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Successive Cultivation of Soybean/Corn Intercropped with *Urochloa brizantha* topdressed with Nitrogen

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ABSTRACT: Corn intercropped with *Urochloa brizantha* (Syn, *Brachiaria brizantha*) has been indicated as a suitable alternative management practice for rational land use in crop-livestock production systems in the *Cerrado* region of Brazil. An experiment was carried out in Maracaju, MS, Brazil to evaluate the effect of sequences of soybean/second-crop corn systems intercropped with *Urochloa brizantha* and the effects of forms of nitrogen on soil chemical and physical properties. A randomized block experimental design was used with four replications; treatments were in a 2 × 4 factorial arrangement with two systems of crop management: second-crop corn intercropped with *Urochloa brizantha*, and monoculture of second crop corn; and four forms of topdressing N: urea, urea + ammonium sulfate, ammonium sulfate, and no N supply. The following chemical properties were evaluated: soil organic matter and exchangeable K contents, cation exchange capacity, base saturation, and K saturation; as well as the physical properties: soil bulk density and aggregate stability. Crop residue cover and agronomic traits of soybean were also assessed. Intercropping induced significant differences in crop residue cover, plant height, soybean yield, stand, 100-seed weight, soil organic matter, exchangeable K, and K saturation in the exchange complex. There was no significant effect of the crop sequences on soil bulk density and mean weight and geometric mean diameter of water-stable aggregates. No significant effect of forms of N was observed on any chemical or physical properties, or on those related to soybean development.

Keywords: aggregate stability, intercropping, soil organic matter, topdressing.

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INTRODUCTION

Particularly for Oxisols and climate conditions of Mato Grosso do Sul state, the implementation of no-tillage without fulfilling minimum requirements (no soil turnover, biodiversity/crop rotation, and soil cover/stubble) has led to degradation in the surface soil layers. Among the recent possibilities of crop residue input into the system, the practice of intercropping species has gained prominence. Producers increasingly plant second-crop corn intercropped with grass as the benefits of this technology for the local production system are becoming better known (Melotto et al., 2013). Most producers in the state use the no-tillage system, mainly in a soybean/second-crop corn succession. Second-crop corn is not only a profitable crop for the farming business in-between the main seasons (Garcia et al., 2012), but also provides large amounts of relatively slow-decomposing organic matter for soil cover, thus mitigating the negative effects of soil exposure between crop seasons (Ceccon, 2007).

Alternative cropping systems for the *Cerrado* (Brazilian tropical savanna) region are being sought to maximize crop yield by improving soil physical, chemical, and biological properties (Portes et al., 2000; Carvalho, 2005) and understanding their inter-correlations (Dufrank et al., 2004; Villar et al., 2004). Intercropping improves soil physical conditions by providing higher crop residue production, which stimulates water infiltration, allows more extensive exploitation of the soil profile by roots, reduces erosion, and, consequently, maintains or even improves system stability (Chioderoli et al., 2012). The success of these systems in the *Cerrado* is that plant residues of cash crops and accumulated residues of cover crops or pasture provide a favorable environment for recovery or maintenance of soil properties (Santos et al., 2008). Intercropping has further benefits, e.g., the possibility of late-season grazing and benefits from crop rotation and organic matter produced by the system.

The use of corn/brachiaria intercropping and similar alternatives for straw production has become a research topic (Salton et al., 2008). However, research data related to the subject of the proposed study are scarce, particularly with regard to soil physical properties and their relation to crop yield. In addition to the benefits of intercropping in increasing soil cover, the use of nutritional management of brachiaria can improve and increase the amount of corn residues and increase corn yield. As in corn, the main limiting macronutrient for pasture yield is N, especially in pastures consisting of species of the genus *Urochloa* (Jakelaitis et al., 2005). The supply of readily available N to plants through N fertilization has had a significant influence on several quantitative and qualitative parameters relevant to pasture management (Ruggieri et al., 1995).

The intercrop of corn and *Urochloa* combined with topdressing N fertilization allow for the improvement of physical and chemical soil characteristics due to the production of increased organic residue, thereby improving soil quality and resulting in increased crop yield and improvement of production system sustainability. The purpose of this study was to evaluate the effect of sequences of soybean/second-crop corn systems intercropped with *Urochloa brizantha* and the effects of forms of nitrogen on soil chemical and physical properties.

MATERIALS AND METHODS

The experiment was conducted at an experimental and demonstration unit of the research institution Fundação MS in Maracaju, Mato Grosso do Sul, Brazil (21° 37’ 12,34” S; 55° 08’ 23,76” W), on a clayey *Latossolo Vermelho Distroférrico* (Santos et al., 2013) or Rhodic Hapludox (Soil Survey Staff, 2010). Beginning in March 2005, the experiment of second-crop corn in monoculture or intercropped with *Urochloa brizantha* followed by soybean was conducted by Fundação MS for three consecutive growing seasons.

A randomized complete block experimental design was used with four replications; treatments were in a 2 × 4 factorial arrangement with two crop sequencing systems: second-crop corn in monoculture, followed by soybean, and second-crop corn intercropped with *Urochloa brizantha,* followed by soybean; and four forms of N fertilization topdressing on second-crop corn: 40 kg ha^{-1} N (urea), 40 kg ha^{-1} N (50 % urea and 50 % ammonium sulfate), 40 kg ha^{-1} N as ammonium sulfate, and no N fertilization. The total area of each experimental unit was 60 m^2 (5 × 12.0 m).

Corn (AG 9010) was sown in March 2005, 2006, and 2007 with a 5-line vacuum seeder, at row spacing of 0.8 m, sowing depth of 0.05 m, and five rows constituting a plot. Fertilization at sowing was 300 kg ha^{-1} of the fertilizer mixture 12-15-15 ($N-P_2O_5-K_2O$) + 9.5 % S + 0.72 % Zn + 0.17 % B in the planting furrow. Nitrogen fertilization was topdressing by hand at the V4 corn growth stage.

The brachiaria pasture species *Urochloa brizantha* cv. Marandu was used for intercropping. Brachiaria cover crop was sown before corn with a flow seeder at a spacing of 0.2 m, using 12.3 kg ha^{-1} seed (percentage of viable seed = 40.6), corresponding to 500 points ha^{-1} of pure live seed (PLS), obtained by multiplying the quantity of seeds by the percentage of viable seed. In the corn V5 growth stage, when *Urochloa* had two tillers, the herbicide Nicosulfuron was applied to all treatments (0.008 kg ha^{-1} a.i.) to delay the vegetative growth of brachiaria and give corn a competitive advantage, reducing the risk of losses in corn yield as a result of competition for light, water, and nutrients.

After corn harvest (August of each year), brachiaria was left to grow until early October, when it was desiccated around 30 days before soybean seeding. Soybean (BRS 239) was sown on the residues of corn or corn + Brachiaria cover crop with a no-tillage seeder (row spacing of 0.45 m, depth of 0.04 m) in early November of each year, with a total of 10 rows per plot, fertilized with 400 kg ha^{-1} of the mixture 00-20-20 ($N-P_2O_5-K_2O$) + 10 % Ca + 4 % S. The method of crop implementation and treatment application was similar in the three crop years.

Soil residue cover was determined by the knotted rope method, proposed by Sloneker and Moldenhauer (1977), five times in the 2007/2008 crop year as follows: a) 1 DAD - one day after desiccation; b) 15 DAD - 15 days after desiccation; c) DAS - 1 day after soybean sowing; d) V4 - in soybean stage V4 (when the 3rd trifoliate leaf is extended with three expanded leaflets and the 4th trifoliate leaf is open); and e) R2 - soybean stage R2 (full flowering, when most of the inflorescences on the main stem had open flowers). All organic matter on top of the soil surface was considered soil residue cover.

Plant height was evaluated in two phases of the soybean crop cycle - in the V3 vegetative stage (when the 2nd trifoliate leaf has three expanded leaflets and the 3rd trifoliate leaf is open) and the R8 reproductive stage (natural dropping of soybean leaves, from the beginning to 50 % defoliation). The data were obtained with a cm ruler, measuring from the soil surface to the height of the last expanded leaf on the stem in 20 plants per plot.

Soybean yield was determined at harvest of soybean plants in six four-meter-long rows, for a total of 10.8 m^2 per experimental unit. Yield data were obtained by weighing the amount of soybean grain per experimental unit and correcting moisture to 13 %. The 100-seed weight value was assessed by determining the weight of a sample of 100 seeds per plot. Plant stand was determined by counting the number of plants in three four-meter-long rows harvested per experimental unit (10.8 m^2).

For analyses of soil physical properties (bulk density and aggregate size distribution), soil samples were collected from the 0.00-0.05, 0.05-0.10, 0.10-0.15, and 0.15-0.20 m layers. Bulk density was determined by the volumetric ring method (Claessen, 1997) and aggregate size distribution by the wet sieving method (Kemper and Chepil, 1965). Soil blocks with disturbed structure were air-dried and sieved (9.52 and 4.76 mm mesh), using an aggregate diameter between these two mesh sizes (9.52 to 4.76 mm) for stability analysis of aggregates in water. Wet sieving was performed with 2.0, 1.0, 0.5, and 0.105 mm sieves, subjected to 15 min of vertical oscillations at a frequency of 32 oscillations per minute, based on the method described by Kemper and Chepil (1965) and the modifications proposed by Reichert et al. (1993), Claessen (1997), Castro Filho et al. (1998), and Palmeira et al. (1999). The mean weight (MWD) and geometric mean (GMD) diameter of water-stable aggregates were calculated as proposed by Kemper and Rosenau (1986).

Chemical characteristics were determined in the 0.0-0.025, 0.025-0.05, 0.05-0.10, and 0.10-0.20 m layers in samples collected from five randomly distributed points per plot between the soybean rows. The chemical properties measured were soil organic matter content, available K content (Mehlich-1), cation exchange capacity (CEC), base saturation (V), and K saturation in accordance with the methods of Claessen (1997).

The data were subjected to analysis of variance and then to the F test, using SAEG software (Ribeiro Júnior, 2001).

RESULTS AND DISCUSSION

Significant differences in soil cover among the successive systems were observed, except in the R2 stage, but not among nitrogen application rates and the interaction between the two factors (Table 1). The soil cover values were greatest in corn intercropped with brachiaria, differing significantly ($p<0.01$) from corn monoculture (Table 1).

Up to the V4 soybean stage, corn/brachiaria intercropping resulted in greater soil cover, but over the course of time, the soil cover percentage decreased until one day after sowing. Subsequently, there was an increase in soil cover in the V4 and R2 stages, due to the dehiscence of soybean leaves with advancing maturity. In a study on residue decomposition rates of cover crops in a Rhodic Hapludox, Kliemann et al. (2006) observed lower residues losses in the corn/brachiaria intercropping system, both in regard to the grasses and the legumes under study.

In the intercropping management system studied, significant differences in plant height were observed through the F test ($p<0.01$) in the V3 stage for final stand ($p<0.01$), grain yield ($p<0.01$), and 100-seed weight of soybean ($p<0.05$). However, there were no significant differences in plant height determined in the R8 stage at the end of the soybean crop cycle (Table 2).

Table 1. Soil residue cover percentage per sampling period, for two crop sequences

Intercropping	Soil residue cover					
	1 DAD	15 DAD	1 DAS	V4	R2	Mean
	%					
Corn monoculture	66.93 b	51.87 b	31.06 b	49.25 b	88.50^{ns}	57.5 b
Corn/brachiaria	95.56 a	92.06 a	70.37 a	77.87 a	95.25	86.2 a
CV (%)	3.69	5.11	7.36	7.56	3.12	

Means followed by the same letter in the column do not differ by the F test at 1 %; ns: not significant; DAD: days after desiccation; DAS: days after sowing; V4 and R2: soybean crop stages.

Table 2. Plant height in the V3 and R8 soybean stages, final stand, grain yield, and 100-seed weight, for two crop sequences

Intercropping	V3	R8	Final stand	Yield	100-seed weight
	m		plants m^{-1}	kg ha^{-1}	g
Corn monoculture	0.11b	0.59 a	15.81 a	2.846 b	14.00 b
Corn/brachiaria	0.12 a	0.60 a	11.17 b	3.132 a	14.32 a
CV (%)	4.99	9.26	8.86	7.17	2.33

Means followed by the same letter in the column do not differ by the F test at 1 %; V3 and R8: soybean crop stages.

Soybean plant height in V3 was greater in corn/brachiaria intercropping. Most likely, greater plant height in intercropping at this growth stage was related to the higher percentage and thickness of the soil residue layer in this system, leading to etiolated growth at the beginning of soybean crop development. With regard to final soybean stand, the number of plants in corn/brachiaria intercropping was lower than in corn monoculture (Table 2). The decreased stand in corn/brachiaria intercropping may be related to poor performance of the seeder in systems with large residue volumes on the soil surface. These results were similar to those reported by Aidar et al. (2000), who studied different residue sources for soil cover and found a higher final population density in the management system of common bean preceding soybean, followed by systems with rice, corn monoculture, corn/*U. brizantha*, and corn/*U. ruziziensis*.

Soybean yield after corn/brachiaria intercropping was higher than after corn monoculture, with a yield increase of about 300 kg ha^{-1}. Yield of soybean grown on residues of corn/brachiaria intercropping was higher than the national mean, which is 3,035 kg ha^{-1}. This may be due to the improvements resulting from soil cover and to the decomposition of organic matter, improving soil structure and nutrient availability.

There were no significant differences in soil bulk density due to the sequences of crop systems or types of N supply and the interaction among the factors. Soil bulk density was 1.45, 1.56, 1.56, and 1.53 Mg m^{-3} in the 0.00-0.05, 0.05-0.10, 0.10-0 15, and 0.15-0.20 m layers, respectively. The crop sequences, forms of N supply, or the interaction among the factors induced no significant differences in mean weight (MWD) and geometric mean (GMD) diameter of water-stable aggregates (Figure 1).

Although no significant effect for the intercropping factor was detected, the values of GMD and MWD in corn intercropped with brachiaria were higher.

In management systems with higher soil carbon contribution, Marcolan and Anghinoni (2006), Salton et al. (2008), and Souza et al. (2012) observed higher aggregate stability indices. In the model proposed by Tisdall and Oades (1982) on organizational processes and formation of aggregates in the soil and interaction with soil organic matter (SOM), free primary particles and silt-sized aggregates are linked by persistent binding agents, such as humified organic matter or complexes with polyvalent cations, oxides, and aluminossilicates, forming microaggregates (Ø from 20 to 250 μm). These stable microaggregates are linked by temporary binding agents and transients, resulting in macroaggregates (>250 μm). Marcolan and Anghinoni (2006) reported higher rates of aggregate stability (DMPU/DMPs) in the surface layer of soil under no-tillage for 12 years, followed by no-tillage for eight years, no-tillage for four years, and conventional tillage.

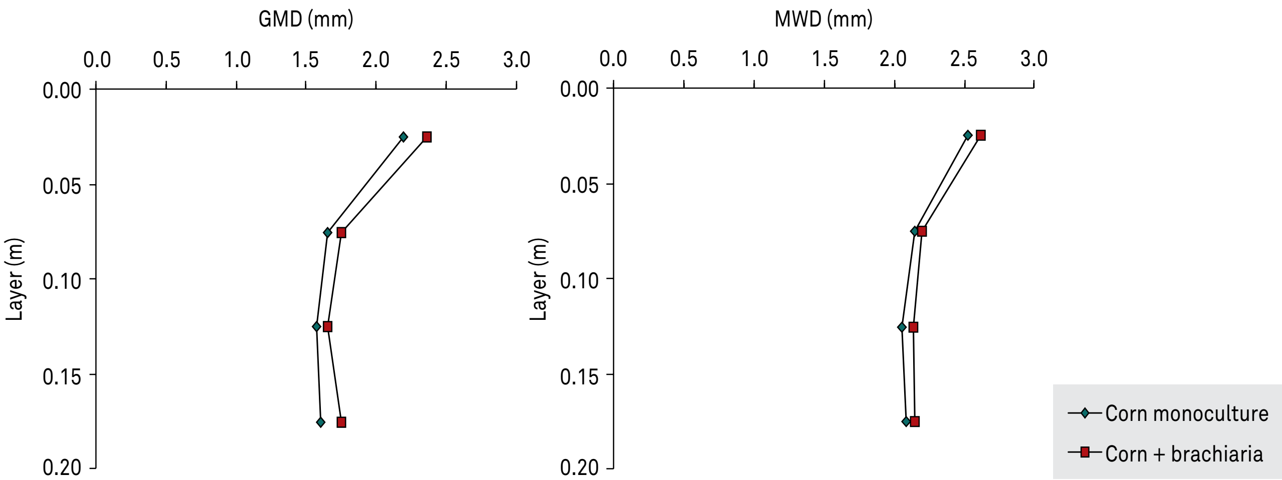

Figure 1. Mean weight (MWD) and geometric mean (GMD) diameter of water-stable aggregates in the soil after three years of two crop sequences.

Some authors emphasize the importance of roots for aggregate formation and stabilization, especially in plants of the Poaceae family. Salton et al. (2008) measured MWD in soil management systems and found greater MWD values in brachiaria cover crop systems (three-year periods) in rotation with soybean and permanent brachiaria cover crop, while the lowest values were observed under no-tillage with annual crops. These authors also concluded that macroaggregate stability is related to soil organic C content.

Significant differences in the levels of SOM were observed at a depth of 0.00-0.025 m, in accordance with the crop succession system (Figure 2). In the other soil layers studied, the values of SOM were not influenced by the factors studied, whether by the crop sequences or the forms of N fertilizer.

Higher SOM values were observed in corn/brachiaria intercropping in the surface layers of the soil (0.00-0.025 and 0.025-0.05 m). After three years, an increase in SOM of 4.0 g kg^{-1} in the 0.00-0.025 m layer and of 2.13 g kg^{-1} in the 0.025-0.05 m layer was noted in corn/brachiaria intercropping in comparison with corn monoculture (Figure 2). Higher SOM values in corn/brachiaria intercropping were possibly related to the higher amount of organic residues on the soil surface resulting from this system. In deeper layers (0.05-0.10 and 0.10-0.20 m), no significant differences were observed.

For the values of cation exchange capacity (CEC), the response was similar to the values of organic matter, with the highest CEC in corn/brachiaria intercropping (Figure 2). Organic matter can also influence CEC because of the higher number of negative charges or decrease in H^+ activity, which includes cations present in the soil solution (Cruz et al., 2009).

For K and K saturation in relation to soil CEC (Figure 3), there was a significant effect of crop sequencing systems in the 0.00-0.025, 0.025-0.05, and 0.05-0.10 m layers. There was no significant effect in the deeper layers. The K and K saturation values were higher in corn/brachiaria intercropping, possibly due to higher production of organic residues in brachiaria. Studying K dynamics in residues of cover crops in the *Cerrado*, Torres and Pereira (2008) found greater accumulation in grasses, and the greatest K release was from decomposing millet, oat, brachiaria, and sunhemp, whereas brachiaria had the highest rate of K release. Thus, greater soil cover, together with biomass production with a rapid rate of K release from brachiaria enables better conditions for soybean development sown in succession since the occurrence of water stress during the crop cycle in the region under study is frequent. In this case, K favors rapid stomatal opening and closure, decreasing water losses and also promoting K accumulation in plant roots, which produces an osmotic pressure gradient that draws water towards the roots (Nelson, 2005).

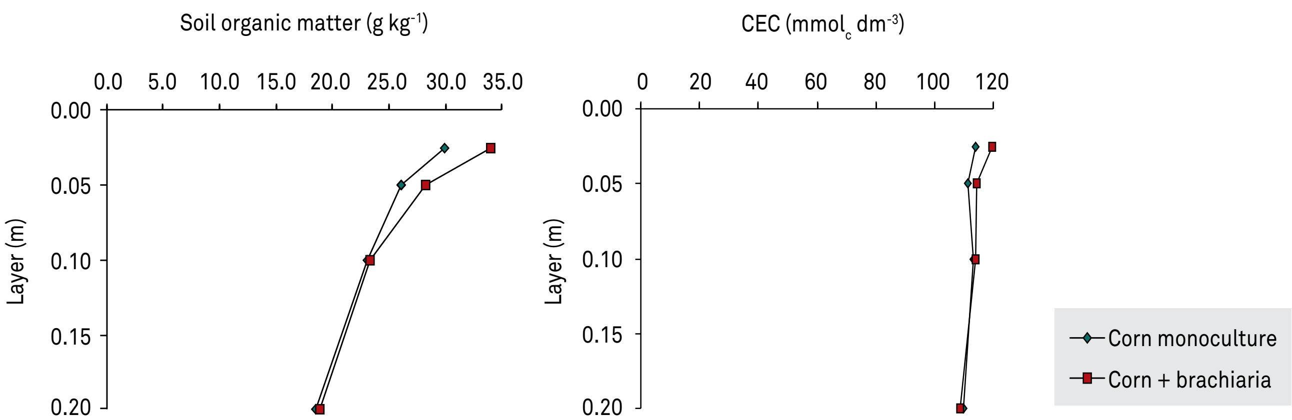

Figure 2. Soil organic matter and cation exchange capacity (CEC) in the soil after three years of two crop sequences.

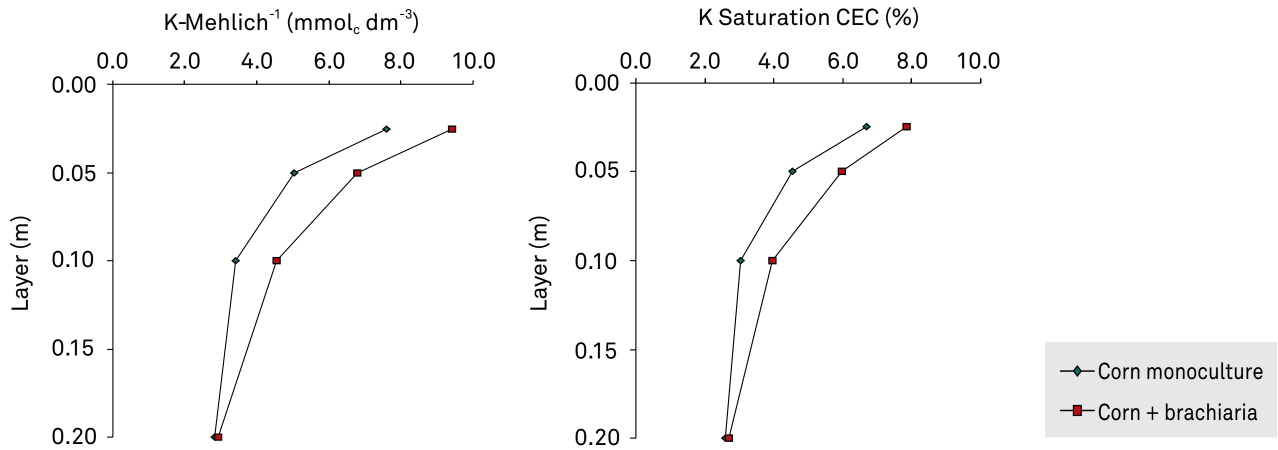

Figure 3. Potassium content and potassium saturation in the soil after three years of two crop sequences.

CONCLUSIONS

The system of crop sequencing with corn/brachiaria intercropping resulted in increases in organic matter and in exchangeable potassium in the soil surface layer.

The cultivation of brachiaria intercropped with corn resulted in higher percentages of soil cover, particularly at the beginning of the soybean crop cycle.

Intercropping led to greater stability and an increase in grain yield of soybean.

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