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Research Article

Evaluation of Intercropping Sorghum × Sudangrass Hybrid (*Sorghum bicolor*) with Legume Crops Based on Growth Characteristics, Forage Productivity, and Feed Values at a Summer Paddy Field

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ABSTRACT

Intercropping cereals with legumes is known to improve forage production and crude protein yield. Sorghum × sudangrass hybrids (SSH) have excellent dry matter content and high cultivation temperatures. In this study, we investigated the growth characteristics, forage productivity, and feed value of intercropping SSH with different legumes in rice paddy fields. We used five treatments in this study SSH monocropping and four intercropping treatments of SSH with, lablab, cowpea, sesbania, and two cultivars of soybean (Chookdu 1 and 2). SSH plant height was not significantly different between the monocropping and intercropping treatments. However, the plant heights of lablab, cowpea, and sesbania were significantly higher than those of the two soybean cultivars. The total dry matter yield (kg/ha) was significantly higher in SSH monocropping than in intercropping; among the intercropping treatments, the one with SSH and Chookdu 2 yielded the highest total dry matter yield. The SSH feed value was significantly different between the monocropping and intercropping treatments, although there were no differences between the intercropping treatments. Among the intercropped legumes, lablab showed the highest neutral detergent fiber and acid detergent fiber contents, and cowpea had the highest crude protein content. These results reveal that intercropping SSH with legumes in paddy fields could be a promising cultivation technique to maintain stable forage productivity.

(Key words: Sorghum, Legume, Intercropping, Paddy field)

Ⅰ. INTRODUCTION

Consumption of livestock products in Korea is steadily increasing, and the importance of forage crops is also emerging. In 2020, 4.82 million tons of roughage was consumed in Korea, of which 3.92 million tons was produced domestically with a self-sufficiency rate of 81.4 % (MAFRA, 2021). To increase the self-sufficiency rate of roughage, the cropping area has to be actively utilized. In addition, crops that can replace summer rice need to be developed, as domestic rice consumption has recently decreased. Legume crops are important for improvingthe soil conditions on paddy fields, enhancing forage productivity and feed value. Legumes can fix nitrogen from the air to the soil through symbiosis with microbes (Unkovitch and Pate, 2000; Lie and Mulder, 1971; Nutman, 1984). However, legume crops have the disadvantages of poor yield inlow productivity. Intercropping legumes with cereal crops can improve forage production compared with monocropping legumes; the cereal crops can provide high dry matter yield and total digestible nutrients and supplement the crude protein content of the legumes For these reasons, intercropping of legumes and cereals has been actively performed worldwide.

Soybean (*Glycine max* (L.) Merr.) is not only a crude protein-rich legume crop for livestock forage but can also fix nitrogen and improve soil nitrogen content. Soybean has been shown to impact maize yield through nitrogen fixation when intercropped (Sheaffer and Seguin, 2003; Song et al., 2019). Several studies concluded that intercropping maize and soybean results in higher forage production and protein content compared withmaize monocrops (Marchiol et al., 1992; Seo et al., 2014; Song et al., 2017). Lablab (*Lablab purpureus* (L.) Sweet) is a forage legume that belongs to the family Fabaceae; grows as an annual crop or, occasionally, as a short-lived perennial. Armstrong et al. (2008) reported that improved maizecrude protein content but

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compromised fiber content and digestibility compared with monocropping maize. Lwing to its climbing nature. Cowpea (*Vigna unguiculata* L. Walp) is an annual herbaceous legume member of the Phaseoleae tribe of the Leguminosae family. Cowpea is one of the most popular grain legumes in Africa. Bryan and Materu (1987) reported that intercropping maize with cowpea increased maize crude protein concentration by approximately 9%; a similar improvement in forage dry matter yield was also verified compared with a monocrop of maize.

From this perspective, legumes provide excellent results when intercropped with maize. It is necessary to evaluate the potential of intercropping legumes with the sorghum × sudangrass hybrid (SSH). SSH has a relatively high cultivation temperature and excellent dry matter content compared to maize. Recently, in the USA, a brown midrib (BMR) variety of SSH with high sugar content in leaves and stems, low lignin content, and superior yield in drought was developed (Chemey et al., 1991; Li et al., 2013). In this study, we investigated the potential of intercropping a BMR SSH with five legumes by evaluating plant growth characteristics, forage productivity, and feed value.

Ⅱ. MATERIALS AND METHODS

1. Details and climate of the experimental site

The experiment was performed at the National Institute of Animal Science (Rural Development Administration), Cheonan, Republic of Korea (36°5’54.1” N, 127°06’21.9” E) from May 13, 2019 to August 14, 2019. The 10-year history of the average temperature and total precipitation at the experimental site, as well as the details recorded during the trial, are given in Table 1.

2. Details of seeds used in the study and the seeding

The SSH seed variety used was ‘revolution’. The legumes (cultivars) used in the study were soybean (Chookdu 1 and Chookdu 2), cowpea (Black type), and lablab (Rongai). SSH was seededusing the drilling method, and the legumes were seeded in alternate rows. Legume-distance was 10 cm, and ridge breadth was 70 cm.

3. Field measurement

Measurements of the plant height were performed before harvesting; the plants on the border were excluded. The forage productivity (kg/ha) of the intercropping treatments was calculated using the weight of the plants harvested from the two central rows, again excluding the border lines. To estimate the dry matter yield, two plant samples were collected from each replicate, and their fresh weights were measured. The samples were then oven-dried at 70 °C for 72 h and weighed again. Dry matter yield (kg/ha; DM) was calculated using the fresh weight and DM.

4. Feed values

Neutral detergent fibers (%; NDF) and acid detergent fibers (%; ADF) were estimated following the procedure described by Van-soest et al. (1991). Crude protein (CP) content was measured using the method described by AOAC (1990). The relative feed value (RFV) and the total digestible nutrient (TDN) values were calculated as follows:

* TDN (%) = 88.9 − (0.79 × ADF %)
* TDN yield (kg/ha) = DM of legume × legume TDN (%)
* DDM (Digestible Dry Matter) = 88.9 − (0.779 × ADF %)
* DMI (Dry matter intake; % of body weight) = 120 / (NDF %)
* RFV = (DDM × DMI) / 1.29

5. Soil analysis

The chemical composition of the experimental soil is given in Table 2. Soil samples were collected from a depth of 20 cm from three different locations in each treatment replicate at the

Table 1. Average temperature and total precipitation in the experimental site in Cheonan, Republic of Korea

Climate	Year	May	June	July	August
Temperature (°C)	2019	17.2	20.4	24.3	24.9
	2009-2018	18.2	22.6	25.5	25.8
Precipitation (mm)	2019	15.1	84.9	235	90.7
	2009-2018	64.2	87.9	327	231

Table 2. Chemical properties of the soil in the experimental site in

pH (1:5)	EC (ds/m)	Available P_2O_5 (mg/kg)	Organic matter (g/kg)	N (%)	Exchangeable cations ($cmol_c$/kg)		
					Ca	K	Mg
6.64	38.23	56.82	17.16	0.152	1.12	0.28	0.36

EC, electrical conductivity; N, nitrogen; Ca, calcium; K, potassium; Mg, magnesium; Na, sodium.

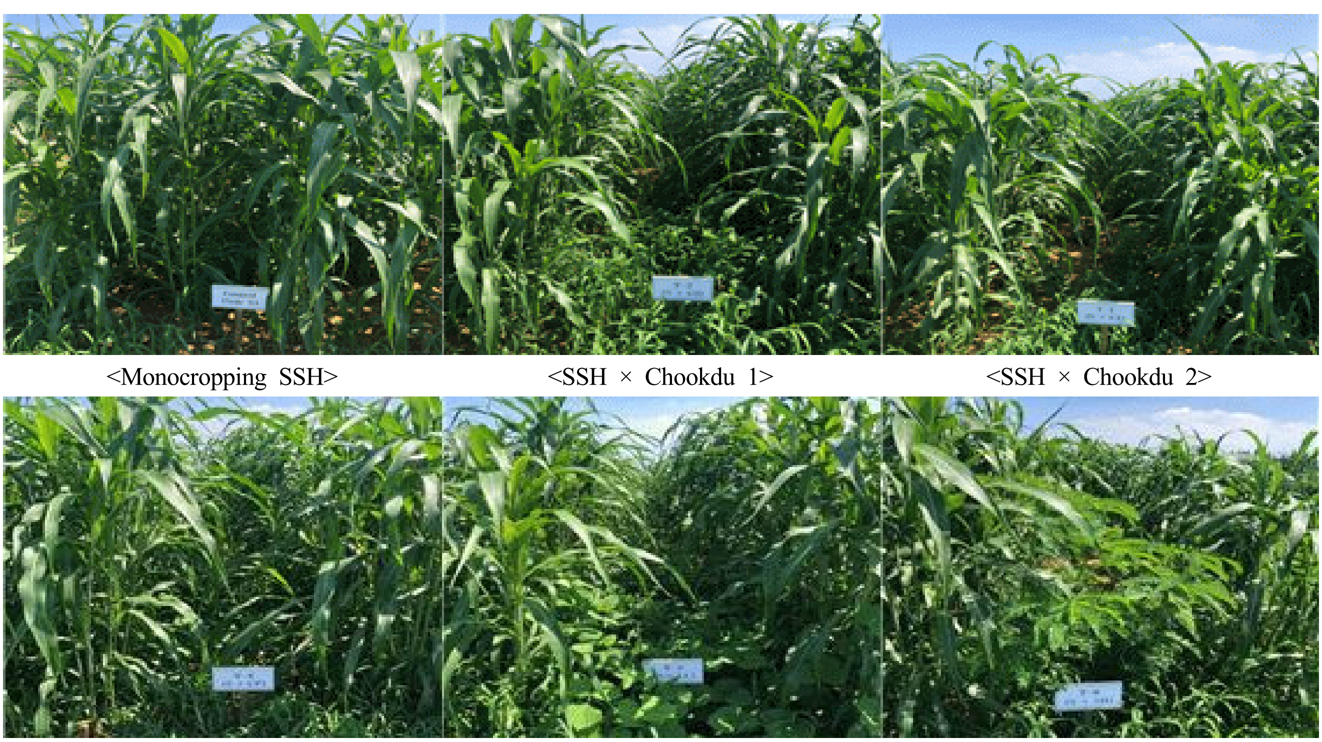
experimental site. The collected soil samples were sieved through a 2-mm mesh and then used to determine the pH, nitrogen content, electrical conductivity (EC), available P2O5, and exchangeable cations, according to the protocol of the National Institute of Agricultural Science and Technology (NIAST, 1988). Soil pH and EC were measured using a pH meter (Orion 3-Star, Thermo Fisher Scientific, Waltham, MA, USA) and an EC meter (Orion 3-Star, Thermo Scientific), respectively. Total soil nitrogen content and available P2O5 were measured using the Kjeldahl (Kjeldahl Auto Sampler System 1035 analyzer) and molybdenum blue (UV spectrometer; UV 1800, Shimadzu, Kyoto, Japan), respectively. The exchangeable cations were measured using inductively coupled plasma-optical emission spectroscopy (ICP-OES; iCAP 7000 Series ICP-OES, Thermo Fisher Scientific, Cambridge, UK) after mixing 5 g of a soil sample with 50 mL of 1-N ammonium acetate (pH 7.0) solution for 30 min.

6. Statistical analysis

The collected data were analyzed using SPSS (version 24.0; IBM Corp., Armonk, NY, USA). The statistical difference between treatments was verified using Duncan's multiple range test at *p*>0.05.

Ⅲ. RESULTS AND DISCUSSION

The plant height and growth characteristics of SSH monocropping and SSH intercropping with the studied legumes are shown in Fig 1 and Table 3, respectively. There were no significant differences between the SSH plant heights in the monocropping and intercropping treatments. Among the intercropping treatments, the SSH plant height was the highest when intercropped with cowpea. We had hypothesized that the nitrogen fixing ability of legumes would



<Monocropping SSH> <SSH × Chookdu 1> <SSH × Chookdu 2>

<SSH × Cowpea> <SSH × Lablab> <SSH × Sesbania>

Fig. 1. Photographs of representative plants from the experimental sites belonging to the different treatment groups.

Table 3. Plant height of SSH monocrop and SSH intercropping with legumes on the paddy fields during summer (2019)

Treatments / Parameters	Plant height (cm)	
	SSH	Legume
Monocropping SSH	283[ns]	-
SSH × Chookdu 1	279	54.5[b]
SSH × Chookdu 2	271	68.9[b]
SSH × Cowpea	283	145[a]
SSH × Lablab	275	143[a]
SSH × Sesbania	274	147[a]
SEM	8.47	22.1

[ns]: not significantly different
[a, b]: within a row, a different superscript letter indicates significant difference ($p<0.05$).
SSH: Sorghum × sudangrass hybrid

Table 4. Effects of different cropping systems on dry matter content

Treatments / Parameters	Dry matter (%)		Dry matter yield (kg/ha)		
	Sorghum	Legume	Sorghum	Legume	Total
Monocropping SSH	18.02[ns]	-	12,703[a]	-	12,703[a]
SSH × Chookdu 1	16.82	16.72[a]	6,791[b]	728[b]	7,519[b]
SSH × Chookdu 2	20.67	15.80[ab]	7,582[b]	634[b]	8,217[b]
SSH × Cowpea	17.93	9.40[c]	6,509[b]	846[b]	7,355[b]
SSH × Lablab	17.21	13.82[b]	6,462[b]	1286[a]	7,748[b]
SSH × Sesbania	17.64	15.66[ab]	6,731[b]	890[b]	7,621[b]
SEM	1.04	0.47	762	76.14	783

[ns]: not significantly different
[a–c]: within a row, different superscript letters indicate significant difference ($p < 0.05$).
SSH: Sorghum × sudangrass hybrid

have had a positive effect on the growth of the SSH; however, this effect was proven to be insufficient. Morris et al. (1986) had reported that nitrogen fixation in legumes improves when there is lesser nitrogen in the soil. Therefore, in our study, nitrogen fixation by the legumes was likely not fully activated in the intercropping treatments because the soil was sufficiently fertilized. Regarding legume plant height, cowpea, lablab, and sesbania were significantly taller than the legume in other treatments ($p<0.05$). Although the soybean cultivars Chookdu 1 and 2 are known to have a climbing habit, they were both significantly shorter than the upright-type sesbania ($p<0.05$).

The dry matter percentage (Table 4) was not significantly different between the SSH monocropping and intercropping treatments. However, the dry matter content of legumes was significantly different; Chookdu 1 had the highest at 16.72%, and cowpea had the lowest dry matterat 9.40% ($p<0.05$). It should be noted here that all legumes, including cowpea, were, as the SSH.

The dry matter yield (kg/ha) was significantly higher in the SSH monocrop ($p<0.05$) than in the other treatments, and there were no significant differences in the DM among the intercropping treatments. Regarding forage productivity, intercropping of SSH resulted in lower forage productivity than that in SSH monoculture, likely due to the seeding method. Song et al. (2021) reported arithmetically higher forage productivity in maize–soybean intercropping treatments than in maize monocultures in summer paddy fields; in addition, Seo et al. (2017) also had similar results. We propose that the plant row distance of 50 cm and the drilling method used for seeding in this study resulted in light competition among the plants, which in turn negatively affected the growth of the legumes.

The feed values of the SSH (monocropping and intercropping) treatments observed in this study are shown in Tables 5 and 6. There were no significant differences in the ADF, CP, or TDN contents among the treatments. The NDF content was significantly higher (70.04%) in the SSH monocropping treatment ($p<0.05$) than in the others, although this result would be difficult to interpret owing to the effects of the cropping systems between the intercropping and monocropping treatments. Choi et al. (2017) reported that the NDF content of SSH was 67.5–67.6% when cultivated in dry farmland, whereas its ADF content was 39.7–42.6%. The NDF and ADF values observed in this study (conducted in paddy fields) were slightly higher than those reported by Choi et al. (2017). The CP content of SSH observed in this study averaged 10.66%; a similar result was reported by Kwon et al. (2014), who found the average CP content of BMR SSH varieties to be 9.2%. We also verified that TDN content was similar between the intercropping and monocropping treatments of SSH.

The feed values of the legumes intercropped with SSH are shown in Tables 7 and 8. The feed values of the legumes varied more than those of the SSH did. The NDF content of lablab was significantly lower than those of the other treatments ($p<0.05$). Many studies have focused on intercropping lablab worldwide (Shehu et al., 1999; Hassan et al., 2014; Mpangne et al., 2004). Hassan et al. (2014) reported that the NDF content of lablab was 53.62–59.70%, which was similar to that found in our results. The average ADF content of the intercropped legumes was 44.71%, of which lablab (38.66%) had significantly more ADF than the other treatments did ($p<0.05$). The CP content in the legumes was significantly higher than that in the SSH. Cowpea showed the highest CP content at 19.04% ($p<0.05$). The CP content in Chookdu 1 and 2, which have been studied previously in Korea, were 16.09% and 15.77%, respectively. The CP content in Chookdu 2 was similar to that reported by Song et al. (2021), which was 15.2%. The TDN content was significantly different among the legume crops. Lablab showed the highest TDN content (58.36%), while sesbania (50.59%) had the lowest ($p<0.05$). DMI and DDM were calculated based on the NDF and ADF contents, and the averages in the legumes were 2.04% and 54.07%, respectively. Lablab had significantly the highest ($p<0.05$) DMI and DDM

Table 5. Effects of different cropping systems on forage feed value (NDF, ADF, CP, and TDN) of SSH

Treatments / Parameters	NDF (%)	ADF (%)	CP (%)	TDN (%)
Monocropping SSH	70.04^{b}	43.71^{ns}	10.40^{ns}	54.37^{ns}
SSH × Chookdu 1	65.87^{a}	39.89	11.51	57.38
SSH × Chookdu 2	65.54^{a}	39.51	12.68	57.69
SSH × Cowpea	69.46^{b}	46.36	8.74	52.27
SSH × Lablab	67.23^{ab}	43.39	9.92	54.62
SSH × Sesbania	67.30^{ab}	41.23	10.68	56.33
SEM	0.68	1.97	1.54	1.56

^{ns}: not significantly different
$^{a,\ b}$: within a row, different superscript letters indicate significant difference ($p < 0.05$).
SSH, sorghum × sudangrass hybrid; NDF, neutral detergent fiber; ADF, acid detergent fiber; CP, crude protein; TDN, total digestible nutrient

Table 6. Effects of different cropping systems on forage feed value (DDM, DMI, RFV, and IVDMD) of SSH

Treatments /Parameters	DDM (%)	DMI (%)	RFV (%)	IVDMD (%)
Monocropping SSH	54.85^{ns}	1.71^{b}	72.86^{ab}	54.79
SSH × Chookdu 1	57.82	1.82^{a}	81.66^{a}	57.88
SSH × Chookdu 2	58.13	1.83^{a}	82.50^{a}	64.92
SSH × Cowpea	52.78	1.73^{b}	70.73^{b}	59.30
SSH × Lablab	55.10	1.79^{ab}	76.36^{ab}	51.50
SSH × Sesbania	56.78	1.79^{ab}	78.73^{ab}	66.50
SEM	1.53	0.02	2.80	-

^{ns}: not significantly different
$^{a,\ b}$: within a row, different superscript letters indicate significant difference ($p < 0.05$).
SSH, sorghum × sudangrass hybrid; DDM, digestible dry matter; DMI, dry matter intake; RFV, relative feed value; IVDMD, *in vitro* dry matter digestibility.

Table 7. Effects of different cropping systems on forage feed value (NDF, ADF, CP, and TDN) of the intercropped legumes

Treatments / Parameters	NDF (%)	ADF (%)	CP (%)	TDN (%)
SSH × Chookdu 1	59.64^{b}	44.26^{b}	16.09^{ab}	53.94^{b}
SSH × Chookdu 2	60.94^{b}	45.82^{b}	15.77^{b}	52.70^{b}
SSH × Cowpea	59.59^{b}	46.30^{b}	19.04^{a}	52.32^{b}
SSH × Lablab	54.77^{a}	38.66^{a}	17.94^{ab}	58.36^{a}
SSH × Sesbania	62.05^{b}	48.50^{b}	17.02^{ab}	50.59^{b}
SEM	0.76	1.00	0.82	0.79

$^{a,\ b}$: within a row, different superscript letters indicate significant difference (p < 0.05).
SSH, sorghum × sudangrass hybrid; NDF, neutral detergent fiber; ADF, acid detergent fiber; CP, crude protein; TDN, total digestible nutrient

Table 8. Effects of different cropping systems on forage feed value (DDM, DMI, RFV, and IVDMD) of the intercropped legumes

Treatments / Parameters	DDM (%)	DMI (%)	RFV (%)	IVDMD (%)
SSH × Chookdu 1	54.42^{b}	2.01^{b}	84.94^{b}	64.35
SSH × Chookdu 2	53.21^{b}	1.97^{b}	81.37^{b}	61.61
SSH × Cowpea	52.83^{b}	2.02^{b}	82.48^{b}	71.61
SSH × Lablab	58.78^{a}	2.19^{a}	100.2^{a}	73.74
SSH × Sesbania	51.12^{b}	1.93^{b}	76.65^{b}	54.53
SEM	0.78	0.03	2.33	-

^{ns}: not significantly different
$^{a,\ b}$: within a row, different superscript letters indicate significant difference (p < 0.05).
SSH, sorghum × sudangrass hybrid; DDM, digestible dry matter; DMI, dry matter intake; RFV, relative feed value; IVDMD, *in vitro* dry matter digestibility.

among the legumes studied. The RFV observed in this study was lower than that reported previously. Among the legumes we studied, lablab had the highest RFV of 100.2 (p<0.05). The generally low RFVs we observed were likely due to the insufficient growth period of the legumes. The legumes did not produce pods at harvest time, then only the leaf and stems were harvested. Furthermore, legume plant heights were lower than those of the SSH. We propose that the legumes were disadvantaged by light competition, which could have affected growth. IVDMD ranged from 54.53–71.61%, of which cowpea had the highest.

Ⅳ. CONCLUSION

This study was conducted to investigate plant characteristics, forage productivity, and feed value of intercropping SSH with legume crops in summer paddy fields. The SSH plant height was not significantly different between the monocropping and intercropping treatments. The monocropping of SSH had the highest dry matter yield, while the legume crops showed excellent feed value. The intercropping treatments showed low dry matter yield, likely due to the fact that the legumes had insufficient growth periods and, thus, had to compete with SSH for light. Despite this result, intercropped cowpea and lablab showed excellent feed values, although the SSH monoculture had the highest feed values of all treatments. Our results reveal that intercropping SSH with legumes in paddy fields could provide desirable forage properties, although novel cropping techniques would be necessary to mitigate the limitations.

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