany risk, because K/(Ca+Mg) ratio in all cultivars was very lower than 2.2 (Bean et al., 2013). Besides, P must be balanced in the diet with adequate Ca and vitamin D for meeting the requirements of ruminant animals. The Ca/P ratio of forage is often discussed when investigating forage quality. As long as there is enough P to meet the nutritional requirements of livestock (Jefferson et al., 2001), an acceptable Ca/P ratio is between 1/1 and 7/1. Therefore, the Ca/P ratios of all studied cvs were within the desirable ranges.

In the present study, although there were differences in times and amount of irrigation or climatic conditions among the experimental years (Table 1 and Table 3), no difference in the results between years was founded. This may be attributed to the similar planting date and growing periods of cvs and the ineffectiveness of differences in precipitation distribution in each year. Indeed in our study, irrigation was implemented according to the method based on observing changes in colour of the plants, curling of the leaves and ultimately plant wilting (Zhang et al., 2011). The results on the effects of year and its interactions are not supported by findings in earlier reports on maize (Farré and Faci, 2006) and sorghum (Afshar et al., 2014). These discrepancies between the findings show that either the differences in times and amount of irrigation or climatic conditions among the years were not at a level that would cause a great difference in the results between years or used forage cvs were more tolerant to climatic and soil conditions in our study (Farré and Faci, 2006; Jahansouz et al., 2014).

4. Conclusions

Our findings indicated that agronomic and nutritional traits as well as IWUE of two maize (*Zea mays* L.) and seven sorghum (*Sorghum bicolor* L. Moench) cvs may change as influenced by irrigation in a shallow soil. In conclusion, 2) the maize and sorghum cvs differed in their responses to irrigation, 3) in terms of yields, IR-cvs had higher values compared to NIR-cvs, and 4) the plant heights and DM, DDM and CP yields of sorghum cvs, except for Rox and Early Sumac were greater than those of maize cvs. These results suggested that in general, the advantage for sorghum cvs over maize cvs increased as the rain deficit occurred in the present experimental condition, and that trying to increase the yields of maize cvs by irrigating is not a good strategy. However, introducing practical methods for improving yield of forage crops and efficient use of limited available water for irrigation in shallow soils with limited moisture retention capacity can enhance the sustainability of forage production in these areas. The sorghum cvs had higher forage yields by saving almost 24.7% of the irrigation water, although IWUE of the sorghum cvs, except for El Rey was similar those of maize cvs. In summary, when cultivars classes were compared for yields of DM, DDM and CP, the classes ranked in the following order: Rx-893 = Karadeniz Yildizi = Rox = Early Sumac ≤ Gözde = Grazer = Hayday = Jumbo = El Rey, irrespective of irrigation.

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