Agronomic performance of common bean in straw mulch systems and topdressing nitrogen rates in no-tillage[1]

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ABSTRACT

In no-tillage systems, straw coverage on soil surface is the key to success, and the choice of crops for rotation is crucial to achieve the sustainability and quality that conservation agriculture requires. The objective of this study was to evaluate the agronomic performance of the common bean cultivar IAC Formoso sown in succession to three straw mulch systems (corn alone, corn/*Urochloa ruziziensis* intercrop and *U. ruziziensis* alone) and topdress nitrogen rates (0; 40; 80; 120 and 160 kg ha^{-1} N), at the four-leaf stage, three years after the implementation of no-tillage. The experiment was arranged in a randomized block split plot design, with three replications. Common bean highest yields were achieved in succession to *U. ruziziensis* alone and intercropped with corn. The corn/*U. ruziziensis* intercrop provided both straw and seed production, allowing for quality no-tillage. Topdressed nitrogen influenced the common bean yield when in succession to corn alone, *U. ruziziensis* alone and corn/*U. ruziziensis* intercrop in no-tillage.

Key words: *Phaseolus vulgaris*, *Zea mays*, *Urochloa ruziziensis*, crop rotation, nitrogen fertilization.

RESUMO

Desempenho agronômico do feijoeiro em sistemas de produção de palha e doses de nitrogênio em cobertura no plantio direto

No sistema plantio direto, a cobertura do solo com palha é a chave do sucesso, sendo a escolha das culturas para a rotação um fator decisivo para atingir-se a sustentabilidade e a qualidade que requer a agricultura conservacionista. O objetivo deste trabalho foi avaliar o desempenho agronômico do feijoeiro, cultivar IAC Formoso, semeado em sucessão a três sistemas de produção de palha (milho exclusivo, milho consorciado com *Urochloa ruziziensis* e *U. ruziziensis* exclusiva) e da adubação nitrogenada (0; 40; 80; 120 e 160 kg ha^{-1} de N), em cobertura, no estádio fenológico caracterizado pela quarta folha totalmente expandida, no terceiro ano após a implantação do sistema plantio direto. O delineamento experimental foi o de blocos casualizados, em esquema de parcelas subdivididas, com três repetições. O feijoeiro apresentou as maiores produtividades em sucessão a *U. ruziziensis* exclusiva e em consórcio com milho, tendo como benefícios a obtenção de palha e a produção de grãos de milho, viabilizando-se o plantio direto de qualidade. A adubação nitrogenada em cobertura influenciou na produtividade do feijoeiro em sucessão a milho e a *U. ruziziensis* exclusivos e milho consorciado com *U. ruziziensis*, sob plantio direto.

Palavras-chave: *Phaseolus vulgaris*, *Zea mays*, *Urochloa ruziziensis*, sucessão de culturas, adubação nitrogenada.

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INTRODUCTION

The success of no-tillage systems (NTS) relies on the production and management of straw coverage on the soil surface, especially in warmer regions such as the Midwest, North and Northeast of the State of São Paulo and other regions of southeastern Brazil, where high temperatures combined with moisture provided by large amounts of rainfall in spring-summer accelerate residue decomposition (Torres *et al*., 2008; Fiorentin *et al*., 2011).

Under these conditions, for the efficient implementation and management of NTS, crop rotation using species with high potential for straw production and high C/N ratio is essential to ensure soil coverage for a longer period. Corn (*Zea mays*) and the brachiarias *Urochloa brizantha* and *Urochloa ruziziensis*, especially the latter, stand out for the easy drying and less tiller cluster formation, which promote a more uniform soil coverage and facilitate the next crop sowing (Fiorentin *et al*., 2011; Costa *et al*., 2012b; Rodrigues *et al*., 2012; Sabundjian *et al*., 2013).

In the first four to five years of NTS, there is need to apply higher nitrogen (N) rates than the recommended to crops in the conventional soil preparation, since the lower decomposition rate and the high straw C/N ratio influence the N immobilization process and may affect crop yields. After this period of time, when the changes that occur with N in the soil achieve balance, it becomes more available and the crop has a lower response to nitrogen fertilization (Stone & Moreira, 2001; Soratto *et al*., 2004; Cantarella, 2007; Farinelli & Lemos, 2010).

Common bean has a high demand for N, which provides increase in leaf area, more efficient sunlight interception, higher photosynthetic rate and higher grain yield (Fageria & Baligar, 2005; Binotti *et al*., 2009; Silva *et al*., 2009). Despite the ability to fix atmospheric N_2 in symbiosis with bacteria of the genus *Rhizobium*, N amounts supplied by this process are, in general, insufficient to produce high yields (Souza *et al*., 2011), and it is recommended the supply via fertilization. Nitrogen fertilizers have high energy cost for their production and difficult management due to losses by leaching, volatilization and denitrification in the soil-plant system, as well as its low use efficiency (Soratto *et al*., 2006b; Fornasieri Filho *et al*., 2007; Sant'Ana *et al*., 2011).

The increasing use of no-tillage systems has provided data on the positive feedback of the nitrogen fertilization on bean productivity (Costa *et al*., 2012a). Silveira *et al*. (2005) found that 120 kg ha^{-1} topdressing N in winter common bean, in succession to brachiaria, corn + brachiaria, Mombasa, sorghum and stylosanthes, was not sufficient to achieve maximum yield. In two winter harvests, IAC Carioca grown after corn and N rates (up to 140 kg ha^{-1}), Soratto *et al*. (2006a) reported that in the first season the highest rate was sufficient for maximum yield; however, for the second crop this same rate was not enough. NTS on corn + brachiaria straw, in Oxisol with 22 g dm^{-3} organic matter, Sant'Ana *et al*. (2010) evaluated five N rates (0; 30; 60; 120 and 240 kg ha^{-1} as urea) and found that 140 kg ha^{-1} N provided the highest grain yield (3,756 kg ha^{-1}) for cultivar BRS Horizonte.

The objective of this study was to evaluate the effect of straw mulch systems using corn and *U. ruziziensis* on the agronomic performance of common bean fertilized with topdressing nitrogen, three years after the implementation of the no-tillage system.

MATERIAL AND METHODS

The experiment was conducted in the municipality of Jaboticabal (SP), at 21º14'33"S latitude and 48º17'10''W longitude, 565 m altitude, Aw climate (tropical humid with summer rainy season and dry winter). Weather data recorded throughout the crop cycle are shown in Figure 1.

The soil of the experimental area is a clayey Oxisol, with 533 g kg^{-1} clay, 193 g kg^{-1} silt and 274 g kg^{-1} sand, gently rolling relief, which in the agricultural years 2008/2009 and 2009/2010 was under corn and *U. ruziziensis* in the summer, in succession to the common bean.

Before the experiment, in the agricultural year 2010/2011, soil samples were collected for fertility analysis in the 0-20 cm layer, obtaining the following results: pH ($CaCl_2$) = 5.1 ; O. M. (g dm^{-3}) = 22; P resin (mg dm^{-3}) = 68; H + Al; K; Ca; Mg; SB; CTC (mmol$_c$ dm^{-3}) = 31; 5.4; 22; 9; 36.4; 67.4 respectively, and V = 54%.

The species for soil coverage, including corn alone, corn / *U. ruziziensis* intercrop and *U. ruziziensis* alone, were sown on 12/18/2010. The simple hybrid DKB YG 390 was used for the cultivation of corn alone in the estimated population density of 60,000 plants ha^{-1} and spaced 0.9 m between lines. The starter fertilization consisted of 300 kg ha^{-1} of the formulation 08-28-16 (N-P_2O_5-K_2O); 80 kg ha^{-1} of N and 80 kg ha^{-1} of K_2O were applied in topdressing, using the 20-00-20 formulation at the V4 growth stage (fourth fully expanded leaf) and 80 kg ha^{-1} N as urea at V6 (50% of the plants with six fully expanded leaves), and then the application of 15 mm of water immediately after topdressing by conventional type sprinkler irrigation system.

The corn intercropped with *U. ruziziensis* was conducted in the same manner as in single crop, sowing

U. ruziziensis at seeding density of 400 agricultural value (AV) points (7.5 kg of viable seeds ha^{-1}) at the time of corn planting, with two rows between the corn rows. *U. ruziziensis* alone was mechanically sown in rows spaced 0.22 m apart, with 400 agricultural value (AV) points ha^{-1}, without the application of mineral fertilizers. The mechanical harvest of corn alone and intercropped was carried out on 05/06/11 and the area was kept resting until the time of desiccation operations with nonselective herbicide glyphosate (1,800 g ha^{-1} acid equivalent) 30 days before common bean sowing.

The experiment was arranged in randomized block split plot design, with 15 treatments consisting of the combination of three straw mulch systems (corn alone, corn / *U. ruziziensis* intercrop and *U. ruziziensis* alone) in the plots and five nitrogen rates (0; 40; 80; 120 and 160 kg ha^{-1} N) applied to the common bean, at the V_{4-4} stage (50% of plants with four fully expanded trifoliate leaves) in the subplots. Urea was used as N source sidedressed at 10 cm from the seeding line and then the application of 15 mm of water. Each subplot consisted of ten common bean rows spaced 0.45 m and 5 m long. The harvest area of each subplot consisted of eight central rows, discarding 0.5 m at each end.

Cultivar IAC Formoso (carioca commercial group and indeterminate growth habit) was used in the experiment. Seeding was performed directly on the straw of corn and *U. ruziziensis* on 08/19/11, 12 seeds per meter, equaling 266,000 plants per hectare to obtain an average final population of 256,000 plants per hectare. The seeds were treated with insecticide (Fipronil) and fungicide (carbendazim + tiran) at the doses 50 g i.a. 100 kg^{-1} $seeds^{-1}$ and 150 g i.a. 100 kg^{-1} $seeds^{-1}$, respectively.

Starter fertilization at seeding consisted of 300 kg ha^{-1} of the formulation 05-15-15 (N-P_2O_5-K_2O). Sprinkler irrigation was applied at the interval of four to five days, depending on the crop needs at the phenological stage, according to Santana *et al*. (2008).

At 20 days after emergence (DAE), post-emergence herbicides fluazifop-p-butyl and bentazon + mineral oil were applied at the doses of 150 g ha^{-1} (ia), 480 g ha^{-1} (ia) and 1 L ha^{-1}, respectively.

Harvest was carried out by pulling-off the plants manually, following mechanized threshing (11/18/2011) with a plot combine harvester, when plants were bare stems and 90% dry pods.

Amounts of straw and soil coverage rate (%) were determined ten days before sowing and five days after harvest using a 0.5 × 0.5 m wooden frame. Samples were washed and dried in a forced-air oven at 65 °C to constant weight. N concentration in straw was determined according to Malavolta *et al*. (1997).

The number of fully developed trifoliate leaves was recorded by collecting five plants at the R6 growth stage (full bloom) in a row of each subplot. Leaf N content at R6 was determined in the third trifoliate leaves with middle third petiole of 30 plants per plot, according to Ambrosano *et al*. (1997). The leaves were washed three times in deionized water and dried in a forced air oven at 65 °C to constant weight. Dried leaves were ground and used to determine N content (Malavolta *et al*., 1997). Shoot dry matter was determined at R6 by collecting randomly ten plants in the subplot. Plants were washed, placed in a forced-air oven at 65 °C for 72 hours and weighed. Before the harvest, ten consecutive plants were collected in a row for the determination of yield components (number of pods per plant, number of seeds per pod and of a hundred seed weight). The grain yield was obtained after harvest of the four central rows in each subplot, determining the seed moisture content standardized at 13% wet basis.

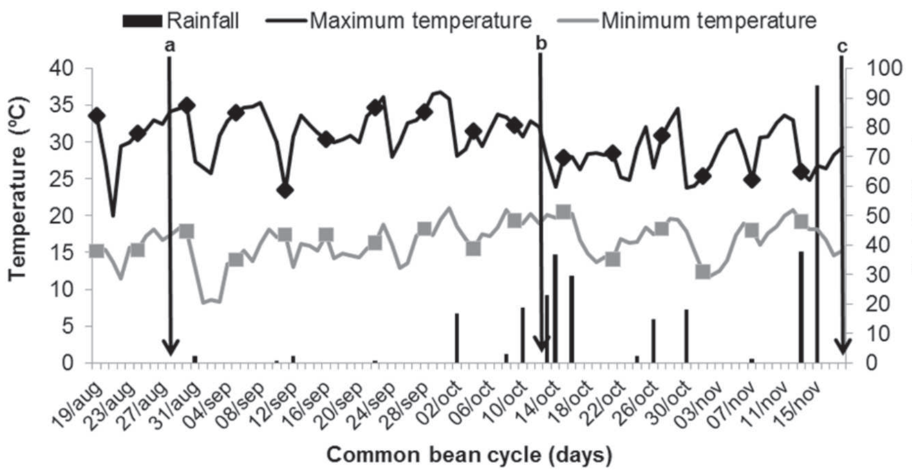

Figure 1: Rainfall (mm), maximum and minimum temperature (° C), average every four days, from August to November 2011, for the common bean cycle: a = emergency - 08/29/11; b = full bloom - 10/13/11; c = harvest - 11/18/11.

Data were examined by analysis of variance using the F test and means were compared by the Tukey test at 5%. Significant effects for N rates and interaction straw mulch systems × N rate were evaluated by polynomial regression fit.

RESULTS AND DISCUSSION

The straw mulch systems with corn/*U. ruziziensis* intercrop and *U. ruziziensis* alone produced greater amounts of straw and mulch on the soil before the common bean sowing in comparison with the corn straw alone (Table 1). In Botucatu (SP), Souza *et al*. (2011) reported high straw yields (13.7 and 16.4 t ha^{-1}) for corn/*U. ruziziensis* intercrop in two years of experimentation. After the common bean harvest, straw residues on the soil surface showed equivalent amounts (Table 1), probably because the corn straw alone has a higher C/N ratio with slower decomposition (Rodrigues *et al*., 2012). The decomposition and release of N from residues of cover crops (millet, *U. brizantha*, sorghum, pigeon pea, *Crotalaria juncea*, black oat and fallow) in Uberaba (MG) during two years, Torres *et al*. (2008) found that brachiaria was the cover crop with the highest decomposition rate, with the highest N release rate occurring 42 days after desiccation.

N content in the straw on the soil before the common bean sowing was influenced by the straw type. The straw of *U. ruzizensis* alone had the highest N content (Table 1). The N content in the straw after the common bean harvest was higher than that measured before sowing in all straw mulch systems because, in the beginning, the amount of straw was higher, causing the effect of nutrient dilution in plant tissues (Table 1). The results show that during the crop cycle, N and other nutrients were released by the corn straw alone, corn/*U. ruziziensis* intercrop and *U. ruziziensis* alone, which may explain, in part, the common bean performance in the three systems even without nitrogen fertilization, i.e., achieving yields around 3,000 kg ha^{-1} (Figure 2).

The leaf nitrogen content in common bean showed increasing linear behavior (Figure 3A), similar to that reported by Binotti *et al*. (2009) and Fiorentin *et al*. (2011) for common bean in NTS. Even without nitrogen fertilizer, the leaf nitrogen contents were within the range considered adequate for common bean (30-50 g kg^{-1}) (Ambrosano *et al*., 1997), or the amount made available by plant residues was enough to promote adequate plant nutrition, similarly to that observed by Fornasieri Filho *et al*. (2007) and Souza *et al*. (2011).

The number of trifoliate leaves increased linearly with the N rates (Figure 3B), in agreement with the reports of Mingotte (2011), who also worked with N rates and straw mulch system in NTS. This increase is because N promotes the rapid expansion of leaves, increasing the efficiency of sunlight interception and the photosynthetic rate, with gains in grain yield (Fageria & Baligar, 2005; Binotti *et al*., 2009; Silva *et al*., 2009).

Table 1: Amount of straw, mulch on the soil and straw nitrogen (N) content corn alone, corn/*U. ruziziensis* intercrop and *U. ruziziensis* alone before and after growing common bean cultivar IAC Formoso in Jaboticabal - SP, 2011$^{(1)}$

Treatments	Amount of straw (t ha^{-1})		Mulch(%)		N content instraw (g kg^{-1})	
	Before^{2}	After^{3}	Before	After	Before	After
Straw mulch system (S)						
Corn	07.8b	6.8	055b	30	08.2b	09.8
Corn + *U. ruziziensis*	13.3a	7.1	100a	39	008.9ab	12.7
U. ruziziensis	14.8a	5.5	100a	41	10.1a	11.3
CV(%)	23.60	19.56	6.35	32.06	15.18	38.36
N rate (kg ha^{-1})						
0	-	5.6	-	34	-	09.5
40	-	6.3	-	41	-	09.7
80	-	6.6	-	37	-	11.7
120	-	5.8	-	36	-	10.6
160	-	8.1	-	36	-	14.6
F Test						
S	25.10**	6.85^{ns}	339.83**	3.50^{ns}	14.80*	1.68^{ns}
N	-	1.65^{ns}	-	0.92^{ns}	-	1.43^{ns}
S × N	-	0.71^{ns}	-	0.92^{ns}	-	0.52^{ns}

(1) Means followed by the same letter in the columns are not significantly different by the Tukey test at 5% probability. *, ** Significant at 5 and 1% respectively and ns - non significant by the F test. $^{(2)}$ Data collected ten days before common bean sowing. $^{(3)}$ Data collected five days after common bean harvest.

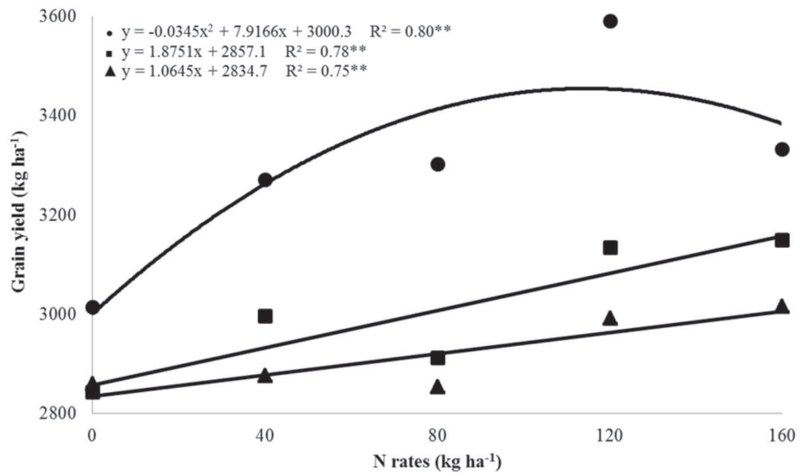

Figure 2: Unfolding of the interaction between straw mulch systems (S) and nitrogen (N) rates for common bean yield, cultivar IAC Formoso, as a function of N rates in succession to corn alone (²%), corn intercropped with *U. ruziziensis* (%) and *U. ruziziensis* alone (Ï%) in Jaboticabal - SP 2011.

The increase in N rates promotes an increase in the amount of plant dry matter, which coupled with the amount of straw on the soil provided less variation of soil temperature, favoring the development of plants (Figure 3C). Souza *et al*. (2011) reported average dry matter production of 12.2 g plant^{-1} for common bean in succession to corn/*U. ruziziensis* intercrop in 2008/2009, in an area of dystrophic red Latosol with 34.2 g dm^{-3} organic matter and under five years of NTS, using four N rates (0, 35, 70 and 140 kg ha^{-1} N), with grain yield of 1,063 kg ha^{-1}. Similar results were obtained by Sabundjian *et al*. (2013) using the cultivar Pérola and topdressing nitrogen rates of 0, 30, 60 and 90 kg ha^{-1}, in a Haplortox with 15.0 g dm^{-3} organic matter.

Among yield components, only the 100 seed weight was influenced by straw mulch system, especially the common bean in succession to *U. ruziziensis* alone (Table 2), differing from reports of Fiorentin *et al*. (2011), who found significant differences in the number of pods per plant and number of seeds per pod. The results for yield components were higher than those found by Fiorentin *et al*. (2011), including grain yield. These authors, however, obtained the results in an area under few years of NTS implementation. Stone & Moreira (2001) observed that the common bean yield increases with the time of NTS usage.

Yield had a quadratic response for the system *U. ruziziensis* alone, peaking at the rate of 115 kg ha^{-1} N, while the other systems had increasing linear responses (Figure 2). Fiorentin *et al*. (2011) evaluated straw mulch systems and N rates in NTS and found that common bean in succession to corn alone had lower grain yield than in succession to *U. ruziziensis*. This decrease in yield may be due to the smaller amount of straw on the soil and the low availability of soil organic matter, as the NTS was

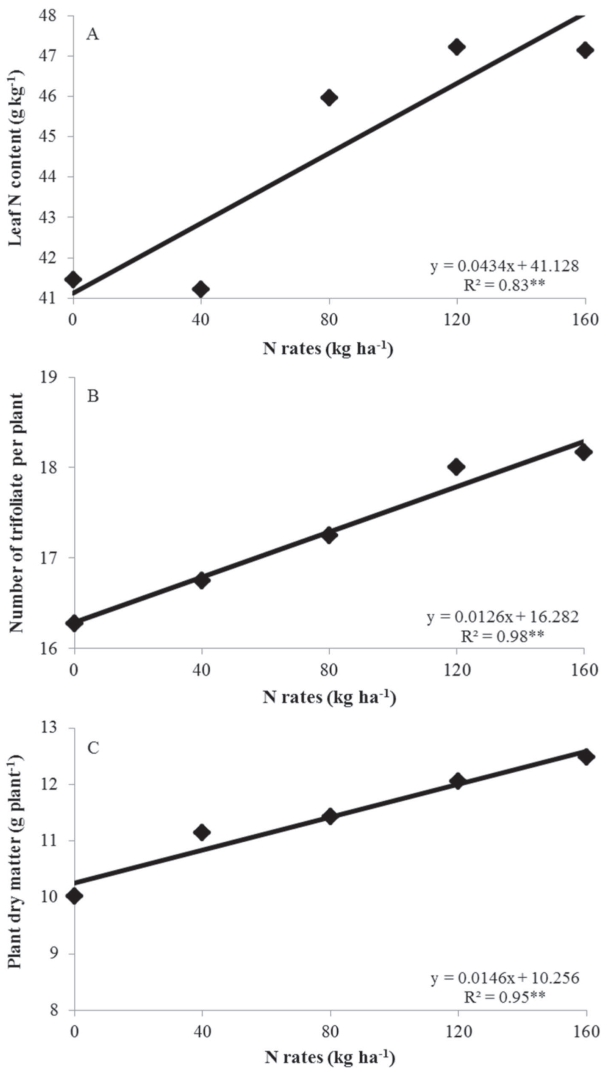

Figure 3. Leaf nitrogen (N) content (A), number of trifoliate leaves (B) and plant dry matter (C) of common bean cultivar IAC Formoso, under different N rates in succession to corn alone, corn intercropped with *U. ruziziensis* and *U. ruziziensis* alone in Jaboticabal-SP 2011.

Table 2: Number of pods per plant, number of seeds per pod and 100-seed weight of common bean, cultivar IAC Formoso, under different nitrogen (N) rates in succession to corn alone, corn intercropped with *U. ruziziensis* and *U. ruziziensis* alone in Jaboticabal-SP, 2011[(1)]

Treatments	Pods/plant (nº)	seeds/pod (nº)	100-seed weight (g)
Straw mulch system (S)			
Corn	11.7	4.9	26.3b
Corn + *U. ruziziensis*	11.8	4.9	26.8ab
U. ruziziensis	12.1	4.8	28.1ab
CV(%)	24.45	10.41	3.82
N rate (kg ha^{-1})			
0	11.7	5.1	26.8
40	11.1	4.6	26.2
80	12.3	5.0	27.6
120	12.7	5.0	27.4
160	11.6	4.8	27.3
CV (%)	16.39	10.95	5.77
F test			
S	0.05^{ns}	0.38^{ns}	12.99*
N	0.92^{ns}	1.37^{ns}	1.19^{ns}
S × N	0.92^{ns}	0.56^{ns}	0.74^{ns}

[(1)] Means followed by the same letter in the column are not significantly different by the Tukey test at 5% probability. * Significant at 5% and ns - non significant by the F test.

still under implementation. Soratto *et al*. (2004) reported increases in common bean yield under NTS in succession to corn, with topdressing nitrogen, in an Oxisol with 24.0 g dm^{-3} of organic matter, with maximum yield (2,308 kg ha^{-1}) at the estimated rate of 182 kg ha^{-1} of N.

Another aspect to be considered in grain yield is the potential release of N by straw mineralization (Farinelli & Lemos, 2010; Costa *et al*., 2012a). In this sense, *U. ruziziensis* may have released a greater N amount and other nutrients in its composition to the soil relative to corn straw because of its smaller C/N ratio, allowing greater nutrient cycling. Perennial forage grasses have high root density, periodic renewal of the root system and even distribution of exudates into the soil (Cunha *et al*., 2011), improving soil biology and promoting biological fixation of atmospheric N_2 through rhizobia strains present in the soil (Silva *et al*., 2009). The use of these species in crop rotation, particularly Brachiaria, help to improve the soil structure, add organic matter, eliminate pathogens and supply N to the production system up to 45 kg ha^{-1} , because of the presence of free-living nitrogen-fixing microorganisms in the rhizosphere such as bacteria of the genus *Azozpirillum* (Fancelli, 2009).

High temperatures during the reproductive phase can also influence the common bean yield. Daytime temperatures above 30 °C and night temperatures above 20 °C can cause abortion of flowers and young pods (Didonet & Victoria, 2006). Although the common bean had the reproductive development in a period with daytime temperatures above 30 °C, these temperature peaks occurred in a relatively short time and night temperatures did not exceeded 20 °C during the cycle, which did not affect the grain yield (Figure 1).

CONCLUSION

The common bean crop had the highest yields in succession to *U. ruziziensis* alone and corn intercropped with *U. ruziziensis,* in addition to the production of straw and corn grain, as well as providing a quality no-tillage system.

The common bean in succession to corn alone and corn intercropped with *U. ruziziensis* did not reach maximum yield at the rate of 160 kg ha^{-1} N, but reached it in succession to *U. ruziziensis* alone at the rate of 115 kg ha^{-1} of N.

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