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Grain yield production of Sudan grass (*Sorghum sudanense* (Piper) Stapf) as influenced by cutting numbers, potassium rates, and intrarow spacing in a semiarid environment

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Abstract: The seed scarcity of Sudan grass plagues the pasture industry in the livestock sector, especially in arid and semiarid regions. The current study was initiated to tackle this challenge. The study evaluates the response of the grain yield and yield components of Sudan grass to cutting numbers, potassium rates, and intrarow spacing over 2 years. A field experiment was conducted using a randomized complete block split-split design with 2 cutting numbers (no cutting and cut 1 time), 2 potassium rates (60 and 120 kg K_2O ha^{-1}), and 3 intrarow spacings (15, 20, and 25 cm between hills) as the main plot, split plot, and split-split plot, respectively. The results showed that the zero-cut treatment produced, as averaged over the 2 seasons, 52.3% and 74.5% higher grain yield and hay yield per hectare than the one-cut treatment, respectively. However, the latter treatment had harvest index and sum of hay and green forage yield values that were 17.0% and 19.9% higher than those of the zero-cut treatment, respectively. The application of potassium at a rate of 120 kg ha^{-1} resulted in the maximum grain yield and yield components as compared to the lower potassium rate (60 kg ha^{-1}), with the exception of 1000-grain weight, hay yield, and sum of hay and green forage yield, which were not significantly different from each other. Averaged over 2 seasons, as the intrarow spacing between hills was increased from 15 cm to 20 and 25 cm, grain weight per panicle decreased by 11.3% and 25.7%, grain yield per hectare decreased by 6.6% and 15.7%, and harvest index decreased by 12.0% and 23.5%, respectively. The interaction among 3 factors had a significant effect on yield and yield components; the highest values for grain and hay yields per hectare were obtained by growing Sudan grass at 15 or 20 cm intrarow spacing under the zero-cut treatment with the application of potassium at rate of 120 kg ha^{-1}. At 15 or 20 cm intrarow spacing, the values for grain yield per hectare under the one-cut treatment and high potassium rate were occasionally comparable to those for the zero-cut treatment and low potassium rate. Finally, when seed production is desired, Sudan grass should not be cut. If growers are interested in producing green forage and grain simultaneously, Sudan grass can be cut 1 time; however, it should be grown at 15 cm intrarow spacing with application of potassium at a rate of 120 kg ha^{-1}.

Key words: Competition, green forage yield, harvest index, hay yield, potassium nutrition, yield components

1. Introduction

Corn silage is used extensively for feeding livestock in summer, especially dairy cows, which require high energy feed for maximum milk production. However, this crop requires a large amount of water in order to simultaneously achieve maximum yield and adequate nutritional values (Howell et al. 2008; Kiziloglu et al. 2009). Therefore, the shortage of water in arid and semiarid regions of the world is likely to hinder the widespread adoption of this crop as summer forage in the livestock sector. To maintain forage production in these regions, corn can be replaced with other promising forage crops such as Sudan grass (*Sorghum sudanense* (Piper) Stapf). Compared to corn, Sudan grass has a number of characteristics that make it well adapted to water shortages. It has a smaller leaf area with waxy bloom, twice as many secondary roots per unit of primary root as corn, and half as much leaf area as corn for evapotranspiration, and Sudan grass has the ability to go dormant during extended drought periods, regrowing when the water returns (Hussain et al. 1991; Merrill et al. 2007; Marsalis et al. 2010; Sowiński and Szydelko 2011). These features make Sudan grass a suitable emergency forage source to fill the feed shortage gap during the lean summer period in arid and semiarid regions, where limited water availability does not allow for the cultivation of corn. However, one of the most serious limitations for increasing the cultivation area of this crop is the lack of adequate quantity and quality of seed.

Generally, the low seed production from forage crops in regions of less intensive production is mainly due to

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the fact that most studies have focused on evaluating the impact of practical management decisions on fodder yield and quality. It is rather unfortunate that very little attention is given to agricultural management techniques and their effects on seed production, especially in a Mediterranean environment.

Plant spacing is one of the most important cultural practices determining grain yield, as well as the other important agronomic attributes of most crops including Sudan grass (Joseph et al. 1980; Akash and Saoub 2002). Plant spacing is recognized as a major factor determining the degree of competition between plants (Hashemi et al. 2005). Generally, high plant density and narrow plant spacing increase forage yield. For instance, when the stem diameter of Sudan grass decreased, the fresh and dry weight of forage was increased due to an increase in plant density (Caravetta et al. 1990; Taleb-nejat 1995; Bahrani and Ghenateghestani 2004). However, grain yield per plant decreases as the density per unit area increases. The rate of yield decrease is a response to decreasing light and other environmental resources available to each plant. To date, no extensive studies have investigated the optimum plant spacing in Sudan grass grown for seed production. Plant spacing factors may be important for seed production in this crop. In general, the very narrowest plant spacing leads to increased competition between plants for production inputs such as solar radiation, water, and nutrients, whereas the very widest spacing leads to the waste of these inputs. Optimum plant spacing facilitates the development of generative organs by enhancing the yield components that are positively correlated with seed yield (Türk and Çelik 2006; Rafiei 2009; Stevovic et al. 2012). Therefore, addressing the plant spacing factor may be a prerequisite for obtaining a higher seed yield in Sudan grass.

In addition to plant spacing, the seed yield of Sudan grass may also be influenced by cutting numbers. Sowiński and Szydelko (2011) reported that increasing the number of cuts of Sudan grass promoted tillering and increased the number of shoots. This trait may be of benefit only when Sudan grass is cultivated for forage production. However, when Sudan grass is grown for seed production, this trait may have a negative impact on the number of fertile tillers per unit area, which in turn affects the quantity and quality of seed yield. Brown et al. (1964) reported that superiority in sorghum grain yield was primarily due to an increase in the number of fertile tillers per unit area rather than changes in panicle weight. Therefore, the unclipped sorghum plants produced a higher grain yield than those clipped once (Akash and Saoub 2002).

Among the various nutrients required to produce high quantity and quality of seed yield, potassium is a very important element due to its influence on the photosynthetic rates of crop leaves and CO_2 assimilation and its ability to facilitate carbon movement and translocation of photosynthates from sources to sinks (Bisson et al. 1994; Bednarz and Oosterhuis 1999; Sangakkara et al. 2000). In addition, K nutrition has pronounced effects on carbohydrate partitioning by affecting either the phloem export of photosynthates (sucrose) or growth rate of sink and/or source organs (Cakmak et al. 1994). Therefore, if K is in limited supply during active reproductive organ development, there will be a significant reduction in yield and quality of seed.

The objective of this study was to evaluate the impact of intrarow spacing, cutting numbers, and potassium rates on seed production of Sudan grass. Our results are expected to be useful for assessing the optimal range for these factors in terms of seed production in Sudan grass, especially in arid and semiarid regions.

2. Materials and methods

2.1. Experimental site description

This study was conducted at the Suez Canal University Faculty of Agriculture's Experimental Farm, Ismailia, Egypt (30°58′N, 32°23′E; 13 m a.s.l.) during the summer seasons of 2010 and 2011. The climate in this region is hot and dry from May to October, and temperatures can reach up to 40 °C. On the other hand, the climate is usually warm during winter months and rainfall is rare. The soil texture of the experimental site is predominantly sandy throughout its profile (68.2% coarse sand, 24.9% fine sand, 4.6% silt, and 3.3% clay) with an EC of 0.49 dS m^{-1} and a pH of 7.7.

2.2. Experimental design and treatments

A randomized complete block split-split plot design with 3 replications was used in each season. The cutting treatments were randomly assigned to the main plot and 2 cutting treatments (no cutting in plants then left for grain production, and 1 cut at 60 days after sowing and plants then left for grain production) were used. Within each main plot of the cutting treatments, 2 potassium rates (60 and 120 kg K_2O ha^{-1}) as potassium sulfate (48%) were randomly nested as split plots. Within each split plot of potassium rates, 3 intrarow spacing treatments (15, 20, and 25 cm between hills) were randomly nested as split-split plots. A few seeds in each hill were sown on one side of a ridge. Two weeks after sowing, the seedlings were thinned to 2 plants per hill to obtain a final plant population of 26.7, 20.0, and 16.0 plants m^{-2} for 15, 20, and 25 cm, respectively. The experimental plot contained 6 ridges 50 cm apart and 3 m in length (9 m^2 in total area).

2.3. Agronomic practices

Giza 2 seeds were sown on 9 May in both growing seasons. Nitrogen fertilizer was applied at a rate of 72 kg ha^{-1} N as ammonium sulfate (20.5%). Nitrogen fertilizer was added 2 weeks after sowing in 3 equal doses. Phosphorus fertilizer was applied at a level of 31 kg ha^{-1} P_2O_5 as calcium super phosphate. Whole phosphorus was applied basally before sowing in all treatments. The plants were irrigated by surface irrigation at 4-day intervals throughout the experiment. Weeds were controlled with atrazine (6-chloro-N-ethyl-N-(1-methylethyl-l, 3, 5-triazine-2, 4-diamine) at 1.6 kg ai ha^{-1}. The herbicide was added immediately after sowing and before irrigation.

2.4. Measurements

The Sudan grass seeds were harvested on 30 August and 30 October for the zero-cut and one-cut treatments, respectively. In total, 10 plants from each plot were harvested at random to determine panicle length, number of panicles per plant, and weight of grains per panicle and plant. The seed samples obtained from each plot were used to determine 1000-grain weight. Seed yield was determined by hand-harvesting an area of 3 internal ridges (3rd, 4th, and 5th ridges), each 3.0 m in length (4.5 m^2 in total area) from each plot. The panicles were separated and threshed to determine seed yield. Total aboveground biomass was calculated by summing the nonthreshed panicle weight and hay weight. Harvest index was estimated as the ratio of seed yield to total aboveground biomass yield.

2.5. Statistical analysis

All measurements in this study were analyzed using an analysis of variance (ANOVA) appropriate for a randomized complete block split-split plot design with cutting treatments as the main factor, K rates as the split factor, and plant density as the split-split factor. Mean separation of treatment effects in this study was accomplished using the least significant difference (LSD) test or Duncan's multiple tests. Significance was judged against a nominal alpha level of 0.05. Statistical analysis was done using the COSTAT system for Windows, version 6.311 (Cohort Software, Berkeley, CA, USA).

3. Results

3.1. Effects of cutting numbers, potassium rates, and plant spacing

There was a significant effect of cutting numbers on all the traits measured in this study, with the exception of 1000-grain weight (Table 1). The zero-cut treatment had the highest values for panicle length, panicle number per plant, and grain weight per plant and produced 43.7% and 60.9% more grain yield and 70.4% and 78.6% more hay yield than the one-cut treatment in 2010 and 2011, respectively. However, the one-cut treatment resulted in increases in grain weight per panicle of 26.5% and 25.9%, increases in harvest index of 20.6% and 13.4%, and increases in sum of hay and green forage yield of 21.6% and 18.2% in 2010 and 2011, respectively, when compared with the zero-cut treatment.

The application of K at a high rate (120 kg K_2O ha^{-1}) resulted in significantly higher values for all traits presented in Table 1 than the low K rate (60 kg K_2O ha^{-1}), with the exception of 1000-grain weight, hay yield, and sum of hay and green forage yield, which were not significantly different from each other. Averaged over the 2 seasons, the high rate of K increased the panicle length, number of panicles per plant, weight of grains per panicle, weight of grains per plant, grain yield per hectare, and harvest index by 15.2%, 20.0%, 26.2%, 26.1%, 25.6%, and 15.6% when compared to the low rate of K, respectively (Table 1).

There was significant variation among the 3 plant spacing treatments with respect to all studied traits, with the exception of hay yield and total of hay and green forage yield (Table 1). Weight of grains per panicle, grain yield, and harvest index decreased significantly as plant spacing between hills increased and vice versa for panicle length, number of panicles per plant, weight of grains per plant, and 1000-grain weight. Averaged over 2 seasons, as plant spacing between hills was increased from 15 cm to 20 and 25 cm, the weight of grains per panicle decreased by 11.3% and 25.7%, grain yield decreased by 6.6% and 15.7%, and harvest index decreased by 12.0% and 23.5%, respectively (Table 1).

3.2. Effects of interaction among the 3 factors

The data presented in Table 2 show that interaction between the 3 factors had a significant effect on all the traits measured in this study. Generally, high intrarow spacing (25 cm between hills) produced the highest values for panicle length, number of panicles per plant, weight of grains per plant, and 1000-grain weight when this factor interacted with the high potassium rate (120 kg K_2O ha^{-1}) under the zero-cut treatment. However, the highest values for grain and hay yield per hectare were obtained when low plant spacing (15 cm between hills) interacted with the high potassium rate under the zero-cut treatment. It is interesting to note that at 15 and 20 cm intrarow spacing, the values of panicle length, 1000-grain weight, and grain yield per hectare for the combination of 120 kg K_2O ha^{-1} and the one-cut treatment were occasionally comparable to those obtained from the combination of 60 kg K_2O ha^{-1} and the zero-cut treatment. However, when Sudan grass was sown at high plant spacing, the combination of low potassium rate and zero-cut produced 79.5% and 61.1% more grain yield than the combination of high potassium rate and one-cut treatment in 2010 and 2011, respectively (Table 2).

3.3. Correlations between yield and yield-related traits

Averaged over the 2 seasons, simple correlation coefficients between the traits calculated in this study are shown in Table 3. Grain yield per hectare was positively correlated with panicle length, number of panicles per plant, weight of grains per plant, and hay yield per hectare but showed no

Table 1. Comparison of yield and yield components of Sudan grass in light of cutting numbers, potassium rates, and intrarow spacing in 2010 and 2011 growing seasons.

	Panicle length (cm)	Number of panicles per plant	Weight of grains per panicle (g)	Weight of grains per plant (g)	1000- grain weight (g)	Grain yield (kg ha^{-1})	Hay yield (t ha^{-1})	Harvest index (%)	Sum of hay and green forage yield (t ha^{-1})
2010									
Cutting number									
Zero-cut	38.4 a	2.9 a	4.9 b	11.0 a	11.9 a	2450.1 a	33.4 a	6.8 b	33.4 b
One-cut	33.4 b	1.4 b	6.2 a	6.6 b	10.8 a	1704.6 b	19.6 b	8.2 a	40.6 a
Potassium rates									
60 kg ha^{-1}	32.9 b	1.9 b	4.9 b	8.0 b	10.8 a	1892.9 b	25.7 a	7.1 b	36.1 a
120 kg ha^{-1}	38.9 a	2.4 a	6.2 a	9.6 a	11.9 a	2261.9 a	27.3 a	8.0 a	38.0 a
Intrarow spacing									
15 cm	32.5 c	1.7 b	6.4 a	7.2 c	9.6 c	2276.6 a	26.5 a	8.6 a	37.4 a
20 cm	36.3 b	2.3 a	5.7 b	8.5 b	11.7 b	2079.9 b	26.4 a	7.5 b	36.9 a
25 cm	38.9 a	2.5 a	4.6 c	10.7 a	12.7 a	1875.6 c	26.6 a	6.5 c	36.7 a
2011									
Cutting number									
Zero-cut	37.3 a	3.0 a	5.4 b	12.9 a	11.5 a	2327.0 a	32.5 a	6.7 b	32.5 b
One-cut	32.8 b	1.8 b	6.8 a	8.8 b	10.5 a	1445.9 b	18.2 b	7.6 a	38.4 a
Potassium rates									
60 kg ha^{-1}	33.1 b	2.2 b	5.4 b	9.3 b	10.8 a	1629.0 a	24.5 a	6.5 b	34.5 a
120 kg ha^{-1}	37.1 a	2.5 a	6.8 a	12.3 a	11.2 a	2143.9 b	26.2 a	7.7 a	36.5 a
Intrarow spacing									
15 cm	31.4 c	1.5 b	6.9 a	9.2 b	9.6 b	2010.2 a	25.0 a	8.0 a	35.6 a
20 cm	35.5 b	2.7 a	6.1 b	10.0 b	11.3 a	1917.7 a	25.6 a	7.1 b	35.0 a
25 cm	38.3 a	3.0 a	5.3 c	13.3 a	12.0 a	1731.5 b	25.5 a	6.2 c	35.8 a

Means followed by the same letter are not significantly different from one another based on LSD or Duncan's multiple tests at $P \leq 0.05$.

correlation with weight of grains per panicle, 1000-grain weight, or harvest index. Harvest index was only positively and strongly correlated with weight of grains per panicle. Weight of grains per panicle was negatively correlated with number of panicles per plant. However, weight of grains per plant was positively and strongly correlated with panicle length and number of panicles per plant (Table 3).

4. Discussion

4.1. Response to cutting numbers

Cutting numbers had an overwhelming influence on Sudan grass, impacting its yield parameters significantly. The present study showed that averaged over 2 seasons, the zero-cut treatment produced grain and hay yields 52.3% and 74.5% higher than those of the one-cut treatment,

Table 2. Interaction effects between cutting numbers, potassium rates, and intrarow spacing and yield components of Sudan grass in 2010 and 2011.

Intrarow spacing	2010				2011			
	Cutting number				Cutting number			
	Zero-cut		One-cut		Zero-cut		One-cut	
	Potassium rates (kg ha^{-1})				Potassium rates (kg ha^{-1})			
	60	120	60	120	60	120	60	120
Panicle length (cm)								
15 cm	32.3 de	37.3 c	27.3 f	33.0 de	33.0 def	34.5 cde	28.2 g	30.0 fg
20 cm	35.7 cd	41.3 ab	29.7 ef	38.7 bc	33.2 def	39.0 b	33.5 def	36.3 bcd
25 cm	39.0 bc	44.7 a	33.3 de	38.7 bc	38.7 bc	45.3 a	31.8 efg	37.2 bcd
Number of panicles per plant								
15 cm	2.4 bc	2.3 bc	1.0 e	1.0 e	2.0 de	2.0 de	1.0 f	1.0 f
20 cm	2.7 b	3.7 a	1.1 e	1.7 d	3.1 b	3.8 a	1.7 e	2.0 de
25 cm	2.7 b	3.6 a	1.7 d	2.1 cd	3.0 bc	3.9 a	2.5 cd	2.4 cd
Weight of grains per panicle (g)								
15 cm	4.4 ef	6.4 bcd	7.1 ab	7.7 a	5.1 de	7.6 ab	6.7 bc	8.2 a
20 cm	4.1 fg	6.6 abc	5.4 cde	6.5 abc	5.1 de	5.7 cd	6.2 cd	7.5 ab
25 cm	3.2 g	4.9 ef	5.1 ef	5.3 def	4.0 e	5.2 de	5.4 cd	6.6 bc
Weight of grains per plant (g)								
15 cm	9.1 c	8.6 cde	5.5 f	5.6 f	7.5 e	12.2 b	7.4 e	9.5 cde
20 cm	9.3 c	11.9 b	6.2 f	6.7 ef	11.6 bc	11.9 bc	8.0 e	8.5 e
25 cm	11.3 b	15.8 a	7.0 def	8.8 cd	12.8 b	21.3 a	8.5 de	10.6 bcd
1000-grain weight (g)								
15 cm	9.9 de	10.1 de	8.6 e	9.7 de	10.1 de	9.5 e	9.3 e	9.3 e
20 cm	11.1 bcd	12.8 ab	10.6 cd	12.3 abc	10.7 cde	13.3 ab	10.7 cde	10.5 cde
25 cm	13.3 a	14.1 a	11.2 bcd	12.3 abc	11.7 bcd	13.5 a	12.1 abc	10.8 cde
Grain yield (kg ha^{-1})								
15 cm	2240.3 cd	2774.4 a	1876.9 e	2214.8 d	1934.9 cd	2774.6 a	1497.4 e	1833.7 d
20 cm	2123.3 d	2630.4 ab	1463.7 f	2102.3 d	1965.2 cd	2730.6 a	1195.7 fg	1779.4 d
25 cm	2445.2 bc	2487.1 b	1207.9 g	1362.2 fg	2139.4 c	2417.2 b	1041.6 g	1327.7 ef
Hay yield (t ha^{-1})								
15 cm	34.3 bc	37.4 a	17.0 h	17.2 gh	33.1 ab	35.7 a	14.9 f	16.1 ef
20 cm	31.6 cd	34.5 b	19.5 fg	20.2 ef	33.5 ab	33.1 ab	16.9 ef	19.0 de
25 cm	30.8 d	31.9 bcd	20.9 ef	22.7 e	28.1 c	31.7 b	20.6 d	21.9 d
Harvest index (%)								
15 cm	6.1 de	6.9 cd	10.0 b	11.4 a	5.5 ef	7.2 d	9.2 ab	10.3 a
20 cm	6.3 cde	7.1 cd	7.0 cd	9.5 b	5.6 ef	7.6 cd	6.8 de	8.6 bc
25 cm	7.4 c	7.3 cd	5.5 e	5.7 e	7.1 d	7.1 d	4.8 f	5.7 ef
Sum of hay and forage green yield (t ha^{-1})								
15 cm	34.3 de	37.4 cd	38.6 bc	39.3 abc	33.1 ef	35.7 cde	35.1 def	38.6 bc
20 cm	31.6 ef	34.5 de	39.5 abc	42.1 a	33.5 def	33.1 ef	36.6 cde	36.8 bcd
25 cm	30.8 f	31.9 ef	41.8 ab	42.6 a	28.1 g	31.7 f	40.3 ab	43.0 a

Means followed by the same letter are not significantly different from one another based on Duncan's multiple test at $P \leq 0.05$.

Table 3. Simple correlation coefficients (lower left) and their significance levels (upper right) with respect to the variables measured in this study (data averaged over 2 seasons).

	1	2	3	4	5	6	7	8
Panicle length (1)	1.00	***	ns	***	***	*	ns	*
Number of panicles per plant (2)	0.85	1.00	*	***	***	***	ns	*
Weight of grains per panicle (3)	−0.32	−0.57	1.00	ns	*	ns	***	ns
Weight of grains per plant (4)	0.88	0.85	−0.42	1.00	***	**	ns	**
1000-grain weight (5)	0.88	0.85	−0.50	0.77	1.00	ns	ns	ns
Hay yield (6)	0.55	0.77	−0.46	0.62	0.37	1.00	ns	***
Harvest index (7)	−0.22	−0.47	0.70	−0.21	−0.36	−0.48	1.00	ns
Grain yield (8)	0.52	0.55	0.02	0.58	0.23	0.75	0.21	1.00

*: significant at P < 0.05; **: significant at P < 0.01; ***: significant at P < 0.001; ns: nonsignificant.

respectively. However, the sum of green forage and hay yield for the one-cut treatment was higher than that of the zero-cut treatment by only 19.9% (Table 1). This implies that when seed production is a target, Sudan grass should not be cut. The significant reduction in grain yield in the treatment cut once and left for grain production may be due to the limited number of days between cutting and harvest; it is not long enough to produce the leaf area necessary to intercept most of the incoming radiation and convert it to chemical energy through photosynthesis. In addition, the shorter grain filling duration and maturity period of the one-cut treatment may result in a significant reduction in fertile panicle numbers and reduced seed-set percentages by increasing seed abrogation and abnormality due to an inadequate energy source. However, the longer growth duration with zero-cut treatment increases the solar radiation available during the crop growth period, leading to an increase in the rate and duration of dry matter accumulation and, ultimately, the final grain yield of a crop. Cross (1990) reported that part of the yield increase was due to a 5-day increase in the grain filling period for plants grown under long photoperiods. Therefore, a good correlation was found between grain yield and number of panicles per plant and hay yield, but there was no correlation with weight of grains per panicle (Table 3). This finding is in good agreement with those reported by Akash and Saoub (2002), who found that unclipped sorghum plants produced a higher grain yield when compared to those clipped once.

4.2. Response to intrarow spacing

In plant density studies, intrarow spacing (plant-to-plant spacing within a row) is one of the most important stresses affecting biomass production, crop yield, and economic profitability. Generally, this factor can affect canopy architecture, light conversion efficiency, duration of vegetative growth, dry matter production, evaporation of water from soil under the crop, weed competition, and, ultimately, the final grain yield of a crop in the farming system (López-Bellido et al. 2005). Hence, the optimization of intrarow spacing is of great importance in maximizing the grain yield of Sudan grass. Brar et al. (1992) reported that sorghum growers were losing about 30% of their potential yield primarily due to inadequate plant density. The present study showed that the highest values for most yield components of individual plants, such as panicle length, number of panicles per plant, weight of grains per plant, and 1000-grain weight, were obtained at high intrarow spacing (25 cm between hills); however, maximum values for weight of grains per panicle, grain yield per hectare, and harvest index were achieved with low intrarow spacing (15 cm between hills) (Table 1). These findings indicate that if intrarow spacing is too low, plants may compete against each other, and the performance of individual plants may become a limiting factor for maximum crop yield. However, when the intrarow spacing is too high, each individual plant may perform at its maximum capacity, but the number total plants may be insufficient to reach optimum yield. In this case, total yield of the crop becomes a limiting factor. Therefore, the low intrarow spacing in this study produced the lowest values for yield components of individual plants but yielded 21.4% and 16.1% more grain per hectare than high intrarow spacing in the 2010 and 2011 growing seasons, respectively (Table 1). The reduction in yield caused by high intrarow spacing may be because canopy development at the early stages in this treatment was insufficient to maximize light interception. Efficient light capture and use by the plant is believed to be a major determinant of final grain yield (Board and Harville

1996). The findings obtained in this study were in good agreement with those of Ball et al. (2000), who reported that increasing the plant population reduced the yield of individual plants but increased yield per unit of area. This allows us to infer that the relationships between plant density and yield can be explained as follows; maximum crop yield can only be achieved if the crop community is able to produce sufficient leaf area to provide maximum light interception during reproductive growth and minimize plant-to-plant competition.

4.3. Response to potassium rates

Only hay yield per hectare and 1000-grain weight did not respond to potassium application rates. However, application of K at a rate of 120 kg ha^{-1} resulted in maximum levels of most yield components and grain yield per hectare as compared to the low K rate (60 kg K_2O ha^{-1}) (Table 1). This favorable response of Sudan grass to yield and yield components following potassium application could be attributed to the role of this nutrient in seed production. It has been reported that potassium is a nutrient that can influence photosynthetic rates of crop leaves and CO_2 assimilation and facilitate carbon movement and the translocation of photosynthates from sources to sinks (Bednarz and Oosterhuis 1999; Sangakkara et al. 2000). Cakmak et al. (1994) reported that potassium nutrition had pronounced effects on carbohydrate partitioning by affecting either phloem export of photosynthates (sucrose) or growth rate of sink and/or source organs.

4.4. Response to interactions

The present study has shown that the maximum grain and hay yield per hectare were obtained by growing Sudan grass at 15 or 20 cm intrarow spacing under zero-cut treatment and the application of 120 kg K_2O ha^{-1}. However, it is interesting to note that at 15 or 20 cm intrarow spacing, the values of grain yield per hectare for a combination of one-cut treatment and 120 kg K_2O ha^{-1} were occasionally comparable to those for zero-cut treatment and 60 kg K_2O ha^{-1} (Table 2). This allows us to recommend that Sudan grass be cut once if growers are interested in producing green forage and grain production simultaneously; the one-cut treatment in this study produced approximately 20 t green forage ha^{-1} after the first cut (Table 1). The interaction among 3 factors has also shown that minimum grain yield per hectare and harvest index were obtained by growing Sudan grass at 25 cm intrarow spacing under one-cut treatment regardless of K rates (Table 2). These results may be due to the cut treatment promoting tillering of the plant after cutting, which increases the number of unfertile tillers while increasing the amount of total hay yield (Sowiński and Szydelko 2011). Therefore, a good correlation was found between grain yield and number of panicles per plant and grain weight per plant, but there was no correlation with weight of grains per panicle (Table 3). This finding is in good agreement with those reported by Brawn et al. (1964), who stated that superiority in sorghum grain yield was primarily due to the increase in the number of fertile tillers per unit area rather than changes in panicle weight.

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