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LEGUMES AND FORAGE SPECIES SOLE OR INTERCROPPED WITH CORN IN SOYBEAN-CORN SUCCESSION IN MIDWESTERN BRAZIL[1]

Gessí Ceccon[2], Luiz Alberto Staut[3], Edvaldo Sagrilo[4], Luís Armando Zago Machado[5], Danieli Pieretti Nunes[6] & Valdecir Batista Alves[7]

SUMMARY

The feasibility of no-tillage in the Cerrado (Savanna-like vegetation of Brazil) depends on the production of sufficient above-ground crop residue, which can be increased by corn-forage intercropping. This study evaluated how above-ground crop residue production and yields of soybean and late-season corn in a soybean-corn rotation were influenced by the following crops in the year before soybean: corn (*Zea mays* L.) intercropped with *Brachiaria* (*Urochloa*) *brizantha* cv. Marandu, *B. decumbens* cv. Basilisk, *B. ruziziensis*, cv. comum., *Panicum maximum* cv. Tanzânia, sunn hemp (*Crotalaria juncea* L.), pigeon pea [*Cajanus cajan* (L.) Millsp]; sole corn, forage sorghum [*Sorghum bicolor* (L.) Moench (cv. Santa Elisa)], and ruzi grass. In March 2005, corn and forage species were planted in alternate rows spaced 0.90 m apart, and sole forage species were planted in rows spaced 0.45 m apart. In October 2005, the forages were killed with glyphosate and soybean was planted. After the soybean harvest in March 2006, sole late-season corn was planted in the entire experimental area. Corn grain and stover yields were unaffected by intercropping. Above-ground crop residue was greater when corn was intercropped with Tanzania grass (10.7 Mg ha^{-1}), Marandu (10.1 Mg ha^{-1}), and Ruzi Grass (9.8 Mg ha^{-1}) than when corn was not intercropped (4.0 Mg ha^{-1}). The

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intercropped treatments increased the percentage of soil surface covered with crop residue. Soybean and corn grain yields were higher after sole ruzi grass and intercropped ruzi grass than after other crops. The intercropping corn with *Brachiaria* spp. and corn with *Panicum* spp. increases above-ground crop residue production and maintains nutrients in the soil without reducing late-season corn yield and the viability of no-till in the midwestern region of Brazil.

Index terms: cerrado, no-till, biomass, above-ground crop residue.

REUSMO: *ESPÉCIES LEGUMINOSAS E FORRAGEIRAS, SOLTEIRAS OU CONSORCIADAS COM MILHO, NA SUCESSÃO SOJA-MILHO NO CENTRO-OESTE DO BRASIL*

*A viabilidade do plantio direto no Cerrado brasileiro depende da produção adequada de palha das culturas, que pode ser aumentada pela consorciação de milho (*Zea mays *L.) com uma espécie forrageira. O trabalho foi implantado em março de 2005 com o objetivo de avaliar a produtividade de resíduos das espécies e de grãos de soja (*Glycine max *L. Merrill) e de milho safrinha em sucessão. Foram avaliados tratamentos de milho safrinha consorciado com* Brachiaria (Urochloa) brizantha *cv. Marandu,* B. decumbens *cv.* Basilisk, B. ruziziensis *cv.* comum, Panicum maximum *cv. Tanzânia, crotalaria juncea (*Crotalaria juncea *L.), guandu [*Cajanus cajan *(L.) Millsp], e também o sorgo (*Sorghum bicolor *L. Moench), a* B. ruziziensis *e o milho safrinha solteiro. Em outubro de 2005, as espécies foram dessecadas com glyphosate e a soja semeada. Após a colheita de soja em março de 2006, o milho safrinha foi cultivado em área total. O rendimento de grãos e palha de milho não foi influenciado pela espécie em consórcio. A massa seca da parte aérea foi maior quando o milho foi consorciado com Tanzânia (10,7 Mg ha^{-1}), Marandu (10,1 Mg ha^{-1}) e* Ruziziensis *(9,8 Mg ha^{-1}) do que com o milho solteiro (4,0 Mg ha^{-1}). Nos tratamentos consorciados, houve aumento na porcentagem de solo coberto com os resíduos vegetais. O rendimento de grãos de soja e milho safrinha em sucessão foram maiores na ruziziensis solteira e no milho safrinha consorciado com ruziziensis. O cultivo de milho safrinha consorciado com* Brachiaria *spp. ou com* Panicum *spp. aumenta a produção de resíduos culturais, preserva os nutrientes no solo sem reduzir a produtividade do milho e viabiliza o plantio direto no Centro-Oeste do Brasil.*

Termos de indexação: cerrado, plantio direto, biomassa, cobertura do solo.

INTRODUCTION

Currently, about 14 % of the total cropland in Brazil is managed in a no-tillage system (Triplett Jr. & Warren, 2008). In the midwestern and southern regions of Brazil, corn grown from February to August is referred to as late-season corn. In 2011, five million hectares of late-season corn were produced after soybean in these regions (IBGE, 2011). This late-season corn can be beneficial because relatively little residue is returned to the soil after soybean grain harvest (Brüggemann, 2011), which in tropical soils can lead to lower soil organic matter (SOM) levels, higher soil bulk density, reduced root development (Corsini & Ferraudo, 1999), and reduced crop yield (Heinrichs et al., 2005). The planting of late-season corn could help maintain the soil quality because it leaves more residue on the soil than wheat (Fontaneli et al., 2000), another late-season crop grown in Midwestern and southern Brazil. The production of above-ground residue by late-season corn can be increased by intercropping corn with forage (Njunie et al., 2004) or pasture crops (Torres et al., 2008).

Crop rotation with forage plants is a way to provide high forage yields (Krupinsky et al., 2007; Singer et al., 2009), reduce weed density (Hartwig & Ammon, 2002), retain soil moisture, and enhance the population and activity of the soil invertebrate macrofauna (Santos et al., 2008). In integrated crop-livestock systems, the animals eat only part of the plant, leaving vegetation to cover the soil and a large amount of roots (Machado et al., 2007). Root and shoot residues produced by the pasture plants can enhance SOM levels, and these residues can increase the size and stability of soil aggregates (Salton et al., 2008), which help protect against soil erosion (Freitas et al., 2000). In addition, crop residues produced by intercrops are a source of nutrients, including the N fixed biologically by forage legumes, which can lead to higher above-ground yields of subsequent crops (Lovato et al., 2004; Vieira et al., 2009).

In Zimbabwe, Jeranyama et al. (2000) found that legume intercrops such as cowpea (*Vigna unguiculata* L.) and sunn hemp could reduce the N fertilizer requirement of the subsequent corn crop when compared to the corn-after-corn systems. In South Dakota, Smeltekop et al. (2002) evaluated the influence of annual alfafa [*Medicago scutellata* Mill (cv. Sava)] interseeded into corn at planting and concluded that the negative effects of alfafa on corn grain yield primarily resulted from N stress and not from increased water stress. Ross et al. (2004) studied the forage potential of intercropping berseem clover *(Trifolium alexandrinum* L.) with barley *(Hordeum vulgare* L.), oat *(Avena sativa* L.), or triticale *(*X *Triticosecale rimpaui* Wittm.), and found that the performance of cereal-berseem clover intercrops was influenced by the cereal species, cereal density, relative emergence time, and environmental conditions. In Canada, Strydhorst et al. (2008) found that forage dry matter (DM) yield was higher in pea (*Pisum sativum* L.) intercropped with barley (*Hordeum vulgare* L.) than with sole faba bean (*Vicia faba* L.), lupin (*Lupinus angustifolius* L.), or barley.

In Brazil, some researchers have reported a reduction in corn grain yield when corn is intercropped with forage plants (Portes et al., 2000; Silveira et al., 2005; Borghi & Crusciol, 2007). The negative effect of forage plants on corn yield could result from the species or seeding rate of the intercrop (Blaser et al., 2007), or from insufficient rainfall during the late-season to support the growth of both crops (Wilkinson et al., 1987). Other researchers, however, detected no competition between corn with forage plants when forages were grown at low plant densitty in rows between corn (Tsumanuma, 2004; Freitas et al., 2005; Torres et al., 2008). The negative effects on corn caused by competition with the intercropped forage can be minimized through the use of herbicides (Freitas et al., 2005) and shading of the forage species by corn, which is enhanced by corn hybrids with expanded leaf architecture and greater leaf area (Torres et al., 2008). These alternatives can slow the growth of forage plants and thereby reduce the negative effects of forage plants intercropped with corn (Jakelaitis et al., 2004). Although intercropping forage plants with corn can reduce corn grain yield, it can also reduce corn yield losses resulting from weed competition (Silva et al., 2004) by shading the soil surface and decreasing weed emergence. Over time, this can reduce the weed seedbank (Ikeda et al., 2007) and improve soil quality by increasing the quantity of above-ground crop residues returned to the soil (Severino et al., 2005).

Rotation of intercropped forage and corn with soybean can lead to higher soybean yield (Cobucci et al., 2007), partly because of improvements in soil physical and chemical properties (Borghi & Crusciol, 2007). However, the yield improvement in the subsequent soybean crop can vary according to the rotation crop (Crusciol & Soratto, 2007). In southern Brazil, Fontaneli et al. (2000) observed an increase in soybean yield due to crop rotation with wheat in only one of four years. In midwestern Brazil, Silveira et al. (2005) reported that the yield of common bean (*Phaseolus vulgaris* L.) was higher after sole pigeon pea or millet (*Pennisetum glaucum* L.) than after mombassa (*Panicum maximum* Jacq cv. Mombaça), sorghum, or ruzi grass. Similarly, Santos et al. (2004) reported that soybean yield was greater when soybean was planted after summer perennial forages (*Festuca arundinacea,* Schreb + *Lotus corniculatus L.* + *Trifolium repens* L.) than after winter perennial forage (*Lolium multiflorum* Lam.).

The objectives of this research, conducted in no-till fields at three locations in Mato Grosso do Sul, Brazil, was to study how the intercropping of forage species with late-season corn affects the DM yield of the intercropped system and the grain yield of subsequent soybean and corn crops. Our hypothesis was that intercropping would increase above-ground crop residue production, maintain nutrients in the soil, increase the percentage of the soil surface covered by crop residue, and increase yields of subsequent soybean and late-season corn crops, while having only a small negative effect on the yield of the intercropped corn.

MATERIALS AND METHODS

Experiments were conducted from March 2005 to August 2006 near Bataypor᾽ã (22° 17' S, 53° 16' W, 334 m asl), Dourados (22° 13' S, 54° 48' W, 430 m asl), and São Gabriel do Oeste (19° 24' S, 54° 34' W, 658 m asl) in the State of Mato Grosso do Sul, Brazil. During the experiment, average rainfall across these three locations was 1,043 mm from September to February and 418 mm from March to August (Table 1). The average mean air temperature across locations was 25 °C from September to February, and 23 °C from March to August (Embrapa, 2007). The soils at the experimental sites were kaolinitic, with 1.1, 2.9 and 4.0 % SOM, in Batayporã, Dourados and Gabriel do Oeste, respectively. Soil surface texture was a fine clay loam at Dourados and São Gabriel do Oeste and a sandy loam at Batayporã. The soils at all three sites are classified as dystrophic Red Latosol in Batayporã and São Gabriel do Oeste and a dystroferric Red Latossol in Dourados (Embrapa, 1999).

The experimental design was a randomized complete block with three replications at each location. Plots were 8.0 m wide and 9.0 m long. In March 2005, the initial experimental layout consisted of eight treatments with late-season corn or forage grown between February and August, and included: 1) corn intercropped with Tanzania grass [*Panicum maximum* Jacq. (cv. Tanzania)]; 2) corn intercropped with marandu grass [*Brachiaria brizantha* Stapf (cv. Marandu)]; 3) corn intercropped with ruzi grass (*Brachiaria ruziziensis* Germain & Evrard); 4) corn intercropped with sunn hemp (*Crotalaria juncea* L.); 5) corn intercropped with pigeon pea [*Cajanus cajan* (L.) Millsp]; 6) sole corn, 7) sole forage sorghum [*Sorghum bicolor* (L.) Moench (cv. Santa Elisa)]; and 8) sole ruzi grass.

The experiments were established in a no-tillage system at the three sites after soybean harvest. The late-season corn hybrid BRS 2020 was planted 5 cm deep, on 7 March 2005, in rows spaced 0.90 m apart in a no-till system with a PAR 2800C mark planter (Semeato Inc., Passo Fundo, RS, Brazil), equipped with cutting discs fixed in front of the seed disc openers. Fertilizer was applied 10 cm deep with the planter in the seed furrows at rates of 24, 60, and 60 kg ha^{-1} of N, P_2O_5, and K_2O, respectively, using 300 kg ha^{-1} of the formula 8-20-20 N-P-K. The average final plant density for the late-season corn crop was 47,000 plants ha^{-1}. The forage species intercropped with corn were planted manually on the same day as the corn in rows spaced 0.90 m apart, in rows running along/between the corn rows. The sole forage species were planted in rows spaced 0.45 m apart, at an average final plant density of 15 plants m^{-1}. Forages were planted by opening rows with hoes, placing the seeds approximately 2 cm deep, and then covering the opened rows with soil. Insect pests were controlled by treating corn seed with Thiodicarb at a rate of 0.6 kg a.i. per 100 kg^{-1} of seed. To control fall armyworms (*Spodoptera frugiperda* Smith), Lufenuron (0.015 kg ha^{-1} a.i.) was applied over the entire experimental area 10-20 d after corn emergence. Weeds were controlled by hand-hoeing between March and April of 2005 because of the lack of information on herbicide tolerance for all forage species.

Table 1. Rainfall registered at the three locations during the experiment, in Mato Grosso do Sul, Brazil

Month/year	Dourados		Batayporã		São Gabriel do Oeste	
	2005	2006	2005	2006	2005	2006
	mm					
Jan	197	138	379	148	377	219
Feb	18	122	12	103	37	288
Mar	35	160	5	269	185	199
Apr	152	116	185	80	100	182
May	47	17	102	35	77	35
Jun	41	46	120	20	60	5
Jul	15	34	18	40	57	0
Aug	0	17	2	10	0	45
Sep	141	58	215	118	70	110
Oct	188	70	231	88	35	385
Nov	156	111	49	80	402	239
Dec	283	250	209	200	313	220

Source: http://www.cpao.embrapa.br/servicos/estacao/EstacaoAuto.php; Sindicato Rural of São Gabriel do Oeste and Cooperativa Coopergrãos (weather station data).

In August 2005, dry matter (DM) yield of the intercropped forage species and late-season corn were quantified separately and were determined by harvesting 5 m of two center rows per plot.

Corn grain yields were determined based on the harvest of plants from 5 m of two center rows per plot. Corn ears were picked and the plants cut at the soil line. Sole sorghum and sole ruzi grass were harvested twice by cutting at a height of 0.20-m to determine DM. One cut was made during flowering to simulate grazing and the other at the time of corn harvest. Above-ground forage was measured in July 2005 by collecting all above-ground forage from a 4.5-m^2 (0.9 x 5.0 m) area.

The quantity of crop residue on the soil surface was measured in October 2005 before soybean planting within a 0.5-m^2 (0.5 x 1.0 m) frame placed perpendicular to the corn rows in each plot. From these above-ground forage and crop residue samples, 0.5-kg subsamples were collected and dried at 60 °C to constant moisture in a forced circulation chamber to determine DM yield. The samples were ground to a particle size of 20 mesh with a Willey mill. The nutrient contents of N, P and K were determined according to Silva (1999). The N was extracted by hot sulfuric acid digestion and determined by the semi-micro-Kjeldahl method. The P and K were extracted by digesting hot nitric and determined by perchloric molecular absorption spectrometry (P) and flame-emission spectrophotometer (K).

In October 2005, after the harvest of late-season corn, the remaining forages were harvested and weeds controlled with a glyphosate application (0.72 kg ha^{-1} a.i.). Twenty days later, no-till soybean (cv. BRS 239) was planted 5 cm deep in rows spaced 0.45 m apart, over the entire experimental area at a density of 311,000 seeds ha^{-1}, with a PAR 2800C mark planter. Fertilizer was applied 10 cm deep with the planter in the seed furrow at a rate of 40 kg ha^{-1} of both P_2O_5 and K_2O, in 200 kg ha^{-1} of the formula 0-20-20 N-P-K. Weeds were controlled 20 d after soybean emergence with bentazon at 0.72 kg ha^{-1} a.i. and haloxyfop-methyl at 0.05 kg ha^{-1} a.i.. The surface residues were measured 10-20 d after soybean emergence, at a 45° angle to the rows, using the method described by Sloneker & Moldenhauer (1977), while weed density was measured within a randomly selected 1.0-m^2 area (1.0 x 1.0 m) in each plot. Soybean yield was determined in February 2006 by hand harvesting of 5 m of two rows in the center of each plot and threshing. Soybean grain moisture was measured with a grain moisture meter (Etec Inc. São Paulo, SP, Brazil), and grain yields were corrected to a moisture content of 150 g kg^{-1}.

After soybean harvest in March 2006, no-till sole late-season corn (hybrid BRS 2020) was planted 5 cm deep in rows spaced 0.90 m apart over the entire experimental area using a PAR 2800C mark planter, with an average final stand of 47,000 plants ha^{-1}. Fertilizer was applied 10 cm deep with the planter in the seed furrow at a rate of 24, 60, and 60 kg ha^{-1} of N, P_2O_5, and K_2O, respectively, using 300 kg ha^{-1} of the formula 8-20-20 N-P-K. Insect pests were controlled by treating corn seed with Thiodicarb at a rate of 0.6 kg a.i. 100 kg^{-1} of seed. Lufenuron was applied 10-20 d after emergence, at a rate of 0.015 kg ha^{-1} a.i. to control fall armyworms. For weed control, Atrazine at 2.0 kg ha^{-1} a.i. was applied 15 d after corn emergence. Corn grain yield was determined by harvesting 5 m of two rows in the center of each plot. Corn grain moisture was measured with a grain moisture meter and grain yields were corrected to a moisture content of 130 g kg^{-1}.

Before statistical analysis, the weed density data were square-root transformed to homogenize variances. Data were subjected to Anova using SAS (SAS, 2003). Locations and treatments were considered random block effect. When Anova indicated a significant interaction between site and treatment, the data are shown separately for each location. Site and treatment means were compared by the Tukey test ($p \leq 0.05$).

RESULTS AND DISCUSSION

Crop yield in the first late-season planting

The grain yield of the first late-season corn crop was not significantly affected by intercropping and averaged 2.2 Mg ha^{-1} in Batayporã, 3.3 Mg ha^{-1} in Dourados, and 4.4 Mg ha^{-1} in São Gabriel do Oeste. Dry matter of corn stover at harvest was also not significantly affected by intercropping, and averaged 5.90 Mg ha^{-1} in Batayporã, 8.86 Mg ha^{-1} in Dourados, and 7.03 Mg ha^{-1} in São Gabriel do Oeste. The DM of the species (Table 2) was highest at Dourados, but the total above-ground crop residue (Table 3) was higher at Batayporã. The differences of climate and soil between the locations may have contributed to these results.

The absence of interference by forage on corn may be due to the relatively wide distance (0.90 m) between the corn rows, which separated the forage from the corn by 0.45 m. This distance may have reduced early-season competition for water and nutrients between forage species and corn. These results are similar to those obtained by Tsumanuma (2004), who researched corn intercropped with marandu and ruzi grass, and by Borghi & Crusciol (2007), who researched corn intercropped with marandu, in São Paulo state, Brazil. Similarly, Heinrichs et al. (2005) found that corn grain yield was not affected by intercropping with green manure species in the first year; in the second year, however, corn grain yield was highest when corn was intercropped with the legumes sunn hemp and pigeon pea.

After the late-season corn was harvested, the forage species continued to grow and produce biomass until the planting of the subsequent soybean crop. Consequently, total above-ground crop residue DM evaluated in July (Table 2) and October 2005 (Table 3) was significantly greater in plots previously used for corn intercropped with Tanzania, marandu, or ruzi grass than in plots previously used for sole corn. These results show that it is possible to produce a considerable quantity of crop residue, which can be used as forage for livestock during the autumn and winter months in tropical regions (Freitas et al., 2000). Intercropped forage plants may also reduce the decomposition of corn residues by reducing the residue - soil contact (Santos et al., 2008). This can lead to biomass accumulation on the soil surface and in the 0-20-cm soil layer (Machado et al., 2007), improving the soil quality (Corsini & Ferraudo, 1999) and decreasing soil erosion (Freitas et al., 2000).

Table 2. Total dry matter yield of late-season corn and forage species when sole or intercropped in July 2005 in Mato Grosso do Sul, Brazil

Crop	Dourados	Batayporã	São Gabriel do Oeste
	Mg ha^{-1}		
Corn	8.8 bA	6.1 bC	7.8 cdB
Tanzania + corn	11.3 aA	6.9 abcC	8.7 bcB
Marandu + corn	11.0 aA	6.9 abcC	9.7 aB
Ruzi grass + corn	11.2 aA	7.5 abB	8.1 bcdB
Sunn crotalaria + corn	8.6 bA	7.5 abB	6.9 dB
Pigeon pea + corn	10.7 aA	5.9 cC	7.7 cdB
Sorghum	4.8 cA	3.6 dB	3.0 fB
Ruzi grass	4.8 cA	1.8 eC	4.0 eB

Means followed by the same lowercase letter in a column, and by the same uppercase letter in a row are not significantly different by the Tukey test ($p \leq 0.05$).

Table 3. Total above-ground dry matter before soybean planting in October 2005 as affected by previous crop and location

Previous crop	Dourados	Batayporã	São Gabriel do Oeste
	Mg ha^{-1}		
Corn	3.3 dB	4.5 fA	4.2 cAB
Tanzania + corn	6.9 bC	16.3 aA	8.9 abB
Marandu + corn	7.4 abC	13.6 bA	9.2 abB
Ruzi grass + corn	7.2 abC	14.1 bA	8.4 abB
Sunn crotalaria + corn	4.1 cdB	6.1 eA	4.5 cB
Pigeon pea + corn	4.2 cdB	6.2 eA	5.1 cB
Sorghum	4.6 cdB	7.3 dA	7.7 bA
Ruzi grass	7.9 abB	9.1 cA	7.8 bB

Means followed by the same lowercase letter in a column, and by the same uppercase letter in a row are not significantly different by the Tukey test ($p \leq 0.05$).

Nutrient levels in above-ground crop residue

The amount of N, P, and K differed significantly among the crops (Table 4). The contents were expressed on a per hectare basis, and were highest for corn intercropped with Tanzania grass, followed by corn intercropped with *Brachiaria* spp., because these forages produced more total biomass than the other treatments (Table 2). The SOM content in São Gabriel do Oeste did not result in more mass and nutrients than Dourados and Batayporã, which can be explained by the longer rain duration at the latter two locations (Table 1), inducing a greater biomass production after corn tillage (Table 3).

Table 4. Amount of nitrogen, phosphorus and potassium in stover before soybean planting in October 2005 in Mato Grosso do Sul, Brazil

Previous crop	Dourados	Batayporã	São Gabriel do Oeste
	Mg ha^{-1}		
		Nitrogen	
Corn	22 dB	36 fAB	44 dAB
Tanzania + corn	122 abB	214 aA	141 abB
Marandu + corn	110 abB	178 bA	112 bB
Ruzi grass + corn	105 abB	172 bA	120 bB
Sunn crotalaria + corn	60 cA	70 eA	77 cA
Pigeon pea + corn	90 bB	111 cA	75 cB
Sorghum	61 cB	91 dAB	78 cAB
Ruzi grass	117 abA	125 cA	124 abA
		Phosphorus	
Corn	2 cB	3 eB	5 cA
Tanzania + corn	9 aC	26 aA	15 abB
Marandu + corn	9 aB	21 bA	7 cB
Ruzi grass + corn	8 aB	24 bA	14 cB
Sunn crotalaria + corn	5 bB	8 dAB	7 cAB
Pigeon pea + corn	8 aB	14 cA	5 cC
Sorghum	9 aC	14 cA	12 bB
Ruzi grass	9 aC	16 cA	13 abB
		Potassium	
Corn	62 dA	50 deA	57 dA
Tanzania + corn	129 bA	81 abcdB	110 abcA
Marandu + corn	138 bA	69 bcdeC	111 abcB
Ruzi grass + corn	95 cA	65 cdeB	101 bcA
Sunn crotalaria + corn	181 aA	86 abcdC	128 abB
Pigeon pea + corn	141 bA	67 bcdeC	95 bcB
Sorghum	51 dA	41 eA	33 eA
Ruzi grass	186 aA	100 aB	85 cB

The amount of nutrients was calculated of the total above-ground part of each species (Table 3) and nutrient concentration in the mass. Means followed by the same lowercase letter in a column, and by the same uppercase letter in a row are not significantly different by the Tukey test ($p \leq 0.05$).

The nutrients contents of Tanzania and brachiaria grass in this study were generally similar to those reported by Crusciol & Soratto (2007) who evaluated cover crop DM production and nutrient accumulation in a no-tillage system in a dystroferric Hapludox in São Paulo, Brazil. The N, P, and K contents in DM sole late-season corn were lower than in the forage species but were similar to those reported by Ferreira et al. (2008) in an experiment with varying water regimens in southeastern Brazil. With the killing of forage plants by herbicide, the decomposition of the forage residues can release nutrients previously located in the soil profile that had been absorbed by the roots. Those nutrients fixed by the intercropped legumes can be mineralized and become available for subsequent crops (Lovato et al., 2004). Therefore, an increase in the biomass production in intercropped systems can increase the nutrient availability, particularly for N in legume-based intercropping systems (Vieira et al., 2009). This helps explain why such intercropping systems can increase the yields of subsequent crops (Santos et al., 2004)

Surface residue cover and weed density

Surface residue cover after soybean planting in November 2005 was significantly affected by the previous crop, and was highest for sole ruzi grass (Table 5) followed by corn intercropped with Tanzania grass, marandu, or ruzi grass, but differed among locations.

The high surface residue cover with sole ruzi grass most likely occurred because this species grows laterally (Portes et al., 2000). In contrast, surface residue cover was lowest with sole corn, which agrees with Brüggemann (2007), who conducted a survey of soybean in midwestern Brazil. Intercropping corn with ruzi grass appears to be a viable alternative for increasing crop residue production without reducing corn grain yield.

Weed density was significantly influenced by the previous crop, but a high surface residue cover by the previous crop did not always result in low weed density (Table 5). The most abundant weed species were sandbur (*Cenchrus echinatus* L.), beggars tick (*Bidens pilosa* L.), amaranth (*Amaranthus viridis* L.), Mexican fireplant (*Euphorbia heterophilla* L.), arrowleaf sida (*Sida rhombifolia* L.), and spiderwort (*Commelina benghalensis* Hort.). Weeds were more abundant after sole corn and corn intercropped with sunn hemp or pigeon pea than after the other treatments in São Gabriel do Oeste and Batayporã (Table 5). When intercropping induced no weed reduction, this may have been due to a low overall weed density or a denser forage soil cover (Silva et al., 2004). Corn intercropped with ruzi, marandu, or Tanzania grass can increase the surface residue cover and help reduce weed incidence (Teasdale, 1993; Silva et al., 2004; Severino et al., 2005). Similarly, Ikeda et al. (2007) reported fewer weeds in soybean following marandu than after sole corn. In Dourados, where weed density was low and averaged five plants m^2, weeds were more abundant after sorghum, sole corn, and sole ruzi grass than after the other treatments (Table 5).

Yields of subsequent soybean and late-season corn

Soybean yield was significantly affected by the previous crop. The soybean yield was highest in Batayporã, followed by São Gabriel do Oeste and Dourados. Soybean yield was highest after intercropping of corn + marandu, corn + Tanzania grass, and corn + ruzi grass in Batayporã, after intercropping of corn +sunn hemp and sole ruzi grass in São Gabriel do Oeste, and after ruzi grass (intercropped or non-intercropped) and intercropped corn + sunn hemp in Dourados (Table 6). In Dourados there was a lack of rain, which is common during this period and can help explain the low grain yield at this site. Intercropping corn with pigeon pea resulted in lower soybean yield than in other treatments. Certain legume species, such as dry pea (*Pisum sativum* L.) and chick pea (*Cicer arietinum* L.) produce lower amounts of residue and tend to have less durable residues than corn (Krupinsky et al., 2007). Increased soybean yield after sole ruzi grass might be due to the fact that *Brachiaria* spp. consist predominantly of leaves and fine stems that quickly decompose (Torres et al., 2008), letting the nutrients immobilized in the residues become available for the following crop.

The intercropping treatments in 2005 affected grain yield of the subsequent late-season corn crop in 2006 (Table 7). The highest late-season corn yield was observed in Dourados, followed by some treatments in São Gabriel do Oeste and lower results in Batayporã.

Corn grain yield was higher after sole sorghum, sole ruzi grass, corn intercropped with ruzi grass, and corn intercropped with sunn hemp than after sole corn

Table 5. Surface residue cover and weed density 10-15 d after soybean planting as affected by the previous crop in 2005 at three locations in Mato Grosso do Sul, Brazil

Previous crop	Dourados	Bataypорã	São Gabriel do Oeste
	Surface residue cover, %		
Corn	36 efB	30 efC	50 dA
Tanzania + corn	79 bA	62 cB	55 cC
Marandu + corn	72 cA	66 cB	68 bB
Ruzi grass + corn	71 cB	82 bA	71 bB
Sunn crotalaria + corn	35 efB	27 efC	59 cA
Pigeon pea + corn	29 fB	33 efB	41 eA
Sorghum	54 dA	54 dA	46 dB
Ruzi grass	97 aAB	94 aAB	90 aB
	Weed density, plant m^{-2}		
Corn	5 abB	11 aA	13 aA
Tanzania + corn	4 bB	8 bcA	9 bcA
Marandu + corn	4 bB	9 bcA	8 bcA
Ruzi grass + corn	3 bB	7 bcA	9 bcA
Sunn crotalaria + corn	4 bB	11 aA	13 aA
Pigeon pea + corn	3 bB	12 aA	13 aA
Sorghum	6 abB	9 bcA	8 bcA
Ruzi grass	5 abA	6 cA	6 cA

Means followed by the same lowercase letter in a column, and by the same uppercase letter in a row are not significantly different by the Tukey test ($p \leq 0.05$).

Table 6. Soybean yield in 2006 as affected by the previous crop at three locations in Mato Grosso do Sul, Brazil

Previous crop	Dourados	Batayporã	São Gabriel do Oeste
	Mg ha^{-1}		
Corn	2.6 cB	3.1 eA	3.2 cdA
Tanzania + corn	2.8 bcB	3.6 abcdA	3.5 bcdA
Marandu + corn	2.5 cC	3.9 abA	3.1 dB
Ruzi grass + corn	3.0 abcB	3.6 abcdeA	3.4 bcdA
Sunn crotalaria + corn	3.0 abcB	3.4 bcdeA	3.6 abcdA
Pigeon pea + corn	2.0 dC	3.2 deA	2.8 eB
Sorghum	2.6 cB	3.3 cdeA	3.4 bcdA
Ruzi grass	3.2 abB	3.5 bcdeA	3.8 abA

Means followed by the same lowercase letter in a column, and by the same uppercase letter in a row are not significantly different by the Tukey test ($p \leq 0.05$).

Table 7. Late-season corn grain yield in 2006 after soybean, as affected by the late-season crop that was grown before soybean between March and August in 2006

Previous crop	Dourados	Batayporã	São Gabriel do Oeste
	Mg ha^{-1}		
Corn	3.2 deA	1.4 abB	3.1 cA
Tanzania + corn	3.1 eA	1.4 abB	3.1 cA
Marandu + corn	3.6 bcdA	1.3 bC	3.0 cB
Ruzi grass + corn	3.5 cdeA	1.5 abB	3.6 abA
Sunn crotalaria + corn	3.9 abcA	1.2 bC	3.7 abA
Pigeon pea + corn	3.6 bcdA	1.7 abC	3.2 bcB
Sorghum	4.2 abA	1.5 abC	3.5 abcB
Ruzi grass	3.9 abcA	1.6 abB	3.8 abA

Means followed by the same lowercase letter in a column, and by the same uppercase letter in a row are not significantly different by the Tukey test ($p \leq 0.05$).

(Table 7). Corn grain yield in 2006 was highest after sole ruzi grass and sole sorghum. Even though the previous cultivation of some sole forage species resulted in high corn grain yield in subsequent crops, these forage species provided no immediate profit for the grower. However, corn-forage intercropping with species such as ruzi grass can increase crop residue production without reducing the grain yield of the subsequent late-season corn crop, making these intercropping systems feasible for improving the sustainability in tropical environments.

CONCLUSIONS

1. Forage species intercropped with corn did not reduce corn yield, probably because the forage species produced little biomass during corn growth.

2. After corn was harvested but before soybean was planted, pigeon pea and sunn hemp grew poorly but *Brachiaria* spp. and *Panicum* spp. grew well and produced a large quantity of biomass; this increased the mass of above-ground crop residue, the proportion of the soil surface covered with residue, and nutrient fixation in soil and reduced weed infestation.

3. Soybean yields and subsequent late-season corn grain yields were higher when these crops followed corn intercropped with ruzi, Tanzania, or marandu grass, or sole ruzi grass than when they followed sole corn.

4. Intercropping late-season corn with *Brachiaria* spp. or *Panicum* spp. increased crop residue production without reducing corn grain yield, and can therefore be considered a viable option for increasing the sustainability of no-till in tropical cropping systems.

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