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JUNG, Sung, Jeong
Grassland & Forage Division, National Institute of Animal Science

CHO, Jin-Woong
Department of Crop Science, Collage of Agricultural and Life Sciences Chungnam National University

YAMAKAWA, Takeo
Laboratory of Plant Nutrition, Division of Molecular Biosciences, Department of Biosciences & Biotechnology, Faculty of Agriculture, Kyushu University

https://doi.org/10.5109/2339057

出版情報：九州大学大学院農学研究院紀要. 64 (2), pp.191-198, 2019-09-02. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **64** (2), 191–198 (2019)

Effects of Seeding Date and Cultivars on Yield and Growth Characteristics of Sorghum × Sudangrass Hybrid [*Sorghum bicolor* (L.) Moench] Cultivars in Central Region of South Korea

Jeong Sung JUNG[1], Jin–Woong CHO[2]* and Takeo YAMAKAWA[3]

Laboratory of Plant Nutrition, Division of Molecular Biosciences, Department of Biosciences & Biotechnology, Faculty of Agriculture, Kyushu University, 744 Motooka, Nishiku, Fukuoka 819–0395, Japan
(*Received April 23, 2019 and accepted May 8, 2019*)

Changing temperatures is one of the major threats to the maintenance of plant yield. Shifting the planting date is the best way to cope with climate change. The aim of this experiment was to determine optimum seeding dates for sorghum × sudangrass hybrid (SSH) cultivars that can provide foundational information to develop improved forage cropping system in central reign of South Korea (CRSK). Three SSHs (Jumbo, Sordan 79 and Revolution) were seeded at four planting dates between April 20 and June 20 (April 20, May 10, May 30 and June 20), respectively. The growing period from the planting to the heading stages was shorter for the cultivars planted on May 10 and longest for those planted on April 20, while those seeded on June 20 could be harvested only once due to the short growing period. Plant height, stem diameter, leaf number, and sugar content were high in the cultivars planted on April 20 and May 10. Among the three cultivars, Jumbo was significantly taller with a large stem diameter, while Revolution was the shortest with a small stem diameter. The highest sugar content was found in Revolution and the lowest in Jumbo. During the 2–year average, the total dry matter yield from the cultivars seeding on April 20 was approximately 54% higher than that of June 20. Additionally, it was difficult to apply seeding on April 20 in the double–cropping system with winter forage because of the prolonged growing period. Based on the yield and agronomic characters observed in this study, seeding on May 10 was ideal for developing improved forage cropping system in CRSK.

Key words: Central Korea, Cultivar, Seeding date, Sorghum × sudangrass, Yield.

INTRODUCTION

Agriculture is an important sector for the economy of a country. Agriculture and crop production are dependent on specific climate conditions. The mean temperature of Korea is continually increasing by approximately 1.7°C, while global temperatures have risen by approximately 0.85°C according to the Climate change report 2014 (Kang 2015; Pachauri *et al*., 2014). Increasing temperatures reduce the growth and yield of several crops such as rice, barley, and soybean, which are greatly affected by changing climates. Climate change may cause an increase in the competition from weeds and lead to an expansion of pathogens, pests, insects and other factors in the crop agro–ecosystem (Kim *et al*., 2013; Son *et al*., 2009). Therefore, it is imperative to apply new cropping systems in distinct growing seasons (Jung *et al*., 2012) and sustainable cropping approach would be beneficial to farmers for increased crop yield and quality in the changing climatic conditions (Laucer *et al*.. 1999).

Temperature is one of the most important factors for growth and development in plants. According to a previous report, plant yield reduced significantly due to the variation in the sowing dates of plants (Pale *et al*., 2003). Early sowing at soil temperatures above 15°C is recommended for sowing sorghum × sudangrass hybrid (SSH) (Eastin 1976; Lee *et al*., 1997). However, it is also imperative to develop adequate cropping system for the supply and improvement of forage (Park *et al*., 2011). The qualitative and quantitative yield in forage plants may be influenced by cropping systems as well as intended applications as silage, hay and in soiling (Lee 2005). Therefore, suitable strategies, including land availability, cultivation management, soil fertility and irrigation facilities should be considered as potential factors to develop specific and effective cropping systems.

SSH is warm season grass and grows well under relatively high temperature, shows better tolerance to multiple stresses including drought, heat, salinity and flooding (Andy, 2008; Ejeta and Knoll, 2007; Schittenhelm and Schroetter, 2013). SSH is one of the most important forage cultivars (Seo *et al*., 1983). It is a suitable source for biomass production, weed suppression and nematode control. SSH is a good source of hay, silage, or green chop and is widely used for silage in Korea (Kim *et al*., 2009). It fits well to crop rotation systems associated with winter crops such as Italian ryegrass, forage barley, rye (Ji *et al*., 2010; Yoana *et al*., 2010) and Park *et al*. (2011) established SSH + rye + red clover as a good forage cropping system in CRSK field soil conditions.

The performance of sudangrass, sudangrass hybrids and SSH have been widely studied in CRSK. The 'Sordan 79' hybrid is one of the good SSH cultivars widely cultivated in CRSK because of the high yield,

[1] Grassland & Forage Division, National Institute of Animal Science, Cheonan, Korea
[2] Department of Crop Science, Collage of Agricultural and Life Sciences Chungnam National University, Daejeon, Korea
[3] Laboratory of Plant Nutrition, Division of Molecular Biosciences, Department of Biosciences & Biotechnology, Faculty of Agriculture, Kyushu University, 744 Motooka, Nishiku, Fukuoka 819–0395, Japan
* Corresponding author (e–mail: jwcho@cnu.ac.kr)

Table 1. Chemical properties of the soil before experiment during growing seasons

Year	pH (1: 5H_2O)	T–N† (%)	OM ‡ (g kg^{-1})	Average P_2O_5 (mg kg^{-1})	CEC§ ($cmol^+$ kg^{-1})	Exchangeable cation ($cmol^+$ kg^{-1})			
						K	Na	Ca	Mg
2014	7.45	0.34	50.15	635.09	9.26	1.65	0.46	6.23	2.77
2015	7.33	0.26	40.05	275.67	6.37	0.93	5.91	2.02	0.17
Mean	7.39	0.30	45.10	455.38	7.82	1.29	3.19	4.13	1.47

†T–N: total nitrogen.
‡OM: organic matter
§CEC: cation exchange capacity

good growth characters, yields and feed value (Ji *et al.*, 2010). According to a previous study, SSH cultivars, including Sordan 79 and Jumbo, were cultivated for evaluating forage yield and quality (Kim *et al.*, 1991). It was observed that Sordan 79 was more resistant to leaf blight compared to that of other hybrids, while Jumbo, Sordan 79 and SX 17 were susceptible to lodging.

The objectives of the present study were to evaluate the effects of distinct sowing dates and cultivars variation on the quantitative and qualitative yield in SSHs. This study may form the basis for further development of improved forage cropping system in CRSK.

MATERIALS AND METHODS

Description of experimental site

The field experiments were conducted between April 2014 and October 2015 at an upland field in Cheonan (latitude 36°49′0″N, longitude 127°10′0″E), the central reign of South Korea. The conditions of the upland field experiment were clay loam soil which was slightly alkaline (pH 7.39), contained higher extractable K and P content (1.29 $cmol^+$ kg^{-1} and 355.38 mg kg^{-1}, respectively) and rich in organic matter (45.10 g kg^{-1}). The nitrogen and phosphate contents were checked from experimental field soil (Table 1). The seasonal rainfall was 861 mm in 2014 and 625 mm in 2015, which was lower than the 30–year precipitation average of 1,066 mm (Fig. 1). The average air temperature from April to September was similar to the 30–year mean air temperature; however, they were higher in May 2014 and 2015 (Fig. 2).

Agronomic practices

Experiments were conducted in a split–split plot design in four factors with three replicates. The main plots consisted of four planting dates (April 20, May 10, May 30 and June 20) and the sub–plots consisted of three SSHs (Jumbo, Sordan 79 and Revolution). Application rates of chemical fertilizers were nitrogen (N) 250 kg ha^{-1}, phosphate (P_2O_5) 150 kg ha^{-1} and potassium (potash, K_2O) 150 kg ha^{-1} each year. Approximately N fertilizer was applied 40% on the seeding date, 30% at the five–leaf stage, and 30% immediately after the first cutting time. P_2O_5 and K_2O fertilizer applied as the basis of fertilizer. SSHs were planted at the rate of 40 kg seed per ha and the plot size of each experimental unit was designed as 12 m^2 (3 m × 4 m) with row spacing of 50 cm.

Measurements of dry matter yield

The harvestable plants were cut down at 15 cm above the ground level for biomass yield measurement when 50% of the plants were at the flowering stage. Sub–samples were randomly selected from the harvested crops and dried at approximately 65–70°C for 72 h to determine the percentage of dry matter content.

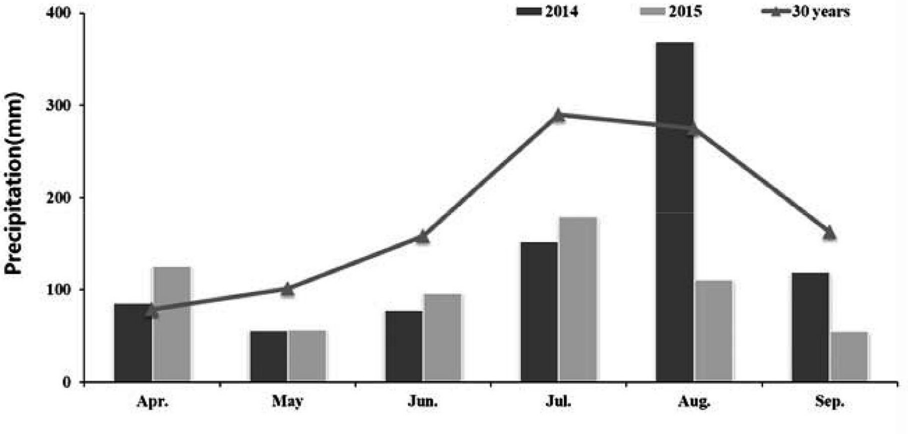

Fig. 1. Mean values of the amount of precipitation during the growing season and 30 years average in Cheonan, Korea, 2014 to 2015.

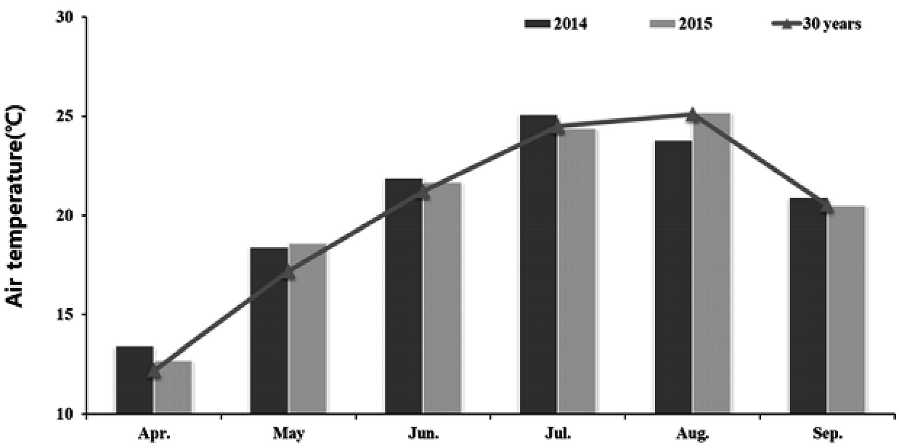

Fig. 2. Mean values of air temperature during the growing season and 30 years average in Cheonan, Korea, 2014 to 2015.

Evaluation of agronomic traits and nutritive values

Plant height measured from above the soil to the tallest leaf was determined from the harvestable crops, among which ten plants were selected for determination of stem diameter (mm) measured by vernier calipers (Mitutoyo, Japan). Sugar content was measured using a digital refractometer (Atago, Tokyo, Japan) and expressed as ˚Brix. All the agronomic traits were examined with the cooperation of standard research and investigation team (RDA, 2012).

Total crude protein contents were analyzed using the AOAC method (1995). Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were analyzed by Goering and Van Soest method (1991). *In vitro* dry matter digestibility (IVDMD) was analyzed by the procedure of Moore (1970). Total digestible nutrients (TDN) was calculated by the formula TDN (%) = 88.9 − (0.79 × ADF%) (Holland, 1990).

Statistical analysis

Statistical analyses were performed using SAS system v.9.2 (SAS Institute. Inc. Cary, NC, USA). Two–factorial field experiments were conducted according to the randomized split–plot design with three independent replications. Data were analyzed using PROC GLM and means were separated on the basis of Duncan's multiple range test ($p \leq 0.05$).

RESULTS

Agronomic characteristics of sorghum × sudangrass hybrid

The heading dates varied due to the variation in seeding date. Plants seeded on April 20 had longer growing period than those on other seeding dates due to cold weather during the early growing season (April) in both years. However, heading dates were no significant difference between Sordan 79 and Revolution. This is probably due to the fact that Sordan 79 and Revolution both were medium maturity cultivars (Table 2).

In this study, plant growth rates were significantly affected by temperature. Lower growth rates were observed in early planting (April 20 and May 10), while the growth rate increased sharply in the delayed planting batch (Fig. 3). Plant height was strongly influenced by planting date and cultivars; the greatest plant height was observed in May 10 planting compared to that of the other planting dates in the first cutting time. In the second cutting time, plant height was higher at early planting (April 20 and May 10), while it reduced sharply after May 10 (Table 3). Among the three hybrid cultivars (Jumbo, Sordan 79, and Revolution), Jumbo was tallest (268 cm) compared to that of Sordan 79 (259 cm) and Revolution (259 cm) at the first cutting time (Table 3).

In this study, stem diameters were strongly correlated to the sowing dates and cultivars. In the first cutting time, stem diameter was higher in the early sowing date (April 20) and lower in the late planting date compared to those of the other planting dates. As expected, delaying the planting date resulted in reduced stem diameters and the lowest stem diameter was recorded for the cultivars planted on June 20 (Table 3). Stem diameters of Jumbo and Sordan 79 were not significantly different, while Revolution had the smallest stem diameter at the first cutting time. Jumbo showed the thickest stem, followed by Sordan 79 and Revolution, respectively (Table 3).

In the present study, the sugar content was similar among the four planting dates in the first cutting time, except for May 30, which was lower than that of the other planting dates (Table 3). This could be due to constant rains for 3 days prior to harvesting. Among the three hybrid cultivars, Jumbo had significantly the lowest sugar content (3.15 ˚Bx) in comparison to Sordan 79 (4.80 ˚Bx) and Revolution (6.52 ˚Bx) in the first cutting time. The second cutting time was also similar to the first cutting time, thereby the highest sugar content was found for Revolution (7.55 ˚Bx) and the lowest for Jumbo (4.63 ˚Bx).

Table 2. Sowing date, day to heading, harvest date and growing period of sorghum × sudangrass hybrids a Cheonan, Korea, during the growing season from 2014 to 2015

Year	Sowing date	Cultivars	Days to heading		Harvest date		Growing period (Days)		
			1st	2nd	1st	2nd	1st	2nd	Total
2014	April 21	Jumbo	–	–	Jul. 16	Sep. 22	87	68	155
		Sordan79	81	62					
		Revolution	85	64					
	May 14	Jumbo	–	–	Jul. 21	Sep. 22	61	63	124
		Sordan79	59	57					
		Revolution	60	61					
	May 29	Jumbo	–	–	Aug. 5	Oct. 1	68	57	131
		Sordan79	66	54					
		Revolution	66	57					
	June 20	Jumbo	–	–	Sep. 4	Oct. 1	81	27	103
		Sordan79	76	–					
		Revolution	79	–					
2015	April 22	Jumbo	–	–	Jul. 10	Sep. 2	79	54	133
		Sordan79	77	54					
		Revolution	75	54					
	May 9	Jumbo	–	–	Jul. 15	Sep. 8	67	55	122
		Sordan79	65	55					
		Revolution	65	53					
	May 29	Jumbo	–	–	Aug. 4	Sep. 24	67	51	118
		Sordan79	65	50					
		Revolution	65	52					
	June 19	Jumbo	–	–	Aug. 17	Sep. 24	59	38	97
		Sordan79	57	–					
		Revolution	57	–					

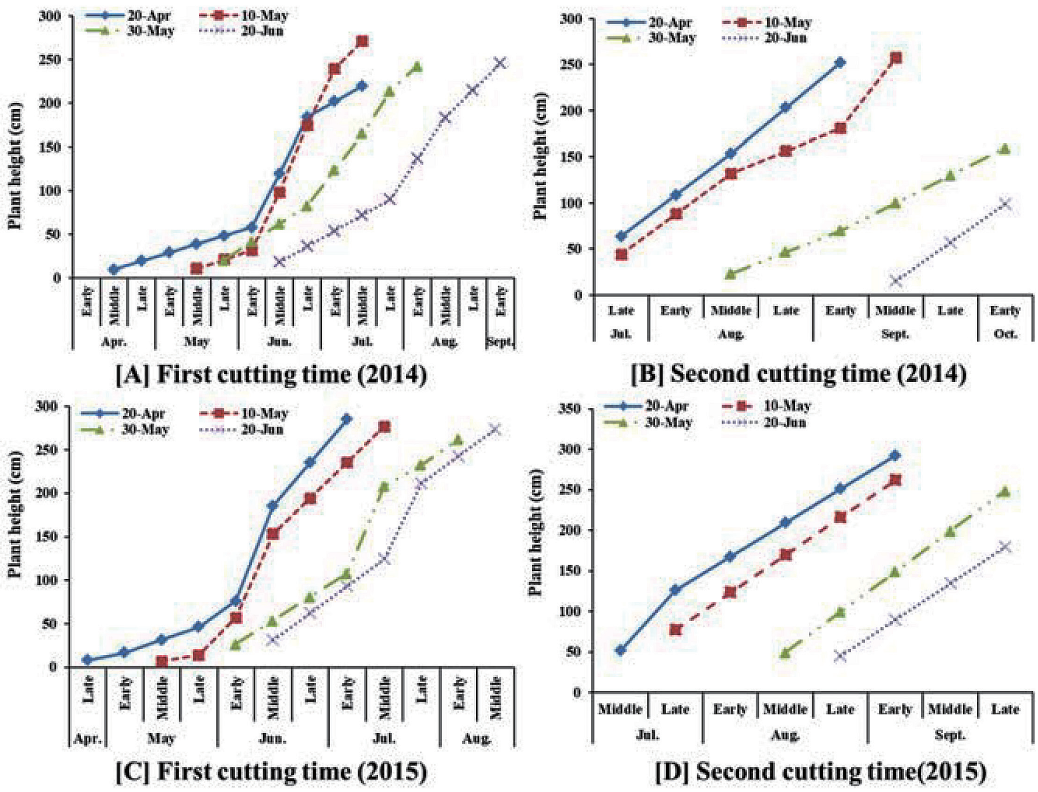

Fig. 3. Effects of sowing dates on growth rate of sorghum × sudangrass hybrids a Cheonan, Korea, during the growing season from 2014 to 2015.

Table 3. Effects of sowing dates and cultivar variation on plant height, stem diameter and sugar content of sorghum × sudangrass hybrids at Cheonan, Korea, during the growing seasons from 2014 to 2015

Item	Plant height		Stem diameter		Sugar content	
	1st	2nd	1st	2nd	1st	2nd
	cm		mm		°Brix	
Main effect						
20 April	262^{b}	265^{a}	11.93^{a}	9.29^{a}	4.92^{a}	7.36^{a}
10 May	274^{a}	260^{a}	10.62^{b}	9.10^{a}	5.62^{a}	7.16^{a}
30 May	252^{c}	203^{b}	9.93^{c}	8.13^{b}	3.56^{b}	6.70^{b}
20 June	260^{bc}	139^{c}	9.12^{d}	7.64^{c}	5.30^{a}	4.46^{c}
Subplot effect						
Jumbo	268^{a}	224^{a}	10.88^{a}	9.06^{a}	3.15^{c}	4.63^{c}
Sordan 79	259^{b}	219^{a}	10.43^{a}	8.72^{b}	4.89^{b}	7.08^{b}
Revolution	259^{b}	207^{b}	9.90^{b}	7.83^{c}	6.52^{a}	7.55^{a}
Main effect (A)	***	***	***	***	***	***
Subplot effect(B)	*	**	**	***	***	***
A×B	ns	ns	ns	ns	*	***

Means with the same letter in a column for each planting date are not significantly different at the 5% level, as determined by Duncan's multiple range test. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: Not significant.

Nutritive values of sorghum × sudangrass hybrid

In this study, we observed that crude protein (CP) is strongly influenced by planting date and cultivars. The highest CP was found at May 30 planting date in the first cutting time. In the second cutting time, delaying the planting date resulted in increased CP content, except for the cultivars sown on May 30. The maximum CP content was obtained for plants sown on June 20 (9.31%) in the second cutting (Table 4). Among the three hybrid cultivars, Jumbo and Sordan 79 had significantly higher CP content than that of Revolution during both the cutting times.

In this study, we observed that acid detergent fiber (ADF) was similar in all the seeding dates in the first harvest except for May 30, which had the highest ADF content in the second cutting time. In the second harvest, highest ADF content was noted in the first planting (April 20 – 42.34%), followed by May 10 (40.35%), May 30 (38.53%), and June 20 (34.90%), respectively. Thus, the reduction in ADF content was induced by delaying the date of planting; this may be due to the cooler and shorter growing period (Table 4). In 2015, no statisti-

Table 4. Effects of sowing dates and cultivar variation on crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF), *In vitro* dry matter digestibility (IVDMD) of sorghum × sudangrass hybrids at Cheonan, Korea, during the growing seasons from 2014 to 2015

Item	CP		ADF		NDF		IVDMD	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
	%							
Main effect								
20 April	7.33^{b}	5.92^{d}	40.68^{a}	42.34^{a}	64.91^{a}	61.91^{a}	65.64^{a}	64.50^{b}
10 May	6.79^{c}	7.00^{b}	39.08^{b}	40.35^{b}	59.54^{c}	61.07^{a}	64.64^{a}	64.84^{b}
30 May	8.74^{a}	6.46^{c}	42.30^{a}	38.53^{b}	65.63^{a}	60.65^{a}	62.14^{b}	66.34^{b}
20 June	6.65^{c}	9.31^{a}	40.84^{a}	34.90^{c}	62.53^{b}	57.70^{b}	65.28^{a}	72.38^{a}
Subplot effect								
Jumbo	7.57^{a}	7.41^{a}	42.18^{a}	40.37^{a}	64.36^{a}	61.93^{a}	64.02^{a}	66.33^{a}
Sordan 79	7.62^{a}	7.21^{a}	39.77^{b}	38.26^{b}	62.45^{b}	58.98^{b}	64.81^{a}	67.98^{a}
Revolution	6.95^{b}	6.90^{b}	40.23^{b}	38.45^{b}	62.65^{b}	60.10^{b}	62.45^{a}	66.74^{a}
Main effect (A)	***	***	**	***	***	*	*	***
Subplot effect(B)	*	*	*	*	**	*	ns	ns
A×B	ns	ns	ns	ns	ns	ns	ns	ns

Means with the same letter in a column for each planting date are not significantly different at the 5% level, as determined by Duncan's multiple range test. * $p < 0.05$; ** $p < 0.01$; *** $p< 0.001$; ns: Not significan cally significant difference in ADF content was observed in both cutting times; the highest ADF content (1st 42.18%, 2nd 40.37%) was observed in Jumbo followed by Revolution (1st 40.23%, 2nd 38.45%) and Sordan 79 (1st 39.77%, 2nd 38.26%) in both cutting times.

Neutral detergent fiber (NDF) contents were influenced by seeding date and cultivars of SSH. In the first harvest, both for April 20 and May 30, NDF contents were 64.91% and 65.63%, higher than those for other seeding dates of SSH (2–year average). In the second cutting time, June 20 (57.70%) was lower in NDF content than that for April 20 (61.91%), May 10 (61.07%), and May 30 (60.65%) planting dates of SSH (2–year average). In three SSHs, the highest NDF content was obtained in Jumbo and there were no significant difference between Sordan 79 and Revolution in the NDF content in the both cutting time (Table 4).

In vitro dry matter digestibility (IVDMD) was strongly influenced by the sowing date. We observed that IVDMD was similar in all the planting dates in the first harvest, expect for May 30, which was lower in IVDMD concentration (62.14%) than that of the other sowing dates. In the second harvest, delayed planting increased the digestible dry matter. However, the highest IVDMD concentration (72.38%) was found for June 20 (Table 4). IVDMD content showed no statistically significant differences among the hybrid cultivars.

Dry matter yield of sorghum × sudangrass hybrid

Total dry matter yield of SSH was significantly influenced by the sowing date and cultivars. In this study, dry matter yield was noted in the following order: April 20 (30,249 kg ha^{-1}), May 10 (26,921 kg ha^{-1}), May 30 (20,585 kg ha^{-1}) and June 20 (16,461 kg ha^{-1}) at the 2–year average (Fig. 4). Dry matter yield of SSH was reduced for the delayed planting while dry matter yield of SSH was obtained at 16,461 kg ha^{-1} from the planting on June 20. Total dry matter yield was 54% at April 20 planting that was higher than that of the June 20 planting (Fig. 4). In the first cutting time, dry matter yield of SSH was the highest in the earliest planting (April 20) and lowest in delayed planting (June 20). In the cultivars, total dry matter yield of SSH was higher in Jumbo (23,879 kg ha^{-1}), followed by Sordan 79 (24,101 kg ha^{-1}) and Revolution (22,683 kg ha^{-1}) in the 2–year average (Fig. 4).

DISCUSSION

The heading dates varied due to the variation in planting date, which was influenced by temperature and day length. The number of days for heading was negatively correlated with temperature and growth period. Pinthus and Resenblum (1961) reported that planting sorghum when soil–surface temperatures were below 18 ˚C resulted in poor seedling stands because of slow emergence rate and reduced growth rate after germination. As shown the results, increasing growing period of SSH was related with low temperature during the early growing season (Lee *et al*., 1997; Thao *et al*., 2015).

Plant height is considered a good indicator of performance of forage crops, including sorghum (Ali *et al*., 2014). Pale *et al*. (2003) and Burks *et al*. (2013) indicated that the plant height was reduced due to the

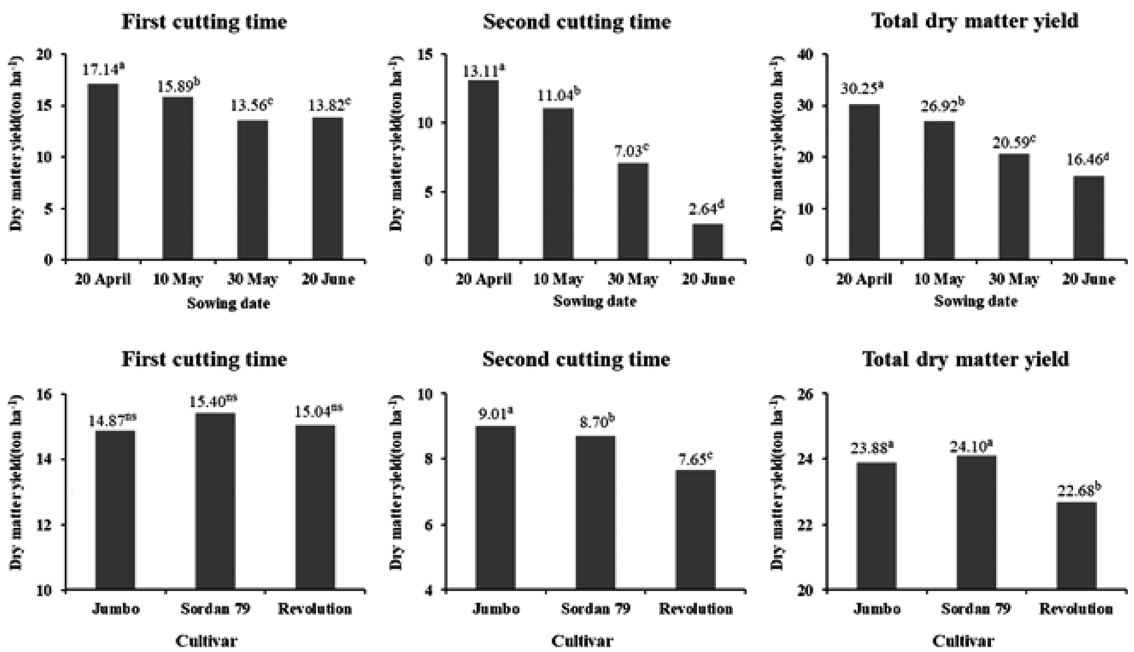

Fig. 4. Comparison of dry matter yield according to seeding dates and cultivar of sorghum × sudangrass hybrids at Cheonan, Korea, during the growing seasons from 2014 to 2015.
Means with the same letter in a column for each planting date are not significantly different at the 5% level, as determined by Duncan's multiple range test.

shorter growing season and low temperatures. In this study, plant height was strongly influenced by seeding date and cultivars. Shin *et al*. (2015) has reported that plant height decreased with delaying seeding date and plant height was strongly influenced by temperature. Shin *et al*. (2015), Kim *et al*. (2012) and Choi *et al*. (2017) have reported that plant height was not strongly influenced by maturity of cultivars. However, Hwang *et al*. (2017) have showed that middle maturing cultivars had significantly higher plant height than late maturing cultivars. Also, the results of this experiment are consistent with the findings of Hwang *et al*. (2017). But, it needs to be interpreted cautiously, because other environmental factors can affect plant height.

We observed that the sugar content of harvested cultivars was strongly influenced by cultivars than seeding dates. In the present study, the sugar content was similar among the four planting dates in the first cutting, except for May 30, which was lower than that of the other planting dates (Table 3). Previous studies have suggested that the juice content depends on stem moisture and sugar content which declined during the rainy season (Maheshwarl *et al*., 1974; Mecann *et al*., 2014). Other many reports support that BMR (brown mid–rib) of SSH has more sugar contents than other varieties (Choi *et al*., 2017; Ji *et al*., 2010; Kim *et al*., 2012).

The stem diameter is an important determinant of sorghum productivity (Ji *et al*., 2010; Tsuchihashi and Goto, 2004). According to Thao *et al*. (2015), the affected percentage from stem border strongly depended on the environmental conditions with inextricably linked to the sowing time. In this study, stem diameters were strongly correlated to the sowing dates and cultivars. These results indicate that the early sowing date would be useful to obtain thick stem diameters in both the cutting times.

The contents of CP, ADF, NDF, and IVDMD are considered as important physiological indices for forage quality measurement (Van Soest *et al*., 1991; Moore, 1970). According to Shin *et al*. (2014), the content of CP was increased by delaying the date of planting; ADF and NDF were decreased by delaying the date of planting. Also, the contents of CP, ADF, NDF were strongly influenced by cultivars (Ji *et al*., 2010; Kim *et al*., 2002; Choi *et al*., 2017). As a result, it is clear that the contents of CP, NDF and ADF were strongly correlated to the seeding date and cultivars.

The total dry matter yield of SSH was significantly influenced by seeding date and cultivars. However, the highest dry matter yield of SSH was found at early seeding (Aril 20) in the first cutting time, while the lowest in delayed seeding (June 20). A previous study has suggested that high dry matter yield of SSH was induced by earlier seeding (April and May). Lee *et al*. (1997) also reported that total dry matter yield was the highest for May 20 (20,937 kg ha^{-1}) and the lowest for June 3 (16,040 kg ha^{-1}) due to relatively shorter period than that of the earlier planting period in the intercropping cultivation research. Our results indicated that April 20 to May 10 was the best time for seeding of the forage SSH to maximize forage yield and permit harvest twice in CRSK. May 30 was the critical date for seeding of the SSH to allow two harvests. We depended only on the first cutting of the SSH in seeding on June 20 because seeding of the SSH on June 20 showed the lowest dry matter yield, especially at the second cutting time.

This study provides a better understanding of the effects of different seeding dates and cultivar variation on quantitative yield, as well as base information upon which to develop improved forage cropping systems in CRSK.

AUTHOR CONTRIBUTIONS

Jeong sung Jung conceived of the presented idea, designed the experiment, carried out the experiment, and wrote the manuscript.

Jin–woong Cho conceived of the presented idea and contributed to the analysis of data and to the final version of the manuscript.

Takeo Yamakawa discussed the results and contributed to the final version of the manuscript.

ACKNOWLEDGMENTS

This work was carried out with the support of "Cooperative Research Program for Agriculture Science & Technology Development (Project title: Developing a new cultivation technology of summer forage crops, Project No. PJ01028401)" Rural Development Administration, Republic of Korea.

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