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Research Paper

Evaluation of corn-soybean inter-cropping systems in southwestern Japan

Evaluación de sistemas de cultivos intercalados de maíz con soya en el suroeste de Japón

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Abstract

To assess the effects of inter-cropping corn and soybean under southwestern Japan's climatic conditions, 5 different treatments were compared, namely: CW (mono-cropped corn - weeded); CTW (corn + soybean cv. Tachinagaha - weeded); CT (corn + soybean cv. Tachinagaha - unweeded); CSW (corn + soybean cv. Suzukaren - weeded); and CS (corn + soybean cv. Suzukaren - unweeded). Parameters measured were plant height, yield, nutrient composition of corn and soybean and the numbers of Japanese beetles (*Popillia japonica*). Plant height of mono-cropped corn was significantly ($P<0.05$) greater than that of corn in most of the inter-cropped treatments. The number of Japanese beetles had increased dramatically, especially on unweeded inter-cropped treatments, at 55 DAS (days after sowing). Fresh and dry matter yields (FMY and DMY) of corn did not differ among treatments ($P>0.05$), while CTW treatment produced higher FMY and DMY for soybean ($P<0.05$) than in CSW and CS. Weeding tended to reduce the number of Japanese beetles on soybean plants, but it did not affect yield of soybean in this study. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations in corn cobs, whole corn plants and whole soybean plants did not differ among treatments ($P>0.05$), while crude protein (CP) concentration in whole corn plants in CTW exceeded ($P<0.05$) those for mono-cropped corn and CSW treatments. These results indicated that soybean can be successfully inter-cropped with corn in southwestern Japan. Soybean plants may be infested with Japanese beetles. It is advisable to control weeds in the stands to reduce the level of beetle infestation and to minimize competition for the planted crops.

Keywords: Corn-legume intercropping, crude protein, forage yield, nutrient composition, *Popillia japonica*.

Resumen

Para evaluar los efectos del cultivo intercalado de maíz y soja en las condiciones climáticas del suroeste de Japón, se compararon 5 tratamientos diferentes, a saber: CW (maíz monocultivo - desyerbado); CTW (maíz + soja cv. Tachinagaha - desyerbado); CT (maíz + soja cv. Tachinagaha - sin desyerbar); CSW (maíz + soja cv. Suzukaren - desyerbado); y CS (maíz + soja cv. Suzukaren - sin desyerbar). Los parámetros medidos fueron la altura, el rendimiento, la composición de nutrientes del maíz y la soja y el número de escarabajos japoneses (*Popillia japonica*). La altura de la planta de maíz monocultivo fue significativamente ($P<0.05$) mayor que la del maíz en la mayoría de los tratamientos entre cultivos. El número de escarabajos japoneses había aumentado drásticamente, especialmente en tratamientos de cultivos intercalados sin deshierbe, a los 55 DAS (días después de la siembra). Los rendimientos de materia fresca y seca (FMY y DMY) del

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maíz no difirieron entre los tratamientos (P>0.05), mientras que el tratamiento CTW produjo FMY y DMY más altos para la soja (P<0.05) que en CSW y CS. El deshierbe tendió a reducir el número de escarabajos japoneses en las plantas de soja, pero no afectó el rendimiento de la soja en este estudio. Las concentraciones de fibra detergente neutra (NDF) y fibra detergente ácida (ADF) en mazorcas de maíz, plantas enteras de maíz y plantas enteras de soja no difirieron entre tratamientos (P>0.05), mientras que se excedió la concentración de proteína cruda (CP) en plantas enteras de maíz en CTW (P<0.05) los de los tratamientos de maíz monocultivo y CSW. Estos resultados indicaron que la soja se puede intercalar con el maíz en el suroeste de Japón. Las plantas de soja pueden estar infestadas de escarabajos japoneses. Es aconsejable controlar las malas hierbas en los rodales para reducir el nivel de infestación de escarabajos y minimizar la competencia por los cultivos plantados.

Palabras clave: Composición nutricional, cultivos intercalados maíz-leguminosa, *Popillia japonica*, proteína cruda, rendimiento de forraje.

Introduction

Maize (*Zea mays* L.), also known as corn, is one of the most important cereal crops in the world, and is grown in a wide range of environments worldwide. It is being increasingly used for a range of purposes, such as human food, feed for livestock and a source of raw material for industrial products. The demand for corn as animal feed will continue to grow faster than the demand for its use as human food, particularly in Asia, where a doubling of production is expected to almost 400 million tonnes in 2030 (Paliwal et al. 2000). Although corn is high in digestible starch and water-soluble carbohydrates (WSC), making it a high-energy feed for ruminants (Masoero et al. 2006), it does not provide sufficient crude protein (8.8%) for high levels of production (National Research Council 2001). Therefore, supplementation with protein feeds is needed to fulfill the requirements of high-producing ruminants. In order to improve yields and forage quality of corn, alternatives are being sought.

One suitable alternative may be inter-cropping of corn with legumes such as soybean [*Glycine max* (L.) Merr.] (Ofori and Stern 1987; Carruthers et al. 1998). Legumes have long been recognized as a good source of crude protein (CP) (Anil et al. 2000). However, leguminous forage is highly difficult to ensile because of its high buffering capacity and low level of WSC (Maasdorp and Titterton 1997), but it is possible to ensile high-energy corn silage with protein-rich forages to obtain a better nutrient composition (Anil et al. 2000). Recently, several studies have found that inter-cropping of corn with legumes is a feasible option to increase CP concentration in forage produced (Prasad and Brook 2005; Contreras-Govea et al. 2009; Zhu et al. 2011; Costa et al. 2012). Herbert et al. (1984) and Putnam et al. (1986) reported that inter-cropping of corn with soybean increased CP concentration by 19–36 and 11–15 percentage units, respectively. However, inter-cropping of corn with soybean in southwestern Japan has not been reported, despite the corn-soybean inter-cropping system becoming popular worldwide.

Ishigaki et al. (2017) investigated the agronomic characteristics and yield of several soybean varieties as forage crops, and reported on the risk of insect damage during the cultivation period. The authors confirmed that leaf damage caused by scarabs, especially Japanese beetles (*Popillia japonica*; Coleoptera: Rutelidae), was remarkable. Since the cultivation period of forage soybeans and the time when scarabs are most prolific overlap, it is important to determine the impact of beetle infestation on production of forage soybeans. In addition, weeds can hamper soybean growth. However, there are no registered pesticides or herbicides for use in forage soybeans in Japan. Therefore, there is a need to document the occurrence of Japanese beetles under the corn-soybean inter-cropping system and the effects on forage yield and quality of corn in southwestern Japan, with the aim of developing a pest management strategy for forage soybeans that does not rely on the use of pesticides.

The present studies were conducted: (i) to assess the occurrence of Japanese beetle on soybean plants under mono-cropped and inter-cropped cultivation; and (ii) to evaluate the effects on growth, forage yield and nutrient composition of inter-cropping corn with 2 forage soybean varieties relative to mono-cropped corn.

Material and Methods

Experimental site

The field experiment was carried out at the Sumiyoshi Livestock Science Station, Field Science Education Research Center, Faculty of Agriculture, University of Miyazaki, Japan (31°55′ N, 131°28′ E; 10 masl), from April to July 2018. Meteorological conditions are shown in Table 1. Air temperature and precipitation during the experimental period were obtained from the database of the Geospatial Information Authority of Japan (jma-net.go.jp/miyazaki), and were recorded 16 km from the experimental site. The soil type of the experimental field was characterized as sand-dune Regosol with moderate organic matter (4.0%), 0.09% N, 0.3% P, 0.2% K and a soil pH of 6.2.

Table 1. Mean temperature and precipitation during April–July 2018 in the area of the field experiment in Miyazaki, southwestern Japan.

Month	Temperature (°C)	Precipitation (mm)
April	17.6	60
May	20.5	409
June	23.6	480
July	27.5	580

Plant material

In this experiment, a corn cultivar, NS118 Super (KANEKO seed company), which matures in a period of 118 days, and 2 soybean cultivars, Tachinagaha and Suzukaren, released by National Agriculture and Food Research Organization (NARO), were used. Tachinagaha is medium-late maturing and Suzukaren is late maturing.

Experimental design and treatments

The experimental plots were laid out in a randomized complete block design (RCBD) with 5 treatments and 3 replications for each treatment. The description of treatments is summarized in Table 2. Individual treatment plots were 12.8 m^2 (4 × 3.2 m) and there were 15 plots in all. The cropping systems were mono-crop corn and corn-soybean inter-cropping. Prior to planting, lime with 10% MgO at 800 kg/ha and compost (2.5% N, 4.0% P and 2.1% K) at 1,114 t/ha were added to the soil in March. After field preparation, corn seed was sown on 16 April 2018 with 5 rows per plot, at an inter-row spacing of 75 cm, and intra-row spacing of 25 cm. Sowing rate of corn was 68,571 viable seeds/ha and sowing depth was 4–5 cm. In inter-cropped treatments, a single row of soybean was sown 20 cm from a corn row, with an intra-row spacing of 6 cm, giving a sowing rate of 285,714 viable seeds/ha; sowing depth was 5–6 cm. No rhizobium was applied to the soybean seeds and no herbicides or insecticides were used. Basal N:P:K fertilizer (14:12:10) was applied at a rate of 400 kg/ha during corn planting and 80 kg N/ha in the form of urea (46% N) was applied on 17 May 2018. The crops were inspected manually and insects (*Popillia japonica*) were first observed feeding on soybean leaves in late May (24–30 May). The CW, CTW and CSW treatments were weeded by hand during the 2nd and 4th weeks after sowing.

Table 2. Description of experimental treatments and cropping systems.

Treatment	Cropping system	Description
CW	Mono-crop	Corn - weeded
CTW	Inter-crop	Corn + soybean cv. Tachinagaha - weeded
CT	Inter-crop	Corn + soybean cv. Tachinagaha - unweeded
CSW	Inter-crop	Corn + soybean cv. Suzukaren - weeded
CS	Inter-crop	Corn + soybean cv. Suzukaren - unweeded

Data collection and analysis

At 24, 45, 68 and 80 DAS (days after sowing), 3 plants (each of corn and soybean) were selected at random from each treatment for measuring plant height. All Japanese beetles (*Popillia japonica*) on all plants in each plot (4 × 3.2 m) were collected and counted at 49, 55, 57, 66, 70 and 78 DAS. Corn and soybean inter-crops were harvested by using sickles on 13 July 2018. All plants were cut at about 10 cm above the ground in the net plot area (3 × 1.7 m), excluding border rows. Fresh matter yield (FMY) was measured in each experimental plot. To determine dry matter (DM), 10 samples of corn and soybean plants were selected from each plot, weighed fresh and dried in an oven at 70 °C for 48 hours to calculate dry matter yield (DMY). The dried samples were ground to 1 mm for chemical analysis. N concentration was measured using the NC-Analyzer (model Sumigraph NC-220F, Sumika Chemical Analysis Service Ltd, Japan), allowing calculation of crude protein concentration (CP%) and crude protein yield (CPY) for each species and cultivar as well as total CPY/ha. Neutral detergent fiber (NDF) was measured using a modified Ankom Filter bag technique (Ankom Technology, ANKOM200 Fiber Analyzer, NY, USA) and acid detergent fiber (ADF) was run sequentially after NDF using the Ankom Filter bag technique.

Statistical analysis

One-way ANOVA was conducted to assess the effects of cropping system and treatment on growth traits and yield traits. Additionally, Tukey's test was conducted to assess the means of these traits. Percentage data were transformed into angular figures (Claringbold et al. 1953). All statistical analyses were carried out with the program R software (version 3.1.1, R Core Team 2014).

Results

Plant height

Plant height of mono-cropped corn (CW) at 24 DAS (days after sowing) was significantly (P<0.05) greater than that for CT treatment (Table 3) and by 45 DAS heights of corn for CW and CSW were greater (P<0.05) than those for CTW and CT. At 68 and 80 DAS, corn in CW was taller (P<0.05) than corn in most inter-cropped treatments (Table 3). Weeding had no significant (P>0.05) effect on plant height of corn. For soybean, plant heights at 24 and 45 DAS for CTW and CT were significantly (P<0.05) greater than those for CSW and CS (Table 3). Differences between cultivars declined with time and by 68 DAS only soybean in CTW was taller than soybean in CSW and CS, while by 80 DAS only CT was taller than CS. As for corn, weeding had no effect on height of soybean.

Table 3. Plant height (cm) of corn and soybean at different growth stages for the inter-crop and mono-crop treatments.

Treatment	24 DAS	45 DAS	68 DAS	80 DAS
Corn				
CW	36±1.3a	233±1.3a	282±1.2a	293±2.0a
CTW	34±1.4ab	217±2.9b	268±2.9b	282±2.4b
CT	30±0.9b	222±3.8b	271±2.2b	284±2.5b
CSW	31±1.5ab	234±2.0a	273±2.4b	287±1.9ab
CS	31±1.1ab	225±2.3ab	272±1.5b	284±1.8b
Soybean				
CTW	13±0.4a	53±2.5a	95±2.9a	92±1.7ab
CT	12±0.5a	53±1.2a	88±3.4ab	94±2.0a
CSW	10±0.5b	39±1.9b	81±4.1b	87±3.0ab
CS	10±0.5b	39±2.6b	76±3.1b	86±1.8b

Data are presented as mean ± s.e.; means within columns and crop type with different letters are significantly different (P<0.05) by Tukey-test. DAS: days after sowing. CW: mono-crop corn - weeded; CTW: corn + soybean cv. Tachinagaha - weeded; CT: corn + soybean cv. Tachinagaha - unweeded; CSW: corn + soybean cv. Suzukaren - weeded; CS: corn + soybean cv. Suzukaren – unweeded.

Insect occurrence

No signs of disease were observed. However, a number of insect pests were observed during the growing season. The most significant one was Japanese beetle (*Popillia japonica*) (Figure 1; Table 4), which was first observed feeding on soybean leaves in late-May (24–30 May) and was present throughout June, with a few individuals still observed in July. At 49 DAS, only low numbers of beetles were collected (0.7–7.1 individuals/plot, i.e. 4 × 3.2 m) with higher, but not significantly so (P>0.05), numbers on unweeded treatments. By 55 DAS, insect numbers had increased dramatically, especially on unweeded inter-cropped treatments. There were significant differences (P<0.05) between unweeded and weeded treatments for cv. Tachinagaha but not for cv. Suzukaren. The situation remained similar at 66 DAS. By 70 DAS and 78 DAS insect numbers had dropped to fewer than 3 individuals per plot on all treatments. Corn plants suffered only minimal damage from insect pests.

Figure 1. Adult Japanese beetles (*Popillia japonica*) feeding on soybean leaves.

Yield traits

Treatments applied had no significant effects (P>0.05) on fresh (FMY) or dry matter (DMY) yields of corn with FMY ranging from 63.3 to 59.8 t/ha and DMY from 21 to 17.5 t/ha (Table 5). However, failing to weed the inter-cropped treatments produced a non-significant decrease in both FMY and DMY of corn (mean 9.2%). Soybean yields varied from 4.5 to 6.6 t FM/ha and 1.0 to 1.5 t DM/ha, with weeded Tachinagaha outyielding other treatments in terms of DMY (P<0.05). Total DMY ranged from 18.7 to 22.5 t DM/ha with no significant differences between treatments (P>0.05; Table 5).

Table 4. Numbers of Japanese beetle (*Popillia japonica*) per plot (4 × 3.2 m) collected on soybean plants.

Treatment	49 DAS	55 DAS	57 DAS	66 DAS	70 DAS	78 DAS
CW	-	-	-	-	-	-
CTW	0.7±0.3a	1.8±0.4b	4.0±0.8ab	8.4±1.6b	2.9±1.0a	0.1±0.1a
CT	7.1±3.4a	23.2±7.6a	21.8±7.2a	22.0±6.3a	1.2±0.7ab	1.9±1.0a
CSW	0.7±0.4a	0.1±0.1b	1.0±0.8b	2.8±0.9b	0.2±0.1b	0.0±0.0a
CS	4.1±1.5a	16.2±5.5ab	19.0±6.5ab	12.1±2.6ab	1.1±0.4ab	0.4±0.2a

Data are presented as mean ± s.e.; means within columns with different letters are significantly different (P<0.05) by Tukey test. DAS: days after sowing. CW: mono-crop corn - weeded; CTW: corn + soybean cv. Tachinagaha - weeded; CT: corn + soybean cv. Tachinagaha - unweeded; CSW: corn + soybean cv. Suzukaren - weeded; CS: corn + soybean cv. Suzukaren - unweeded.

Table 5. Fresh and dry matter yields (t/ha) of corn and soybean.

Treatment	FMY		DMY		Total DMY
	Corn	Soybean	Corn	Soybean	
CW	62.7±3.5		19.6±1		19.6
CTW	63.3±1.1	6.6±0.1a	21.0±1.2	1.5±0.1a	22.5
CT	59.8±4.1	5.4±0.3ab	17.5±0.8	1.2±0.1b	18.7
CSW	67.3±2.6	4.7±0.3b	20.0±0.9	1.1±0.1b	21.1
CS	60.7±0.8	4.5±0.3b	18.7±0.3	1.0±0.1b	19.7

Data are presented as mean ± s.e.; means within columns with different letters are significantly different (P<0.05) by Tukey test. CW: mono-crop corn - weeded; CTW: corn + soybean cv. Tachinagaha - weeded; CT: corn + soybean cv. Tachinagaha - unweeded; CSW - corn + soybean cv. Suzukaren – weeded; CS: corn + soybean cv. Suzukaren – unweeded. FMY: fresh matter yield; DMY: dry matter yield.

Nutrient composition

Treatments applied had very little effect on chemical composition of forage produced (Table 6). The only significant effect was for CP concentration, where CP% of corn forage from the Tachinagaha inter-cropped weeded treatment exceeded that of whole corn forage grown as a sole crop (7.0 vs. 5.3%; P<0.05). As a result, CP yield from corn in the Tachinagaha inter-cropped weeded treatment exceeded (P<0.05) those of all other treatments except inter-cropped weeded corn + cv. Suzukaren, while CP yields of soybean of both Tachinagaha treatments exceeded those of Suzukaren (P<0.05; Table 7). Similarly, total CP yield of the inter-cropped weeded Tachinagaha treatment exceeded those of all other treatments (P<0.05). NDF concentration in whole corn ranged from 54 to 57.9%, while concentration in soybean ranged from 44.4 to 48.5%. On the other hand, ADF concentrations for corn ranged from 35.1 to 37.2% and for soybean from 36.9 to 42.1%.

Table 6. Nutrient composition (% DM basis) of corn and soybean.

Nutrient	Treatment				
	CW	CTW	CT	CSW	CS
NDF					
Corn - cobs	35.0±1.6	36.6±0.9	38.7±1.7	38.3±0.5	38.7±0.9
Corn – whole plant	56.1±0.4	54.0±1.5	57.9±2.1	54.0±1.1	55.2±0.4
Soybean - whole plant	-	44.4±1.8	47.0±0.4	48.5±0.4	47.6±0.8
ADF					
Corn - cobs	18.4±1.0	20.0±1.0	19.3±1.4	19.5±0.5	19.4±0.2
Corn – whole plant	37.2±0.3	35.1±0.3	37.1±1.4	36.9±0.8	36.3±0.9
Soybean – whole plant plant	-	36.9±2.3	39.6±1.0	42.1±0.7	40.0±1.7
CP					
Corn - cobs	6.3±0.2	5.4±0.2	5.6±0.3	5.9±0.2	6.1±0.2
Corn – whole plant	5.3±0.1b	7.0±0.3a	6.0±0.4ab	5.6±0.1b	5.8±0.2ab
Soybean – whole plant	-	17.8±0.7	18.9±0.9	17.6±0.9	16.6±0.9

Data are presented as mean ± s.e.; means within columns with different letters are significantly different (P<0.05) by Tukey test. CW: mono-crop corn - weeded; CTW: corn + soybean cv. Tachinagaha - weeded; CT: corn + soybean cv. Tachinagaha - unweeded; CSW: corn + soybean cv. Suzukaren - weeded; CS: corn + soybean cv. Suzukaren - unweeded.

Table 7. Crude protein yield (t/ha) of corn and soybean.

Treatment	Corn	Soybean	Total
CW	1.04±0.1b	-	1.04±0.1b
CTW	1.48±0.3a	0.27±0.03a	1.75±0.2a
CT	1.04±0.1b	0.23±0.03ab	1.27±0.1b
CSW	1.13±0.1ab	0.19±0.03b	1.32±0.1b
CS	1.08±0.1b	0.17±0.03b	1.25±0.1b

Data are presented as mean ± s.e.; means within rows with a different letter are significantly different (P<0.05) by Tukey test. CW: mono-crop corn - weeded; CTW: corn + soybean cv. Tachinagaha - weeded; CT: corn + soybean cv. Tachinagaha - unweeded; CSW: corn + soybean cv. Suzukaren - weeded; CS: corn + soybean cv. Suzukaren - unweeded.

Discussion

Plant height

The reduction in plant height of corn in inter-cropped treatments relative to the mono-cropped corn treatment would have been a response to increased competition for light, moisture and nutrients, where corn was sown with the legumes. Baker (1979) and Mbah et al. (2007) indicated that inter-cropped treatments have reduced growth relative to mono-crops because of competition for resources. This hypothesis is reinforced by the fact that differences were not significant during the early stages of growth but increased as plants matured and available resources were consumed. Surprisingly, weeding of inter-cropped treatments had no significant effect on plant height of corn, despite the fact that competition for resources in the unweeded treatments might have been expected to be greater than in weeded treatments. While Tachinagaha plants were significantly taller than Suzukaren plants in the early growth stages, differences were no longer significant at the end of the study, despite absolute values favoring Tachinagaha. These differences appear to be merely varietal differences as opposed to any superiority of Tachinagaha in terms of competitive ability. Unfortunately, we failed to record biomass yields of weeds in unweeded treatments, as Rose et al. (1984) reported up to 45% differences in weed biomass production when in competition with various soybean genotypes.

Occurrence of insects

The significant insect injury to soybean caused by Japanese beetle (*Popillia japonica*) was not surprising as this insect is a voracious feeder on soybean leaves and could pose problems for soybean growth and yield under corn-soybean inter-cropping systems in the study location. The higher populations of insects in unweeded treatments indicated that weeding has more advantages than merely reducing competition for resources. Our results suggest that weeding and physical insect control under corn-soybean inter-cropping systems should be carried out to prevent possible yield loss. However, in Japan, there are no registered pesticides for control of scarab beetles, including Japanese beetle. Thus, pesticide-free control methods, such as the use of light traps, should possibly be tested for control of this insect under southwestern Japan's climatic conditions.

Yield traits

The absence of significant differences in total dry matter yield (TDMY) between mono-cropped corn and corn-soybean inter-cropped treatments suggests that competition for resources prevented any marked increase in dry matter production from a given area regardless of species involved. However, absolute DMYs for the inter-cropped weeded treatments were greater than for mono-cropped corn, suggesting that more and larger studies should be conducted to verify these findings. Similarly, the consistent, though non-significant, reductions in yields of forage in unweeded treatments also suggest that more and larger studies seem warranted to verify these findings. Reta Sánchez et al. (2010) and Baghdadi et al. (2016) reported that total DMY of corn-soybean inter-cropped treatments was similar to that of mono-cropped corn. The higher DMYs for Tachinagaha than for Suzukaren suggest that the former cultivar might be more suitable for growing in this environment. Different competitive ability of the soybean cultivars could be a factor in the different yields displayed (Callaway 1992), although we did not have any pure legume treatments in this study. Gutu et al. (2015) in their experiment on corn-soybean inter-cropping also stated that forage and grain yields of soybean were significantly different for different soybean varieties.

Nutrient composition

The absence of significant differences in NDF and ADF of corn in the different treatments was not surprising, as all crops were harvested at the same maturity stage of corn plants as suggested by Mugweni et al. (2001). While CP concentration in corn forage in inter-cropped treatments was generally not significantly greater than that of mono-cropped corn, absolute values consistently favored the inter-cropped treatments. Added to this was the much higher CP concentration in the soybean forage than in the corn forage, so overall forage produced in inter-cropped treatments was of higher quality than the mono-cropped corn. As a result, animals fed the mixed forage would be expected to perform at a higher level than those fed mono-cropped corn. Numerous studies, e.g. Lithourgidis et al. (2006), and Eskandari et al. (2009), have reported similar results indicating that inter-cropping cereal crops with legumes significantly increased the CP yield per hectare.

In conclusion, the findings of this study clearly showed that corn and soybean can be inter-cropped with simultaneous sowing under southwestern Japan's climatic conditions without any deleterious effects on the corn. While dry matter yields of forage produced might not be significantly greater than that for mono-cropped corn, the overall quality of the forage would be superior in the inter-cropped system, especially in terms of CP concentration. It appears that cv. Tachinagaha might be superior to cv. Suzukaren for growing in this environment. Again, it appears that weeding may reduce the level of insect infestation on the soybeans and possibly increase yields. These findings need verification on a larger scale and in a range of seasonal conditions to ensure recommendations are soundly based. Further investigations are required to determine the most effective non-chemical control methods for insects (Japanese beetle) and for control of invasive weeds in corn-soybean inter-cropping systems under southwestern Japan's climatic conditions.

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(Note of the editors: All hyperlinks were verified 13 July 2021).

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