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EFFECT OF INTEGRATED SOYBEAN WITH SORGHUM AND BRACHIARIA SYSTEM ON SOIL CARBON AND NITROGEN

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ABSTRACT
The objective of this work was to analyze the effect of the integrated soybean system with sorghum and brachiaria on the levels of organic carbon, total N and mineral N in the soil. Super short cycle soybean BRS 7580 was planted, and subsequently, forage sorghum BRS 655 and BRS Piatã brachiaria were planted between the lines of the soybean. The levels of organic carbon, total nitrogen, ammonium, nitrate and mineral nitrogen/total nitrogen ratio were evaluated. The soil under Cerrado showed higher levels of organic carbon at all depths. There were no significant differences between treatments and the Cerrado for total nitrogen content in the deepest layers of the soil. All treatments showed a stratified distribution for the ammonium content, with higher values in the more superficial layers, decreasing in the deeper layers. Nitrate was not detected in the soil under Cerrado. Integrated crop treatments showed higher nitrate values than singles systems. In general, nitrate values were higher in the more superficial layers, with a significant decrease in the intermediate layers, increasing again in the 40-60 cm layer. The mineral nitrogen/total nitrogen ratio treatments with single or intercropped soybean maintained the same nitrate results pattern.
Key words: Super short cycle soybean;; intercropped system;; agroecosystems.

INTRODUCTION

Intercropped systems with legumes and grasses usually tend to increase the soil organic carbon and nitrogen content and alter other properties. On the other hand, agricultural systems based on monoculture and continuous soil plowing negatively affect soil physical, chemical and biological quality (COSTA et al., 2003; FENG et al., 2020). For this reason, management systems that maintain soil quality have been required, and integrated crop-livestock (ICL) system has stood out and is increasingly being adopted due to the various benefits previously mentioned. This system can increase the organic carbon content in the soil over the years due to the continuous growth of plants, crop rotation and greater nutrient cycling (TRACY and ZHANG, 2008). According to Amado et al. (2001), legumes in rotation or succession systems increase carbon and nitrogen retention in the soil, promoting better environmental quality.

The increase in the soil carbon content under ICL initially occurs in the most superficial layers (RUSSELL and ISBELL, 1986; SOARES et al., 2019). However, over time, there is also an increase in the deeper layers (HAYNES and WILLIANS, 1999; MARCHÃO et al., 2009), which is a consequence of correct soil management, which also has a positive effect on the system productivity (DUBEUX et al., 2004; MORAES et al., 2014). The soil carbon content is closely linked to the nitrogen content. Nitrogen is the nutrient most demanded by plants, and most of it is found in organic form. The transformation of organic nitrogen into mineral forms (ammonium and nitrate), which are absorbed by plants, is done through the decomposition and mineralization processes of organic matter (SCIVITTARO and MACHADO, 2004). The availability of this nutrient for plants in addition to other factors is essential for good crop productivity hence the importance of quantifying the mineral nitrogen content in the soil.

Soybean has a low C/N ratio, which, combined with soluble compounds presence, favors decomposition and mineralization by soil microorganisms, promoting nutrient cycling (SHOLIHAH et al., 2012). Intercropped systems with grasses provide an increase of soil organic matter, which directly influences mineralized nutrients. Thus, the soil management may alter soil total N with consequent changes in soil mineral N and soil ammonium and nitrate content (BUSO and KLIEMANN, 2003).

The objective of this work was to analyze the effect of the intercropped system of soybean with forage sorghum and brachiaria on the soil organic carbon, total nitrogen and mineral nitrogen.

MATERIAL AND METHODS

The experimental design was in randomized blocks, with seven replications. The super-short cycle soybean cultivar was planted in November 2012 and, 30 days after planting, forage sorghum and brachiaria were sown among the soybean lines. The treatments were as follows: 1. Single soybeans 2. Single brachiaria; 3. Single forage sorghum 4. Consortium soybean - brachiaria; 5. Consortium soybean - forage sorghum; 6. Forage sorghum in the off-season. The blocks were implanted between rows of native trees. The native species used were red angico (Anadenanthera colubrina var. Cebil), cedar (*Cedrela fissilis*), guapuruvu (*Schizolobium parahybae*), jequitibá (*Cariniana estrellensis*) and mahogany (*Swietenia macrophylla*). Seedlings were planted from January to March 2009. The spacing was 12 meters between rows and 4 meters between plants. The seedlings were sent using seeds from the Embrapa Cerrados nursery. The area's soil was a red latosol with a clay texture.

The super-short cycle soybean, variety BRS 7580, was planted mechanically on November 21, 2012, and the seeds had a cultural value of 90%, spacing of 50 centimeters and 20 plants/meter. The soybean seeds were inoculated with *Bradyrhizobium japonicum* at a dose of 500 grams of inoculant for each 60 kg of seed. Fertilization was done at planting, applying 420 kg ha^{-1} of NPK 0-20-20. On December 12, 2012 the plots were demarcated, each with 12 m2 (3 x 4 meters). In early January, glyphosate was applied at a dose of 1.5 l ha^{-1} in the area for weed control before planting other crops. On January 7 and 8, 2013, brachiaria and forage sorghum were planted manually. The cultivar of *Brachiaria brizantha* used was BRS Piatã, with a cultural value of 50%, and 0.014 kg of seed/plot was used. Three furrows were made between the lines of soybeans for planting the brachiaria, and the seeds were sown.

The cultivar of forage sorghum used was BRS 655, and 17 seeds/meter was used. A groove was made between the lines of the soybeans for planting the sorghum. This cultivar is a simple hybrid with a cycle of 100 to 110 days, a plant height of 250 cm, resistance to drought, lodging, and a high potential for green mass production. On January 18 and 19, 2013, the sorghum plots were fertilized with 300 kg ha^{-1} of NPK 4-30-16, and additional fertilization of 80 kg ha^{-1} of urea was used. On March 21, 2013, cover fertilization was applied to the forage and brachiaria sorghum plots, using 100 kg ha^{-1} of urea. On March 28, 2013, the planting of forage sorghum in the off-season was carried out in the plots planted with soybean in a single system. The variety used was BRS 655, and 300 kg ha^{-1} of NPK 4-30-16 was fertilized. On April 15, the cover fertilization was performed with 80 kg ha^{-1} of urea. In early April 2013, soybean was harvested manually, shredded, and the beans were weighed. On May 5 and 6, forage and brachiaria sorghum plants were harvested with a manual brush cutter. The fresh weight of plant biomass was done in the field, and a small sample was stored in a paper bag and then taken to the oven at 65 ºC for 72 hours for drying and weighed. At the end of May, forage sorghum was also harvested in the off-season, adopting the previously described harvesting practices.

For the determinations of organic carbon, total nitrogen, nitrate and ammonium samples were collected in three of the seven blocks of the experiment. Samples were collected in the soybean, forage and brachiaria plots in a single system, soybean in a consortium with sorghum and brachiaria and in the off-season sorghum plots. Soil samples were also collected in a native Cerrado area as a reference. The samples were collected after harvesting each culture with the aid of an auger in the soil layers: 0-5; 5-10; 10-20; 20-40, and 40-60 cm. For each composite sample, five simple samples were collected. These were placed in a bucket, crushed and homogenized, removing approximately 500 grams of soil, which were stored in plastic bags and identified. A small amount of soil was removed from each sample, stored in a plastic bag, identified, and placed in a polystyrene box with ice. These samples were kept frozen until the time of nitrate and ammonium analysis.

All samples were taken to the Soil Biochemistry Laboratory at the University of Brasília for further analysis. The samples were air-dried, macerated, and sieved through a 0.5 mm sieve and stored to analyze organic carbon and total nitrogen. For the nitrate and ammonium analysis, 10 grams of soil were removed from each sample and placed in the oven for two days at 105 ºC to determine the humidity. Soil organic carbon was determined by the method of Walkey and Black (1934). The total N was determined by the Kjeldahl method (BREMNER and MULVANEY, 1982). The nitrate and ammonium analysis were determined by the Kjeldahl method, described in EMBRAPA (2010). The data were analyzed using the statistical program Sisvar (FERREIRA, 2003), and the comparison of means was performed by the Tukey test at the level of 5% probability.

RESULTS AND DISCUSSIONS

Soil organic carbon

The soil organic carbon content was higher in the 0-5 cm layer than a 40-60 cm layer for all treatments (Table 1). Higher levels of organic carbon in the most superficial layer were also found by Salton et al. (2011) in a crop-livestock integration experiment carried out in Mato Grosso do Sul and this is due to the greater accumulation of crop residues on the surface and the absence of soil disturbance in this system (BAYER et al., 2002). The Cerrado was used as a reference, and a more stratified distribution of organic carbon in the soil can be observed, with a higher value in the 0-5 cm layer (51.28), lower value in the 40-60 layer (22.17) and intermediate values in the other depths (39.66; 29.25; 29.78). In general, the Cerrado showed the highest values of organic carbon in relation to the other treatments.

The decrease in C-org in cultivated soils may be the result of the management adopted and the consumption of carbon by microbial biomass (JAKELAITIS et al., 2008). There were no significant differences, in any of the depths, between the intercropped treatments and those in the single system, except for the 0-5 cm layer in which the soybean + sorghum consortium provided the highest values than in the treatments with single soybean (Table 1). The short period of time may explain this result (PILLON et al., 2007). In long-term experiments, as in Salton et al. (2011), with areas of 9 and 11 years in ILP system, differences differences between treatments, in which the treatments with secondary pasture have carbon contents in comparison to the systems of single tillage. The cultural residues of forages have a higher C/N ratio, which generates a slower degradation and favors the accumulation of soil organic carbon. In this work, only in the 0-5 cm layer differences were observed between treatments with single soybean and as a single or intercropped forage (brachiaria and sorghum) and despite being the first year of implementation of this system, the soy+sorghum consortium improved soil carbon contents. However, this effect was not observed in the other soil layers, possibly due to the short period of time and the uniform distribution of organic matter throughout the area, once that before the installation of the experiment, the experimental area was planted with sorghum and was desiccated before the work.

Total Nitrogen

The native Cerrado soil showed the highest levels of total nitrogen in the soil layers 0-5, 5-10 and 10-20 cm in comparison to the other treatments. In the deeper layers, there was no statistically significant difference between treatments. Among the treatments, there was a significant difference only in the 0-5 cm layer in which the single soybean presented a lower total N than the soybean + sorghum. These same treatments showed behavior similar to the organic carbon of the soil.

Table 1. Soil organic carbon and total nitrogen (g kg^{-1}) under soybean and forage cultivated in single system and intercropped.

Treatments	**Depth (cm)**				
	0-5	5-10	10-20	20-40	40-60
			C (g kg^{-1})		
Soybean	23.24Ca[1]	21.13Bab	19.14Bab	20.31Bab	16.32abB
Sorghum	24.59bcA	22.87Ba	20.16Bab	19.50Bab	16.56abB
Soybean + Sorghum	30.41Ba	21.76Bb	21.49Bb	19.02Bb	16.79abB
Sorghum off-season	28.19bcA	22.06Bb	17.85Bbc	17.11Bbc	17.29Bc
Brachiaria	26.03bcA	24.15Bab	22.47Bab	19.27Bbc	15.06Bc
Soybean+brachiaria	23.96bcA	21.95Ba	19.41Bab	18.78Bab	15.88Bb
Cerrado	51.28Aa	39.66Ab	29.25Ac	29.78Ac	22.17Ad
			N (g kg^{-1})		
Soybean	1.38cA	1.18bAB	1.07bB	1.05aB	0.78aC
Sorghum	1.49bcA	1.31bAB	1.17bBC	1.04aCD	0.81aD
Soybean + Sorghum	1.66bA	1.28bB	1.18bBC	0.98aCD	0.81aD
Sorghum off-season	1.45bcA	1.19bB	1.08bBC	0.91aCD	0.77aD
Brachiaria	1.47bcA	1.34bAB	1.21bBC	1.04aC	0.75aD
Soybean+brachiaria	1.37cA	1.29bAB	1.10bBC	0.97aCD	0.80aD
Cerrado	2.51aA	1.83aB	1.54aC	1.12aD	0.88aE

(1) Averages followed by the same lowercase letters in the column and uppercase letters in the row do not differ from each other by the tukey test ($p < 0.05$).

Loss et al. (2011), also found a higher total N content in soil under native Cerrado compared to crop-livestock integration systems and, as well as for organic carbon levels, this is due to the greater deposit of plant residues in this soil and less disturbance of this system, which generates greater accumulation of this nutrient in the soil (SIQUEIRA NETO et al., 2009). In the present experiment, no statistical differences were observed between the total N levels in the deeper layers of the treatments and in the Cerrado, and this may be due to the application of nitrogen fertilizers and their leaching, since high levels of nitrate were found in the subsurface, mainly in consortium treatments. In general, the greatest results found were in the most superficial layers, with a decrease in the soil profile. The 0-5 cm layer showed higher nitrogen values than the 10-20, 20-40 and 40-60 cm layers for all treatments.

The decrease in the total nitrogen content was more uniform in the soil under Cerrado (Table 1). The higher values of total N in layers 0-5 and 5-10 cm are due to the greater accumulation of organic matter on the soil surface. There were no significant differences between the treatments in single system and those in consortium, with the exception of the treatments single soybean and soybean + sorghum in the 0-5 cm layer. The treatment with single forage sorghum showed the same levels of total nitrogen as the treatments in consortium with soybean and sorghum in off-season. Similar results were obtained in the treatment with brachiaria. The treatment with single soybeans also did not differ from the others (Table 1). This result shows that the soybean culture did not interfere in the consortium treatments regarding the total nitrogen content in the soil, with the exception of the 0-5 cm layer.

Ammoniacal nitrogen (NH_4^+)

Regarding the ammonium content in the soil in the superficial layers (0-5 and 5-10 cm), the Cerrado showed the highest values and in the other layers, in general, there was no difference in the ammonium contents between the native Cerrado and the others agroecosystems studied. In the layers of 10-20 and 20-40 cm the highest levels of ammonium were found in the plots with forage sorghum off-season. This same treatment, together with sorghum and brachiaria in a single system, exhibited the highest levels in the deepest layer (Table 2). In general, all separation blocks have a uniform distribution in relation to the ammonium content, with higher values in the superficial layers, decreasing the deeper layers (Table 2). Possibly due to the binding of NH_4^+ to molecules of organic matter, which have a negative charge. In general, the consortia between soybean and forage lower ammonium values at different depths. This may be due to the higher rate of nitrification that occurred in treatments.

Table 2. Soil ammonium and nitrate content (mg N kg^{-1}) under soybeans and forage cultivated in a single and intercropped systems.

Treatments	**Depth (cm)**				
	0-5	5-10	10-20	20-40	40-60
			NH_4^+ (mg kg^{-1})		
Soybean	4.89bcAB[(1)]	5.34bA	3.37bcAB	3.36abB	0.82bcC
Sorghum	5.28bA	5.12bA	3.28bcB	1.61bcC	2.51abBC
Soybean + Sorghum	5.42bA	3.09cBC	3.29bcB	1.55cCD	0.40cD
Sorghum off-season	5.12bAB	3.05bAB	6.29aA	4.15aBC	3.33aC
Brachiaria	4.99bAB	5.91bA	4.24bB	2.18bcB	1.58aC
Soybean+brachiaria	3.12cA	2.61cAB	2.26cAB	1.66bcAB	0.99bB
Cerrado	10.28aA	5.32aB	2.93bcC	1.72bcC	1.53bcC
			NO_3^- (mg kg^{-1})		
Soybean	20.57bA[(1)]	1.93cD	2.43bD	6.88aC	14.38aB
Sorghum	0.93eA	1.07cA	1.17bA	2.89bcA	2.40bA
Soybean + Sorghum	24.42aA	17.39aB	0.94bD	8.11aC	15.07aB
Sorghum off-season	17.25cA	2.98cC	6.48aB	4.94abBC	2.87bC
Brachiaria	1.14eA	1.37cA	1.76bA	0.79cA	0.30bA
Soybean+brachiaria	6.28dB	8.10bB	1.10bC	1.25cC	14.22aA
Cerrado	ND	ND	ND	ND	ND

[(1)] Averages followed by the same lowercase letters in the column and uppercase letters in the row do not differ from each other by the tukey test ($p < 0.05$).

Nitrate (NO_3^-)

In the soil under Cerrado the presence of nitrate was not detected (Table 2). There is a low adsorption of nitrate ion causing its leaching to the deeper layers (OLIVEIRA et al., 2000). The treatments with sorghum and brachiaria in a single system did not present significant differences in the levels of nitrate in all depths. In all layers, nitrate values were low in these treatments. These values may be due to the high C/N ratio of these materials and consequently low mineralization.

With regard to intercropped systems and single systems (forage sorghum and brachiaria), in general the intercropped systems showed higher nitrate values in all layers. The treatment with sorghum off-season showed a high nitrate content in the 0-5 cm layer, decreasing in depth (Table 2). This high value in the 0-5 cm layer may be due to nitrogen originating from the soybean planted before sorghum. In general, soybean treatments (soybean in single system and soybean intercropped with forage sorghum and brachiaria) showed the highest nitrate content in all soil layers. The treatments with soy did not show a uniform distribution in relation to the depths. In general, the nitrate values were higher in the more superficial layers (0-5 and 5-10 cm), with a significant decrease in the intermediate layers (10-20 and 20-40 cm), increasing the values in the 40-60 (Table 2). The high nitrate values found in the most superficial layers can be attributed to the mineralization of plant residues and the subsequent action of nitrifying bacteria that transformed ammonium into nitrate. In cases where an increase in nitrate concentration was observed at greater depths, this can be attributed to the inversion of charges in the clay fraction that can occur in soils of the Cerrado environment (Oxisols). Due to the higher concentration of positive charges in depth, nitrate can be adsorbed to soil particles under these conditions.

CONCLUSIONS

Integrated systems did not modify soil carbon and nitrogen content.

The areas under Cerrado showed higher levels of soil organic carbon in all the depths, however nitrate was not detected.

In the deepest layers of the soil, there were no significant differences between treatments and the Cerrado regarding soil total nitrogen content.

For the ammonium content, in general, all treatments showed a stratified distribution, with higher values in the most superficial layers, decreasing in the deeper layers.

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