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COTTON RESPONSE TO NITROGEN FERTILIZATION IN THE INTEGRATED CROP-LIVESTOCK SYSTEM

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ABSTRACT - Cotton has been widely cultivated in the Cerrado region, including the crop-livestock integration system under no-till. The objective of this study was to evaluate the effects of plant residues from ruzigrass [*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins] and nitrogen fertilization on nitrogen use efficiency, growth, and yield of cotton crop (*Gossypium hirsutum* L. R. *latifolium* Hutch.), cv. TMG 44 B2RF. The experimental design was randomized blocks, in a split plot scheme, with four replications. The plots consisted of three production systems: i) conventional cotton cropping in fallow area; ii) cotton cropping in the presence of straw from the shoots and roots of ruzigrass plants; iii) cotton cropping only in the presence of residues from the ruzigrass roots. The subplots consisted of five rates of N (0, 40, 80, 120 and 160 kg ha^{-1}), applied at 30 and 50 days after seedling emergence. The presence of ruzigrass straw provided less growth and development of cotton, in addition to less N uptake by plants. The cotton cropping in the crop-livestock integration system in the presence of residues from the roots and shoots of the ruzigrass plants resulted in the greater cotton yield in the second year, demonstrating the importance of the straw formation of the cover crops for the sandy soils of the Cerrado region. The optimal application rate of N in topdressing for the cropping of cotton in succession or not with ruzigrass residues in sandy soil varies from 100 to 110 kg N ha^{-1}.
Keywords: *Brachiaria ruziziensis* Germ. & Evrard, *Gossypium hirsutum* L., nitrogen, *Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins.

RESPOSTA DO ALGODOEIRO À ADUBAÇÃO NITROGENADA EM COBERTURA NO SISTEMA DE INTEGRAÇÃO LAVOURA-PECUÁRIA

RESUMO - O cultivo do algodoeiro tem se expandido no Cerrado, incluindo a integração agricultura-pecuária em sistema de semeadura direta. Objetivou-se com este estudo avaliar os efeitos dos resíduos vegetais de braquiária [*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins (Syn. *Brachiaria ruziziensis* Germ. & Evrard)] e da adubação nitrogenada em cobertura no crescimento e produtividade do algodoeiro herbáceo, cv. TMG 44 B2RF. O delineamento experimental foi blocos ao acaso, em esquema de parcelas subdivididas, com quatro repetições. As parcelas foram constituídas por três sistemas de produção: i) cultivo do algodoeiro convencional em área de pousio; ii) cultivo do algodoeiro na presença de palhada e resíduos das raízes de braquiária; iii) cultivo do algodoeiro apenas na presença de resíduos das raízes de braquiária. As subparcelas foram constituídas por cinco doses de N em cobertura (0, 40, 80, 120 e 160 kg ha^{-1}), aplicadas aos 30 e 50 dias após a emergência das plântulas. A presença de palhada de braquiária proporcionou menor crescimento e desenvolvimento do algodoeiro, além de menor absorção de N pelas plantas. O cultivo do algodoeiro no sistema de integração agricultura-pecuária na presença de resíduos das raízes e da parte aérea das plantas de braquiária resultou na maior produção de algodão em caroço no segundo ano, demostrando a importância da formação de palhada das plantas de cobertura para os solos arenosos do Cerrado. A dose ótima de aplicação de N em cobertura para o cultivo do algodoeiro em sucessão ou não com resíduos vegetais de braquiária em solo arenoso do Cerrado varia de 100 a 110 kg ha^{-1} de N.
Palavras-chave: *Brachiaria ruziziensis* Germ. & Evrard, *Gossypium hirsutum* L., nitrogênio, *Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins.

INTRODUCTION

The cultivation of cotton (*Gossypium hirsutum* L. r. *latifolium* Hutch.) in soil conservation systems such as no-till, including the crop-livestock integration, has intensified in the Brazilian Cerrado, a region responsible for more than 95% of Brazil's cotton production (BERGER et al., 2019). The crop-livestock integration system is a soil management system that results in increased crop yields and improved soil quality and, therefore, has contributed to the sustainability of agricultural land use (KLUTHCOUSKI; STONE, 2003).

An important characteristic of crop-livestock integration systems is the production of straw and the use of crop rotation, especially with the inclusion of forage

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grasses, which are essential conditions to enable the no-tillage system, especially in the Cerrado region (BORGHI; CRUSCIOL, 2007). Among the species used for forage and, or soil cover crop in crop-livestock integration systems, forage grasses of the genus *Urochloa* spp. has stood out. Forage grasses have desirable characteristics for previous cultivation before cotton cultivation, such as high dry matter production, straw persistence in the soil, reduction in the incidence of pests, diseases and weeds, vigorous and deep root system that contributes to the nutrient cycling and improvement of soil and water conservation, among others (LAMAS; STAUT, 2005; CORREIA et al., 2005).

However, cover crops with high C/N ratio in both shoots and roots, may impair growth and development of the subsequent crop (SILVA; ROSOLEM, 2001; ROSOLEM et al., 2004; SOUZA et al., 2006) mainly due to a temporary immobilization of the soil and fertilizer nitrogen (N) (AITA; GIACOMINI, 2003; ROSOLEM et al., 2012). Nitrogen immobilization after addition of plant residues to soil may last a few months, but it is more intense in the initial days. The C/N ratio has been most widely used in models for predicting N availability during plant residue (NICOLARDOT et al., 2001). When the crop residues have C/N ratio around 25:1, there is a balance between N mineralization and immobilization (ALLISON, 1966). Trinsoutrot et al. (2000) tested 47 types of crop residues to soil and reported that net N mineralization occurred only in two of them within a 168-day period, both with C/N ratio lower than 24:1.

Nitrogen is required in large quantities by cotton plants. During its cycle, the cotton absorbs from 60 to 80 kg of N to produce a ton of cotton (FERREIRA; CARVALHO, 2005). Most of this demand is provided by nitrogen fertilization, in addition to the amount supplied by the soil. Adequate N rates are essential for plant growth and flowering, increase crop yield and improve fiber length and strength. However, excess N can induce excessive plant growth, extend the plant cycle, and decrease fiber yield and quality (HUTMACHER et al., 2004; REDDY et al., 2004). Studies reported that the yield response of the crop to nitrogen fertilization of the main cotton cultivars grown in Brazil has been increasing up to the 120 kg N ha^{-1} (GRESPAN; ZANCANARO, 1999; BORÉM; FREIRE, 2014). Rosolem (2001) reported that the maximum economic efficiency rate for the cotton crop is between 100-120 kg N ha^{-1}. However, when the cotton is grown in rotation with grasses, the proper management of N in the soil–plant–straw system is normally difficult, due to the variability of the processes of mineralization, leaching, volatilization, denitrification, and absorption by the crop.

The initial growth of cotton was reduced when cultivated after *Urochloa* spp. (ECHER et al., 2012). The dry matter production of the shoots and the roots of the cotton was reduced by up to 79% with the incorporation, in the soil, of plant residues of signalgrass [*Urochloa decumbens* (Stapf) R. D. Webster] with a C/N ratio of 44:1 (SOUZA et al., 2006). Studies by Rosolem et al. (2012) reported that the presence of ruzigrass roots [*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins] in the soil to be cultivated with cotton resulted in less growth and dry matter production of the shoots and roots of the cotton, in addition to less absorption of N. These results indicate that soil microorganisms can compete for available N during the period of decomposition of *Urochloa* spp. roots, leaving N unavailable to cotton during its growth. However, these studies were carried out in pots under greenhouse conditions, and it is necessary to review the effects of forage grass residues on growth and cotton yield in field conditions.

In general, high temperatures associated with adequate humidity in the Cerrado region during the summer promote the rapid decomposition of plant residues on the soil surface (REZENDE et al., 1999). However, the carbon (C) mineralization of the roots is significantly less than that of the leaves and stems. Estimates made by Urquiaga et al. (1998) and Abiven et al. (2005) pointed out that more than 50% of the C present in the *Urochloa* spp. roots are not decomposed, even considering a period of 90 to 120 days under incubation conditions. Therefore, grass roots can play an important role in soil N immobilization and mineralization processes, and, eventually, change the availability of mineral N in the soil (Rosolem et al., 2012).

This study was conducted with the objective of evaluating the effects of plant residues from ruzigrass [*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins] and nitrogen fertilization on nitrogen use efficiency, growth, and yield of cotton crop (*Gossypium hirsutum* L. R. *latifolium* Hutch.), cv. TMG 44 B2RF.

MATERIAL AND METHODS

Two field experiments were conducted in a deep, sandy Arenic Entisol (Neossolo Quartzarênico in the Brazilian classification) with 84–86% of sand, in Cassilândia, Mato Grosso do Sul, Brazil (19º05’45” S, 51º48'51” W, and altitude of 510 m), during the 2016/2017 and 2017/2018 growing seasons. The regional climate according to the Köppen classification is Aw, characterized as tropical climate with hot summers and a tendency towards high rainfall levels, and dry winters, with a dry season between May and September. The 30-year mean annual temperature is 24.1°C with a July minimum of 16.4°C and a January maximum of 28.6°C, and mean annual rainfall of 1,520 mm (ALVARES et al., 2013). Rainfall data gathered during the experiments are shown in Figure 1.

Prior to this experiments, the experimental area had been occupied with natural pasture typical of the Cerrado and without any history of agricultural cultivation. Before starting the experiments, the soil was sampled from the 0.0–0.20 and 0.20–0.40 m layer and the results of the chemical analysis are shown in Table 1.

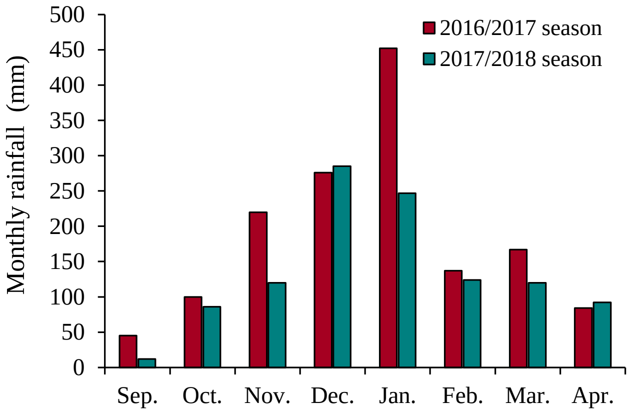

FIGURA 1 - Monthly rainfall (mm) between the months of September and April during the two growing seasons (2016/2017 and 2017/2018) of cotton cropping in the municipality of Cassilândia (Mato Grosso do Sul), Brazil.

TABLE 1 - Soil chemical properties at 0.0–0.20 and 0.20–0.40 m depth at the beginning of the experiments

Season	Depth	pH	$P_{Mehlich-1}$	OM	H + Al	Al	K	Ca	Mg	CEC	V
	(m)		(mg dm^{-3})	(g dm^{-3})	------------------ cmol$_c$ dm^{-3} ---------------------------						(%)
2016/2017	0.00-0.20	5.0	9.0	18.2	2.60	0.15	0.10	1.70	0.50	4.9	47
	0.20-0.40	4.9	7.8	15.0	3.25	0.22	0.15	1.50	0.50	5.4	40
2017/2018	0.00-0.20	5.6	12.3	19.0	1.90	0.00	0.10	2.60	1.00	5.6	66
	0.20-0.40	5.2	10.7	16.4	2.30	0.00	0.12	2.10	0.90	5.4	57

OM: Organic matter. CEC: Cation exchange capacity at pH 7.0. V: Soil base saturation.

In September 2016, the correction of soil acidity was carried out with the application of 1,225 kg ha^{-1} of limestone (effective calcium carbonate equivalence: 92%), aiming to raise the soil base saturation to 70% (SOUSA; LOBATO, 2004). The field soil was plowed and harrowed to a depth of 0.20 m and divided into plots before sowing. In the 2017/2018 growing season, there was no need for liming due to the soil base saturation in the 0.0–0.20 m layer being around 66% (Table 1). According to the recommendations of Sousa and Lobato (2004), liming should be recommended when the soil base saturation is below 60%.

The experimental design used was randomized blocks, in a split-plot scheme, with four replications. The plots consisted of three cotton production systems, which consisted of the grown in succession or not to the ruzigrass residues: system 1) cotton cropping in fallow area without ruzigrass residues [simulating a conventional cotton production system (control)], system 2) cotton cropping in the presence of straw from the shoots and roots of ruzigrass plants [simulating an crop-livestock integration system where the forage crop (ruzigrass) was used as a cover crop], and system 3) cotton cropping only in the presence of residues from the ruzigrass roots [simulating a system of crop-livestock integration where the forage crop (ruzigrass) was used for grazing, silage or hay making]. The subplots consisted of five rates of N (0, 40, 80, 120 and 160 kg ha^{-1}), applied at 30 and 50 days after seedling emergence. The experimental units consisted of five 5.0-m long rows, with 0.80-m between-row spacing. The useful area (9.6 m^2) comprised the three central rows of each subplot, disregarding 0.50 m of each edge.

The three experimental production systems were initially established in September 2016. The sowing of the ruzigrass was carried out manually at haul using 12.0 kg ha^{-1} of seeds with a cultural value of 40%. The ruzigrass crop was not fertilized with the purpose of not having fertilization interference in the experimental treatments and, therefore, it is possible to investigate only the effect of plant residues from successive crop systems. At 98 and 110 days after sowing for the 2016/2017 and 2017/2018 growing seasons, respectively, the ruzigrass plants were desiccated with glyphosate herbicide (1,800 g ha^{-1} of the active ingredient) at a spray volume of 200 L ha^{-1}). Subsequently, the shoots of the ruzigrass plants was cut and, in the plots where the cotton was grown only in the presence of residues from the ruzigrass roots, the straw from shoots was removed from the experimental plots.

After the chemical management of the ruzigrass plants, the amount of straw produced by forage crop was estimated by taking samples from two random points per subplot, using a 0.25 m^2 wooden frame. The collected plant material was then dried in a forced-air oven for 72 h at 60°C (± 2°C), weighed, ground, and N content was determined by the Kjeldahl method with digestion in sulfuric acid solution and vapor distillation as described by Malavolta et al. (1997). The total amount of N accumulated in forage crop was calculated by multiplying the nutrient contents by the shoot dry matter produced. The C/N ratio of brachiaria straw was calculated considering that 40% of the plant's dry matter is organic carbon, according to Rosolem et al. (2012).

Cotton seeds from cultivar TMG 44 B$_2$RF were sown mechanically on December 20, 2016 (2016/2017 growing season) and December 28, 2017 (2017/2018 growing season), in rows 0.80 m apart at a density of 10 seeds m^{-1}. Base fertilization was carried out by applying 800 kg ha^{-1} of 04-14-08 formulation at sowing furrow. Cotton fertilization was carried out according to the requirement of the crop (SOUSA; LOBATO, 2004) and the soil analysis (Table 1).

The phytosanitary management of cotton crop, including monitoring of pests and diseases, chemical control of weeds, insecticide and fungicide applications were carried out in accordance with the technical recommendations of the crop. Weed control was carried out with the application of glyphosate herbicide, at a rate of 900 g ha^{-1} of the active ingredient (a.i.). Pest and disease control were performed with applications of the insecticides deltamethrin and triazophos (0.40 and 140 g a.i. ha^{-1} and the fungicides propiconazole, trifloxytrobin and mancozeb (75, 75 and 1,600 g a.i. ha^{-1}). The management of the growth regulator was not performed due to the low demand of the cultivar used.

Relative chlorophyll index (RCI) was measured at the beginning of cotton flowering using a portable chlorophyll meter, Apogee model MC-100 (Apogge Instruments Inc., Logan, UT, USA), with sixteen measurements in the subplots at the fourth trifoliolate leaf totally expanded. In each evaluation, two readings per leaflet were performed for all the diagnostic leaves evaluated, along the leaf blade and avoiding the ribs. After measuring the RCI, the leaves were collected for the determination of N content. The leaf samples were dried for three days at 55 °C, ground in a Willey mill, and N was determined by sulfuric acid digestion and vapor distillation by the semi-micro Kjeldahl method (MALAVOLTA et al., 1997).

At cotton harvest, plant height, number of bolls per plant and boll weight were measured in a random sample of 20 plants from the useful area of each subplot. Cotton yield was determined at the end of the crop's cycle, from a central portion of each subplot of 4.00 × 2.40 m (9.60 m^2). Cotton fibers were cleaned, weighed and then the seed cotton yield was estimated in kg ha^{-1}.

Nitrogen use efficiency from nitrogen fertilizer applied to the soil was determined by the ratio of the increase in cotton yield (in kg ha^{-1}) of each treatment with nitrogen fertilization compared to the control treatment (without application of N) divided by the amount of N applied in each treatment (in kg ha^{-1}).

The normality of data was previously tested by the Kolmogorov-Smirnov test at the 5% level and then data were submitted to analysis of variance (ANOVA) and, when significant, the means of production systems were compared by the Least Significant Differences (LSD) test at the 0.05 confidence level. Regression analysis was used for the N fertilizer rates and significant equations (F test, $P \leq 0.05$) with the highest coefficients of determination were adjusted. The analyses were performed using Sisvar® software, version 5.6 for Windows (Statistical Analysis Software, UFLA, Lavras, MG) (FERREIRA, 2010).

RESULTS AND DISCUSSION

Dry matter production and nitrogen accumulation in ruzigrass plants

The dry matter production, N content and accumulation and the C/N ratio of the shoot straw of ruzigrass plants obtained in the 2016/2017 and 2017/2018 growing season are shown in Table 2. The average dry matter production of ruzigrass plants was 10,472 kg ha^{-1} and 6,136 kg ha^{-1}, respectively, for the 2016/2017 and 2017/2018 season (Table 2). This amount of straw is close to the pre-established values by Silveira and Stone (2010), who reported that the dry matter production capacity of the *Urochloa* spp. for the Cerrado conditions varies from 4,000 to 18,000 kg ha^{-1}. These results show that the use of ruzigrass as a cover crop is capable of producing an adequate amount of straw on the soil surface, making it important for maintaining the no-tillage system.

The straw amount on the soil surface can serve as a reference for the preliminary assessment of the conditions under which no-tillage is being conducted. It has been considered that 6,000 kg ha^{-1} of straw on the surface is an adequate amount for the no-tillage system, with which adequate soil coverage is achieved (SILVEIRA; STONE, 2010).

TABLE 2 - Dry matter production, N content and accumulation and C/N ratio in the shoots of ruzigrass [*Urochloa ruziziensis* (R. Germ. & C.M. Evrard) Crins (Syn. *Brachiaria ruziziensis* Germ. & Evrard)] to 98 days (2016/2017 season) and 110 days (2017/2018 season) grown in sandy soil in the Cerrado of Mato Grosso do Sul, Brazil.

Season	Dry matter	N content	N accumulation	C/N ratio[(1)]
	(kg ha^{-1})	(g kg^{-1})	(kg ha^{-1})	
2016/2017	10,472±624	9.8±0.5	102.6±4.3	40.8±2.4
2017/2018	6,136±498	10.6±0.6	64.6±3.1	37.7±2.1

(1) Estimated value considering that 40% of the dry matter is carbon, as reported by Rosolem et al. (2012).

The higher dry matter production from ruzigrass plants in the 2016/2017 season may be due to the higher rainfall rate between September and December 2016, when compared to the same period in 2017 (Figure 1). The total accumulated rainfall between September and December 2016 and 2017 was 627 and 498 mm, respectively. The scarcity or less availability of soil water during the development of the crop is pointed out as the main factor that limits the growth and production of the crops in the last decades (MERTZ-HENNING et al., 2018; CABRAL et al., 2020). The essentiality of water for plants comes from its contribution to the maintenance and preservation of vital functions. Water constitutes more than 90% of the plant fresh matter, acting in practically all physiological and biochemical processes, in addition to playing an important role in the thermal regulation of the plant, acting both in cooling and in the maintenance and distribution of heat (TAIZ et al., 2017).

The N accumulation in the shoot straw of the ruzigrass plants varied from 64.6 to 102.6 kg ha^{-1} (Table 2). Silveira and Stone (2010) reported that the maximum N accumulation in the *Urochloa* spp. can reach up to 150 kg ha^{-1} of N at 120 days after sowing. The C/N ratio of ruzigrass straw ranged from 37.7 to 40.8. The C/N ratio has been the main characteristic inherent to plant material with direct effects on its rate of decomposition and, consequently, the release of N to the production system (NICOLARDOT et al., 2001). Rosolem et al. (2012) evaluating the ruzigrass-cotton succession in greenhouse conditions, found that the average dry matter decomposition of the ruzigrass shoots with a C/N ratio of 38:1, at 45 days after management, varied by 19% at 30%, respectively, without N fertilization and with application of 150 mg dm^{-3} of N.

Cotton nutrition and yield

The presence of ruzigrass residues (production systems 1 and 2) resulted in the lowest relative chlorophyll index and the lowest N content in the cotton crop leaves in the 2016/2017 growing season, when compared to the conventional system without the previous ruzigrass cropping (Table 3). These results suggest that part of the applied N was immobilized in the microbial biomass of the soil, during the decomposition of ruzigrass straw. In order to use carbon from plant residues in biosynthesis and as an energy source, microorganisms immobilize the inorganic N of the soil, thus decreasing its availability to plants.

Such an effect can be observed in the N content of cotton leaves grown in systems 2 and 3 with the presence of ruzigrass residues, which was 25% and 29% lower than the N content of plants grown in the conventional system (1). These results were caused by the high C/N ratio of ruzigrass residues. The C/N ratio has been the most used characteristic in models to predict the N availability in the soil during the decomposition of plant residues (NICOLARDOT et al., 2001). However, this effect can be mitigated by stabilizing agricultural production systems, as seen in the second year of the experiment (2017/2018 season). This is because the N availability in the soil depends on the net balance between the mineralization and immobilization processes.

TABLE 3 - Effect of production systems on the relative chlorophyll index (RCI), leaf nitrogen content (N), plant height (PH), number of bolls per plant (NBP), boll weight (MW), seed cotton yield (YIELD) and nitrogen use efficiency (NUE) applied to the soil by cotton crop (cv. TMG 44 B_2RF) grown in a sandy soil in the Cerrado of Mato Grosso do Sul, Brazil, during the 2016/2017 and 2017/2018 growing season.

Production system	RCI	N (g kg^{-1})	PH (cm)	NBP	BW (g)	YIELD (kg ha^{-1})	NUE (kg kg^{-1})
			2016/2017 growing season				
System 1	49.80 a*	42.80 a	1.31 a	15.10 a	6.05 a	2,340 a	9.90 b
System 2	45.50 b	32.10 b	1.28 a	12.80 b	6.41 a	2,684 a	12.00 a
System 3	43.80 b	30.30 b	1.22 b	12.70 b	5.37 b	2,208 a	11.30 a
CV (%)	8.84	10.87	13.53	9.24	7.61	8.42	9.74
			2017/2018 growing season				
System 1	55.80 a	48.80 a	1.02 a	13.80 a	6.72 a	1,848 b	16.70 a
System 2	56.20 a	45.60 a	0.99 a	11.60 b	6.01 a	2,120 a	18.20 a
System 3	49.20 a	41.20 b	0.97 a	11.50 b	5.96 a	1,744 b	14.40 a
CV (%)	11.48	12.18	11.25	8.49	8.21	10.54	11.31

*Means followed by different letters differ in the column by the t test (LSD), at 5% probability of error. System 1: cotton cropping in fallow area without ruzigrass residues [simulating a conventional cotton production system (control)]; System 2: cotton cropping in the presence of straw from the shoots and roots of ruzigrass plants [simulating an crop-livestock integration system where the forage crop (ruzigrass) was used as a cover crop] and, System 3: cotton cropping only in the presence of residues from the ruzigrass roots [simulating a system of crop-livestock integration where the forage crop (ruzigrass) was used for grazing, silage or hay making].

Assessing N dynamics in the soil after using different cover crops, Aita et al. (2004) reported lower availability of inorganic N after black oats, a species Poaceae, which was attributed to the lower rate at which the poaceae N is mineralized, due to the high C/N ratio of its crop residues. The N availability in the soil is controlled by microbial processes of mineralization and immobilization, which basically depend on the C/N ratio and the biochemical composition of the decomposing crop residues (MARY et al., 1996). Amado et al. (1998) found that the addition of oat straw with a C/N ratio of 46:1 caused a 60% reduction in the N content in the soil when compared to the fallow system.

The effect of the management of ruzigrass residues and their C/N ratio on the dynamics of N should be further investigated, especially in field conditions, in order to establish the real potential for immobilization of N from the soil by the microbial population decomposer of crop residues from the genus Poaceae. Rosolem et al. (2003) studying the dynamics of N and pH of the soil due to liming on the surface and application of N fertilizer, in the presence of millet plant remains also obtained an increase in the amount of immobilized N with the increase of applied N rates. Malhi et al. (2001) reported that the N applied in topdressing is subject to immobilization process. This is true in the presence of large amounts of waste with a high C/N ratio, which increases the incorporation of N into microbial biomass. Such conditions occurred in this study, since the brachiaria residues had a C/N ratio of about 38:1 and 41:1 (Table 2).

The results obtained for plant height, number of bolls per plant, boll weight and seed cotton yield in the different production systems during the 2016/2017 and 2017/2018 growing season are shown in Table 3. In the 2016/2017 season, the lowest plant height was obtained in the presence of only residues from the ruzigrass roots (system 3), which may be due to the immobilization of N by soil microorganisms, decreasing the availability of the nutrient for cotton plants. However, there was no difference in plant height in the 2017/2018 growing season. The addition of crop residues with a high C/N ratio (> 30:1) on the surface or incorporated into the soil, has been one of the main causes of the lower growth of crops in succession (SOUZA et al., 2006). Therefore, it is usually necessary to add a greater amount of N fertilizer to the agricultural production system (THOMPSON; WHITNEY, 1998). According to Vaughan and Evanylo (1998), the necessary supplementary amount of N varies with the amount of plant residues incorporated into the soil, with the chemical composition of the residue and with the period between the management of the cover crop and the sowing of the subsequent crop.

Ernani et al. (2002) reported higher N absorption and dry matter production of maize crop when sowing was carried out 30 and 60 days after the addition of oat residues and application of N. The period of nitrogen immobilization after crop management is normally a few months (TRINSSOUTROT et al., 2000), but it is more intense in the first days.

The presence of ruzigrass residues (systems 1 and 2) resulted in a lower number of bolls per plant in both harvests when compared to the conventional system without the previous ruzigrass cropping. In the 2016/2017 season, the boll weight of plants grown only under residues of ruzigrass roots was lower when compared to the other production systems. This indicates that there was immobilization of N by the residues of the ruzigrass roots. However, the boll weight was not significantly influenced by the production systems in the 2017/2018 growing season, indicating that there was a stabilization of the N immobilization and mineralization processes in the soil. Seed cotton yield was not significantly affected by the different production systems in the 2016/2017 season. In the 2017/2018 growing season, the largest seed cotton yield was obtained in the system in succession to residues from the roots and shoots of the ruzigrass plants. These results show the importance of stabilizing agricultural production systems with the use of *Urochloa* spp. as a cover crop that is able to improve the availability of nutrients in the soil and improve crop yield, as reported by Amado et al. (1998) and Urquiaga et al. (1998).

The relative chlorophyll index and the N content in the cotton leaves increased linearly with the application of N fertilizer rates (Figure 2). Similar results were observed in other studies, which showed that there is a linear relationship between the amount of N absorbed by cotton and the rates applied to the soil (ZHAO et al., 2005; ZHAO et al., 2010). The linear increase in the relative chlorophyll index with the application of N rates was because N is a constituent of the chlorophyll molecule (TAIZ et al., 2017). Maia et al. (2012) also found an increase in the values of the relative chlorophyll index with an increase of the N fertilizer rates. Research conducted by Zhao et al. (2005) reported that the increase in the availability of N in the root environment increased the reading value of chlorophyll in cotton plants indicating that the greater availability of N increases the absorption and assimilation of this nutrient by the plant.

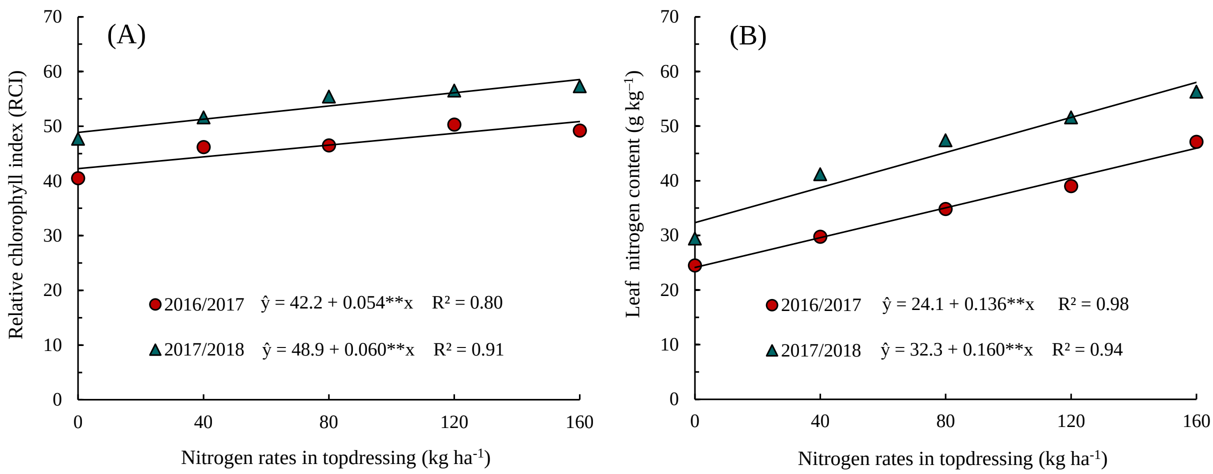

FIGURE 2 - Effect of application rates of nitrogen fertilizer in topdressing on the relative chlorophyll index (A) and nitrogen content (B) of cotton crop (cv. TMG 44 B_2RF) grown in a sandy soil in the Cerrado region of Mato Grosso do Sul, Brazil during the 2016/2017 and 2017/2018 growing seasons. *significant at 1% probability of error.

The highest N contents in the cotton leaves were obtained with the application of the highest N fertilizer rates. The higher N content obtained in the higher N fertilization rates may be due to the improvement in the photosynthetic process of cotton plants. This inference is because N is a component of the structure of chlorophyll, enzymes, and proteins. Chlorophylls act in the conversion of light radiation into chemical energy, in the form of ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide reduced phosphate) (TAIZ et al., 2017), therefore, chlorophylls are related to the photosynthetic efficiency of plants. Therefore, the highest N contents in the leaf tissues promoted a greater amount of chlorophyll, resulting in an increase in the photosynthetic rate in the plants, providing gains in the production of photoassimilates and, consequently, a higher fiber yield.

The application of N fertilizer rates significantly affected the plant height, number of bolls per plant and boll weight in both seasons (Figure 3). The highest plant height in the 2016/2017 season was obtained with the application of 150 kg N ha^{-1}, whereas in the 2017/2018 season the plant height increased linearly with the application of N fertilizer rates (Figure 3A). The highest number of bolls per plant was obtained with the application of 112 and 98 kg N ha^{-1} in topdressing, respectively, for the 2016/2017 and 2017/20018 growing season (Figure 3B). The largest boll weight in the 2016/2017 and 2017/2018 seasons was obtained with the application of 95 and 85 kg N ha^{-1}, respectively (Figure 3C).

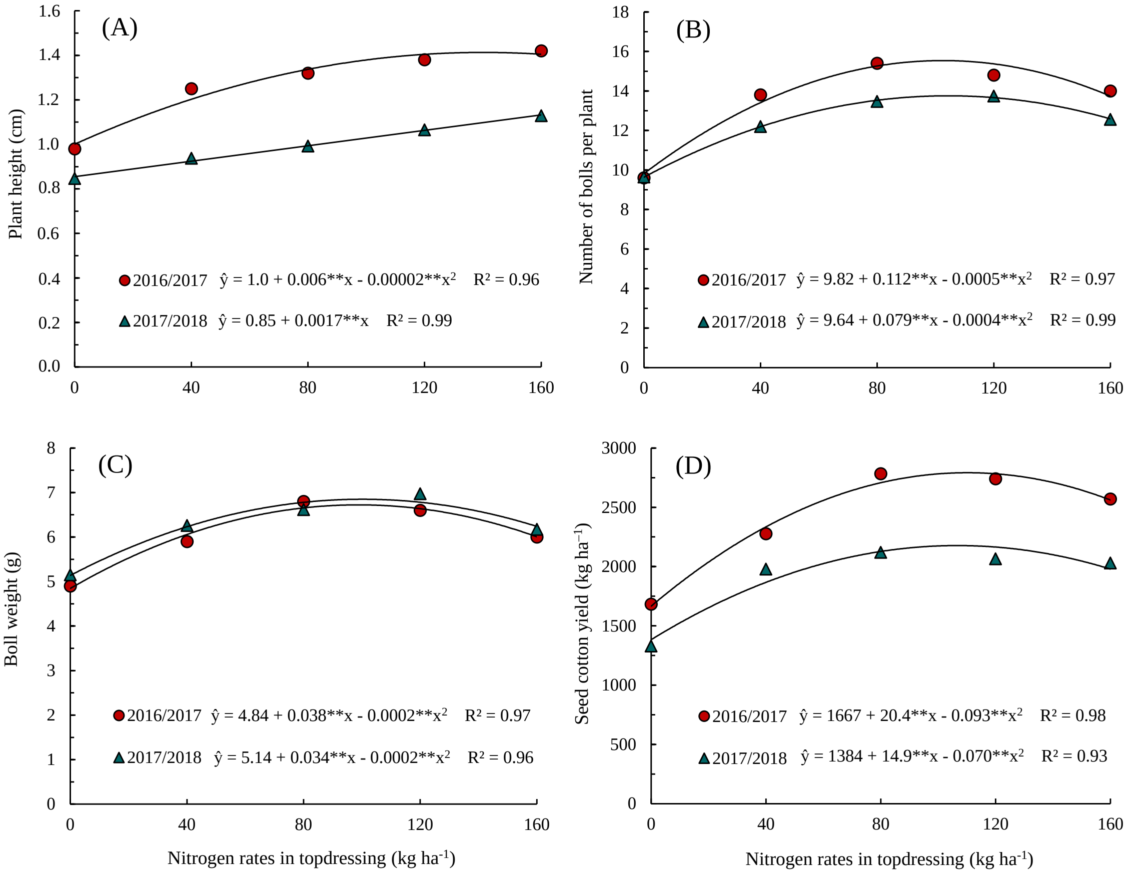

FIGURE 3 - Effect of application rates of nitrogen fertilizer in topdressing on the plant height (A), number of bolls per plant (B), boll weight (C) and seed cotton yield (D) of cotton crop (cv. TMG 44 B_2RF) grown in a sandy soil in the Cerrado region of Mato Grosso do Sul, Brazil during the 2016/2017 and 2017/2018 growing seasons. *significant at 1% probability of error.

The seed cotton yield was significantly affected by nitrogen fertilization in topdressing in the two growing seasons (Figure 3D). In the 2016/2017 season, the largest cotton yield was obtained with the application of 110 kg N ha^{-1}, whereas in the 2017/2018 season the largest cotton yield was obtained with the application of 106 kg N ha^{-1} in topdressing.

Nitrogen is required in large quantities by the cotton crop, during its cycle, it absorbs from 60 to 80 kg of N to produce one ton of seed cotton (FERREIRA; CARVALHO, 2005). Research has reported that the yield response of the main cotton cultivars in Brazil to N fertilization is increasing up to the rate of 120 kg N ha^{-1} (GRESPAN; ZANCANARO, 1999; BORÉM; FREIRE, 2014). In general, the maximum economic efficiency rate for the cotton crop is between 100 to 120 kg N ha^{-1} (ROSOLEM, 2001).

The efficiency of N use applied to the soil ranged from 5.5 to 17.4 kg kg^{-1} in the 2016/2017 season and from 9.4 to 24.2 kg kg^{-1} in the 2017/2018 season (Figure 4). The greater efficiency of N use in the 2017/2018 growing season when compared to the 2016/2017 season may be related to a lower rate of rainfall in the 2017/2018 season (Figure 1). The total rainfall during the 2016/2017 and 2017/2018 growing seasons was 840 and 582 mm, respectively. The lower rainfall rate in the 2016/2017 season may have resulted in the lower loss of N from the soil caused by leaching, which is related to the amounts of water percolated in the soil profile. In turn, the increase in N fertilize rates in topdressing resulted in lower efficiency of N use by cotton plants in both growing season. Excessive application of fertilizer leads to excessively positive balances, and results in low efficiency of use and low economic performance (BALIGAR et al., 2001), in addition to intensifying losses by leaching (ERNANI et al., 2002).

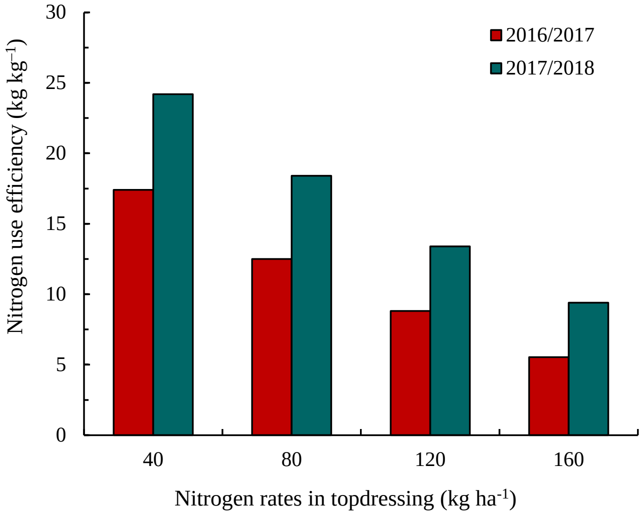

FIGURE 4 - Effect of nitrogen fertilizer rates applied in topdressing on the nitrogen use efficiency (NUE) by cotton crop (cv. TMG 44 B_2RF) grown in a sandy soil in the Cerrado region of Mato Grosso do Sul, Brazil during the 2016/2017 and 2017/2018 growing seasons.

The efficiency of N use by cotton plants was low, and the main causes for this low efficiency may be related to the rate and time of fertilizer application, as well as by the processes of leaching, denitrification, immobilization and erosion of soil N (FAGERIA; BALIGAR, 2005). Therefore, for the proper management of N fertilization, the synchronization between the application time and time of greatest requirement of the plants must be improved, in order to maximize the absorption and the crop yield (SANTOS; FAGERIA, 2008). Improving the efficiency of N use is desirable to increase crop yield, reduce production costs and maintain environmental quality (SANT'ANA et al., 2011).

In general, our results allow us to establish new strategies for the adequate management of the N fertilization rate applied in topdressing in the cotton crop. This is because the demand and the efficiency of N use by cotton plants can be altered, due to the production system adopted. In this study it was evidenced that the efficiency of N use by the cotton plants can be optimized when the crop is cultivated in succession to the *Urochloa* spp., and therefore, the necessity of application of N fertilizer can be reduced from the second year of cotton cropping on sandy soils in the Cerrado region. However, further medium- and long-term studies should be conducted to confirm this increase in the use of N by cotton plants in the crop-livestock integration system for other edaphoclimatic conditions in the Cerrado region.

CONCLUSIONS

The presence of ruzigrass straw provided less growth and development of cotton (cv. TMG 44 B_2RF), in addition to less N uptake by plants.

The presence of residues from the roots and shoots of the ruzigrass plants did not reduce the seed cotton yield in the first year of cultivation.

The cotton cropping in the crop-livestock integration system in the presence of residues from the roots and shoots of the ruzigrass plants resulted in the greater cotton yield in the second year, demonstrating the importance of the straw formation of the cover crops for the sandy soils of the Cerrado region.

The optimal application rate of N fertilizer in topdressing for the cotton cropping in succession or not with ruzigrass residues in sandy soils of Brazilian Cerrado region varies from 100 to 110 kg N ha^{-1}.

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