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Evaluation of Yield and Quality of Sorghum and Millet as Alternative Forage Crops to Corn under Normal and Deficit Irrigation Regimes

Mohammad Reza Jahansouz[1]✉, Reza Keshavarz Afshar[1], Hassan Heidari[2], Masoud Hashemi[3]

ABSTRACT

Two field experiments were conducted to evaluate the possibility of increasing diversity of winter cereals- based double cropping systems and their responses to deficit irrigation. In experiment 1, forage yield and quality of three corn hybrids, three sorghum cultivars and three species of millet (foxtail, common and pearl millet) were evaluated. Based on the results obtained from experiment 1, corn hybrid S.C. 704, sorghum cultivar Jumbo, and pearl millet were selected for further investigations. In experiment 2, the effects of irrigation treatments of I_{100}, I_{75} and I_{50} (providing 100%, 75%, and 50% of the corn estimated water requirement, respectively) were investigated on selected crops. Sorghum showed higher drought tolerance, but produced lower yield than pearl millet and corn, except at I_{50}. The highest dry forage yield in I_{100} was produced by corn followed by pearl millet. A reduction of 25% in the amount of irrigation water reduced the yield of corn, sorghum and millet by 28, 13 and 24%, respectively. Corn had the highest value of digestibility and relative feed value (RFV). Deficit irrigation led to a rise in crude protein (CP) and acid detergent fiber (ADF) content, and caused significant reductions in digestibility and RFV values in the three crop species. Results indicated that pearl millet and sorghum could be considered as reasonable alternatives to corn in a double cropping system under moderate and severe deficit irrigation conditions, respectively.

Keywords: Drought stress; double cropping; Forage quality; Pearl millet; Water use efficiency

INTRODUCTION

In arid and semi-arid areas of the world, water is the principal limiting factor of agricultural production primarily due to low and/or uneven distributions of annual rainfall (Keshavarz Afshar et al., 2014a; Jahanzad et al., 2011). Despite water scarcity, excessive use of ground water is a common practice in these areas when irrigation is employed. In recent years the rapid expansion of irrigation has resulted in massive exploitation of groundwater resources (Fang et al., 2010). Deficit irrigation has been considered as a practical method to overcome shortage of irrigation water in these regions (Keshavarz Afshar et al., 2012). Deficit irrigation systems are techniques to maximize water use efficiency (WUE) and to achieve higher yields per unit of applied irrigation water. In these methods, the crop is exposed to a certain level of water stress, either during a specific growth period or throughout the whole growing season (Keshavarz Afshar et al., 2014a; Bekele and Tilahun, 2007).

[1] Department of Agronomy and Plants Breeding, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran.
✉jahansuz@ut.ac.ir
[2] Department of Agronomy and Plants Breeding, College of Agriculture, University of Razi Kermanshah, Kermanshah, Iran.
[3]Stockbridge School of Agriculture, University of Massachusetts Amherst, MA, USA.
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Like other types of multiple cropping, double cropping is considered as a means for expanding the time of land use, increasing gross profit and an innovative approach for more efficient use of recourses. Winter cereals – corn (*Zea mays* L.) double cropping system is a common practice in many irrigated regions (Meng et al., 2012) including Iran. Growing high quality forage crops with greater water use efficiency in winter cereal_based double cropping systems might be the key for sustainable crop production in these areas. Corn is the most common crop that is cultivated after winter wheat (*Triticum asestivum* L.) or barley (*Hordeum vulgare* L.) but it is considered a high water demanding crop (Al-Kaisi and Yin, 2003). Pearl millet (*Pennisetum millaceum* L.) and sorghum (*Sorghum bicolor* L.) are important forages in several arid and semi-arid regions of the world and are well adapted to environments with limited rainfall, high temperatures and low soil fertility (Keshavarz Afshar et al., 2014b; Amer et al., 2012). It has been shown that sorghum and millet were more drought resistant and have higher water-use efficiency compared with corn and are able to produce acceptable forage yields when exposed to drought (Jaster et al., 1985; Singh and Singh, 1995). Therefore, they might be a good alternative to corn in double cropping or at least provide more options to winter cereals based-double cropping systems in areas with limited water resources.

Therefore, two field experiments were conducted to evaluate the possibility of increasing diversity of wheat based-double cropping system. In experiment 1, the primary objective was to compare the productivity of three corn hybrids, three sorghum cultivars and three commonly cultivated millet species; foxtail millet (*Setaria italica*), common millet (*Panicum miliaceum*) and pearl millet (*Pennisetum americanum*) cultivar Nutrifeed to evaluate appropriate forage crop cultivars and hybrids thus to receive further investigations of their aptness for double cropping with winter cereals. In experiment 2, selected cultivars and hybrids were evaluated based on their forage yield as well as quality under different deficit irrigation regimes.

MATERIALS AND METHODS

Site description

Field experiments were conducted at the Research Farm of College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran (N35°56", E50°58", altitude 1312.5 m), during 2010 and 2011. The prevailing climate is considered as semi-arid where average of 30-year air temperature, soil temperature, and precipitation are 15.8°C, 14.5°C, and 262 mm, respectively.

The region is highly prone to scanty and unevenly distributed rainfall and hence drought is the primary constraint to crop production. Before planting, soil samples were taken from depths that ranged from 0 to 30 and were analyzed for various physicochemical properties. The soil had a clay loam texture (33% sand, 36% silt and 31% clay) with no salinity and drainage problem. The water holding capacity of the soil was 105 mm for 1200 mm soil profile. Other chemical properties of the soil are presented in Table 1.

Table 1. General properties of the soil of the experimental site (depth of 0–30 cm).

Year	Texture	EC (dS/m)	OC (%)	pH	Available P (mg kg-1)	Available K (mg kg-1)	N (%)
2010	Clay loam	0.96	0.89	8.30	11	214	0.11
2011	Clay loam	1.45	0.73	8.32	10	237	0.09

Experimental layout and crop management

Experiment 1

A randomized complete block design (RCBD) with four replicates was used to evaluate three corn hybrids (S.C. 301, S.C. 647 and S.C. 704), three sorghum cultivars (Speed feed, Sugar graze and Jumbo) and three species of millet (foxtail millet, common millet and pearl millet hybrid [cv. Nutrifeed]) which were planted as a double crop after winter wheat was harvested. These crops can also be classified according to their maturity period under common planting time (i.e. mid spring). Hybrid S.C. 301of corn, Speed feed cultivar of sorghum and common millet are considered as early maturating crops, whereas hybrid S.C. 647 of corn, Sugar graze cultivar of sorghum and foxtail millet are mid-maturating crops, and hybrid S.C. 704 of corn, Jumbo cultivar of sorghum and pearl millet are late maturating cultivars. Wheat was harvested on July 1st. After wheat harvested, the experimental field was chisel plowed, disked and all crops were planted on July 16th, imitating the practices performed in the region. Plants were seeded in 37.5 m^2 plots (7.5 m wide and 5 m long). Further details of cropping operations are illustrated in Table 2.

Crops received the common management practice as performed in the region. Nitrogen and phosphorous fertilizer were applied based on soil test and recommendations. All plots received 250 kg ha^{-1} triple superphosphate (46% P_2O_5) and 200 kg ha^{-1} granular urea (46%N) during field preparation and prior to planting. Other 200 kg ha^{-1} granular urea was applied when crops reached 30 to 40 cm height.

Table 2. Details of agronomic practices used for cultivation of each plant

	Corn			Sorghum			Millet		
	S. C. 704	S. C. 647	S. C. 301	Jumbo	Speed feed	Sugar graze	Foxtail millet	Common millet	Pearl millet
Row spacing (cm)	75	75	75	50	50	50	50	50	50
Within a row spacing(cm)	15	15	15	10	10	10	5	5	10
Date of planting	16 July	16 July	16 July	16 July	16 July	16 July	16 July	16 July	16 July
Date of harvesting	23 Oct.	11 Oct.	3 Oct.	21 Oct.	5 Oct.	9 Oct.	24 Sep.	15 Sep.	23 Oct.

Experiment 2

The entries from each group in experiment 1 were selected for the experiment 2. The experimental unit was arranged in a factorial combination with three levels of crop species (hybrid S.C. 704 of corn, cultivar Jumbo of sorghum and pearl millet [cv. Nutrifeed]) and three levels of irrigation water volume (I_{100}, I_{75} and I_{50} by providing 100%, 75%, and 50% of corn estimated water requirement, respectively). Thereafter I_{75} and I_{50} are considered as moderate and severe drought stress. A randomized complete block design with four replicates was employed for data analysis.

Forages were double cropped after wheat. After harvesting the wheat in early July, the soil was plowed and disked. Plot size, row and within row spacings, fertilizer and weed management were similar to the experiment 1.

In order to avoid runoff after irrigations in each plot, both ends of rows were blocked by soil. A border of 2m between adjacent plots in each replication and 5 m between replicates were maintained to avoid entrance of drainage water from other plots.

The first two irrigations in all irrigation treatments were applied based on 100% of the corn estimated water requirement to ensure maximum germination and successful crop establishment. Irrigation intervals were 10-days apart as is commonly practiced in the area.

Irrigation system and estimating crop water requirements

Irrigation was performed using polyethylene pipes (63 mm) installed between the replications. One flow meter (3/4 inch) was used to measure the volume of irrigation water in each plot. Irrigation water volume was measured using the following equation (Jury et al., 1991):

$$I + P - R = ET + D + SW \qquad \text{(Eq. 1)}$$

Where I is the amount of irrigation water, P is precipitation, R is surface runoff, ET is estimated evapotranspiration, D is drainage or deep percolation and SW is the water storage change of the soil moisture profile. Surface runoff was negligible due to the control of water consumption by using the earth dike. Deep percolation or drainage did not occur, based on controlled water use to satisfy only the depleted soil moisture. Soil available water capacity (105 mm for 1200 mm soil profile) represented that the soil had the capacity to hold the amount of irrigation water applied in each irrigation interval. The amount of rainfall during the growing season was negligible and considered non effective due to high temperature and low relative humidity. Evapotranspiration of corn was calculated using equation 2.

$$ET_C = K_C\,(ET_R) \qquad \text{(Eq. 2)}$$

Where ET_C is crop evapotranspiration (mm day^{-1}), K_C is crop coefficient and ET_R is the reference crop evapotranspiration. A ten-year meteorological data, including climatic parameters such as relative humidity and wind speed along with the table published by F.A.O (FAO 1998) was used for calculating the crop coefficient (Kc).

The evapotranspiration rate of alfalfa was used as the reference crop evapotranspiration (ET_R) which was previously calculated by Farshi et al. (1997) for the target area. K_C is the ratio of the evapotranspiration of the crop (ET_C) to a reference crop (ET_R) (Piccinni et al., 2009). Fig. 1 shows the K_C variation of corn at various growth stages. The crop coefficient for initial stage (K_{Ci}) depends on the irrigation interval (I_f) and ET_R . K_{Ci} was estimated from equation 3.

$$K_{ci} = 2(I_f)^{-0.49}\exp\,[(-0.01 - 0.042\,\mathrm{Ln}I_f)\,Et_{ri}] \qquad \text{(Eq. 3)}$$

Where I_f denotes irrigation interval at the initial stage (day), K_{ci} denotes the crop coefficient for the initial stage, Et_{ri} denotes average daily reference crop ET during the initial stage (mm day^{-1}). K_C value for stage 3 and 4 were obtained from James (1988).

Crop measurements

The edge effect was discarded, and the rest of the plot was completely harvested and weighed. Two kg of fresh forage from each plot was selected to determine the moisture content and forage quality analysis. Plant samples were dried in a forced-air oven at 70°C for 72 hours before weighing.

Irrigation water use efficiency (IWUE)

Irrigation water use efficiency (kg m^{-3}) was calculated as dry forage yield (kg ha^{-1}) divided by the volume of irrigation water (m^3 ha^{-1}).

Forage quality measurement

To determine forage quality, two kg of dried forage from each plot was grinded and then 20 g of each sample was used for forage quality analysis. Near Infra-Red Spectroscopy (NIR) was used to determine various forage quality indices, including crude protein (CP), water soluble carbohydrate (WSC), acid detergent fiber (ADF) and neutral detergent fiber (NDF). Crude protein yield was calculated by multiplying forage dry yield and CP content.

Total digestible nutrients (TDN), digestible dry matter (DDM), dry matter intake (DMI), net energy for lactation (NE_L) and relative feed value (RFV) were estimated by following equations (Horrocks and Vallentine, 1999):

TDN= (-1.291 × %ADF) + 101.35 (Eq. 4)

DMI= 120/%NDF dry matter basis (Eq. 5)

DDM= 88.9 – (0.779 × %ADF dry matter basis) (Eq. 6)

RFV = %DDM × %DMI × 0.775 (Eq. 7)

NE_L = (1.044 – (0.0119 × %ADF)) × 2.205 (Eq. 8)

Statistical analysis

Analysis of variance (ANOVA) was performed separately for each year. The LSD test was implemented for the separation of the means ($P \leq 0.05$). All statistics were done using the SAS (version 9.1) statistical software.

RESULTS AND DISSCUSSION

Experiment 1

Forage Yield

Forage yield and yield components were all significantly affected by crop species and cultivars ($P \leq 0.01$) (Table 3). The highest forage fresh yield was obtained from pearl millet (61,865 kg ha^{-1}) followed by corn hybrid S.C. 704 (59,386 kg ha^{-1}), while the lowest yield was produced by common millet (16,088 kg ha^{-1}) and foxtail millet (18,685 kg ha^{1}). Among the three millet species, forage fresh yield of pearl millet was almost four times greater than the other two millet species. This might be due to the inherent characteristics of pearl millet as a vigorous and more demanding crop with at least one month longer growth period than the other two types of millet. Among sorghum cultivars, the lowest forage fresh yield was obtained from Speed feed (38,111 kg ha^{-1}), whereas Jumbo and Sugar graze cultivars out-yielded Speed feed by 19% and 13%, respectively. Speed feed has lower leaf to stem ratio than the other two sorghum cultivars (Table 3), therefore; it contains less moisture and lower fresh weight. In fact, stem dry weight of speed feed was highest among all forages used in this study (data not shown). Higher forage fresh yield was obtained from later maturity corn hybrid (S.C. 704) compared with shorter-season hybrids (S.C. 647 and S.C. 301). Full-season hybrids have a longer life cycle to grow and are able to produce higher biomass than short-season plants.

Corn hybrids out-yielded sorghum cultivars and millet species in terms of forage dry yield (Table 3). The greatest forage dry yield was obtained from corn hybrids S.C. 704 (13,652 kg ha^{-1}) followed by S.C. 647 (12,148 kg ha^{-1}), whereas foxtail and common millets were the lowest producing forage species. Pearl millet was the only millet species with dry yield of 12,285 kg ha^{-1} which was comparable to corn and sorghum cultivars. As mentioned earlier, foxtail and common millets were not as productive as other forages because of their short growing duration. Similarly, Zegada-Lizarazu and Iijima (2005) reported that under normal irrigation, forage dry yield of pearl millet was greater than foxtail and common millet. However, planting foxtail and common millet might be successful in double cropping systems in areas with shorter growing seasons where the cold season starts earlier therefore; provides sufficient time for the subsequent crop. Among sorghum cultivars, Jumbo produced more dry forage than Speed feed and Sugar graze (Table 3).

In forage crops, leaf to stem ratio is customarily considered as an important criteria which highly affects ration selection, forage quality and intake (Jahanzad et al., 2013). Significant difference in leaf to stem ratio was found among the forage species ($P \leq 0.01$). The highest leaf to stem ratio was obtained in pearl millet (1.50) followed by Jumbo sorghum (1.25). Pearl millet seems to consistently produce high leaf-stem ratio among forage cereals (Rostamza et al., 2011).

Forage quality

Results showed significant differences existed among the crop species in terms of CP content where millet species contained the highest CP (Table 4). Among millet species, the highest crude protein content was obtained from pearl millet (118.5 g kg^{-1} dry matter) which was significantly higher than the other two millet species. The greatest CP content in corn group belonged to S.C. 704 (Table 4) and among sorghum cultivars Sugar glaze had the highest CP content (99.9 g kg^{-1} dry matter) followed by Jumbo (86.4 g kg^{-1} dry matter). Leaves are the main contributor of protein in forages, therefore lower leaf to stem ratio, such as in Speed feed sorghum (Table 3), will be translated into lower CP (Table 4). Crude protein content is often considered as one of the major quality criteria in forages (Amer et al. 2012), because low levels of CP in forages may reduce their buffer capacity during ensilage for enabling fast ensilage with minimal losses (Mirron et al., 2007).

Although CP is an important quality trait, the total protein yield per unit area is even more important in evaluating the superiority of forages. Protein yield combines the total forage dry yield and forage CP content therefore; growers are often more interested in higher protein yield per unit area rather than specific values of protein content and percentage (Jahanzad et al., 2013). The highest protein yield was obtained from pearl millet (1,456 kg ha^{-1}) followed by corn hybrid S.C. 704 (1,249 kg ha^{-1}). The low protein yield of foxtail and common millet was related to their low forage dry yield rather than CP content. Our results confirmed the earlier reports by Ward et al. (2001) which indicated that corn hybrid S.C. 704 and pearl millet are among forages with highest crude protein yield.

Dry matter intake (DMI), total digestible nutrient (TDN) and digestibility of dry matter (DDM) are also important indices for evaluating forage quality. The greatest value of DMI, DDM and TDN was found in corn hybrids S.C. 704 and S.C. 647 and the lowest was found in foxtail and common millet (Table 4). In general the results indicated that corn S.C. 704 had the highest and foxtail and common millet had the lowest digestibility among the studied forages.

NDF and ADF are two other important quality components in forages, and show opposite trends to digestibility (Table, 4). The highest and lowest values of NDF and ADF were found in millets and corn hybrids, respectively. NDF and ADF content of sorghum cultivars were within the ranges reported for corn and millet species. It is well documented that high-quality forages have low values of NDF and ADF, which result in higher digestibility

(Keshavarz Afshar et al., 2012; Jensen et al., 2003).

Water soluble carbohydrates (WSC) in corn hybrids were significantly higher than sorghum and millets (Table 4). The greatest and lowest WSC content was measured in S.C. 640 (337.3 kg ha^{-1}) and common millet (62.9 kg ha^{-1}), respectively. WSC content along with the activity of lactic acid bacteria, determine the rate of decline in pH during the early stages of ensiling, which is important for the production of stable silage. It has been reported that initial WSC contents between 60 and 80 g kg^{-1} DM is adequate to produce good quality grass silages (Amer et al. 2012). Accordingly, with the exception of common millet and foxtail millet, all other forages in this study had adequate WSC to produce good quality silage.

Corn cultivars S.C. 704 and S.C. 647 had the highest NE_L and RFV (Table 3), which reconfirm their high forage quality. When RFV value is greater than 151 the forage is considered as a prime (Horrocks & Vallentine 1999). In our study the highest value of RFV was obtained from S.C. 704 (124.3) whereas the lowest values were found in foxtail (63.7) and common millet (60.1) (Table 4).

Overall, except crude protein content, corn possessed the highest quality indices compared with sorghum cultivars and millet species. However, in semi-arid regions, efficient use of irrigation water plays a crucial rule in forage production and should be considered along with yield and quality characteristics.

Experiment 2

Experiment 2 was conducted based on the information about forage yield and quality obtained from experiment 1. In this experiment, corn hybrid S.C. 704, Jumbo cultivar of sorghum and pearl millet (cv. Nutrifeed) were selected for further investigations. In experiment 2, the effect of deficit irrigation on yield and quality of the three superior forage species was investigated.

Table 3. Forage fresh and dry yield and leaf to stem ratio of nine forage crops.

Plant species		Fresh forage yield kg ha^{-1}	Dry forage yield kg ha^{-1}	Leaf / stem ratio
Millet	Pearl millet	61865 ^{a}	12285 ^{b}	1.50 ^{a}
	Foxtail millet	18685 ^{g}	4533 ^{f}	0.73 ^{def}
	Common millet	16088 ^{h}	3610 ^{g}	0.60 ^{efg}
Sorghum	Sugar graze	43074 ^{e}	9184 ^{e}	0.99 ^{c}
	Jumbo	45430 ^{d}	10161 ^{d}	1.25 ^{b}
	Speed feed	38111 ^{f}	9653 ^{de}	0.53 ^{g}
Corn	S.C. 704	59387 ^{b}	13652 ^{a}	0.59 ^{fg}
	S.C. 647	50704 ^{c}	12148 ^{b}	0.80 ^{d}
	S.C. 301	46119 ^{d}	11333 ^{c}	0.75 ^{de}
LSD		**1516**	**512**	**0.15**
Level of significance		**	**	**

Within columns, means followed by different letters are significantly different at ($P < 0.05$)

** Significant at $P \leq 0.01$

Table 4. Forage quality indices of nine forage crops.

Plant species		CP content g kg^{-1}	Protein yield kg ha^{-1}	DMI g kg^{-1}	TDN g kg^{-1}	DDM g kg^{-1}	NDF g kg^{-1}	ADF g kg^{-1}	WSC g kg^{-1}	NE_L Mcal kg^{-1}	RFV
Millet	Pearl millet	118.5^{a}	1456.1^{a}	19.8^{e}	500.1^{c}	579.1^{d}	604.7^{c}	397.7^{b}	97.8^{f}	1.25^{d}	89.1^{f}
	Foxtail millet	101.1^{c}	457.5^{f}	16.6^{f}	360.1^{d}	494.7^{e}	722.7^{b}	506.1^{a}	74.0^{g}	0.97^{e}	63.7^{g}
	Common millet	109.1^{b}	395.1^{f}	15.7^{g}	357.4^{d}	493.1^{e}	763.4^{a}	508.2^{a}	62.9^{h}	0.98^{e}	60.1^{h}
Sorghum	Sugar griz	99.9^{c}	917.3^{d}	22.1^{c}	606.6^{b}	643.5^{c}	544.3^{e}	315.2^{c}	191.9^{e}	1.47^{c}	110.0^{c}
	Jumbo	86.4^{de}	877.9^{d}	21.3^{d}	593.2^{b}	635.4^{c}	563.2^{d}	325.5^{c}	237.9^{d}	1.44^{c}	104.9^{d}
	Speed feed	83.1^{e}	802.3^{e}	21.9^{c}	500.8^{c}	597.6^{d}	547.8^{de}	397.1^{b}	194.7^{e}	1.26^{d}	98.4^{e}
Corn	SC 704	91.5^{d}	1249.9^{b}	23.2^{ab}	663.4^{a}	677.8^{ab}	518.0^{fg}	271.2^{de}	306.7^{b}	1.59^{ab}	121.7^{ab}
	SC 647	84.3^{e}	1024.4^{c}	23.5^{a}	667.6^{a}	680.3^{a}	509.2^{g}	267.9^{e}	337.3^{a}	1.59^{a}	124.3^{a}
	SC 301	83.9^{e}	951.4^{cd}	22.9^{b}	658.1^{a}	669.9^{b}	525.0^{f}	281.3^{d}	295.3^{c}	1.56^{b}	118.7^{b}
LSD		**5.1**	**75.4**	**0.53**	**15.4**	**8.6**	**15.5**	**11.0**	**10.9**	**0.02**	**3.2**
Level of significance		**	**	**	**	**	**	**	**	**	**

CP, crude protein; DMI, dry matter intake; TDN, total digestible nutrient; DDM, digestible dry matter; NDF, neutral detergent fiber; ADF, acid detergent fiber; WSC, water soluble carbohydrate; NE_L, net energy for lactation; RFV, relative feed value.

Within columns, means followed by the different letters are significantly different at $P \leq 0.05$

** Significant at $P \leq 0.01$

Forage Yield

Fresh and dry forage yield of the three forage species responded significantly to deficit irrigation (Table 5). When irrigation was optimal (I_{100}) pearl millet produced the highest fresh weight (57,666 kg ha^{-1}) which was 2% and 20% higher than corn and sorghum yield, respectively (Table 6). A reduction of 25% in irrigation water volume (I_{75}) resulted in considerable reduction in yield of millet (21%), corn (17) and sorghum (14%). Although, sorghum yield reduction in I_{75} was comparably smaller than corn and millet, its overall yield was still the lowest among the forage species. Under severe drought stress condition (I_{50}), the yield of pearl millet, corn and sorghum were 41%, 47% and 28% lower than I_{100}, respectively. Pearl millet performed as the champion forage crop under normal irrigation (I_{100}), moderate drought stress (I_{75}) and severe drought stress (I_{50}) in terms of fresh forage yield.

As expected, the forage crops reached their highest dry matter production under normal irrigation where the highest dry forage yield obtained from corn (12,470 kg ha^{-1}) followed by pearl millet (11,680 kg ha^{-1}) and sorghum (9,682 kg ha^{-1}) (Table 5). Deficit irrigation led to a significant forage yield reduction in all three forage species. A reduction of 25% in the amount of irrigation water reduced the yield of corn, sorghum and millet by 28, 13 and 24%, respectively. Despite of grater yield reductions that occurred in corn and pearl millet under moderate stress, these two species still out-yielded sorghum in terms of dry weight (Table 6). It is assumed that when soil water content is not enough to facilitate nutrient uptake by roots, plants face difficulties in uptaking the essential nutrients such as nitrogen and phosphorus which leads to yield reduction (Jahanzad et al., 2013). Moreover, reduced transpiration due to insufficient water in the soil can also intensify disruption of nutrient uptake by roots and ion transportation from roots to shoots (Jahanzad et al., 2013).

With 50% reduction in irrigation water, corn, sorghum, and pearl millet produced 49, 28 and 44% less forage dry yield, respectively compared with the full irrigation (Table 6). In I_{50} treatment, the highest dry forage yield was produced by sorghum followed by pearl millet and corn (Table 6). Sorghum is a drought tolerant crop which avoids dehydration by enhanced water uptake through its dense and prolific root system (Keshavarz Afshar et al., 2014b; Sher et al., 2013; Singh and Singh, 1995). Also, sorghum has the ability to maintain its stomatal opening at low levels of leaf water potential and tolerates dehydration through osmotic adjustment (Sher et al., 2013; Farre´ and Faci, 2006). Worth noting that, a more drought tolerant crop is not always as productive as sensitive crops and this fact needs to be considered in planning crop rotation in water limited areas.

Leaf to stem ratio was significantly influenced by plant species, irrigation treatments and their interactions ($P \leq 0.01$) (Table 5). Pearl millet and corn had the highest and lowest leaf to stem ratio, respectively. Higher leaf to stem ratio often results in higher forage quality since leaf contains more valuable ingredients such as protein and considerably lower ADF and NDF. As the water deficiency intensified, the leaf to stem ratio of the three species decreased (Table 6). It has been reported that one of the first impacts of drought stress on plants is a reduction in leaf number per plant and leaf area in order to reduce transpiration (Rostamza et al., 2011; Carraw, 1996).

Table 5. Fresh forage yield, dry forage yield, leaf to stem ratio and Irrigation water use efficiency (IWUE) of corn, sorghum and pearl millet as affected by irrigation treatment.

Treatment	Forage fresh yield kg ha^{-1}	Forage dry yield kg ha^{-1}	Leaf / stem ratio	IWUE kg m^{-3}
Plant				
Corn	44131.9^{b}	9242.1^{a}	0.4^{c}	2.16^{a}
Sorghum	39441.0^{c}	8344.2^{c}	0.8^{b}	2.00^{c}
pearl millet	45687.5^{a}	9029.0^{b}	1.0^{a}	2.13^{b}
Irrigation volume				
I_{100}	53343.8^{a}	11277.6^{a}	1.0^{a}	2.18^{a}
I_{75}	43718.8^{b}	8743.9^{b}	0.7^{b}	2.08^{b}
I_{50}	32197.9^{c}	6593.6^{c}	0.5^{c}	2.03^{b}
LSD	**601.22**	**125.8**	**0.05**	**0.03**
Level of significance				
Plant	**	**	**	**
Irrigation	**	**	**	**

Plant × irrigation	**	**	**	**

Irrigation treatments: I_{100}, I_{75} and I_{50} means providing 100, 75 and 50% of the corn estimated water requirement, respectively.

Within columns, means followed by the different letters are significantly different at $P \leq 0.05$

** Significant at $P \leq 0.01$

Table 6. Interaction effect of crop species and irrigation treatment on fresh forage yield, dry forage yield, leaf to stem ratio and Irrigation water use efficiency (IWUE) of corn, sorghum and pearl millet

Plant species	Irrigation treatment	Forage fresh yield kg ha^{-1}	Forage dry yield kg ha^{-1}	Leaf / stem ratio	IWUE kg m^{-3}
Corn	I_{100}	56375^{b}	12470 ^{a}	0.47^{e}	2.41^{a}
	I_{75}	46250^{c}	8954 ^{d}	0.35^{f}	2.13^{c}
	I_{50}	29770^{g}	6301 ^{h}	0.30^{f}	1.94^{e}
Sorghum	I_{100}	45989^{c}	9682 ^{c}	1.09^{b}	1.87^{f}
	I_{75}	39458^{d}	8408 ^{e}	0.76^{d}	2.00^{d}
	I_{50}	32875^{f}	6942 ^{f}	0.51^{e}	2.14^{c}
Pearl millet	I_{100}	57666^{a}	11680 ^{b}	1.43^{a}	2.26^{b}
	I_{75}	45447^{c}	8869 ^{d}	0.97^{c}	2.11^{c}
	I_{50}	33947^{e}	6537 ^{g}	0.70^{d}	2.01^{d}
LSD		**1038**	**317**	**0.10**	**0.08**

Irrigation treatments: I_{100}, I_{75} and I_{50} means providing 100, 75 and 50% of the corn estimated water requirement, respectively.

Within columns, means followed by the different letters are significantly different at $P \leq 0.05$

Irrigation Water Use Efficiency (IWUE)

In regions with water shortage, the relationship between yield and the amount of irrigation water is considerably important (Farre´ and Faci, 2009). A significant linear relationship was found between dry forage yield and amount of irrigation water in all forage crops (Fig. 2). This simply emphasizes the importance of irrigation water for optimum dry matter production in forage species in this study. The relationship between dry forage yield and irrigation water amount could be affected by many factors such as climate, soil properties and irrigation management practices. These factors therefore should be taken into account when proposing deficit irrigation strategies (Farre´ and Faci, 2009). The slopes of regression lines within a normal range of irrigated water indicate the sensitivity of the crops to water deficit (Fig. 2). Thus, sorghum and corn were most and least tolerant species to water deficit, respectively.

Results indicated that forage species did not respond similarly to drought stress in terms of IWUE. As water stress intensified, the IWUE of corn and pearl millet followed a steady declining trend (Table 6), whereas an opposite trend was observed in sorghum. In normal irrigation (I_{100}), the highest IWUE (2.41 kg m^{-3}) was calculated in corn, followed by pearl millet (2.26 kg m^{-3}) and the lowest IWUE belonged to sorghum (1.87 kg m^{-3}). Moderate and severe drought stress caused a progressive decrease in IWUE in corn and pearl millet while improved IWUE of sorghum.

Documented reports on IWUE response to deficit irrigation are not consistent and in many cases are controversial. While reduction in IWUE as a result of deficit irrigation has been reported (Farre´ and Faci, 2009), several reports have shown an increase in WUE in deficit irrigation (Rostamza et al., 2013; Zegada-Lizarazu and Iijima, 2005). Apparently the effect of water stress on IWUE depends on the severity of the stress, plant genotype, and developmental stage when water stress is imposed. Under the condition of this study, sorghum responded differently to deficit irrigation compared with corn and millet in terms of IWUE. This may have important economic implications since it means that under water limited conditions sorghum can produce more yield per monetary unit spent in irrigation water compared to corn and millet.

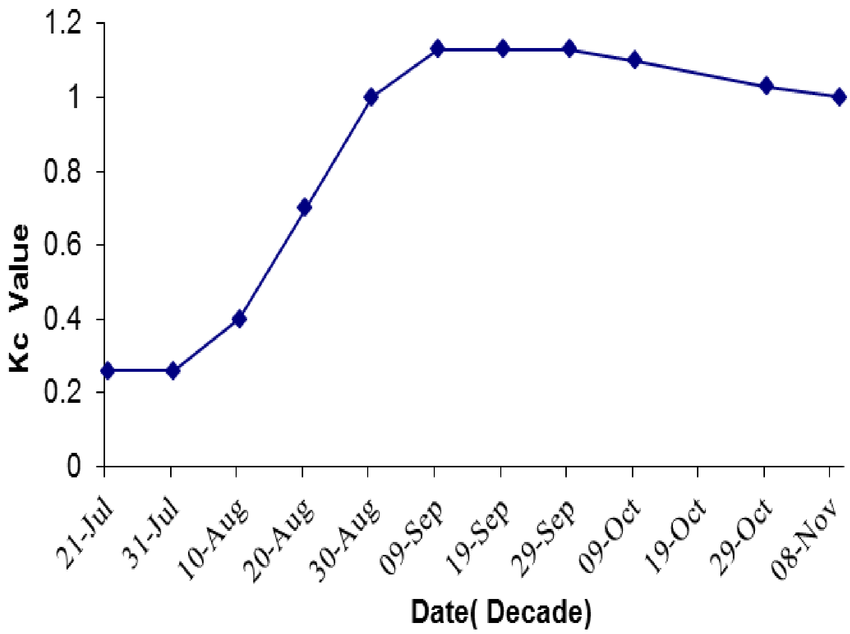

Fig. 1. K_C Value for corn fitted to the experimental site condition.

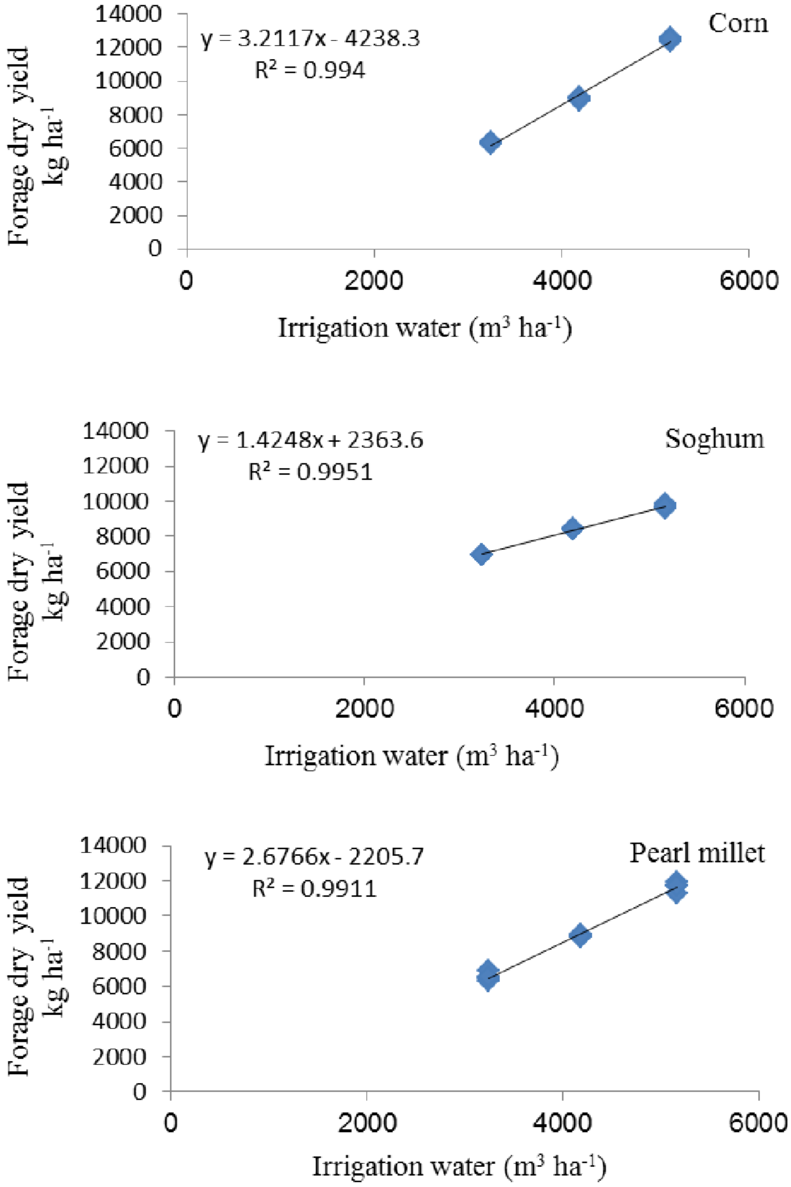

Fig. 2: Relationship between forage dry yield of corn, sorghum, and pearl millet with amount of irrigation water

Forage quality

Crop species and irrigation treatment had significant influence on forage quality (Table 7). The interaction of plant × irrigation was significant only on NDF, DMI and RFV values (Table 7). Pearl millet had the highest CP content (117. 2 g kg^{-1} DM) and protein yield (1,047 kg ha^{-1}) among the three species. Higher leaf to stem ratio in pearl millet compared with sorghum and corn could justify the higher CP content of millet. The results of experiment 1 and findings by Ward et al. (2001) well support these outcomes. Deficit irrigation led to an improvement in CP content in forage species which is consistent with earlier reports by Jahanzad et al. (2013) on sorghum, Rostamza et al. (2011) on pearl millet and Crasta and Cox (1996) in corn. Increase in CP content as a result of water stress could be explained by rising in nitrogen concentration in plant tissues under drought stress (Jensen et al., 2003). Despite an increase in CP content of plants under deficit irrigation, protein yield followed an opposite trend due to significant reduction in dry matter production.

The highest WSC content was recorded for corn which was considerably higher than the other two forage crops (Table 7). WSC content did not significantly respond to drought stress. Lower WSC results in poorer silage quality (Ward et al., 2001); therefore, corn is a more suitable silage crop compared with sorghum and pearl millet.

ADF and NDF were higher in pearl millet followed by sorghum (Table 7 and 8). Other researchers also reported higher content of fiber, especially NDF in sorghum than corn (Marsalis et al., 2010). Deficit irrigation increased ADF and NDF content of all three species. Haung and Duncan (1997) reported that drought stress may stimulate forage structural carbohydrates content (fiber) which leads to a reduction in forage digestibility. Increase in insoluble fibers in cell walls is one of the physiological responses of plants towards water stress to prevent moisture loss under water stress conditions (Keshavarz Afshar et al., 2012).

Among the three crops, corn had the highest value of DDM, DMI and TDN (Table 7). TDN refers to nutrients that are available for livestock and is related to the ADF content in forages. In parallel to ADF increase, TDN content decreases which limits animal's ability to utilize the nutrients (Jahanzad et al., 2013). Deficit irrigation imposed negative impacts on TDN, DMI and DDM. Similarly, it has been reported that water deficiency increased the amount of structural carbohydrates and fibers which in turn lowered forage digestibility (Haung and Duncan, 1997).

The highest value of NE_L (1.7 Mcal kg^{-1}) and RFV (123.9) was found in corn which was significantly higher than sorghum and pearl millet (Table 7). Forages with higher RFV are more digestible and palatable. Similarly, higher NE_L and RFV for corn compared with sorghum and millet have been reported (Marsalis et al., 2010). Deficit irrigation caused a significant reduction in NE_L and RFV value in all three species (Table 7). Experiment 2 reconfirmed that corn had higher forage quality than sorghum and pearl millet, but contained lower crude protein.

Table 7. Forage quality indices of corn, sorghum and pearl millet as affected by irrigation treatment.

Treatment	CP g kg^{-1} DM	Protein yield kg ha^{-1}	DMI	TDN g kg^{-1} DM	DDM	NDF g kg^{-1} DM	ADF g kg^{-1} DM	WSC g kg^{-1} DM	NE_L Mcal kg^{-1}	RFV
Plant species										
Corn	95.6b	879.4b	22.2a	693.5a	695.9a	542.6c	247.9c	356.0a	1.7a	119.5a
Sorghum	92.9b	771.6c	21.1b	612.3b	646.9b	569.8b	310.7b	229.9b	1.5b	105.7b
Millet	117.2a	1047.1a	17.0c	490.7c	573.5c	713.6a	405.0a	118.4c	1.2c	75.6c

Irrigation Treatment										
I_{100}	97.1b	1099.6a	21.1a	618.7a	650.7a	572.1c	305.8b	225.4a	1.5a	106.9a
I_{75}	103.6ab	906.9b	19.8b	589.8b	633.3b	618.5b	328.2a	238.0a	1.4b	98.3b
I_{50}	104.9a	691.6c	19.3b	588.0b	632.3b	635.4a	329.6a	240.9a	1.4b	95.6b
LSD	**6.045**	**27.9**	**0.5821**	**24.805**	**14.967**	**17.821**	**19.214**	**19.848**	**0.0504**	**4.0189**
Level of significance										
Plant	**	**	**	**	**	**	**	**	**	**
Irrigation	*	**	**	*	*	**	*	NS	*	**
Plant × irrigation	NS	NS	**	NS	NS	**	NS	NS	NS	**

CP, crude protein; DMI, dry matter intake; TDN, total digestible nutrient; DDM, digestible dry matter; NDF, neutral detergent fiber; ADF, acid detergent fiber; WSC, water soluble carbohydrate; NE_L, net energy for lactation; RFV, relative feed value.

Irrigation treatments: I_{100}, I_{75} and I_{50} means providing 100%, 75%, and 50% of the corn estimated water requirement, respectively.

Within columns, means followed by the different letters are significantly different at $P \leq 0.05$

**, * and NS means significant at $P \leq 0.01$, significant at $P \leq 0.05$, and no significant, respectively.

Table 8. Interaction effect of crop species and irrigation treatment on forage quality indices of corn, sorghum and pearl millet

Plant species	Irrigation tretament	Protein yield kg ha^{-1}	NDF g kg^{-1} DM	DMI	RFV
Corn	I_{100}	1153.0b	531.0de	22.6a	123.9a
	I_{75}	878.2d	522.3e	22.0ab	116.7b
	I_{50}	607.0g	549.4de	21.9ab	118.0ab
Sorghum	I_{100}	856.9d	556.3d	21.6b	108.7c
	I_{75}	791.7e	558.2d	21.5b	107.1cd
	I_{50}	666.2f	594.9c	20.2c	101.3d
Pearl millet	I_{100}	1289.0a	628.9b	19.1d	88.2e
	I_{75}	1050.7c	750.1a	16.0e	71.1f
	I_{50}	801.5e	761.9a	15.8e	67.5f
LSD		**47.9**	**29.1**	**1.0**	**6.7**

NDF, neutral detergent fiber; DMI, dry matter intake; RFV, relative feed value.

Within columns, means followed by the different letters are significantly different at $P \leq 0.05$

Irrigation treatments: I_{100}, I_{75} and I_{50} means providing 100%, 75%, and 50% of the corn estimated water requirement, respectively.

CONCLUSION

Results of this study showed that corn, sorghum and pearl millet differed in their responses to deficit irrigation. Deficit irrigation reducedforage production which was more profound in corn and pearl millet than in sorghum. It was concluded that under optimum irrigation condition corn out-yielded sorghum and pearl millet with considerably higher forage quality. However, under moderate water deficiency pearl millet can substitute corn to produce high quality forage with acceptable yield. If the scarcity of irrigation water is more crucial, sorghum could potentially be a good substitute for corn and pearl millet.

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تقييم إنتاجية ونوعية الذرة البيضاء والدخن كبديل عن علف الذرة الصفراء تحت احتياجات نظامي الري العادي والمتناقص

محمد رظا شاهانسوز[1*]، رظا كيشافارز افشار[1]، حسن حيدري[2]، مسعود هاشمي[3]

ملخــص

أُجريت تجربتان لتقييم امكانية زيادة تنوع الحبوب الشتوي معتمدة على أنظمة الزراعة المتداخلة وتأثرها بالنقص في مياه الري. ففي التجربة الاولى (1) كان انتاج الاعلاف ونوعيتها لثلاثة أنواع من هجائن الذرة الصفراء، وثلاثة من الذرة البيضاء، وثلاثة أصناف من الدخن (ذنب الثعلب، والعادي، والدخن اللؤلؤي) تم تقييمها. وبناءً على النتائج، تم اختيار الذرة الصفراء الهجين أس.سي. 704، والذرة البيضاء صنف العملاق (جنبو) والدخن "لؤلؤة" لدراسات موسعة. وفي التجربة الثانية، فإن تأثير معاملات الري I_{100}، I_{75}، I_{50} (تزويد 100% و 75% و 50% من متطلبات المياه على التوالي) تم دراستها على تلك المحاصيل. أظهرت النتائج أن الذرة البيضاء تحملت الجفاف أكثر من الذرة الصفراء والدخن باستثناء I_{50} حيث أعطت كمية انتاج اقل. كان أعلى انتاج للمعاملة I_{100} عند الذرة الصفراء ثم للدخن اللؤلؤي. إن الهبوط بنسبة 25% في كمية مياه الري سبب انخفاض في انتاج الذرة الصفراء والذرة البيضاء والدخن بنسب 28 و 13 و 24% على التوالي. كانت الذرة الصفراء أعلى قيمة الهضم وقيمة العلف النسبي (RFV) أدى نقص مياه الري لارتفاع كمية البروتين الخام (Crude Protein) والياف حامض الغسيل (ADP) أدى الى انخفاض ملحوظ في قيمة العلف النسبي (RFV) وفي قيمة الهضم. في النباتات الثلاث بينت النتائج أن الدخن اللؤلؤي والذرة البيضاء تُعتمَد بدائل مقبولة للذرة الصفراء في انظمة الزراعة المتبادلة تحت أنظمة الري المتناقص.

الكلمات الدالة: إجهاد الجفاف، زراعة متداخلة، جودة الاعلاف، دخن لؤلؤي، كفاءة استعمال المياه.

[1] قسم المحاصيل وتربية النباتات، كلية الزراعة والموارد الطبيعية، جامعة طهران، كراج إيران
jahansuz@ut.ac.ir
[2] قسم المحاصيل وتربية النباتات، كلية الزراعة، جامعة رازي كيرمانشاه، كيرمانشاه، ايران
[3] كلية ستوكبريدج الزراعية، جامعة ماساشيوسيتس، ام هيرست، الولايات المتحدة
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