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Agronomic and qualitative traits of common bean as a function of the straw and nitrogen fertilization[1]

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ABSTRACT

The no-tillage system can change the nitrogen dynamics in the soil, being necessary to adjust the nitrogen fertilization in order to provide this nutrient during critical phases of the common bean growth. This study aimed at evaluating the agronomic and qualitative traits of common bean grown under different straw types, as a function of the topdressing nitrogen fertilization splitting. A randomized block experimental design, in a split-plot arrangement, with four replications, was used. The plots consisted of three straw types (maize, maize intercropped with brachiaria and brachiaria), while the subplots comprised the combination of these straw materials with 8 topdressing nitrogen fertilization splitting arrangements. The common bean on brachiaria straw shows higher grain yields and crude protein contents. The nitrogen fertilization splitting, as topdressing, interacts with the straw types, increasing the number of pods per plant. The common bean plants growing on plots with single-maize straw had a shorter time for maximum hydration. The topdressing nitrogen fertilization splitting has no effect on the common bean qualitative traits.

KEY-WORDS: *Phaseolus vulgaris*; *Urochloa ruziziensis*; *Zea mays*; no-tillage system.

RESUMO

Características agronômicas e qualitativas de feijoeiro em razão da palhada e adubação nitrogenada

O sistema plantio direto pode alterar a dinâmica do nitrogênio no solo, sendo necessária a adequação da adubação no feijoeiro, para disponibilizar esse elemento nos períodos críticos de necessidade da cultura. Objetivou-se avaliar as características agronômicas e qualitativas de feijoeiro cultivado sobre diferentes tipos de palhadas, em função do parcelamento da adubação nitrogenada em cobertura. Utilizou-se delineamento de blocos casualizados, em esquema de parcelas subdivididas, com quatro repetições. As parcelas foram constituídas por 3 tipos de palhada (milho, milho consorciado com braquiária e braquiária), enquanto as subparcelas foram compostas pela combinação de palhadas com 8 arranjos de parcelamento de nitrogênio em cobertura. O feijoeiro sobre palhada de braquiária apresenta maior produtividade de grãos e maior teor de proteína bruta. O parcelamento da adubação nitrogenada em cobertura apresenta interação com o tipo de palhada, aumentando o número de vagens por planta. No feijoeiro sobre palhada de milho solteiro, o tempo para a máxima hidratação dos grãos é menor. O parcelamento da adubação nitrogenada em cobertura não influencia os atributos qualitativos do feijoeiro.

PALAVRAS-CHAVES: *Phaseolus vulgaris*; *Urochloa ruziziensis*; *Zea mays*; sistema plantio direto.

INTRODUCTION

The main principles of a no-tillage system are the lack of tillage, crop rotation and straw production. The latter is the most limiting factor for food production in tropical soils, since high temperature and humidity may affect its maintenance, accelerating its decomposition (Borghi & Crusciol 2007, Fiorentin et al. 2011).

The monocropping and intercropping of maize (*Zea mays*) and brachiaria (*Urochloa ruziziensis*) provide high straw yields and a suitable soil cover (Borghi & Crusciol 2007, Lara-Cabezas & Pádua 2007, Batista et al. 2011, Pariz et al. 2011, Fiorentin et al. 2012, Sabundjian et al. 2013). However, the nitrogen (N) dynamics in the soil can be altered by increased immobilization rates, with a direct influence on the use of this nutrient by crops. In the case of short-cycle common bean, which has a reduced and shallow root system, N is extracted in large amounts (Silveira et al. 2011, Perez et al. 2013, Partelli et al. 2014). Therefore, if N fertilization is

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poorly managed, N immobilization under a no-tillage system may have a negative effect on crop yield (Vargas et al. 2005).

In a no-tillage system, however, the N fertilization used for conventional systems should not be regarded as the most adequate, since the processes of decomposition and mineralization of plant residues vary with the type of straw used. With this in mind, studies on N fertilization for common bean, as a function of the cropping system, are required, aiming at reducing soil N immobilization losses and providing N supply at critical periods of absorption by crops, improving the agronomic traits and, consequently, yield (Soratto et al. 2006 and 2013, Farinelli & Lemos 2010, Mingotte et al. 2014).

Few studies on the influence of straw and N fertilization on the quality traits of common bean under no-tillage, such as protein content, cooking time and hydration ability, are found (Farinelli & Lemos 2010, Fiorentin et al. 2011, Carmeis Filho et al. 2014). Furthermore, quality characters in common bean are affected by genetic and environmental factors (Chiorato et al. 2012, Perina et al. 2014). Nitrogen has a paramount importance for plant growth, influencing, directly and indirectly, crop yield and quality (Cantarella 2007).

Thus, the main objective of this study was to evaluate the agronomic and quality attributes of common bean, as a function of N fertilization splitting and straw types.

MATERIAL AND METHODS

The experiment was performed during the 2012/2013 growing season, in Jaboticabal, São Paulo state, Brazil. The local climate is Aw, which, according to the Köppen's classification, stands for a tropical humid weather, with rainy summers and dry winters.

The no-tillage system had been established during the 2008/2009 summer season, using maize and brachiaria as a pure stand and intercropped, preceding the winter-spring planting of common bean. These crop successions were maintained until the experiment installation, in the 2012/2013 crop season. The local soil is a clayey eutrophic Red Latosol - Oxisol (clay content of 533 g kg^{-1}). Prior to sowing, soil samples were collected at the 0-20 cm layer, for chemical analysis (Raij & Quaggio 1983) (Table 1).

A split-plot randomized block experimental design, with four replicates, was used. The plots consisted of straw types: maize (S1), maize and brachiaria intercropped (S2) and brachiaria (S3). The subplots comprised the combination of S1, S2 and S3 with 8 different N splitting methods, applied as topdressing, which consisted of splitting a dose of 90 kg ha^{-1} of N, as urea (45 % of N), into three stages: at the first trifoliolate stage (V_3), third trifoliolate stage (V_4) and pre-flowering (R_5), as it follows: 30 + 60 + 00, 60 + 30 + 00, 30 + 00 + 60, 60 + 00 + 30, 00 + 60 + 30, 45 + 45 + 00, 00 + 45 + 45 and 45 + 00 + 45. Additionally, a single dose of urea was applied at V_4 (00 + 90 + 00), in addition to a control (no fertilization). The urea was applied to the soil near the sowing line, in a continuous fillet, in order to optimize the N use by roots, which are poorly developed in common bean.

The AG 7088 VTPRO 2 maize hybrid was sown for straw production. The plants were sown on December 7 (2012), at a population density of 60,000 plants ha^{-1}, with plants spaced at 0.90 m. Sowing fertilization consisted of 330 kg ha^{-1} of the 08-28-16 NPK formulation. Topdressing fertilizations were performed when plants were at V_4 (400 kg ha^{-1} of 20-00-20 NPK) and at V_8 (80 kg ha^{-1} of N via urea).

Brachiaria was sown intercropped with maize at a row spacing of 0.22 m, using 400 points of cultural value per hectare, i.e., 10 kg of seeds ha^{-1}. Single brachiaria plots received no fertilization. After maize harvest (May 25, 2013), brachiaria was desiccated with potassium glyphosate (1,860 g a.e. ha^{-1}) and carfentrazone-ethyl (40 mL a.i. ha^{-1}) (July 13, 2013).

Before sowing the common bean, the amount of straw on the soil surface was determined using samples collected with the aid of a 0.25-m^2 square quadrat (Laflen et al. 1981). Moreover, the N content in straw samples was determined by the Kjeldahl method (AOAC 1995).

Table 1. Soil chemical analysis prior to the winter-spring season of common bean.

Soil layer	pH	OM	P resin	K	Ca	Mg	H + Al	CEC	BS
cm	($CaCl_2$)	g dm^{-3}	mg dm^{-3}	———	———	$mmol_c$ dm^{-3}	———	———	%
0-20	5.6	26	83	3.7	45	26	26	102	71

The common bean was sown on August 2 (2013), using an early cycle cultivar (IAC 'Imperador') with a growing habit type I, belonging to the commercial group "Carioca" (Chiorato et al. 2012). The sowing was carried out by distributing 12 seeds per furrow meter. The rows were spaced at 0.45 m, aiming at a final plant stand of 260,000 plants per hectare, as recommended by Chiorato et al. (2012).

The sowing fertilization for the common bean consisted of 210 kg ha^{-1} of the commercial formulation 08-28-16 (NPK). Seedlings emerged on the ninth day after sowing. The crop was irrigated via conventional sprinkling, applying 10-50 mm water depth, depending on the phenological stage and weather conditions at the moment (Pavani et al. 2008). Irrigation was performed until the end of the crop cycle, within 70 days (Figure 1).

The common bean quality traits were ascertained using grain samples from each subplot. Firstly, these samples were homogenized and classified through a set of 12/64 x ¾" oblong sieves (4.76 mm x 19.05 mm). Afterwards, these samples were packed in paper bags and stored in a dry chamber at 25 ºC and 40 % of relative humidity, where they remained for 60 days after harvesting.

The cooking time was estimated with samples hydrated in water for 16 h, using a Mattson cooker (Farinelli & Lemos 2010). The bean maximum hydration time and ratio were ascertained for a soaking period of 20 h (Farinelli & Lemos 2010). Grain samples were milled and subjected to sulfuric digestion for total-N content, as previously described. The crude protein content was obtained by multiplying the total N by the factor 6.25 (AOAC 1995).

Data underwent an analysis of variance by the F-test ($p < 0.05$). When significant, means were compared by the Tukey test ($p < 0.05$). Significant interactions between straw types and N splitting methods were subjected to a statistical breakdown.

RESULTS AND DISCUSSION

Results on straw quantity, soil cover rate and total N content pointed to the single brachiaria as a superior straw type, if compared to the others (Table 2).

In addition, if compared to the single maize straw, the maize-brachiaria intercropping increased

Table 2. Soil cover rate, straw quantity and N content in the straw dry matter for single maize, maize intercropped with brachiaria and single brachiaria, before sowing the common bean.

Treatment	Soil cover rate	Dry matter	N content
	%	t ha^{-1}	g kg^{-1}
Maize	89 c*	11.0 c	7.16 b
Maize + brachiaria	92 b	12.5 b	7.23 b
Brachiaria	97 a	14.9 a	9.01 a
CV (%)	3.63	7.11	7.91
F-test	50.31**	187.77**	96.36**

*, ** Means followed by equal letters do not differ from each other by the Tukey test ($p < 0.05$) and by the F-test ($p < 0.01$), respectively. Sampling was carried out at 10 days before sowing the common bean.

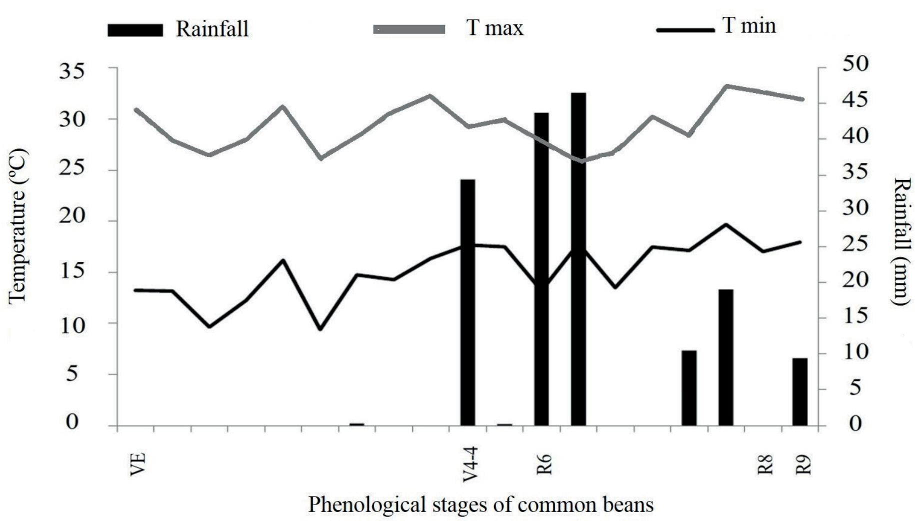

Figure 1. Rainfall (mm) and maximum and minimum air temperature (ºC) every 5 days, during the common bean growth, from August to November 2013, in Jaboticabal, São Paulo state, Brazil. VE = emergence; V4-4 = fourth trifoliolate; R6 = full flowering; R_8 = grain filling; R_9 = physiological maturity/harvest.

the amount of straw and the rates of soil cover, standing out as an interesting alternative for a no-tillage system.

Another interesting aspect is the brachiaria C/N ratio between 21 and 35 (Rosolem et al. 2010), within which degradation by microorganisms responsible for N mineralization is favored (Cantarella 2007, Pariz et al. 2011), releasing this nutrient to the following crop. In contrast, maize straw exhibits a high C/N ratio - around 50 (Borghi & Crusciol 2007, Silva et al. 2009), which may hinder this process.

Nitrogen leaf contents and total accumulation were superior in plants succeeding the single brachiaria, but with no influence by the splitting of topdressing N (Table 3). These leaf levels are considered suitable for common bean (Ambrosano et al. 1997), being of 30-50 g kg^{-1} of N. Conversely, our results were slightly higher than the range of 41.1-43.7 g kg^{-1} reported by Partelli et al. (2014). The N accumulation was of 83.2 kg ha^{-1} in the shoot of beans succeeding *U. ruziziensis*, being similar to that for the 'Pérola' cultivar verified by Perez et al. (2013) (84.2 kg ha^{-1} of N), after applying 60 kg ha^{-1} of N at pre-sowing and 60 kg ha^{-1} of N as topdressing at V_4, reaching a grain yield of 2,684 kg ha^{-1}.

Regarding the number of trifoliate leaves and shoot dry mass, no differences were found among the factors studied (Table 3). The results for shoot dry mass and trifoliate leaves were lower than those obtained by Sabundjian et al. (2013) and Mingotte et al. (2014), respectively. This difference might have occurred due to cultivar differences, since those authors used the 'IPR 139' and 'Pérola' cultivars, which have an indeterminate growth habit, unlikely 'IAC Imperador'. This cultivar is featured as a sparsely branched plant of low size, in which leaf and branch emission and elongation cease at flowering.

Productive traits, such as number of grains per pod and 100-grain mass, showed no significant difference (Table 4), neither for straw types nor for N topdressing splitting, corroborating the results obtained by Soratto et al. (2006, 2013).

Table 3. Leaf N content, trifoliate number, shoot dry mass and total N accumulation in the 'IAC Imperador' common bean, as a function of N fertilization in succession to single maize, maize intercropped with brachiaria and single brachiaria, before sowing the common bean.

Treatment		Leaf N content	Trifoliate number	Shoot dry matter	Total N accumulation
		g kg^{-1}		g $plant^{-1}$	kg ha^{-1}
Maize		44.7 b*	16.9	9.8	71.3 b
Maize + brachiaria		44.8 b	16.7	10.2	78.9 ab
Brachiaria		47.5 a	17.1	10.9	83.2 a
CV (%)		1.36	17.38	18.76	71.3
F-test	Crop System (C)	25.73*	0.15^{ns}	3.04^{ns}	7.06*
	Splitting (S)	0.93^{ns}	0.60^{ns}	0.92^{ns}	1.91^{ns}
	C x S	0.47^{ns}	0.60^{ns}	0.99^{ns}	1.64^{ns}

* Means followed by equal letters do not differ from each other by the Tukey test ($p < 0.05$); ^{ns} non-significant by the F-test. The amount of N was applied as topdressing at V_3 (first trifoliate unfolding), V_4 (third trifoliolate unfolding) and R_5 (pre-flowering), respectively.

Table 4. Number of pods per plant and grains per pod, 100-grain mass and grain yield for the 'IAC Imperador' common bean, as a function of N fertilization in succession to single maize, maize intercropped with brachiaria and single brachiaria, before sowing the common bean.

Treatment		Pods per plant	Grains per pod	100-grain mass	Grain yield
		nº		g	kg ha^{-1}
Maize		9.7 ab*	5.0	25.1	2.344 ab
Maize + brachiaria		9.2 b	5.0	25.4	2.289 b
Brachiaria		11.3 a	5.1	26.0	2.697 a
CV (%)		12.38	9.86	8.85	24.26
F-test	Crop System (C)	29.53**	0.45^{ns}	1.54^{ns}	5.56*
	Splitting (S)	6.29**	1.70^{ns}	1.09^{ns}	0.97^{ns}
	C x S	2.95**	0.56^{ns}	1.37^{ns}	1.11^{ns}

* Means followed by equal letters do not differ from each other by the Tukey test ($p < 0.05$); ^{ns} non-significant by the F-test. The amount of N was applied as topdressing at V_3 (first trifoliate unfolding), V_4 (third trifoliolate unfolding) and R_5 (pre-flowering), respectively.

Distinctively, straw types and N splitting as topdressing, besides having an influence on the number of pods per plant, showed a significant interaction with each other for this trait (Table 4). A major production was achieved when beans were grown on single brachiaria straw, if compared to the others (Table 5). It is worth highlighting that the splitting of 30 + 60 + 00 reached values above 13 pods per plant, differing from those found by Sabundjian et al. (2013). Notably, it should be said that the number of pods per plant is the most contributing productive attribute for grain yield in common bean (Barili et al. 2011).

Studying forage biomass such as brachiaria and grains in a no-tillage system, Torres et al. (2008) and Vargas et al. (2005) observed improvements in the soil moisture and temperature by the large amounts of residue added to the soil, as well as changes in the N mineralization and immobilization in the soil. In the present study, such an addition (Table 2) reflected positively on the N utilization by the common bean, increasing grain yield. As a result, beans were properly nourished with N and could branch vigorously, producing many flowers and, consequently, a larger number of pods, thus increasing grain yield. It should also be pointed out that, when grown on single brachiaria, common bean grain yields exceeded by 18 % those of plants growing on single maize, also being 15 % higher than those on maize-brachiaria straw (Table 4). Moreover, the treatment with no N application showed no significant difference with the others. This result indicates that the amount of N applied at sowing, added to that from soil organic matter mineralization, was enough to supply the crop requirements on this nutrient.

The crude protein contents of the common bean, in succession to brachiaria, were around 15 % higher than those of the other straw types (Table 6). The highest leaf N content (Table 3) was obtained from beans grown in succession to brachiaria. Possibly, it resulted in a greater accumulation of N in grains and, consequently, larger protein contents. These results were similar to those verified by Farinelli & Lemos (2010) and Fiorentin et al. (2011).

Regarding the cooking time, no differences were found neither for straw types nor for N splits (Table 6). On the other hand, the mean time of 29 min was lower than that reported by Chiorato et al. (2012) (35 min) and that by Perina et al. (2014) (34 min),

Table 5. Statistical breakdown of the interaction between crop system x nitrogen splitting for number of pods per plant, for the 'IAC Imperador' common bean, as a function of N fertilization splitting, as topdressing, in succession to single maize, maize intercropped with brachiaria and single brachiaria, before sowing the common bean.

N splitting(2)	Pods per plant (nº)		
	Maize	Maize + brachiaria	Brachiaria
00 + 00 + 00	10.17 abA(1)	10.70 aA	10.75 bcA
00 + 90 + 00	8.87 bA	8.95 abA	10.17 cA
30 + 60 + 00	11.60 aB	9.25 abC	13.32 aA
60 + 30 + 00	9.30 bB	8.20 bB	11.32 abcA
30 + 00 + 60	8.57 bB	9.95 abB	11.80 abcA
60 + 00 + 30	9.60 abA	9.70 abA	10.67 bcA
00 + 60 + 30	10.67 abB	8.27 bC	12.90 abA
45 + 45 + 00	9.15 bA	8.55 abA	10.10 cA
00 + 45 + 45	9.50 abAB	8.32 bB	10.47 cA
45 + 00 + 45	10.17 abA	10.65 aA	11.57 abcA

(1) Means followed by equal letters do not differ from each other by the Tukey test ($p < 0.05$); (2) the amount of N was applied as topdressing at V_3 (first trifoliate unfolding), V_4 (third trifoliolate unfolding) and R_5 (pre-flowering), respectively.

Table 6. Crude protein content, cooking time, maximum hydration time and hydration ratio of the 'IAC Imperador' common bean, as a function of nitrogen fertilization splitting, as topdressing, in succession to single maize, maize intercropped with brachiaria and single brachiaria, before sowing the common bean.

Treatment		Crude protein	Cooking time	Maximum hydration	Hydration ratio
		$g\ kg^{-1}$	min	h:min	
Crop system					
Maize		215 b*	29	14:19 a	2.05
Maize + brachiaria		212 b	29	15:27 b	2.05
Brachiaria		247 a	29	15:25 b	2.04
CV (%)		9.77	22.39	4.40	1.63
F-test	Crop System (C)	31.36**	0.12^{ns}	38.22**	0.91^{ns}
	Splitting (S)	0.26^{ns}	1.77^{ns}	1.69^{ns}	1.03^{ns}
	C x S	0.48^{ns}	1.07^{ns}	0.87^{ns}	0.96^{ns}

* Means followed by equal letters do not differ from each other by the Tukey test ($p < 0.05$). The amount of N was applied as topdressing at V_3 (first trifoliate unfolding), V_4 (third trifoliolate unfolding) and R_5 (pre-flowering), respectively.

for the same cultivar. This way, we may infer that the evaluated grains had a medium susceptibility to cooking, as stated in the scale designed by Proctor & Watts (1987), and acceptable according to Ramalho & Abreu (2006).

The common bean growing on single maize straw required one hour less than those growing on the other crop systems to reach a maximum hydration, being of 14:19 h (Table 6). This result was higher than reported by Fiorentin et al. (2011) (8:55 h), for the 'Pérola' cultivar in succession to single maize. This outcome evidenced the need for more studies on this trait, testing different production conditions. Also concerning hydration, we noticed that beans absorbed water mass nearly their initial mass, without differences among the factors studied (Table 6), reaching values above two, which are similar to the findings by Farinelli & Lemos (2010) and Carmeis Filho et al. (2014).

CONCLUSIONS

1. Common bean growing on single brachiaria straw show higher grain yield and crude protein content;
2. The splitting of nitrogen as topdressing has no effect on the agronomic traits of common bean. However, there are differences among fertilization splits, as a function of the straw type used, only for number of pods per plant;
3. The splitting of nitrogen as topdressing has no influence on the quality traits of common beans.

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