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Forage yield and quality of intercropped corn and soybean in narrow strips

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Abstract

Maize-soybean intercropping can increase forage quality with no detrimental effect on dry matter (DM) yield. The objective of this study was to compare corn-soybean intercrop in narrow strips with corn as monocrop in terms of DM yield and forage quality. This study was conducted in Matamoros, Coahuila (Mexico) in 2006 and 2007. Intercrops were established in rows spaced 0.50 m apart, evaluating alternate corn-soybean strips with one, two, three, and four rows per crop, and a treatment using an alternate twin-row planting pattern per crop, with a 1.0-m row-spacing. As control treatments, monocrops of corn in rows 0.76 m apart and soybean in rows 0.50 m apart were evaluated. A randomized complete block design with four replications was employed. Corn-soybean intercrop produced DM yields similar to those of monocropped corn due to higher corn yields in border rows adjacent to soybean. Crude protein (CP) yields per hectare in intercrop treatments were higher (27.5 to 42.8%) than those of monocropped corn, due to greater CP concentrations in intercrops (16 to 21 g kg^{-1}). When soybean was harvested at the beginning maturity stage (R7), neutral detergent fiber concentration was reduced by 60 to 63 g kg^{-1} in corn-soybean intercropping compared to corn monocrop. Acid detergent fiber was not altered by intercropping. Results indicate that maize-soybean intercrop in narrow strips can provide forage quality advantages without affecting yield.

Additional key words: chemical composition, dry matter and ear yields, dry matter partitioning, *Glycine max,* intraspecific competition, *Zea mays.*

Resumen

Rendimiento y calidad de forraje de maíz y soya asociados en franjas angostas

La asociación maíz-soya puede incrementar la calidad del forraje sin disminuir el rendimiento de materia seca (MS). El objetivo del estudio fue comparar la asociación maíz-soya en franjas angostas con maíz en unicultivo en términos de rendimiento de MS y calidad de forraje. El estudio se realizó en 2006 y 2007 en Matamoros, Coahuila, México. Las asociaciones se establecieron en surcos a 0,50 m, en franjas alternas de maíz y soya con uno, dos, tres y cuatro surcos por cultivo y un tratamiento en surcos alternos a 1 m con doble hilera del mismo cultivo. Los testigos fueron maíz y soya en unicultivo establecidos en surcos a 0,76 m y 0,50 m, respectivamente. Se utilizó un diseño experimental de bloques completos al azar con cuatro repeticiones. La asociación maíz-soya produjo rendimientos de MS similares a maíz en unicultivo como resultado de un mayor rendimiento del maíz en los surcos adyacentes a la soya. Debido al mayor contenido de proteína cruda (PC) (16 a 21 g kg^{-1}), las asociaciones produjeron rendimientos de PC ha^{-1} superiores a maíz en unicultivo entre 27,5 y 42,8%. Cuando la soya se cosechó en la fase de inicio de maduración (R7), el contenido de fibra detergente neutro en las asociaciones se redujo entre 60 y 63 g kg^{-1} en relación a maíz en uni-

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Abbreviations used: ADF (acid detergent fiber), CP (crude protein), DAS (days after sowing), DM (dry matter), NDF (neutral detergent fiber).

cultivo. La concentración de fibra detergente ácido no fue modificada con la asociación. Los resultados indican que la calidad de forraje puede mejorarse con la asociación maíz-soya en franjas angostas sin afectar el rendimiento.

Palabras clave adicionales: competencia intraespecífica, composición química, distribución de materia seca, *Glycine max,* rendimientos de materia seca y mazorca, soja, *Zea mays.*

Introduction

Due to its high dry matter (DM) yield and high energetic content, maize is the major annual forage crop for intensive dairy livestock production in arid and semiarid regions in Mexico (Núñez *et al*., 2003). However, it also presents some less desirable characteristics such as low protein content (74 to 95 g kg^{-1}). Also, its fiber concentration may be high, with neutral detergent fiber (NDF) values oscillating between 447 and 633 g kg^{-1} (Núñez *et al*., 2001), which may limit the potential forage consumption by cattle when such values exceed 550 g kg^{-1} (Van Soest, 1965). These conditions require finding alternatives to improve forage quality without sacrificing DM yield.

In order to improve forage quality, intercropped maize and annual legumes have been assessed, reporting not only similar total dry matter yield but also an increase in crude protein (CP) concentration from 19 to 27 g kg^{-1} (Herbert *et al*., 1984; Geren *et al*., 2008) and in CP yields per hectare (13.0 to 37.8%) (Geren *et al*., 2008; Javanmard *et al*., 2009) when compared to monocropped corn. As for fiber concentration, Javanmard *et al*. (2009) found reductions of 124 to 146 g kg^{-1} in NDF values and of 75 to 77 g kg^{-1} in acid detergent fiber (ADF) values in corn-soybean intercropping as compared to monocropped corn (Murphy *et al*., 1984; Demirel *et al*., 2009).

In intercropped corn-soybean in narrow strips there is interaction between both crops. Being taller, corn not only receives a greater amount of solar energy but also a better distribution on the leaves located in border rows, resulting in higher yield of these rows compensating the lower yield of soybean (Herbert *et al*., 1984; Ghaffarzadeh, 1999). In intercropping systems, corn represents a good alternative due to its strong yield response resulting from the border-row effect (Cruse, 2008). Soybean can also represent a good option for intercropping systems, due to its high quality forage, especially when harvested at the beginning of the pod maturation stage (R7). During this stage Reta *et al*. (2008) reported CP, ADF, and NDF concentrations of 246, 255 and 319 g kg^{-1}, respectively. The objective of this study was to compare the DM yield and quality forage of corn-soybean intercropping in narrow strips to monocropped corn.

Material and methods

A two-year study was conducted at the La Laguna Experimental Station of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, located in Matamoros, Coahuila, México (25° 32' N, 103° 14' W, and 1,150 m above sea level), on clay loam soil. The experimental site has deep soils (> 1.8 m), with available water values of 150 mm m^{-1} (Santamaría *et al*., 2008) and an organic C content of 0.75% (Santamaría *et al*., 2006). Soil preparation consisted of plowing, disking, leveling and layout. In both years one 200-mm irrigation was applied 12 days before sowing, followed by fertilization with granular mono-ammonium phosphate and urea, with 100 kg N and 100 kg P_2O_5 ha^{-1}, incorporated to moist soil by disking. Sowing was performed on moist soil on May 16 and May 18 in 2006 and 2007, respectively.

The mid-season corn hybrid '3025W' (Pioneer[MR]) with intermediate plant height, semi-erect leaves, and high yield potential was used in 2006. As for soybean, the late maturing cultivar 'Huasteca 200' (group VI) was used. In 2007, the same corn hybrid as in 2006 and the intermediate maturing cultivar 'Hutchinson' (group V) were used. As control treatments, corn monocrops in rows 0.76 m apart (Treatment 1) and soybean in rows 0.50 m apart (Treatment 2) were sown. For treatments 3, 4, 5, and 6 corn and soybean were established in alternate strips. Each strip had one, two, three, and four 0.50 m wide rows, while for treatment 7 corn and soybean were established in alternate twin rows with the same crop, with a distance of 1 m between twin rows and 0.25 m between plant lines in rows.

Sowing density was 50% higher than the desired population for each treatment. Plant thinning was performed 20 days after sowing (DAS) to achieve desired population densities. An intra-row density of 140,000 plants ha^{-1} was used in intercropped corn, while in monocropped corn, density for whole plot was 93,000 plants ha^{-1}. As for soybean, a density of 250,000 plants ha^{-1} for whole plot was used both in intercrops and monocrops in 2006, and of 540,000 plants ha^{-1} in 2007.

A randomized complete block design with four replications was employed. Experimental plot sizes were as follows: Eight rows in monocropped treatments 1 (corn) and 2 (soybean); Treatment 3, five rows of corn and four of soybean; Treatment 4, six rows of corn and four of soybean; Treatment 5, six rows of corn and three rows of soybean; Treatment 6, eight rows of corn and four of soybean; Treatment 7, three twin rows of corn and two twin rows of soybean (ten planting lines). In all cases, row length was 5 m. The plot sizes used for measurements were: the four central 3 m length of rows for treatments 1 and 2; the four central 3 m length of rows of each crop for treatments 4, 6, and 7; and the three central 3 m length rows of each crop for treatments 3 and 5. To maintain adequate soil moisture and fertilizer requirements in both seasons, 120-mm irrigation was applied on 29, 47, 64 and 81 DAS. Additional N applications as urea were made during the first and second irrigation, with 100 and 50 kg ha^{-1}, respectively. During the 2006 growing season 86.6 mm rainfall was received compared with 125.6 mm in 2007. Average maximum, minimum and mean temperatures were 33.8, 20.8 and 27.3°C in 2006 and 33.6, 20.2 and 26.9°C in 2007. Evapotranspiration from meteorological data was estimated in both growing seasons using Penman-Monteith equation (Allen *et al*., 1998). Crop evapotranspiration in 2006 and 2007 was covered by the water received (precipitation and irrigation) during both seasons by 117 and 132%, respectively.

Pest control in the two seasons was conducted by means of two insecticide applications: at 27 DAS, Clorpirifos 480 CE® at 1 L ha^{-1} for fall armyworm (*Spodoptera frugiperda*) control, and at 43 DAS Endosulfan® 35% C.G. (Endosulfan) at 1.5 L ha^{-1} and Rescate 20 PS® (Acetamiprid) at 0.400 kg ha^{-1} for whitefly (*Bemisia argentifolii*) control. Weed control was achieved manually.

Harvesting was performed 94 DAS, when corn had reached the one third milk line stage, and soybean had reached the beginning pod stage (R3) in 2006, and at the beginning maturity stage (R7) in 2007. At harvest time, fresh forage yield was determined and the number of plants harvested was counted. Dry matter content of corn was determined from a random plant sampling of 0.54 m^2 in monocrop treatment and of 0.36 m^2 in intercrop treatments. In soybean, a random plant sampling of 0.5 m^2 was used for monocrop and intercrop treatments. These plants were dried in a forced-air oven at 60°C, until a constant weight was obtained. Dry matter yield was determined multiplying fresh forage yield times the DM content obtained on each plot.

Dry matter partitioning into plant aerial organs was also determined at harvest time. For this purpose a similar plant sampling to that for DM content was done. Then, the ears of corn (cob + corn) were separated, as were also the soybean pods. Plants were dried at 60°C until constant weight. With these data, dry weight per plant and per ear was determined, as well as ear percentage and, in the case of soybean, the percentage of DM allocated to pods.

Plants sampled to measure DM content were also used to evaluate quality forage in terms of CP, ADF, and NDF. The dried plants were ground in a Wiley mill to pass through a 1.0-mm screen. Samples were analyzed according to the procedures described by Goering and Van Soest (1970) for NDF and ADF, and the Kjeldahl procedure for N (Bremner, 1996). Crude protein yields per hectare were also determined multiplying corn and soybean CP concentration times each crop's DM yield.

Because soybean cultivar was not the same in the 2 yr of the study, the analysis of all variables measured is presented by year. Analyses of variance were made for DM yield, agronomical characteristics, and forage quality parameters ($P \leq 0.05$), and the Tukey test was used for comparing means ($P \leq 0.05$). Data were analyzed using SAS statistical software (SAS Inst., 1985).

Results

Dry matter yield

Data analyses in this study did not allow to evaluate the year effect. For this reason treatment responses are presented by year. All intercropped treatments produced total DM yields (maize + soybean) similar to those of monocropped corn ($P > 0.05$) in 2006. Similar response was observed in 2007, except for Treatment 6, with strips of four rows per crop, where a 23.9% yield decrease ($P \leq 0.05$) was observed when compared to monocropped corn. Considering corn yield in intercrops, in 2006 yields were statistically equal to those of monocropped corn ($P > 0.05$), while in 2007 only Treatments 3 and 5 had similar yields than monocropped corn ($P > 0.05$), which evidenced a higher yield than that of the previous cycle. Soybean contributed between 5.7 and 14.3% to total DM yield, with the highest values corresponding to treatments with the

Table 1. Dry matter yield (kg ha^{-1}) of corn and soybean sown as monocrops and as strip-intercropping with various spatial arrangements during the spring of 2006 and 2007 seasons

Treatment[1]	2006			2007		
	Corn + Soybean	Corn	Soybean	Corn + Soybean	Corn	Soybean
1. Mz0.76	17,201[abc2]	17,201[ab]	—	18,572[ab]	18,572[a]	—
2. Sy0.50	5,507[d]	—	5,507[a]	6,145[d]	—	6,145[a]
3. Mz+Sy1:1	20,223[ab]	19,064[a]	1,159[c]	20,026[a]	18,208[ab]	1,818[b]
4. Mz+Sy2:2	19,822[abc]	18,103[a]	1,719[bc]	17,025[abc]	15,198[bc]	1,827[b]
5. Mz+Sy3:3	16,808[bc]	15,263[ab]	1,545[bc]	17,765[ab]	15,863[abc]	1,902[b]
6. Mz+Sy4:4	16,072[c]	14,040[b]	2,032[b]	14,131[c]	12,108[d]	2,022[b]
7. Mz+Sysd2:2	20,721[a]	18,643[a]	2,078[b]	16,624[bc]	14,684[cd]	1,940[b]

[1] Mz0.76 = corn in rows 0.76 m apart; Sy0.50 = soybean in rows 0.50 m apart; Mz + Sy1:1, Mz + Sy2:2, Mz + Sy3:3, Mz + Sy4:4 = intercropped corn-soybean in alternate-row strips with one, two, three, and four rows respectively; Mz + SySD2:2 = corn + soybean in alternate rows with twin rows of one crop. [2] Mean values in each column followed by the same letter are not significantly different (Tukey, 0.05).

greatest number of rows per strip, and when the earlier cycle 'Hutchinson' cultivar was used. Intercropped soybean DM yield was reduced as compared to that of monocropped soybean ($P \leq 0.05$) between 62 and 79% in 2006, and 67.0 to 70.4% in 2007 (Table 1).

All intercropped treatments had 50% of the surface harvested with each crop, but every treatment had a different topological arrangement. When DM yields obtained from intercrops were compared, significant differences ($P \leq 0.05$) were found in both years of this study. Total DM yield decreased as the number of rows per crop increased; nevertheless, only the treatment with four rows per strip (Treatment 6) was statistically lower than treatments 3 and 7 in 2006 and lower than treatments 3 and 5 in 2007. Dry matter reduction of treatment 6 was due to corn yield reduction, since soybean yield was not affected when compared to other intercropped treatments ($P > 0.05$). In fact, only in 2006 soybean yield showed statistical differences among intercropped treatments. Soybean in alternate rows (Treatment 3) yielded ($P \leq 0.05$) less than when grown in 4-row strips (Treatment 6) or in twin-rows (Treatment 7) (Table 1).

Intercropped treatments recorded DM yields ($P > 0.05$) similar to those of monocropped corn, due to increased DM and ear yields in corn rows adjacent to soybean rows. Corn response to DM yield increase was similar ($P > 0.05$) in all topological arrangements assessed in the 2006 intercrops. During 2007, DM production increased by 24.8% and ear production by 30.0% in the treatment with alternate corn and soybean rows (Treatment 3) as compared to all the other intercropped treatments (Table 2).

Table 3 shows dry weight per plant and per ear, as well as ear percentage in every treatment for both years. Only in 2006, dry weight per plant in treatments 5 and 6 decreased compared to that of monocropped corn ($P \leq 0.05$). Dry weight per plant in 2007, and ear weight and ear percentage in both cycles were not affected by intercropping ($P > 0.05$).

Quality forage

Crude protein concentration in forage from intercrops was 16 to 22 g kg^{-1} greater than in forage from monocropped corn, except for Treatment 4 in 2006 and Treatment 7 in 2007, which presented CP concentrations ($P > 0.05$) statistically equal to those of monocropped corn. In 2006, intercroppings with alternate rows (Treatment 3), in strips with two rows per crop (Treatment 4), and alternate twin rows of the same crop (Treatment 7) presented a 27.5 to 48.0% increase in CP yields per hectare ($P \leq 0.05$) compared to monocropped corn. In 2007, only Treatment 3 surpassed monocropped corn CP yields per hectare ($P \leq 0.05$) by 36.2% (Table 4).

Soybean forage fiber concentration varied according to each genotype used. In 2006, the 'Huasteca 200' cultivar harvested at phase R3 (beginning pod) presented NDF values equal to those of corn ($P > 0.05$) and higher ADF concentrations ($P \leq 0.05$). In 2007, when the 'Hutchinson' cultivar was harvested at phase R7 (beginning maturity), forage quality was higher than that of corn, with lower NDF concentration ($P \leq 0.05$) and similar ADF values ($P > 0.05$). Only in 2007 was NDF concentration modified in intercrops,

Table 2. Dry matter yield (kg ha^{-1}) of corn sown as monocrop and as strip-intercropping with soybeans under various spatial arrangements, from border rows adjacent to soybean, and from central rows in intercropped treatments during the spring of 2006 and 2007 seasons

Treatment[1]	Border rows		Central rows	
	Dry matter	Ear	Dry matter	Ear
2006				
1. Mz0.76	—	—	17,201[b]	9,806[a]
3. Mz+Sy1:1	38,128[a2]	20,284[a]	—	—
4. Mz+Sy2:2	36,207[a]	20,323[a]	—	—
5. Mz+Sy3:3	33,331[a]	16,451[a]	25,886[a]	11,550[a]
6. Mz+Sy4:4	32,428[a]	17,593[a]	22,404[ab]	10,472[a]
7. Mz+Sysd2:2	37,285[a]	19,324[a]	—	—
2007				
1. Mz0.76	—	—	18,573[a]	8,808[a]
3. Mz+Sy1:1	36,416[a]	19,066[a]	—	—
4. Mz+Sy2:2	30,396[b]	15,020[b]	—	—
5. Mz+Sy3:3	30,395[b]	15,195[b]	25,126[a]	13,020[a]
6. Mz+Sy4:4	26,600[b]	13,744[b]	21,833[a]	10,790[a]
7. Mz+Sysd2:2	29,367[b]	14,682[b]	—	—

[1] Mz0.76 = corn in rows 0.76 m apart; Mz + Sy1:1, Mz + Sy2:2, Mz + Sy3:3, Mz + Sy4:4 = intercropped corn-soybean in alternate-row strips with one, two, three, and four rows respectively; Mz + SySD2:2 = corn + soybean in alternate rows with twin rows of one crop. [2] Mean values in each column followed by the same letter are not significantly different (Tukey, 0.05).

decreasing between 60 and 63 g kg^{-1} as compared to monocropped corn (Table 4).

Discussion

Dry matter yield

Corn-soybean intercropping caused a 62 to 70% decrease in soybean DM yield. Therefore, intercropped treatments capability to obtain DM yields similar to those of monocropped corn was due to the higher corn yield per row, and this effect was present in total DM and ear DM accumulation. In two studies conducted at the same location, Núñez *et al*. (2001) and Reta *et al*. (2007) reported similar DM yields for corn (18,000 to 22,000 kg ha^{-1}) to those recorded in this study. Forage production response to intercropping in relation to monocropped corn was similar to that reported by other researchers in corn-soybean intercrop (Herbert *et al*., 1984) and in studies with corn intercropped with cowpea, and bean (Geren *et al*., 2008).

Table 3. Yield components of corn sown as monocrop and as strip-intercropping with soybean under various spatial arrangements during the spring of 2006 and 2007 seasons

Treatment[1]	2006			2007		
	Dry weight (g) per		Ear (%)	Dry weight (g) per		Ear (%)
	Plant	Ear		Plant	Ear	
1. Mz0.76	250.5[a2]	120.3[a]	48.1[a]	195.9[ab]	94.9[ab]	47.2[a]
3. Mz+Sy1:1	254.5[a]	115.7[ab]	45.5[a]	244.6[a]	118.8[a]	52.3[a]
4. Mz+Sy2:2	243.6[ab]	121.7[a]	49.8[a]	202.0[ab]	101.5[ab]	49.2[a]
5. Mz+Sy3:3	215.2[b]	94.6[b]	44.0[a]	186.6[b]	96.9[ab]	50.4[a]
6. Mz+Sy4:4	213.6[b]	105.5[ab]	49.4[a]	161.8[b]	80.4[b]	50.7[a]
7. Mz+Sysd2:2	239.4[ab]	110.1[ab]	45.8[a]	192.6[b]	99.0[ab]	50.0[a]

[1,2] See Table 2.

Table 4. Corn and soybean forage quality sown as monocrops and as strip-intercropping with various spatial arrangements during the spring of 2006 and 2007 seasons

Treatment[1]	Crude protein		Acid detergent fiber	Neutral detergent fiber
	g kg^{-1}	kg ha^{-1}	(g kg^{-1})	(g kg^{-1})
2006				
1. Mz0.76	84[c2]	1,448[c]	311[b]	526[a]
2. Sy0.50	151[a]	834[d]	424[a]	526[a]
3. Mz+Sy1:1	100[b]	2,027[ab]	304[b]	476[a]
4. Mz+Sy2:2	93[bc]	1,846[ab]	306[b]	514[a]
5. Mz+Sy3:3	100[b]	1,670[bc]	312[b]	542[a]
6. Mz+Sy4:4	105[b]	1,691[bc]	336[b]	530[a]
7. Mz+Sysd2:2	100[b]	2,068[a]	300[b]	498[a]
2007				
1. Mz0.76	64[c]	1,197[b]	288[ab]	490[a]
2. Sy0.50	192[a]	1,176[b]	306[a]	408[b]
3. Mz+Sy1:1	82[b]	1,630[a]	258[b]	427[b]
4. Mz+Sy2:2	82[b]	1,394[ab]	272[ab]	449[ab]
5. Mz+Sy3:3	84[b]	1,489[ab]	258[b]	429[b]
6. Mz+Sy4:4	85[b]	1,206[b]	285[ab]	428[b]
7. Mz+Sysd2:2	81[bc]	1,338[ab]	270[ab]	430[b]

[1,2] See Table 1.

Analysis of yield contribution from the different corn rows in intercrops indicated that an increase in yield potential occurred in border rows adjacent to each soybean strip (Table 2). This response was related to corn capability to attain dry weight per plant and ear weight values in intercrop treatments similar to those in monocrops, regardless of greater population density in intercropped corn (47,000 plants ha^{-1}). Evidence of this is that in 2006 the corn dry weight per plant decreased only in treatment 5 and 6 in relation to that of monocropped corn. Partitioning of DM to ear was unaffected in both years (Table 3). In other studies, corn yield advantage in border rows when intercropped with shorter crops are related to greater sunlight utilization (West and Griffith, 1992; Ghaffarzadeh, 1999).

Greater forage yield from intercropped corn was determined by strip width and by a larger proportion of border rows than that of central rows. Intraspecific competition was significantly reduced in border rows of the strips. In Treatments 5 and 6 with three and four rows per strip, yield increases in border rows as compared to central rows were between 21.4 and 36.2% for total DM and between 21.5 and 54.6% for ears (Table 2). Cruse (2008) reported an increase of 10 to 30% in DM yields in border rows. Ghaffarzadeh (1999) indicated that the positive effect of border rows on corn can be extended to the second row from each border, and that central rows in strips with more than four rows are equivalent to monocropped corn. In this study, such behavior was present only in 2006, when the central row in the three rows per crop treatment produced a total DM yield higher than that of monocropped corn. Central rows in four-row strips showed the same behavior as rows in monocropped corn (Table 2).

Putnam *et al*. (1986) and Cruse (2008) reported that the increase of intercropped corn population density compared to that of monocropped corn generates an additional increase in DM and ear yields in border rows. In this study that effect can be appreciated by comparing forage yield in rows with competition in monocropped corn (93,000 plants ha^{-1}) to the yield of border rows in intercrops (140,000 plants ha^{-1}), which increased their DM yield between 57.2 and 91.2% and their ear yield between 66.4 and 116% (Table 2). The former explains the response capability of intercropped corn for producing yields similar to those of monocropped corn with lower number of rows harvested per plot.

Quality forage

Soybean produced forage of good quality in terms of CP and NDF, especially during the second year, when an earlier cultivar was used. This allowed for a high DM allocated to pods (38.4 to 43.5%). In 2006, with unfilled pods at harvest time, forage quality in terms of CP was similar to that of forage soybean collected at stage R3 described by Sheaffer *et al*. (2001). In 2007, a high proportion of filled pods increased CP concentration and decreased NDF, in agreement with other studies of soybean genotypes harvested at the beginning of the maturity stage (R7) (Albro *et al*., 1993; Sheaffer *et al*., 2001). Increase in CP concentration and decrease in fiber value in soybean improved forage quality of intercropped treatments.

Soybean contribution to total DM yield in intercrops increased CP concentration in both years (16 to 22 g kg^{-1}), as compared to monocropped corn. This means that the difference in pod proportion at harvest between the soybean cultivars used each year did not significantly affect CP concentration among intercropped treatments (Table 4). Crude protein increases were similar to those found in corn-soybean intercrops by Herbert *et al*. (1984), with 19 to 27 g kg^{-1} and Martin *et al*. (1990) 15 to 21.5 g kg^{-1}. Moreover, Geren *et al*. (2008) obtained a CP increase between 24 and 27 g kg^{-1} in corn intercropped with cowpea in comparison to monocropped corn.

It has been found that in a corn-soybean intercrop with 30% proportion of soybean in the forage harvested, CP concentration increased between 20 and 25 g kg^{-1} compared to that of monocropped corn (Evangelista, 1986), while Demirel *et al*. (2009) with soybean harvest proportions of 10, 20, and 30% increased CP contents by 20.4, 22.1 y 26.5%, respectively. In the present study, CP concentration in corn-soybean intercrops was not significantly modified when soybean in forage increased from 5.7% (Treatment 3) to 12.6% (Treatment 6) in 2006, and from 9.1% (Treatment 3) to 14.3% (Treatment 6) in 2007 (Table 4).

In some intercropped treatments, CP yields per hectare were higher than that of monocropped corn (Table 4), due to a CP concentration increase; however, differences among intercrops were mainly related to higher DM production in corn. In this study, CP yields per hectare increases (27.5 to 48%) were higher than those obtained by Geren *et al.* (2008), 13.8 to 37.8%, and by Javanmard *et al*. (2009), 21.2 to 23.3%.

The influence of soybean on intercrops fiber concentration depended on cultivars characteristics. In intercrops ADF concentration was not modified by soybean contribution, since ADF values were higher than, or equal to, those of monocropped corn. A high pod proportion in the 'Hutchinson' cultivar used during 2007 decreased NDF concentration in forage from intercrops between 60 to 63 g kg^{-1} (Table 4). This is due to the fact that soybean pod has high protein, carbohydrate, and lipid contents (Albro *et al*., 1993; Sheaffer *et al*., 2001) which significantly contribute to improve forage quality in terms of energy and NDF. Several studies assessing corn-soybean intercrops have found results similar to those obtained by this study in 2006, when forage quality improved in terms of CP only, and fiber concentration was not affected (Murphy *et al*., 1984; Kuttel *et al*., 2008; Demirel *et al*., 2009). On the other hand, Javanmard *et al*. (2009) found that forage in intercrops not only improved in CP yield, but NDF concentration decreased between 124 and 146 g kg^{-1} and ADF between 75 and 77 g kg^{-1} as compared to that of monocropped corn.

From the standpoint of forage produced in corn-soybean intercrops, it is important not only to profit from the increase in CP content, but also from the decrease in NDF content. This may represent greater forage potential consumption (Van Soest, 1965; Argamentería *et al*., 2005), higher milk production (Argamentería *et al*., 2005), and a more profitable operation since dietary supplement requirements decrease (Tobía *et al*., 2007). For this reason, the best option in corn-soybean intercropping is to use soybean genotypes which providing forage with the greatest amount of pods at harvest. To this end, the soybean pod maturation stage (R6 or R7) must be synchronized with the best corn harvesting stage, in order to obtain the best forage quality from the intercrop.

In conclusion, corn-soybean intercrops established in narrow strips increased forage quality in terms of CP and NDF, without decreasing yield as compared to that of monocropped corn. Intercrop treatments capability to obtain yields similar to those of monocropped corn was related to the increase in DM and ear yields in corn border rows adjacent to soybean. In these rows, corn had dry weight per plant and ear weight values similar to those of monocropped corn, but with an additional harvest of 47,000 plants ha^{-1}, due to the increase in population density of intercropped corn.

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