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Assessing the Productivity and Effectiveness of Various Sorghum (Sorghum bicolor L. Moench) Genotypes in Semi-arid Environments

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Abstract

Jordan as a Mediterranean country is facing climatic change which results in increasing temperatures and a reduction in precipitation. So, there is a need to find sorghum genotypes that can resist such variations in environmental conditions. Field experiments were conducted under semi-arid conditions at the Dir-Alla agriculture research station in Jordan Valley to evaluate eight sorghum genotypes (ICSV_745, CSV_93046_9, CSV_15, JJ_1041, ICSV_112, S_35, ICSR_93034, EZRA' 7) for their stability, above-ground biomass, seed yield, and number of cuts under drought-prone environment. Results showed genotypic differences in WUE, above-ground biomass, seed yield, and HI. WUE increased with an improved HI leading to higher above-ground biomass. Linear relationships were observed between aboveground biomass, HI, and WUE. The results showed differences between the first cut compared to the following cuts. We recommend using VSV-15 with the highest value for both above-ground biomass and seed yield, followed by S_35. The S-35 showed optimistic potential to be used as fresh green forage when the whole plant is used at maturity, or can simply utilize the highest fresh weight achieved from its first cut.

Keywords: semi-arid, Jordan Valley, sorghum, climate change, above-ground biomass, Sorghum bicolor L.

1. Introduction

One of the perilous defies that face the world is the necessity to fulfill the food requests of the intensely rising population (Al-Ghzawi et al., 2018). The world population is estimated to rise by 34% by 2050, with an extra 2.3 billion people, based on the FAO forecasts (FAO, 2009). To confirm worldwide growth, cereal production must be increased by 43% on a global scale. This growth will be enhanced by changing climate and new defies facing agriculture (Barbeau et al., 2015; Al-Ghzawi et al., 2019). The most significant obstacle to agricultural productivity in arid and semi-arid regions is water, which is usually caused by low and/or uneven rainfall distributions (Jahanzad et al., 2013, Keshavarz et al., 2014). Crop growth depends on climate as plant physiological processes react directly to changes in temperature and moisture availability (McKenzie and Andrews, 2010). These factors have numerous impacts on established plant behaviors, including defects in photosynthesis, reductions in leaf area, and the sugar content of cereals including sorghum (Sorghum bicolor L.) (Plaut, et al., 2004).

Several studies have been conducted to improve crop production including sorghum to fulfill the higher demand to face the expected increase in world population. Since the future scenarios of climate change predict decreasing precipitation and increasing temperature, Jordanian scientists demonstrated that sustainable cereal yield growth is crucial, and new breeding strategies are needed to develop high-yielding, stress-resistant genotypes. Developing new genotypes with improved drought adaptation and increased yield per unit area is also essential for crop improvement under rainfed conditions in Jordan (Al-Abdallat et al., 2017).

In Jordan, the climate varies considerably across different regions. For instance, the western areas experience a Mediterranean climate, marked by hot, dry summers and mild, wet winters (Al-Bakri et al., 2011). Rainfall in this region exhibits notable variability both within and between years. The climate in the highlands of Jordan and its surrounding areas is characterized by mild summers and cold winters (Al-Bakri et al., 2011). Rainfall starts in October up to March. The annual rainfall ranges from 30 to 100 mm in the steppe desert, while it exceeds 600 mm in the highlands, with significant variability between and within the regions. Rainfall decreases while moving from west to east and from north to south. Since almost 91.4% of Jordan's land is desert and has no economic significance except from occasional, short-term grazing during specific seasons of the year, the country is categorized as a low rainfall zone (Al-Karablieh and Jabarin, 2010). According to the Third National Communication on Climate Change produced by Jordan in 2014 (MoEnv, 2014), it is predicted that Jordan is anticipating a warm climate with possible temperature increases of 2.1 ºC to 4 ºC by the end of the

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century. It also expects a dry climate with potential cumulative precipitation decreases of up to 21%, particularly in the western region of the country, and more frequent and severe droughts.

Sorghum is the fifth-most significant cereal crop regarding global sowing and distribution (Kimber, 2000, Gognsha and Hiruy, 2020). Rainfed crops adapted to dry climates in arid and semiarid environments (Saddam, S. et al., 2014) and are utilized for both seed and biomass purposes as food, fodder, forage, and biofuel (Assefa et al., 2020; Bollam, 2021; Ostmeyer et al., 2022). Sorghum forage production is influenced by various factors such as high-yielding cultivars, effective weed control strategy, seed vigor, sowing date, and depth, fertilizer, and irrigation. Because it can withstand unusual abiotic challenges like heat and drought (Pennisi, 2009; Chiluwal et al., 2018), use available resources efficiently (Van Oosterom et al., 2001, Qi et al., 2016), and adapt genetically to a variety of ecological conditions with limited water and soil fertility (Ahmad, W., et al., 2016), it is a great alternative feed source. It also shows promise for future growth. (Bibi and others, 2012).

In Jordan, Sorghum is not well known and is distributed as animal feed and mostly grown by limited resource farmers with low inputs and limited resources. Sorghum is planted in very small quantities in Jordan as a winter crop (FAO, 2022). Therefore, the objective of the current study was to evaluate the productivity of sorghum grown under full irrigation using mixed water (fresh and treated wastewater) effluent based on potential evapotranspiration calculated from meteorological data.

2. Materials and Methods

2.1. Study area and site description

This study was conducted at Deir-Alla Regional Agriculture Research Center, Located in Jordan Valley at 35°37´N longitude, 32° 13´ E latitude, and 224 m below sea level. Deir-Alla has a semi-arid climate with warm winters (minimum temperature is 15 ºC) scorching summers and an average of 280 mm of yearly rainfall. The mean yearly temperature is 30 ºC. In summer, the typical relative humidity is 30% compared to 70% in winter. The area experiences erratic rainfall patterns and is particularly vulnerable to drought. A potential evapotranspiration measures 2175.065 mm. The soil is extremely calcareous and non-saline.

2.2. 2.2 The experimental design and field experiment

2.2.1. water and irrigation schedules

The King Talal Dam (KTD) at the Zarqa River provided the study area's water resources through pressurized convey pipes. The water's moderate salinity ranges from 1.4 dS m-1 in the winter to roughly 3.0 dS m-1 in the summer, which could have a negative impact on salt accumulation in the soil profile and the degradation of land productivity.

Based on potential evapotranspiration calculated using the Penman-Monteith equation from meteorological data, the drip irrigation method used various kinds with mixed water effluent from King Talal Dam as full irrigation. It was used with 0.4 meters between lateral emitters and inline emitters (4 l h^{-1}). Disc filters was employed to reduce clogging of the water outflow to achieve and maintain irrigation efficiency. A drip irrigation system with four-liter-per-hour inline emitters spaced 40 centimeters apart and 40 centimeters apart between lateral lines based on the water demand of the crop (every 10 days).

To make sure that the water content in the soil was within the permitted range (75% of field capacity), soil water content was measured for each location at three distinct soil depths: 0–20, 20–40, and 40–60 cm. Soil water measurements were obtained in the time domain "Trime -FM3 TDR" (Imko GmbH, Ettlingen, Germany) using a reflectometer. Experimental plots were managed following the standard practices of the National Agriculture Research Center (NARC) including the application of fertilizers and pathogen and weed control.

2.2.2. cultivation and experimental design

At the end of June 2019, eight different Sorghum genotypes (ICSV_745, CSV_93046_9, CSV_15, JJ_1041, ICSV_112, S_35, ICSR_93034, EZRA' 7) were planted at Dair Alla agricultural station. The eight genotypes were grown in a randomized complete block design with twelve replications. Four replicates were kept for harvest, while the other eight replicates were used for growth analysis throughout the growing season. The plot area was 3 m^2 with 8 rows (0.40 m apart and 3.2 m long). The eight cultivars were randomly distributed in each plot, and two rows were cultivated with EZRA' 7 as borders to avoid edge effect.

To evaluate the crop productivity throughout the season, four replicates were kept to measure green above-ground biomass at harvest (before pod formation) with no cuttings throughout the season. The other four replicates were used to measure seed production at maturity (4 replicates) with no cuttings throughout the season, while the rest of the replicates (4 replicates) were cut three times throughout the season to measure the green above-ground biomass at three different growth stages to examine progressive vegetative growth (i.e. fresh forages from different cuts were subjected to air drying).

The first cut was harvested 65 days after planting; the second cut was taken 35 days after the first cut; and the third cut was taken at harvest time (physiological maturity), leaving at least 10 to 18 cm of stubble for fast recovery purposes following each cut.

The following traits were measured: Number of Branches Plant Height (cm); Stem Diameter (cm); Brush Length (cm); above-ground Biomass Fresh Weight (ton/ha); above-ground Biomass Dry Weight (ton/cut); Total Mature Fresh above-ground biomass (ton/ha); Total Mature Dry above-ground biomass (ton /ha); Seed Yield (ton /ha). Data for forage above-ground biomass & seed yields were calculated based on plants cut at ground level (net plot area) after physiological maturity (total above-ground biomass) or needed growth stage (cut). The height of the plant (cm) measured at 50% of its linear meter blooming from the bottom to the top. The green forage above-ground biomass per plot were determined using a spring balance and converted into fresh above-ground biomass weight per hectare, the dried plants were weighed again using a precision balance after being left in the sun for 10 days to determine the dry weight (DW). The weight loss percentage was calculated by dividing DW / FW by 100 for each sample.

2.3. Water Use Efficiency and HI

Three WUEs were calculated as water use efficiency at maturity fresh weight, at maturity dry weight, and seed harvesting, measuring fresh weight / each cut and dry weight/cut. The water use efficiency (WUE) was calculated by dividing the produced above-ground biomass weight (fresh above-ground biomass, dry above-ground biomass, and seed weight) per amount of water applied (m^3). Harvest Index (HI): the weight of grain produced expressed as a proportion of the total weight of the plant.

2.4. Statistical Analyses

A Turkey-Kramer test within JMP statistical software version 11.0.0 (SAS Institute Inc., 2011) was used to evaluate the differences in means for all crop parameters among different Sorghum genotypes. The test is a genuine test with a 95% confidence level.

3. Results and Discussion.

Significant differences (P≥0.05) were observed among the eight tested genotypes in terms of plant height, stem diameter, and brush length (Table 1). Plant heights range from 97.0 cm in EZRA' 7 to 226 cm in ICSV_93046_9. Similarly, the stem diameter ranged from 1.4 cm in JJ_1041 to 2.20 cm in EZRA' 7. The brush length was 21.00 cm in S_35, followed by 20.88 cm in ICSR_93034, and the least was seen in EZRA' 7 with 8.96 cm.

Table 1. Comparison of mean physical parameters of different genotypes of sorghum*

Genotypes	Number of Branches	Plant height	Stem Diameter	Brush Length
		cm		
ICSV_745	4.8a	118.8g	2.02b	19.25e
ICSV_93046_9	3.3e	226.0a	1.91e	18.96f
CSV_15	4.3b	176.8d	1.78f	18.67g
JJ_1041	3.8d	200.3b	1.40h	20.42c
ICSV_112	4.0c	142.0f	1.68g	20.21d
S_35	2.8f	187.3c	1.99c	21.00a
ICSR_93034	3.8d	150.8e	1.97d	20.88b
EZRA' 7	4.8a	97.0h	2.20a	8.96h

*Means followed by the same letter are not statistically significant at P<0.05

S-35 genotype showed optimistic potential to be used as fresh green forage (147.6 ton/ha) when the whole plant is used at maturity, while EZRA' 7 was the lowest (32.9 ton/ha; Table 2). S-35 ranked first among the genotypes and yielded 147.6 ton/ha of above-ground biomass (Table 2). The same trend was observed in the three cuttings with a total of 138.2 ton/ha (Table 4). S-35 produced 41.3 ton/ha still has the highest dry weight (Table 2), followed by ICSR93034 (40.2 ton/ha), while the least dry weight was produced by EZRA' 7 (8.3 ton/ha). Table 2 illustrates that S-35 loses 72% of its original fresh weight, which represents a moderate value of percentage water loss compared to the rest of the genotypes. The highest percentage of water loss was seen at ICSR93034 with 90.3%, followed by CSV-15 with 88%, while EZRA' 7 lost just (43.4 %) as the least weight loss. WUE followed the same trend as fresh above-ground biomass weight, in that S-35 showed the highest value with 9.84 kg/m^3, as well as in the case of dry above-ground biomass weight with 2.75 kg/m3. EZRA' 7 has the lowest WUE value (2.19 & 0.55 kg/m3) at fresh and dry above-ground biomass respectively

Table 2. aboveground biomass (ton/ha) and WUE (kg/m^3) *

Genotypes	Aboveground biomass ton/ha (Yield)		%weight loss after drying	Aboveground biomass WUE (kg/m3)	
	Fresh	Dry		Fresh	Dry
ICSV_745	110.1d	28.0e	71.35937c	7.34d	1.87e
ICSV_93046_9	126.4c	32.0c	77.48677b	8.43c	2.14c
CSV_15	136.2b	28.6d	88.00977a	9.08b	1.91d
JJ_1041	65.3g	16.5g	62.16353d	4.35g	1.10g
ICSV_112	97.4e	24.6f	57.48891e	6.50e	1.64f
S_35	147.6a	41.3a	72.53442c	9.84a	2.75a
ICSR_93034	85.9f	40.2b	90.28372a	5.72f	2.68b
EZRA' 7	32.9h	8.3h	43.36373f	2.19h	0.55h

*Means followed by the same letter are not statistically significant at P<0.05.

3.1. Seed Production and WUE

The seed yield (Table 3) showed CSV_15 with 12.72 ton/ha as the highest value, followed by JJ_1041 with 11.36 ton/ha. In contrast, the ICSR_93034 and ICSV_745 genotypes show the least seed yield of 0.06 ton/ha. The same trend is shown in terms of seed WUE, in that the CSV_15 genotype exhibits the highest WUE value with 0.85 kg/m^3 followed by JJ_1041 with 0.76 kg/m^3, while the lowest value is seen at ICSR_93034 with a 0.004

kg/m^3. The highest HI value was seen for JJ_1041 genotypes with 0.687, and the lowest HI value was seen at the S-35 genotype.

Table 3. Seed productivity of different genotypes of sorghum at maturity*

Genotypes	Seed wt. ton/ha (Yield)	Seed WUE (kg/m^3)	HI
ICSV_745	0.06g	0.004g	0.002g
ICSV_93046_9	2.05d	0.137d	0.064e
CSV_15	12.72a	0.848a	0.444b
JJ_1041	11.36b	0.757b	0.687a
ICSV_112	5.22c	0.348c	0.212c
S_35	1.59e	0.106e	0.039f
ICSR_93034	0.06g	0.004g	0.001h
EZRA' 7	1.30f	0.087f	0.156d

*Means followed by the same letter are not statistically significant at P<0.05.

3.2. Productivity of sorghum genotypes at various cuts.

Table 4 shows the extent of statistical significance in the first cut (P≥0.05). The S-35 genotype showed the highest above-ground biomass obtained in the first cut with a 92.2 ton/ha, as well as WUE with a 13.2 ton/m^3, followed by the ICSR-93034 genotype with an 86 ton/ha above-ground biomass and a 12.3 kg/m^3 WUE. The lowest value was shown in EZRA'7 with 48.3 ton/ha of aboveground biomass and 6.9 kg/m^3 for WUE.

Table 4. Productivity of different genotypes of sorghum at different cuts*

Genotypes	Cut1		Cut2		Cut3		Total Yield		Average WUE	
	Yield	WUE	Yield	WUE	Yield	WUE	Fresh	Dry	Fresh	Dry
	ton/ha	kg/m3	ton/ha	kg/m3	ton/ha	kg/m3	ton/ha		kg/m3	
ICSV_745	70.8f	10.1f	64.5b	12.9b	5.7g	0.99g	141.0c	42.3c	8.00b	2.38c
ICSV_93046_9	85.2c	12.2c	48.6d	9.7d	7.9d	1.37d	141.6b	45.9b	7.75c	2.58b
CSV_15	77.6e	11.1e	33.3h	6.7h	3.9h	0.67h	114.8h	34.4g	6.14h	1.94h
JJ_1041	65.0g	9.3g	56.3c	11.3c	7.2e	1.24e	128.5f	38.5f	7.26g	2.17f
ICSV_112	84.6d	12.1d	44.0f	8.8f	11.4c	1.99c	140.0d	42.0d	7.62d	2.37d
S_35	92.2a	13.2a	40.2e	8.0g	5.8f	1.00f	138.2e	41.5e	7.41e	2.31e
ICSR_93034	86.0b	12.3b	68.3a	13.7a	13.7b	2.38b	168.1a	50.4a	9.45a	2.84a
EZRA' 7	48.3h	6.9h	47.2g	9.4e	32.0a	5.56a	127.5g	38.4g	7.30f	2.16g

*Means followed by the same letter are not statistically significant at P<0.05.

The results of the second cut demonstrate variations in above-ground biomass cuts and WUE. ICSR-93034 genotype demonstrates the highest above-ground biomass with 68.3 ton/ha as well as with a WUE of 13.7. kg/m^3, followed by ICSU-745 with 64.5 ton/ha and a WUE value of 12.9 kg/m^3. On the other hand, the values that were the lowest in WUE (Table 4) were seen at CSV_15 with 33.3 ton/ha and a WUE of 6.7 kg/m^3.

On the other hand, in the third cut, the EZRA' 7 genotypes showed the highest above-ground biomass with 32.0 ton/ha as well as with a WUE of 5.56. kg/m3. Followed by ICSR_93034 with 13.7 ton/ha and a WUE of 2.38 kg/m3. The lowest above-ground biomass in the second cut was seen for ICSV_745 with 5.7 ton/ha and a WUE of 0.99 kg/m3. The total above-ground biomass obtained as a sum of all the three cuts illustrated in Table 4 showed that ICSR_93034 has the highest above-ground biomass with 168.1 ton/ha and a WUE average value of 7.3 kg/m3, whereas CSV_15 had the lowest above-ground biomass, measuring 114.8 tons/ha and having a WUE of 34.4 kg/m3..

4. Discussion

Currently, Jordan's mean annual temperatures have increased dramatically, and this increase has been accompanied by less and unequal precipitation distribution (Ormann, 2018). This effect was seen in changes in vegetative cover deterioration and reduction in dominated genotype production (Aukour et al., 2013). Consequently, using well-adapted germplasm is a useful strategy to mitigate climate change related to heat stress and drought (Fita et. al., 2015; Al-Ghzawi et al., 2017). Predictions indicate that water demand will rise significantly owing to population growth, climate change, and the development of agricultural practices. Therefore, plant breeders are focused on creating water-use-efficient cultivars to avoid heat stress and drought in order to preserve sustainable agricultural production.

Sorghum is a vital crop in drier areas assisting more than 500 million people (Yahaya et al., 2021). It is a reasonably drought-tolerant crop adapted to cultivate and yield in marginal locations where it is difficult to other leading crops such as maize and wheat to survive. However, the yield of sorghum in the semi-arid regions is still below the world average of 2.5 ton/ha, primarily due to repeated droughts and heat stress. Therefore, the objectives of this study were to assess the impact of drought stress on eight sorghum genotypes to identify their ability to withstand semiarid conditions in the Jordan Valley. Results showed differences among tested genotypes. At maturity, statistical analysis for the whole cultivated (without cut) plants showed significant differences among genotypes regarding above-ground biomass, percentage of weight loss after drying, and WUE for above-ground biomass. In other words, sorghum genotypes varied in their adaptation to arid environments and thus their aboveground biomass at drought-prone conditions. This was consistent with Zegada-Lizarazu et al. (2012) and Bani Hani et al. (2022), who demonstrated that Under drought stress, WUE is the main concern rather than the production itself, keeping in mind that WUE is the amount of above-ground biomass produced per unit of water used. Indeed, the current study revealed that WUE is the determinant of yield under stress and even as a component of crop drought resistance, since genotypes with the highest WUE produce the highest above-ground biomass and seed yield. In the current study, JJ_1041 genotypes showed the highest HI followed by CSV_15 as the most tolerant genotypes to the semiarid environment, while the least tolerant genotype (ICSR_93034), had the lowest HI values. This indicates that this genotype is non-tolerant to drought and cannot grow properly. These results suggested that HI can be a useful indicator by breeders for sorghum tolerance to semi-arid environments.

The current study showed a converse relationship was observed between the above-ground biomass production and the number of cuts. It is noticeable that in all genotypes above-ground biomass yield is reduced by repeated cuts, whereas the third cut yield is always the lowest in all genotypes. On the other hand, all other genotypes show that the WUEs were high in the second cut compared to the third cut. The results showed a slight difference in the case of the first cut compared with the second cut. For example, in the first cut, S-35 sorghum genotypes do not conserve the same orientation as other genotypes, the production value drops to the closest lower value. The genotype S-35 showed the highest WUE at the first cut which might be related to high production records when compared to other genotypes. Variations in WUE are shown in the second cut results, with ICSR-93034 showing the highest value and ICSU-745 following. In the second cut, the above-ground biomass obtained in all genotypes was less than that in the first one. ICSR_93034 genotype showed the highest above-ground biomass as well as WUE, while S-35 became the fifth genotype in harvested above-ground biomass. The same trend was seen in the third cut in which EZRA' 7 showed the highest above-ground biomass as well as the highest WUE. Additionally, the sum of the above-ground biomass from the three cuts revealed that ICSR_93034 had the highest above-ground biomass and WUE, while S-35 had the freshest above-ground biomass from the entire plant and CSV_15 had the lowest above-ground biomass and WUE. From all the above, the results show that the S-35 genotype has a high level of above-ground biomass production. This genotype has the potential to be drought-resistant and can be used as a substitute for animal feeds in Jordan, provided that continuous feeds are obtained through multiple rapid cultivations, first cut, or the entire plant. In terms of propagation characteristics, Sorghum JJ_1041 yielded 11.36 tons/ha, which was less compared to the highest seed output of 12.72 tons/ha produced by CSV_15. However, the S_35 genotype had a significantly low seed yield of just 1.59 tons/ha, indicating its inability to reproduce well under dry and drought-prone conditions

5. Conclusions

Results presented in this study showed that as the number of cuts increased during the sorghum lifespan, above-ground biomass decreased. A significant difference is presented among genotypes. Also, the high HI genotype had high WUE, hence producing more above-ground biomass and seed yield. To cultivate sorghum for dual purposes (fresh above-ground biomass and seed production), it is recommended to use VSV-15 with the highest value for both above-ground biomass and seed production.

Ethical Responsibilities of Authors

The manuscript is not under consideration or submitted to other journals for simultaneous consideration. The submitted work is original and has not been published elsewhere in any form or language (partially or in full).

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