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EFFECTS OF DIFFERENT WATER STRESS LEVELS ON BIOMASS YIELD AND AGRONOMIC TRAITS OF SWITCHGRASS (*Panicum virgatum* L.) VARIETIES UNDER SEMI-ARID CONDITIONS*

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ABSTRACT

This experiment was conducted to determine the effects of different water stress levels on biomass yield, plant height, number of stalks per meter, single stalk weight, yield reduction ratios and irrigation water use efficiency (IWUE) values of switchgrass (Panicum virgatum L.) varieties under Central Anatolia conditions. The study was conducted for two years (2016 – 2017) in the Randomized Complete Block Design arranged in split plots with three replications under Konya ecological conditions. Six switchgrass varieties (Shelter, Alamo, Cave in rock, Shawnee, Kanlow and Trailblazer) and five different irrigation treatments (water stress levels: S1: Full irrigation; S2: 75% of full irrigation; S3: 50% of full irrigation; S4: 25% of full irrigation and S5: Rain-fed without irrigation) were used in this experiment.

Kanlow, Alamo and Trailblazer varieties had greater biomass yields than the other varieties in all water stress treatments. Under different water stress treatments, dry biomass yields varied between 48300 kg ha-1 (S5- Cave in rock) and 25120 kg ha-1 (S1- Kanlow); plant heights varied between 70 cm (S5) and 180 cm (S1); number of stalks per meter varied between 221 (S5) and 356 (S1); single stalk weights varied between 0.56 g (S5) and 2.25 g (S1). IWUE was calculated as 5.7 kg m-3 for the first harvest and as 2.1 kg m-3 for the second harvest. Considering the biomass yields from single harvest of rain-fed treatments (S5) and two harvests of the other irrigation treatments (S1-S4), IWUE values and water deficits of the region, it was concluded that single harvest was more suitable for switchgrass plants grown under ecological conditions.

Keywords: Biomass yield, climate change, switchgrass, water stress, yield components.

INTRODUCTION

In Turkey, Central Anatolia region and especially the Konya basin is the arid region. The basin has quite low annual precipitation and water resources are not sufficient to irrigate the agricultural lands. Konya basin has 1.8 billion m^3 available water potential, but annual amount of water used in the region is around 2.6 billion m^3 (Anonymous, 2009). Therefore, there is a significant water deficit in the basin and such a case exerts serious threats on sustainability of water resources. Irregular and decreasing precipitations also decrease ground and surface water resources (Anonymous, 2009). Konya basin constitutes about 10% of agricultural lands of Turkey. Together with plant production, number of livestock also increased especially with state supports provided for agricultural sector. Such an increase in livestock inventory increased forage needs significantly. However, it is quite hard to meet such increasing needs with crop species grown under rain-fed conditions or crop species with less water consumptions.

Switchgrass is a perennial, environment-friendly warm season crop with a high water use efficiency (Xu et al., 2006), able to produce biomass under marginal and arid and semi-arid conditions (Parrish and Fike, 2005) and prevent soil erosion. Therefore, it is commonly used as low-cost silage material and forage source. Since it has quite a high biomass production capacity, it is also used in establishment of artificial pasture and in pasture improvement practices (Ma et al., 2000). There are two different ecotypes of switchgrass based on morphological characteristics and growing environments as of: upland (highland type) and lowland (plain type). Plant heights of switchgrass varies between 1-3 m. Lowland ecotypes generally have higher plant heights, thicker stalks and greater biomass and they are mostly used for bioethanol.

On the other hand, upland ecotypes are shorter plant heights, greater number of tillers, thinner stalks and they are mostly used as forage crop (Soylu et al., 2010).

North America-originated switchgrass is able to produce quite a high number of seeds, highly tolerant to cold and drought and has quite a high adaptation capacity. Soylu et al. (2010) conducted adaptation and growing experiments with switchgrass (*Panicum virgatum* L.) under Konya ecological conditions and obtained promising outcomes. Since switchgrass has less water use and able to grow under marginal conditions, it can be considered as an alternative forage crop in Konya basin with deficit irrigation levels.

This experiment was conducted to investigate the effects of different irrigation levels on yield and some yield components of six switchgrass varieties in Karapinar district of Konya province of Turkey. This region has high agricultural potential area but irregular and decreasing precipitation and insufficient water resources are important issues in this region. Alternative forage crop species that tolerant of drought is an important issue for this region.

MATERIALS AND METHODS

Experiment was conducted in Konya-Karapinar region (37^0 41' N and 33^0 30' E) for two years in 2016 and 2017. Six different switchgrass varieties obtained from USDA (United States Department of Agriculture) and foreign companies were used as the plant material of the experiments. Two of these varieties (Kanlow- Alamo) were lowland ecotypes commonly used for bioethanol production and four of them (Shawnee, Shelter, Trailblazer and Cave in rock) were upland ecotypes commonly used for forage production or grazing.

Long-term annual average precipitation of the experimental site is 291.12 mm and majority of this precipitation falls out of the growing season of switchgrass (November – April). Total precipitation was 286.2 mm in 2016 and 249.6 mm in 2017 and both values were lower than the long-term average. The lowest temperature was observed as -19.2 ºC in January of 2016 and as -18.7 ºC in February of 2017. These values were lower than the long-term average (-18.2 ºC in January). Thus, the extreme cold resistance of switchgrass varieties was also seen.

Soil samples were taken from 0-30, 30-60 and 60-90 cm soil profiles of the experimental site. Analyses revealed that experimental soils were sandy-clay-loam in texture with lime contents of between 28.9 - 33.5% (high), pH values of between 7.8 - 8.2, organic matter contents of between 0.7 - 1.3 (low) and salinity levels of between 0.42 - 0.45 dS m^{-1} (unsaline). Soil bulk density was 1.37 g cm^{-3} for 0-30 cm layer, 1.29 g cm^{-3} for 30-60 cm layer and 1.22 g cm^{-3} for 60-90 cm layer. Soil infiltration rate was measured as 10 mm h^{-1}.

The seeds were planted on 1st of July, 2015. In establishment year, fertilizers were applied at sowing as to have 100 kg P205 and 30 kg N per hectare. Considering germination and dormancy, it was planted with 400 plant m-2 (Soylu et al., 2010). Seeds were planted manually to 1 cm depth 15 cm row spacing and seedbeds were compacted. Experimental plots were 5 m long and 1.5 m wide (5 x 1.5 = 7.5 m2) and each plot had 10 rows. At the harvest, two rows from both side and 1 m sections from the top and bottom of the plots were omitted (harvest was made from 2.7 m2). The design of the experiment was the Randomized Complete Blocks arranged in split plots with 3 replications (5 water stress treatments x 6 varieties x 3 replicates = 90 plots). Main plots included water stress treatments (S1, S2, S3, S4 and S5) and sub-plots included switchgrass varieties (Kanlow, Alamo, Shelter, Trailblazer, Cave in rock and Shawnee). In full irrigation treatment (S1), irrigation water was applied when the 50-55% of available water capacity was depleted as to bring the soil moisture level to field capacity. In water stress treatments (S2, S3 and S4), respectively 75, 50 and 25% of full irrigation were applied. Irrigation was not practiced in rain-fed treatment (S5).

In establishment year between the planting (1 July 2015) and the end of September, 150 mm irrigation water was applied to each plot with sprinkler (the initial one) and drip irrigation systems as to provide homogeneous germination and emergence. In the establishment year, harvest was made 15 cm above the ground surface and winter was passed through. In the experiment, different water stress treatments were applied in 2016 and 2017 years. In both years, 150 kg ha^{-1} pure nitrogen was applied to experimental plots in May (Soylu et al., 2010).

Except for S_5 treatment, two cuttings were made in other irrigation treatments (S_1, S_2, S_3 ve S_4). The first cutting was made a week after 50% flowering stage as specified by Soylu et al. (2010) 15 cm above the ground surface with a motor scythe. Then harvested plants were weighed to determine fresh biomass yield of the first cutting. Irrigations were continued until the second harvest. Considering early autumn frosts, the second cutting was made on 19 October in 2016 and 10 October in 2017 and fresh biomass yield of the second cutting was determined.

For dry matter ratio, as specified by Muir et al. (2001), 500 g sample was weighed and dried in an oven at 70 ºC for 48 hours. Dry mater ratio was then multiplied by fresh biomass yield to determine dry biomass yield. Harvest date, plant height, number of stalks per meter and single stalk weights were determined according to the method applied by Muir et al. (2001).

Drip irrigation system was used to irrigate switchgrass plants. Amount of irrigation water applied to each plot was measured with a water meter. Irrigations were initiated when the 50-55% of the available water within 90 cm effective root zone was depleted. The first irrigation was practiced on 4th of May in 2016 and 17th of May in 2017. The last irrigation was practiced on 7^{th} of September in 2016 and 20^{th} of September in 2017. Following the determination of soil bulk density, field capacity and permanent wilting point, amount of irrigation water to be applied in full irrigation treatment (S_1) was calculated with the use of Equation 1 (Kara, 2011);

$$dn = \frac{(FC - CM) \times D}{100} \qquad (1)$$

where; dn = Net amount of irrigation water to be applied in each irrigation (mm);

FC = Field capacity (% volume basis);

CM = Current moisture when the 50-55% of available water within 90 cm rooting zone was depleted (% volume);

D = Effective root depth (mm).

Equation 2 was used to determine yield reduction ratio (Golestani and Assad, 1998);

$$Yr = 1 - (Ys/Yp). \qquad (2)$$

where; Yr = Yield reduction ratio (%);

Ys = Yield under stress (kg da^{-1});

Yp = Yield under irrigated conditions (kg da^{-1}).

In the experiment, the following equation (Equation 3) was used to determine irrigation water use efficiency (Howell et al., 1990):

$$IWUE = Y/I \qquad (3)$$

where; IWUE = Irrigation water use efficiency (kg m^{-3});

Y = Dry biomass yield (kg da^{-1});

I = Irrigation water quantity (mm).

Statistical analysis of experimental data was conducted using the JMP 11.2 statistical software according to Randomized Complete Block Design in split plots, and the LSD test was used to compare the means as described by Steel and Torrie (1980).

RESULTS AND DISCUSSION

This experiment was conducted for two years to investigate the effects of water stress treatments on biomass yield, some yield components, irrigation water use efficiency and yield reduction ratios of different switchgrass varieties. Data were initially subjected to homogeneity tests and then combined years were subjected to variance analysis. Fresh and dry biomass yield, plant height, number of stalks per meter, single stalk weight, irrigation water use efficiency and yield reduction ratio were significantly affected by water stress levels. Data were provided in tables as the average of two years and LSD $_{(0.05)}$ groupings were provided accordingly.

The amount of irrigation water

Applied amount of irrigation water in both years are given in Table 1. In the experiment, amount of irrigation water varied between 176.5 - 704 mm in 2016 and between 281 - 800 mm in 2017.

Table 1. Applied irrigation water quantities (mm)

Years	Irrigation period	S_1	S_2	S_3	S_4	S_5
2016	Irrigation water quantity until the first harvest	490	367.5	245	123	0
	Irrigation water quantity between the first and second harvest	214	160.5	107	53.5	0
	Total	704	528	352	176.5	
2017	Irrigation water quantity until the first harvest	436	327	218	109	0
	Irrigation water quantity between the first and second harvest	364	273	182	91	0
	Total	800	600	400	281	
2016-17 avr.	Irrigation water quantity until the first harvest	463	347.3	231.5	115.8	0
	Irrigation water quantity between the first and second harvest	289	216.8	144.5	72.3	0
	Total	752	564.1	376	188.1	

Fresh and dry biomass yields of the first harvest

The fresh and dry biomass yields of the first harvest are given in Table 2. As the average of two years, fresh biomass yields of the varieties varied between 33880 kg ha^{-1} (Cave in rock) and 58300kg ha^{-1} (Kanlow) and dry biomass yields varied between 10080kg ha^{-1} (Cave in rock) and 16440kg ha^{-1} (Kanlow). Trailblazer variety with thin stalk structure and potential use as forage crop was also prominent with fresh biomass yield of 42120 kg ha^{-1} and dry biomass yield of 13330 kg ha^{-1} just after Kanlow and Alamo varieties (Table 2).

As it was in previous experiments (Seflek, 2010; Zhu et al., 2014), lowland ecotypes of Kanlow and Alamo varieties had greater fresh and dry biomass yields than the upland ecotypes. Nasso et al. (2015) conducted an experiment in Italy and reported that dry biomass yields as 32500 kg ha^{-1} for lowland ecotype Alamo variety and as 16500 kg ha^{-1} for upland ecotype Blackwell variety. In another experiment conducted in Mediterranean climate zone, Wullschleger et al. (2010) reported dry biomass yield as 9000 kg ha^{-1} for upland ecotypes and as 13000 kg ha^{-1} for lowland ecotypes. Contrary to in this experiment results, Geren et al. (2016) reported that Cave in rock variety had high biomass yield in their experiment. This result is due to probably because of differences in climate and soil conditions and agronomic practices (Nasso et al., 2015).

Table 2. Fresh and dry biomass yields of the first harvest (kg ha^{-1})

		Water stress treatments						
	Varieties	S_1	S_2	S_3	S_4	S_5	Mean	
	Kanlow	94480 a	77770 c	62250 f	36650 j	19360 o	58300 a	
	Alamo	87220 b	72890 d	58630 g	33380 k	18650 o	54150 b	LSD (0.05)
FBY_1	Shelter	66650 e	49280 h	39140 j	29920 l	14500 p	39900 d	Variety: 1140
(kg ha^{-1})	Trailblazer	64820 e	51560 h	42960 ı	33890 k	17380 o	42120 c	Water: 1040
	Cave in rock	57680 g	44480 ı	32360 kl	23810 n	11970 p	33880 e	Variety *water: 2560
	Shawnee	57060 g	42320 ı	32570 k	26860 m	13250 p	34410 e	
	Mean	71330 a	56380 b	44650 c	30750 d	15850 e	43790	
F value (*Water stress: 46190; * Variety: 6270 ; *Water stress x Variety interaction: 510)								
	Shelter	20880 cd	15710 g	13120 ı	8660 kl	6170 no	12910 d	LSD (0.05)
	Alamo	23810 b	20460 d	17280 ef	9110 jk	7150 mn	15560 b	Variety: 470
DBY_1	Cave in rock	15720 g	12640 ı	10150 j	7040 mn	4830 p	10080 f	Water: 740
(kg ha^{-1})	Shawnee	16680 fg	13200 ı	9910 j	7820 lm	5750 op	10670 e	Variety *water: 1060
	Kanlow	25120 a	21630 c	18300 e	9660 jk	7500 m	16440 a	
	Trailblazer	21500 cd	17840 e	14430 h	10150 j	7700 lm	14320 c	
	Mean	20620 a	16910 b	13860 c	8740 d	6520 e	13330	
F value (*Water stress: 6460; * Variety: 2360; *Water stress x Variety interactions: 166)								

FBY_1 : First harvest fresh biomass yield DBY_1: First harvest dry biomass yield
*: significant at P ≤ 0.05. Means followed by the same letters are not different for P ≤ 0.05 according to LSD test.

Considering water stress x variety interactions, in S_1 treatments, the lowest and the greatest dry biomass yields were respectively obtained from Cave in rock (15720 kg ha^{-1}) and Kanlow (25120 kg ha^{-1}) varieties; in S_2 treatments, from Cave in rock (12640 kg ha^{-1}) and Kanlow (21630 kg ha^{-1}) varieties; in S_3 treatments, from Shawnee (9910 kg ha^{-1}) and Kanlow (18300 kg ha^{-1}) varieties; in S_4 treatments, from Cave in rock (7040 kg ha^{-1}) and Trailblazer (10150 kg ha^{-1}) varieties; in S_5 treatments without irrigation, from Cave in rock (4830 kg ha^{-1}) and Trailblazer (7700 kg ha^{-1}) varieties (Figure 1).

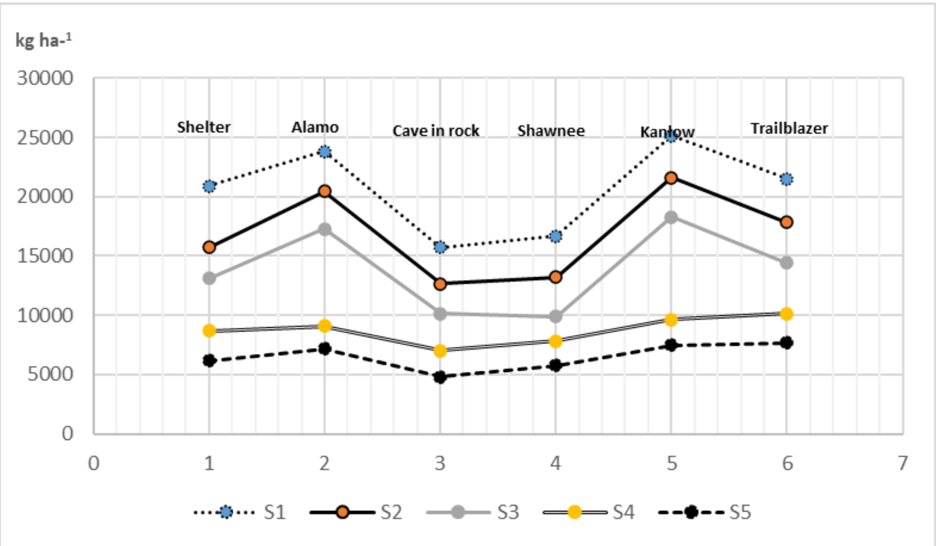


Figure 1. Change in the first harvest dry biomass yields of switchgrass varieties under different water stress levels

As can be inferred from Figure 1, lowland ecotypes of Kanlow and Alamo varieties and upland ecotype of Trailblazer variety had the greatest biomass yields in all water stress treatments and these varieties had greater biomass yields even in S_2 and S_3 water stress treatments than full irrigation treatment (S_1) of Shawnee and Cave in rock varieties.

In terms of yield reduction ratios of switchgrass varieties under water stress conditions, Kanlow (S_2:0.14 -

S_5:0.70), Alamo (S_2:0.14 - S_5:0.70) and Trailblazer (S_2:0.17 - S_5:0.64) varieties had the lowest yield reduction ratios almost in all water stress treatments (Figure 2).

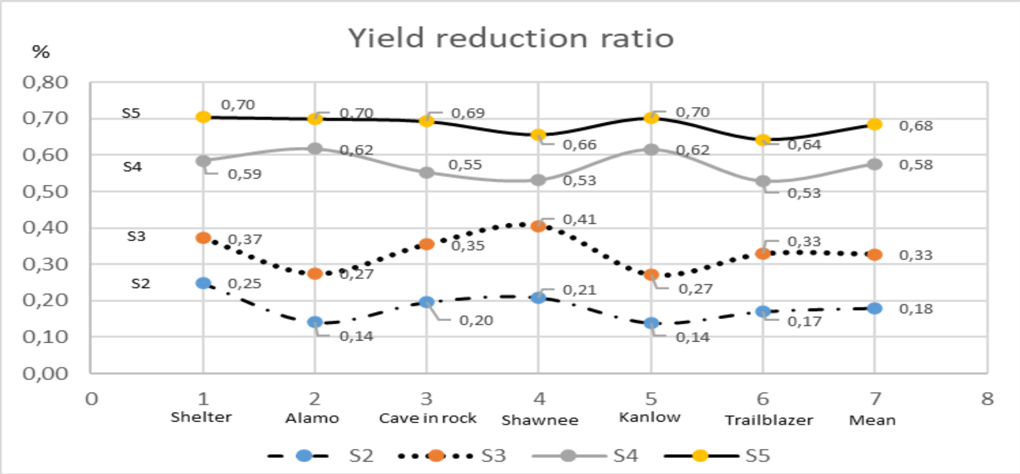


Figure 2. Yield reduction ratios in the first harvest

As it was indicated in previous water stress experiments in switchgrass (Barney et al., 2009; Vamvuka et al., 2010), reductions were observed in switchgrass biomass yields with water stress, however, plants were able to survive under the most severe stress conditions, even in rain-fed conditions (S4 and S5) and able to have certain biomass yields (Table 3). Similarly, Giannoulis et al. (2016) conducted an experiment under irrigated and rain-fed conditions and they reported that dry biomass yield as 14300 kg ha^{-1} under irrigated conditions and as 9200 kg ha^{-1} under rain-fed conditions. In this present experiment, Alamo, Kanlow and Trailblazer varieties were prominent for biomass yield under water stress and rain-fed conditions. Besides high yields in full irrigation, from these varieties was obtained sustainable biomass yields under water stress levels (Figure 1).

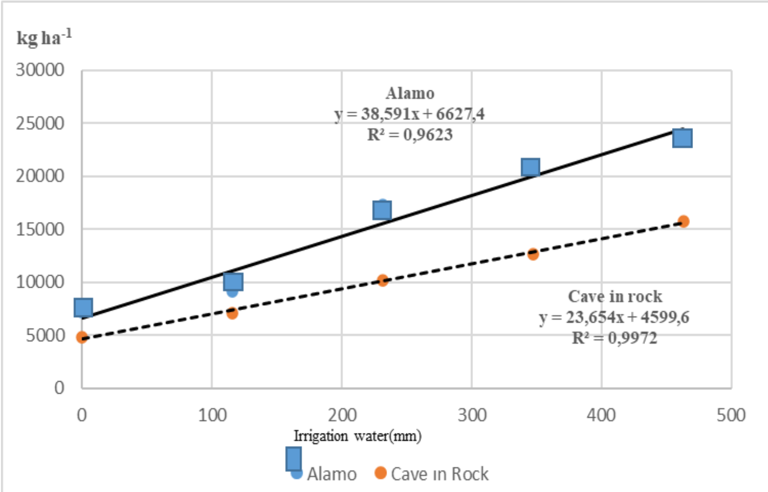
Table 3. Second harvest fresh and dry biomass yields (kg ha^{-1})

		Water stress treatments						
	Varieties	S_1	S_2	S_3	S_4	S_5	Mean	
	Shelter	11680 cd	9570 e	5670 h	3430 kl	----	7590 b	LSD (0.05)
	Alamo	16070 a	12330 c	7530 g	5850 h	----	10440 a	Variety: 470
FBY_2	Cave in rock	9540 e	7130 g	4790 ı	3180 kl	----	6160 d	Water: 290
(kg ha^{-1})	Shawnee	10180 e	6890 g	4330 ıj	3880 jk	----	6320 d	Variety *water: 1060
	Kanlow	11430 d	8340 f	4390 ıj	3660 j-l	----	6950 c	
	Trailblazer	14210 b	8350 f	5080 hı	2880 l	----	7630 b	
	Mean	12180 a	8770 b	5300 c	3810 d	----	7520	
F value (*Water stress: 19420; * Variety: 1010;* Water stress x Variety interaction:104)								
	Shelter	6400 b	5380 c	2960 g	1870 k-m	---	4150 a	LSD (0.05)
	Alamo	6910 a	5010 cd	2960 g	2510 hı	---	4350 a	Variety: 210
DBY_2	Cave in rock	4640 d	3520 f	2350 h-j	1520 m	---	3010 d	Water: 350
(kg ha^{-1})	Shawnee	5310 c	4710 d	2220 ı-k	1900 k-m	---	3530 c	Variety *water: 420
	Kanlow	4780 d	3520 f	2020 j-l	1620 lm	---	2990 d	
	Trailblazer	7100 a	4100 e	2690 gh	1540 m	---	3860 b	
	Mean	5860 a	4370 b	2540 c	1830 d	---	3650	
F value (*Water stress: 3260; * Variety: 597; *Water stress x Variety interactions:116)								

FBY_2: Second harvest fresh biomass yield DBY_2: Second harvest dry biomass yield

*: significant at $P \leq 0.05$. Means followed by the same letters are not different for $P \leq 0.05$ according to LSD test.

The regression analysis for water-yield relations of switchgrass varieties is given in Figure 3. There was a linear relationship in all varieties between amount of water irrigation and biomass yields.



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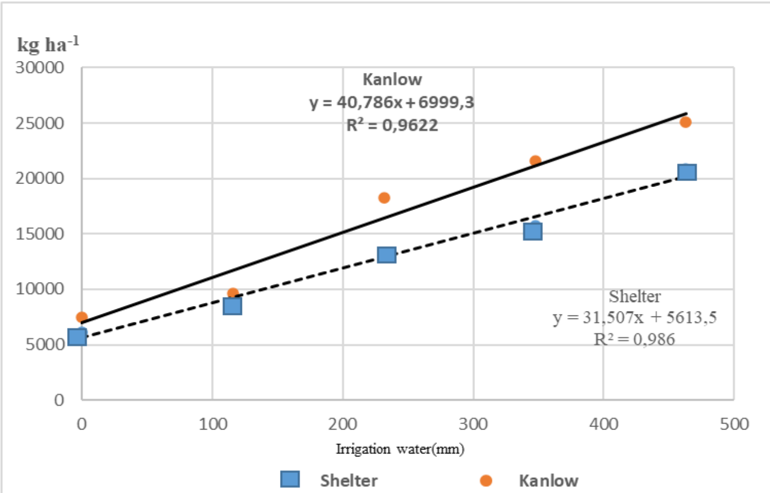

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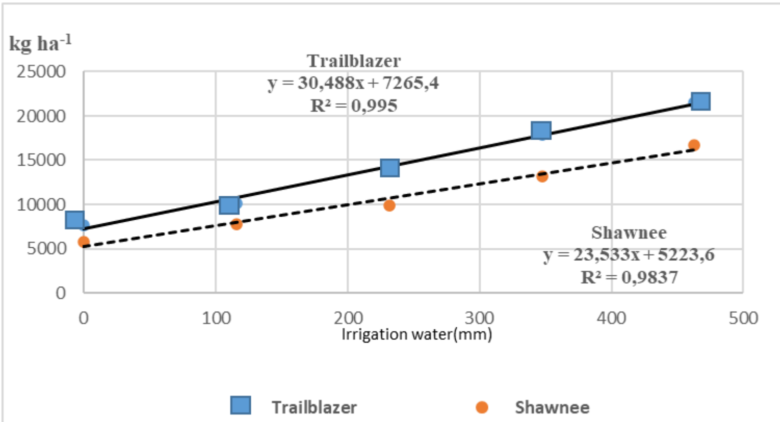

Figure 3. Water – yield relations of switchgrass varieties (a- Regression analysis for Alamo and Cave in rock varieties; b- Regression analysis for Shelter and Kanlow varieties; c- Regression analysis for Trailblazer and Shawnee varieties)

In previous experiments conducted about water stress tolerance of switchgrass varieties, similar with the present findings, better yields were reported especially for Kanlow and Alamo varieties than for the others under stress conditions in several regions (Barney et al., 2009; Aimar et al., 2014; Liu et al., 2015).

Fresh and dry biomass yields of the second harvest

Following the first harvest, with the decrease in weather temperatures, the growth of switchgrass varieties has decreased under Konya ecological conditions. As the average of two years, second harvest fresh and dry biomass yields of the switchgrass varieties are given in Table 3.

As it was in the first harvest and as indicated also in previous experiments, decreasing biomass yields were observed with decreasing amount of irrigation water in second harvest (Vamvuka et al., 2010).

As the average of two years, in the second harvest, the lowest and the greatest fresh biomass yields were respectively obtained from Cave in rock (6160 kg ha^{-1}) and Alamo (10440 kg ha^{-1}) varieties; the lowest and the greatest dry biomass yields were respectively obtained from Kanlow (2990 kg ha^{-1}) and Alamo (4350 kg ha^{-1}) varieties (Table 3).

Second cutting biomass yield values obtained from this experiment are similar to the yield results obtained by Soylu et al. (2010). They reported that second harvest dry biomass yields varied between 1180 kg ha^{-1} (Kanlow) and 4250 kg ha^{-1} (Shelter). In present experiment, single harvest was made in rain-fed treatment without irrigation (S_5) (Table 3). Number of harvest in switchgrass vary with the purpose of cultivation, irrigation conditions and ecological conditions; single harvest is made especially in water deficit conditions and in cultivation for bioethanol production (Sanderson et al. 1999; Soylu et al., 2010). With regard to variety performance under water stress conditions, in S_1 treatments, the lowest and the greatest second harvest dry biomass yields were respectively obtained from Cave in rock (4640 kg ha^{-1}) and Trailblazer (7100 kg ha^{-1}) varieties; in S_2 treatments, from Cave in rock and Kanlow (3520 kg ha^{-1}) and Alamo (5010 kg ha^{-1}) varieties; in S_3 treatments, from Kanlow (2020 kg ha^{-1}) and Alamo and Shelter (2960 kg ha^{-1}) varieties; in S_4 treatments, from Cave in rock (1520 kg ha^{-1}) and Alamo (2510 kg ha^{-1}) varieties. In present the experiment, in both years, the first harvest was made at the end of July and the second growth season included August and September. In this experiment, since there is not enough precipitation in both years in August biomass yields reduced in water stress treatments. Early Autumn frosts of the region also influenced second harvest biomass yields.

Irrigation water use efficiency (IWUE) was calculated as 5.7 kg m^{-3} for the first harvest and as 2.1 kg m^{-3} for the second harvest (Table 5). These values indicated that for irrigation second harvest was not economic and sustainable in present research site and similar ecologies with deficit water resources. Thus, single cutting is recommended for the semi-arid conditions.

Plant height

As the average of two years, plant height was measured as 130 cm. Plant heights of water stress treatments varied between 70 cm (S_5) and 180 cm (S_1). Alexopoulou et al. (2017) reported the average plant height of switchgrass varieties as 152 cm in their experiment conducted in the marginal lands of Greece. In this the experiment result, as it was in biomass yield, decreasing plant heights were observed with increasing water stress levels. While plant heights of full irrigation (S_1) and S_2 treatments were close to each other, height difference and relative decrease in plant heights were more remarkable in increasing water stress treatments (S_3, S_4 and S_5) (Table 4). Supporting the results of this experiment, Giannoulis et al. (2016) reported that decreasing plant heights of switchgrass varieties under water stress and reported average plant height as 193 cm under irrigated conditions and as 131 cm under rain-fed conditions. Similarly, Soylu et al. (2010) reported plant height of lowland ecotype Kanlow variety in the third year as 186 cm and upland ecotype of Blackwell variety as 132 cm under irrigated conditions; reported plant height as 78 cm for Kanlow variety and as 63 cm for Blackwell variety under rain-fed conditions. Both the peresent experiment and previous experiment results indicated that plant heights decreased under in water stress conditions and lowland ecotypes had greater plant heights.

As can be inferred from Table 4, as the average of two years, plant heights of switchgrass varieties varied between 121 cm (Shawnee) and 151 cm (Alamo). The greatest plant heights were observed in lowland ecotypes of Kanlow and Alamo varieties. Alexopoulou et al. (2017) reported average plant height as 164 cm for lowland ecotypes and as 137 cm for upland ecotypes.

Considering the water stress x variety interactions, as the average of two years, plant heights varied between 152 cm (Trailblazer) and 209 cm (Kanlow and Alamo) in S_1 treatments; between 142 cm (Trailblazer) and 185 cm (Kanlow) in S_2 treatments; between 121 cm (Trailblazer) and 163 cm (Kanlow) in S_3 treatments; between 94 cm (Trailblazer) and 115 cm (Alamo) in S_4 treatments; between 59 cm (Cave in rock) and 87 cm (Kanlow) in S_5 treatments (Table 4). In general, Kanlow and Alamo varieties yielded greater plant heights in all water stress treatments than the upland ecotypes.

Number of stalks per meter

As the average of two years, number of stalks per meter of water stress treatments varied between 221 stalks (S_5) and 356 stalks (S_1). As it was in biomass yields and yield components, number stalks per meter decreased with increasing water stress. Since number of stalks per meter affect biomass yield, values obtained under rain-fed conditions indicated that switchgrass was also a promising forage crop under arid and semi-arid conditions. As the average of two years, number of stalks per meter of varieties varied between 272 stalks (Alamo) and 337 stalks (Trailblazer). Since switchgrass is a perennial crop, number of stalks per meter in establishment year and subsequent years (2 and more) largely depend on climate, soil and soil conditions, agronomic practices and tillering capacities. Increasing number of stalks per meter also increase biomass yields and the other yield components.

Table 4. Agronomic traits of switchgrass varieties in different treatments

	Varieties	S1	S2	S3	S4	S5	Mean	
		Water stress treatments						
PH (cm)	Shelter	171 c	148 fg	124 ıj	95 m	68 p	121 c	LSD (0.05)
	Alamo	209 a	185 b	161 de	115 kl	83 o	151 a	Variety: 3.4
	Cave in rock	171 c	162 d	138 h	96 m	59 q	125 b	Water: 8.7
	Shawnee	167 cd	154 ef	129 ı	90 m-o	63 pq	121 c	Variety *water: 7.7
	Kanlow	209 a	179 b	163 d	113 l	87 no	150 a	
	Trailblazer	152 f	142 gh	121 jk	94 mn	61 pq	114 d	
	Mean	180 a	161 b	139 c	100 d	70 e	130	
	F value (*Water stress: 284; * Variety: 169 ; *Water stress x Variety interaction: 5.7)							
NS (number/m²)	Shelter	405 a	384 a-c	338 d-g	293 h-j	210 m	326 a	LSD (0.055)
	Alamo	342 d-f	283 ı-k	309 f-ı	218 m	209 m	272 c	Variety: 15.7
	Cave in rock	318 e-h	305 g-ı	288 h-k	257 kl	213 m	276 c	Water: 14.7
	Shawnee	340 d-f	336 d-g	296 hı	280 ı-k	221 m	294 b	Variety *water: 35.2
	Kanlow	366 b-d	386 a-c	281 ı-k	257 kl	209 m	300 b	
	Trailblazer	363 b-d	391 ab	352 c-e	314 f-ı	266 kl	337 a	
	Mean	356 a	347 a	310 b	270 c	221 d	301	
	F value (*Water stress: 103; * Variety: 26.5 ; *Water stress x Variety interaction: 3.4)							
SW (g)	Shelter	1.93 de	1.37 h-j	1.19 jk	0.70 m-o	0.61 n-p	1.16 bc	LSD (0.05)
	Alamo	3.48 a	2.20 c	2.08 cd	1.25 ı-k	0.69 no	1.94 a	Variety: 1.09
	Cave in rock	1.60 f-h	1.53 gh	1.44 hı	0.83 mn	0.40 p	1.16 bc	Water: 0.12
	Shawnee	1.91 de	1.73 e-g	1.21 ı-k	0.94 lm	0.51 op	1.26 b	Variety *water: 0.24
	Kanlow	2.81 b	2.79 b	2.25 c	0.94 lm	0.77 mn	1.91 a	
	Trailblazer	1.80 ef	1.25 ı-k	1.09 kl	0.72 m-o	0.42 p	1.06 c	
	Mean	2.25 a	1.81 b	1.55 c	0.90 d	0.56 e	1.42	
	F value (*Water stress: 335; * Variety: 106; * Water stress x Variety interaction: 12.5)							

PH: Plant height; NS: Number of stalks; SW: Single stalk weight
*: significant at P ≤ 0.05. Means followed by the same letters are not different for P ≤ 0.05 according to LSD test.

Table 5. IWUE values (kg m^{-3}) calculated with the use averages of dry biomass yields

	First harvest IWUE (kg m^{-3})					**Second harvest IWUE (kg m^{-3})**				
Variety /water stress	S1	S2	S3	S4	Average of varieties	S1	S2	S3	S4	Average of varieties
Shelter	4.5	4.5	5.7	7.5	5.5	2.2	2.5	2.1	2.6	2.3
Alamo	5.1	5.9	7.5	7.9	6.6	2.4	2.3	2.1	3.5	2.6
Cave in Rock	3.4	3.6	4.4	6.1	4.4	1.6	1.6	1.6	2.1	1.7
Shawnee	3.6	3.8	4.3	6.7	4.6	1.8	2.2	1.5	2.6	2.0
Kanlow	5.4	6.2	7.9	8.3	7.0	1.7	1.6	1.4	2.2	1.7
Trailblazer	4.6	5.1	6.2	8.8	6.2	2.5	1.9	1.9	2.1	2.1

In this experiment, upland ecotypes had greater number of stalks per meter than the lowland ecotypes. Similarly, Geren et al. (2016) and Sauerbeck et al. (2002), reported had greater number of stalks per meter for upland ecotypes.

Different from the results of this experiment, Min et al. (2017) in an experiment conducted in the USA with 22 varieties, they reported that the greatest and the lowest number of stalks as 26.8 stalks per plant (Alamo) and 23.5 stalks per plant (Cave in rock), respectively. Such differences were mainly caused from morphological characteristics, ecological conditions, soil and climate factors and growing techniques (Cassida et al., 2005; Nasso et al., 2015).

According to Table 4, in terms of water stress x variety interactions, the greatest and the lowest number of stalks per meter were respectively obtained from Kanlow (366 stalks) and Cave in rock (318 stalks) varieties in S_1 treatments; from Trailblazer (391 stalks) and Alamo (283 stalks) varieties in S_2 treatments; from Trailblazer (352 stalks) and Kanlow (281 stalks) varieties in S_3 treatments; from Trailblazer (314 stalks) and Cave in rock (218 stalks) varieties in S_4 treatments; from Trailblazer (266 stalks) and Cave in rock and Kanlow (209 stalks) varieties in S_5 treatments. In water stress treatments, lowland ecotypes had lower number of stalks per meter than the upland ecotypes. Similarly, Soylu et al. (2010) investigated yield and yield components (SDs) in different switchgrass varieties on Konya ecological conditions. They reported that number of stalks per meter of Kanlow variety as 218 stalks per meter under irrigated conditions and as 89 stalks per meter under rain-fed conditions, also reported number of stalks per meter for upland ecotype Blackwell variety as 313 stalks per meter under irrigated conditions and as 188 stalks per meter under rain- fed conditions.

Single stalk weight

Single stalk weights decreased with water stress. As the average of two years, single stalk weights of the water stress conditions varied between 0.56 g (S_5) and 2.25 g (S_1). Again, as the average of two years, single stalk weights of the varieties varied between 1.06 g (Trailblazer) and 1.94 g (Alamo) (Table 4).

As can be inferred from Table 4, lowland varieties (Kanlow and Alamo) had greater single stalk weights than upland varieties. Kanlow and Alamo varieties are mostly used for bioethanol production and erosion control, thus they had greater plant heights and single stalk weights than the other varieties. When the biomass yields and single stalk weights of lowland ecotypes were assessed together, it was observed that these varieties with high biomass yields also had greater single stalk weights than the other varieties. Besides, Trailblazer variety with a low single stalk weight had a high biomass yield because of greater number of stalks per meter of this varieties. In present experiment, four upland varieties had lower single stalk weights than the lowland varieties and these varieties are mostly used as forage crop. Similarly, Cicek (2017) reported that fresh single stalk weights as 16.8 g for Alamo variety and as 10.1 g for Cave in rock variety. Present findings on single stalk weights also comply with the findings of earlier experiments conducted in different ecologies (Madakadze et al., 1998; Alexpoulou et al., 2002).

Considering the interactions (Water stress * varieties), Kanlow and Alamo varieties had greater single stalk weights in all water stress treatments than the upland varieties. Single stalk weight of lowland varieties were less influenced by water stress, thus had greater single stalk weights and consequently greater biomass yields in water deficit regions or non-irrigated sites as compared to upland varieties. Similar with the present findings, Soylu et al. (2010) reported that fresh single stalk weight of Kanlow variety as 10.8 g under irrigated conditions and as 3.3 g under rain-fed conditions and single stalk weight of Blackwell variety as 6.4 g under irrigated conditions and as 1.6 g under rain-fed conditions.

Irrigation water use efficiency

Ratio of biomass or grain yield of a plant to amount of irrigation water applied to get this yield is so called as irrigation water use efficiency (IWUE). High IWUE values indicate greater yields per unit of water applied. In present experiment, two-year averages of dry biomass yield in the first and second harvest were used and IWUE values were separately calculated (Table 5).

As can be inferred from Table 5, the lowest and the greatest IWUE values in the first harvest were respectively obtained from Cave in rock (3.4 kg m^{-3}) and Kanlow (5.4 kg m^{-3}) varieties in S_1 treatments; from Cave in rock (3.6 kg $m^{-3)}$ and Kanlow (6.2 kg m^{-3}) varieties in S_2 treatments; from Shawnee (4.3 kg m^{-3}) and Kanlow (7.9 kg m^{-3}) varieties in S_3 treatments; from Cave in rock (6.1 kg m^{-3}) and Trailblazer (8.8 kg m^{-3}) varieties in S_4 treatments. When all water stress treatments were assessed together, it was observed that dry matter yield per unit water increased with decreasing amount of irrigation water. Kanlow variety had the greatest dry matter production per unit of water in all irrigation treatments. In this case, Kanlow variety had the greatest dry biomass production per unit of water both in full irrigation and water stress treatments, thus this variety could be recommended for both irrigated and rain-fed conditions.

The lowest and the greatest IWUE values of the second harvest were respectively obtained from Cave in rock (1.6 kg m^{-3}) and Trailblazer (2.5 kg m^{-3}) varieties in S_1 treatments; from Cave in rock and Kanlow (1.6 kg m^{-3}) and Shelter (2.5 kg m^{-3}) varieties in S_2 treatments; from Kanlow (1.4 kg m^{-3}) and Shelter and Alamo (2.1 kg m^{-3}) varieties in S_3 treatments; from Cave in rock and Trailblazer (2.1 kg m^{-3}) and Alamo (3.5 kg m^{-3}) varieties in S_4 treatments. In second harvest, when all water stress treatments were assessed together, the greatest dry biomass production per unit of consumed irrigation water varied with the varieties. The greatest IWUE values in full irrigation were obtained in Trailblazer variety and the greatest values in S_4, S_3 and S_2 water stress treatments were respectively obtained in Alamo and Shelter varieties (Table 5). With this experiment, it was concluded that the Alamo variety had the highest biomass yield under water stress conditions in the second harvest.

IWUE is a significant parameter for water deficit regions. Selection, adaptation and widespread of species and varieties more efficiently using irrigation water and thus able to produce greater quantities of biomass per unit of water are significant issues for sustainability of agricultural practices in these regions. Since switchgrass is mostly grown under rain-fed conditions with precipitations throughout the growing season, water-yield relations, thus irrigation water use efficiencies should be well identified.

IWUE values of the second harvest were quite lower than the values of the first harvest. Therefore, considering the current water deficits and irrigation costs, it is recommended to be irrigated of switchgrass plants until the first harvest and not to irrigate after the first harvest in Konya ecological conditions.

CONCLUSION

The experiment results have shown that switchgrass, which is a new plant for Turkey, was well adapted to ecological conditions of Konya province and was able to produce quite significant quantities of biomass. Switchgrass plants was used irrigation water quite efficiently and produced high biomass quantities both under irrigated and rain-fed conditions. Trailblazer variety, mostly used as forage crop and Kanlow and Alamo varieties, commonly used for bioethanol production and erosion prevention have had high biomass yields and IWUE values in all water stress treatments. The experiment results could be used in further experiments to be conducted over the marginal lands.

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