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Nitrogen levels and rotation with cover crops in wheat under no-tillage

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Abstract

The spread of the conservationist agriculture system involving green fertilization, crop rotation, and no-tillage has altered the dynamics of production, which can benefit the development and productivity of the successor crop, as well as the N fertilizer economy. In this context, the objective of this experiment was to study the effect of single maize cropping and maize intercropping with four cover crops in conjunction with the application of N doses under cover on wheat. The experiment was carried out in 2015 and 2017, in an experimental area using a 5 × 4 factorial randomized block experimental design with four replicates. Treatments consisted of the combination of five cover crops (maize, maize + *Crotalaria spectabilis*, maize + *Cajanus cajan*, maize + *Canavalia ensiformis*, and maize + *Urochloa ruziziensis*) with four N doses (0, 40, 80, and 120 kg ha^{-1}) in no-tillage wheat production. The main production components and yield of wheat were evaluated. It was concluded that the plant residues of maize + *Canavalia ensiformis* and maize + *Urochloa ruziziensis* enhanced the yield of wheat cultivated in the winter of 2015 and 2017, when compared with the other treatments. The effect of N doses on wheat grain yield was positive (with significant increase in grain yield) and the maximum average was obtained with the application of 74 and 86 kg ha^{-1} of N in 2015 and 2017, respectively.

Keywords: green adubation; crop rotation; conservationist system; *Triticum aestivum* L; urea.
Abbreviations: DAE_days after emergence; Kc_coefficient of culture; Kp_coefficient Class A tank; w.b._wet basis; O.M._organic matter.

Introduction

Wheat, together with rice and maize, is one of the most widely produced cereals in the world. It is one of the major crops used in human and animal feed, occupies approximately 17 % of the area currently cultivated in the world, and accounts for about 30 % of the world's grain production (De Mori, 2015, Usda, 2017). Brazil is an important producer and consumer of the cereal, achieving a production of 4.9 million tons in the 2018 harvest (Conab, 2018), owing to the existence of cultivars adapted to the Cerrado conditions under irrigation, which allows cultivation in this region during the winter period (Megda et al., 2009).

For triticulture to be established as an economically profitable activity, it is necessary to use management systems that maximize productivity and guarantee sustainability. Among the management practices available for the wheat crop, the no-tillage system (which involves such practices as green manuring and crop rotation) stands out for improving the chemical, physical, and biological attributes of the soil at a low cost (Nunes et al., 2011).

N fertilization is also used intensively in triticulture, as N is one of the nutrients most required by the crop, being linked to the formation of proteins and, consequently, to the industrial quality of the flour produced (Becker et al., 2008). In the no-tillage system, however, the adequate supply depends on the amount and quality of residues of the previous crop remaining in the soil, which can release or immobilize N for the subsequent crop. Soil cover facilitates water storage, decreases weed incidence, improves soil texture and structure and increases soil organic matter content. The decomposition of plant material causes the mineralization of organic compounds and release of nutrients (such as N, P, K and S) to later cultivated plants (Marsola, 2008). Grass species, such as soil cover, provide nutrients for successor crops in the medium and long term, with increases in phosphorus and potassium levels in the topsoil (Zotarelli, 2005). On the other hand, legumes play a fundamental role as nutrient suppliers when SPD is already stabilized, because their decomposition is faster (Torres et al., 2005) and, due to their low C / N ratio, there is greater N mineralization and availability for the following crops (Crews and Peoples, 2005). Thus, mulching has the potential to benefit an agricultural system by improving soil characteristics in general and providing nutrients as a result of decomposition of plant material on the soil. This may

benefit the development of plants and also reduce the need for fertilizers to meet the nutritional demand of the crop, as part would be supplied by the nutrients released by the decomposition process of this plant material.
The objective of this work was to evaluate the effect of mulching on maize or in combination with grasses and legumes and N rates of mulching on the development and yield of rotated wheat in no-tillage system, seeking also to verify if the mulching would allow the reduction of mineral nitrogen fertilization in the crop in view of the N supply with the decomposition of plant material on the soil.

Results and discussion

N application and uptake

The increase in N rates resulted in increases in leaf N content (Table 1), and the values fit a linear regression equation in the first year and a quadratic one in the second year, with a maximum at the dose 120.07 kg ha^{-1} of N under cover, resulting in about 44.03 g kg^{-1} of leaf N, which is above the adequate range described by Cantarella et al. (1997).
For all types of vegetation cover, leaf N content was above the appropriate range and, in general, values greater than 35 g kg^{-1} were obtained, but there was no significant difference among the vegetation covers in terms of this characteristic.
In terms of the leaf N values across N doses, it was observed that in the two years of cultivation, plants were well nourished in terms of this nutrient, even in the treatments without N fertilizer as topdressing. This high N availability for the crop, in the present study, results from low nutrient loss by volatilization, given the type of soil (clayey), the correct use of irrigation (Sangoi et al., 2007; Kissel et al., 2004), and the application of N in the area at the time of sowing. In addition to this, further N was provided by the decomposition of vegetal residues of the previous crops, as it is an area under a consolidated no-tillage system.
A difference in the dry mass of plants owing to the plant cover was observed in 2015, with the lowest dry mass value obtained in the treatment of the previous maize crop intercropped with *Urochloa ruziziensis*. For the other vegetation covers, the combination with legumes generally resulted in higher values of dry matter, similar to that found in the area of single maize cropping (70.6 g m^{-1} per line). Therefore, it can be said that legumes, in association with maize, play an important role as suppliers of nutrients to the soil, owing to the rapid decomposition of their residues.
For the N application rates, applied as topdressing, the results of the dry mass of plants were adjusted to a linear increasing function, with the increase in the amount of dry mass of wheat produced as a function of the increase in the N doses applied under cover, for the two years of cultivation.
The cultivation of green manures previously established in the area did not significantly influence the height of the wheat plants (Table 1). However, the behavior was positive for the N application rates, applied as topdressing, with an adjustment to an increasing linear function in 2015 and a quadratic function with a maximum at the dose 80.16 kg ha^{-1} of N, in the year of 2017, resulting in an average plant height of approximately 77.56 cm.
Melero et al. (2013), in their study on plant cover and N doses in wheat, found that the dry mass of wheat was influenced by the vegetation cover used. The study does not verify the interaction between the vegetation cover and the N doses used nor the effect of the vegetation cover on plant height, corroborating part of the results observed in the present study.
Number of grains per spike and mass of one thousand grains
Regarding the number of grains per spike and mass of one thousand grains, both were not significantly influenced by the parameters analyzed in any of the years of cultivation (Table 2). According to Trindade et al. (2006), in wheat, the number of spikelets per spike depend mainly on the genotype, but also on the environment and crop management, which justifies the absence of variation in the number of grains per spike in this work.
Nunes et al. (2011) showed an increase in the number of grains per ear of wheat because of the use of green manures before the crop, where the maximum value obtained was 32.7 grains per spike in the treatment with *Crotalaria spectabilis* as the green manure, owing to better nutrition of wheat plants. In contrast, Melero et al. (2013) did not obtain a significant response for the number of grains per ear of wheat as a function of the vegetal covers used, finding averages close to 40 grains per spike.
It is worth noting that in the first case the values found were lower, and in the second case the mean values were close to those of the present study. Thus, it can be assumed that under conditions of lower nutrition of wheat plants, plant cover is able to benefit the number of grains per spike, but in situations where plants are already well nourished, there are no benefits to the use of vegetative covers.
Teixeira Filho et al. (2010) working with wheat cultivar E21 in the no-tillage system irrigated by sprinkler did not observe an influence of N rates under cover on the amount of grain per spike in the two years of their study. The mass of one hundred grains was only affected by the doses of N in one of the years. In this study, the doses of N used were higher than those of the present study, reaching 200 kg ha^{-1} of N.
As for the mass of a thousand grains, the responses described in the literature are very variable, and there is no influence of N fertilization on this production component (Zagonel et al., 2002). Frank and Bauer (1996) elucidated that N deficiency between the emergent phase of the seedlings and the differentiation of the floral primordium reduces the mass of a thousand grains, which did not occur in the present study because of the fertilization done at the time of sowing.

Hectoliter mass

Regarding the hectoliter mass, it was verified that there was interaction between the two factors analyzed only for the year 2015. In 2017, only the doses of N under cover resulted in a significant difference for this variable, such that the data fit a linearly decreasing equation (Table 2).
Analyzing the nature of the significant interaction between plant cover and N doses for the hectoliter mass component in the year 2015 (Table 3), it was observed that there was a linear decreasing response for the N rates after single maize and maize + *Cajanus cajan* intercropping and a quadratic response for the combinations maize + *Crotalaria spectabilis*

Table 1. N-content, dry mass of plants, and height of wheat plants grown after single maize cropping or maize intercropping with grasses and legumes, and as a function of N doses under cover. Selvíria - MS, 2015 and 2017.

Treatments	Foliar N-content ($g\ kg^{-1}$)		Dry mass of plants ($g\ m^{-1}$)		Wheat plant height (cm)	
Year	2015	2017	2015	2017	2015	2017
Vegetal cover						
Maize	39.5	39.9	70.6 a	76.4	67.0	74.8
Maize + *Crotalaria spectabilis*	39.8	39.9	62.9 ab	77.0	66.8	74.5
Maize + *Cajanus cajan*	39.9	39.7	66.0 a	75.9	66.8	72.3
Maize + *Canavalia Ensiformis*	40.1	40.4	60.4 ab	77.4	67.4	72.8
Maize + *Urochloa Ruziziensis*	40.3	40.1	53.2 b	79.0	66.9	74.5
N ($kg\ ha^{-1}$)						
0	37.6[1]	33.8[2]	48.4[3]	62.7[4]	57.5[5]	66.7[6]
40	39.1	39.8	64.2	76.9	67.3	76.6
80	41.3	42.4	65.7	79.2	70.6	76.0
120	41.7	43.9	72.3	89.8	72.5	75.8
F Test						
Vegetal cover (C)	0.38^{ns}	0.08^{ns}	4.41*	0.08^{ns}	0.08^{ns}	0.89^{ns}
N	18.92**	8.746**	13.63**	8.746**	86.04**	19.89**
C × N	0.73^{ns}	0.48^{ns}	0.58^{ns}	0.48^{ns}	0.97^{ns}	0.61^{ns}
DMS	-	-	12.43	-	-	-
CV (%)	2.01	21.87	16.97	21.87	4.8	6.41

**, *, and ^{ns} – significant at 1 % of probability, significant at 5 % of probability, and not significant by the F test, respectively. Means followed by the same letter in the columns do not differ by Tukey's test at the 5 % probability level; DMS – least significant difference; CV - coefficient of variation.

[1] $y = 37.7283 + 0.0364x$ ($R^2 = 0.95$)

[2] $y = -0.0007x^2 + 0.1681x + 33.937$ ($R^2 = 0.99$)

[3] $y = 51.6567 + 0.1831x$ ($R^2 = 0.87$)

[4] $y = 0.2089x + 64.606$ ($R^2 = 0.93$)

[5] $y = 59.70 + 0.121x$ ($R^2 = 0.88$)

[6] $y = -0.0016x^2 + 0.2565x + 67.277$ ($R^2 = 0.91$)

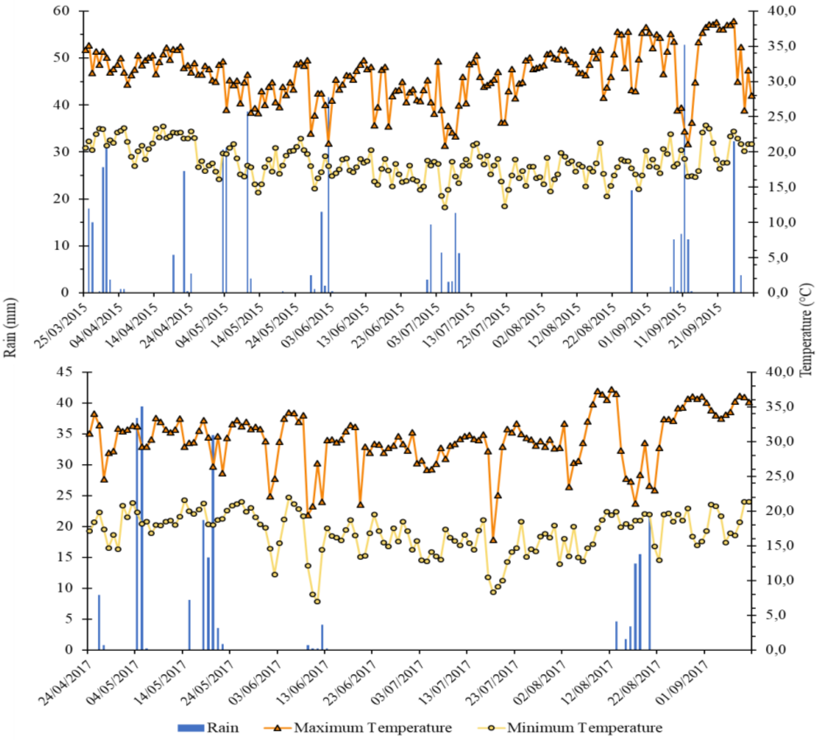

Fig 1. Average daily rainfall (mm) and the maximum and minimum temperatures (ºC) recorded during the experimental period. Selvíria (MS), 2015 and 2017.

Table 2. Number of grains per ear, mass of one thousand grains, hectoliter mass, and yield of wheat grown after single maize cropping or maize intercropping with grass and legumes, and as a function of N doses under cover. Selvíria - MS, 2015 and 2017.

Treatments	Number of grains per ear		Mass of 1000 grains (g)		Hectoliter mass (kg)		Grain yield (kg ha^{-1})	
Year	2015	2017	2015	2017	2015	2017	2015	2017
Cover crop								
Maize	26.9	37.4	36.2	35.9	79.3 bc	83.0	2,371 b	2,999 ab
Maize + *Crotalaria spectabilis*	26.5	38.5	35.4	36.4	80.0 ab	83.6	2,339 b	2,618 ab
Maize + *Cajanus cajan*	26.9	37.4	36.1	35.6	80.2 a	83.7	3,189 a	2,462 b
Maize + *Canavalia ensiformis*	26.4	35.4	34.5	35.7	78.6 cd	83.3	2,879 ab	3,080 ab
Maize + *Urochloa ruziziensis*	27.4	36.1	34.9	36.2	78.0 d	83.0	2,514 b	3,126 a
N (kg ha^{-1})								
0	26.6	35.0	37.0	36.0	81.3	84.3[1]	2,190[2]	1,925[3]
40	26.7	36.8	35.1	37.0	80.4	83.1	2,724	3,115
80	27.0	37.8	35.0	35.2	79.0	83.0	3,075	3,189
120	27.0	38.3	34.5	35.7	76.7	83.0	2,645	3,199
F test								
Vegetal cover (C)	0.21^{ns}	1.18^{ns}	0.78^{ns}	0.49^{ns}	18.9**	0.6^{ns}	5.3**	3.6**
N	0.10^{ns}	2.11^{ns}	2.26^{ns}	2.91^{ns}	22.3**	3.5*	6.5**	19.7**
C × N	0.85^{ns}	0.69^{ns}	1.21^{ns}	0.48^{ns}	7.2**	0.8^{ns}	1.5^{ns}	0.3^{ns}
DMS	-	-	-	-	0.824	-	-	624.54
CV (%)	3.3	12.2	9.5	5.6	1.0	1.9	20.7	21.9

**, * and ^{ns} – significant at 1 % of probability, at 5 % of probability, and not significant by the F test, respectively. Means followed by the same letter in the columns do not differ by Tukey's test at the 5 % probability level; DMS – least significant difference; CV - coefficient of variation. [1] $y = -0.0104x + 83.971$ ($R^2 = 0.67$). [2] $y = 2160.1817 + 22.3615x – 0.1506x^2$ ($R^2 = 0.95$). [3] $y = -0.1843x^2 + 31.861x + 1977.3$ ($R^2 = 0.95$)

Table 3. Significant interactions of the variance analysis referring to the wheat hectoliter mass. Selvíria, 2015.

Vegetal cover	N (kg ha^{-1})			
	0	40	80	120
Maize[1]	81.3 a	80.4 a	79.0 a	76.7 d
Maize + *Crotalaria spectabilis*[2]	81.3 a	79.2 a	79.5 a	79.9 ab
Maize + *Cajanus cajan*[3]	80.2 ab	80.5 a	79.1 a	80.9 a
Maize + *Canavalia ensiformis*	79.6 b	79.1 ab	79.0 a	76.8 cd
Maize + *Urochloa*[4]	79.7 ab	77.5 b	76.6 b	78.4 bc

Means followed by the same lower-case letters do not differ between columns by Tukey's test at 5 %. [1] $y = 81.6233 – 0.0379x$ ($R^2 = 0.96$). [2] $y = 81.2156 – 0.0579x + 0.0004x^2$ ($R^2 = 0.90$). [3] $y = 79.9335 – 0,0214x$ ($R^2 = 0.78$). [4] $y = 79.7704 – 0.0854x + 0.0006x^2$ ($R^2 = 0.98$) .

Table 4. Soil chemical characteristics of the study area. Selvíria, 2015.

Soil Depth	O.M.* (g dm^{-3})	P-resina (mg dm^{-3})	pH ($CaCl_2$)	K	Ca	Mg	Al	H+Al	SB	CTC	V (%)
				--------------------- (mmolc dm^{-3})---------------------							
0-10	23	22	5.7	3.7	35	26	0	21	64.7	85.7	75
10-20	18	18	5.1	2.3	21	17	1	28	40.3	68.3	59

*O.M._organic matter. Source: Soil Fertility Laboratory (UNESP Ilha Solteira).

Table 5. K values (crop coefficient × Class A tank coefficient) of different treatments involving water management.

	Stages of development					
	0 – 2	3	4 - 10	10.1 - 10.5.4	11.1	11.12
K value	0.36	0.6	0.84	0.96	0.84	0.62

and maize + *Urochloa ruziziensis*. There was no response to the N dose for the *Canavalia ensiformis* combination. For the unfolding of the interaction between mulch and N rates, it was observed that the combined treatment with maize + *Urochloa ruziziensis* presented the smallest hectoliter mass under the majority of N doses used for mulching. The average mass value of the hectoliter obtained was 79.2 kg for the two years of cultivation; which makes the produced grains belonging to type 1, indicating good grain quality (Silva et al., 2016), which results from favorable environmental and nutritional conditions for grain filling. In contrast, Nunes et al. (2011) determined the adjustment of the values of hectoliter mass with a quadratic equation for N doses under cover, with a maximum response point at the dose of 105 kg ha^{-1} of N, resulting in 78.5 kg hL^{-1} (below the values found in the present study). Teixeira Filho et al. (2010) noted a linear decrease in hectoliter mass due to the increase of N doses in one of the growing seasons of their study. This decrease in hectoliter mass may be related to the highest number of grains per spike or per area, as verified by Cazetta et al. (2008). In addition, the occurrence of rainfall on mature crops, as occurred in the present study, reduces the hectoliter mass and, consequently, affects grain quality (Furlani et al., 2002).

Crop productivity

Analyzing crop productivity, it was observed that in the two years of cultivation there was no interaction between the two factors, although both the vegetation cover and the N rates under cover affected this variable significantly (Table 2).

In 2015, the yield values found were adjusted to a quadratic regression equation for N rates, with an estimated maximum grain yield of 3,075 kg ha^{-1}, obtained with the dose of 74 kg ha^{-1} of N. In 2017, the values found were also adjusted for a quadratic regression equation, but this time with an estimated maximum yield of 3,354 kg ha^{-1} of grains, obtained by applying 86 kg ha^{-1} of N in coverage.

Regarding plant covers, the highest yields were obtained from the areas where maize was intercropped with *Cajanus cajan* or with *Canavalia ensiformis* in the 2015, indicating the effectiveness of using legumes to increase productive potential, even when disregarding other production factors.

Melero et al. (2013) also reported an effect of plant cover on wheat yield; the succession of *Crotalaria juncea*, *Cajanus cajan,* and *Pennisetum americanum* + *Crotalaria juncea* residues resulted in higher yields. Nunes et al. (2011) demonstrated the occurrence of interaction between green manures and N doses as topdressing for wheat yield, with higher yields occurring in areas that were previously cultivated with *Crotalaria juncea*. This makes it possible to say that wheat cultivation in succession to legumes reduces the demand for N as a topdressing (Braz et al., 2006).

This result may also have been verified in the present study if the wheat had been cultivated immediately after the cultivation of intercropped maize (in this case, after maize, beans were grown in the winter, rice in the following summer, and then wheat alone), as the Cerrado, like all tropical regions, is characterized by the rapid decomposition of organic remains in the soil, especially if it is a legume straw (lower C/N ratio).

Materials and methods

Study site

The study was conducted in Selvíria (MS), in an experimental area belonging to UNESP, Ilha Solteira/SP - Brazil, located between the geographic coordinates 20°20’53’’ S, 51°24’02’’ W at an altitude of 335 m, during the winter of 2015 and 2017. The soil is classified as RED LATOSOL, Alloic distrophic, clayey texture (Santos et al., 2018). Soil fertility characteristics were obtained according to the methodology proposed by Raij et al. (2001), with soil sampling at the depths of 0-0.10 m and 0.10-0.20 m and the values obtained are described in Table 4. The climate of the region, according to Koppen's classification, is of Aw type, with mean annual rainfall of 1322 mm, average annual temperature of 23 °C, and relative humidity of 66 % (Alvares, 2013). The daily values of mean temperature and relative air humidity, as well as the daily rainfall totals, during the experimental period, are presented in Figure 1.

Treatments

The treatments comprised the combination of five types of cultural residues (Exclusive maize - *Zea mays*, Maize + *Crotalaria spectabilis*, Maize + *Cajanus cajan*, Maize + *Canavalia ensiformis*, Maize + *Urochloa ruziziensis*) cultivated before the summer crop (rice) in the 2013/14 and 2015/16 crops, and four N doses (0, 40, 80, and 120 kg ha^{-1}) applied as a topdressing to the wheat crop, in the form of urea. The plots consisted of 20 rows, 7.5 m in length, spaced 0.17 m apart. The central rows were considered as the useful area for sampling, excluding two lateral rows and 0.50 m at both ends of each row.

After harvesting and managing vegetation cover, the area was cultivated with winter beans, and, later, with upland rice irrigated by sprinkler; the wheat crop was cultivated subsequently. The previous vegetation was desiccated two weeks before sowing wheat with glyphosate (1,560 g ha^{-1}). After treatment of the seeds with the insecticide fipronil (50 g for 100 kg of seeds) to control soil pests, the inoculation of the seeds with *Azospirillum brasilense* strains Ab-V_5 and Ab-V_6, was done shortly before sowing. The inoculation was performed in the shade using a liquid inoculant containing 2 × 10^8 viable cells per ml of the commercial product using the 100 ml dose of inoculant for 50 kg of seeds.

Experimental design

In the first year, sowing was performed mechanically, on 03/30/2015, using IPR Catuara TM, and emergence occurred on 04/05/2015. Based on the chemical characteristics of the soil and considering the recommendations of Camargo et al. (1996) for expected productivity of 3.5 to 5.0 Mg ha^{-1}, the basic mineral fertilization in the sowing groove comprised a mixture containing 20 kg ha^{-1} of N as urea and 200 kg ha^{-1} of formulation 00-20-20 (NPK). In the 2017, sowing was carried out on 05/09/2017 with CD 150 and emergence occurred on 05/15/2017. Basal fertilization of 250 kg ha^{-1} of formulation 08-28-16 (NPK) was used. In both years, sowing was performed at a density of 370 viable seeds m^{-2}.

Weed management in both years of cultivation was carried out in a post emergence period by the application of the herbicides clodinafope-propargil (48 g ha^{-1} of active ingredient) and metsulfuron-methyl (3.6 g ha^{-1} of active ingredient) to control narrow and broad-leaved weeds.

N fertilization was performed manually at 23 days after emergence (DAE) (04/28/2015) in the 2015 and at 25 DAE (06/08/2017) in 2017, as recommended by Camargo et al. (1996), followed by sprinkler irrigation to minimize N losses by volatilization. The other cultural and phytosanitary treatments were those normally recommended for the cultivation of wheat.

During the experiment, irrigation was performed using a fixed sprinkler irrigation system. In terms of water management, six K coefficients (K = Kc × Kp) distributed over six periods between seedling emergence and harvesting were used. The values of the K coefficients are presented in Table 5 and are those suggested by the Technical Information for Wheat and Triticale - Harvest 2017 (Silva et al., 2016).

Harvesting was done manually and individually per experimental unit and the harvested material was dried in full sun. In 2015 the harvest occurred on 10/07/2015, at 96 days after the emergence of the plants, and in 2017, harvest occurred on 04/09/2017, at 113 days after emergence.

Evaluations

- Dry matter of plants: At full bloom, the plants were collected at 0.50 m of the row, at two points in the useful area of the plots, and were taken for drying in a forced ventilation oven at a temperature of 60-70 °C, until equilibrium in mass was reached, extrapolated in g plant^{-1};
- Height of plants: At maturity, the distance (m) from the level of the soil to the apex of the spikes was determined, excluding the awns and taking into consideration the average of four points of the useful area of each plot;
- Foliar N content: At full bloom, the leaf limbs of 50 leaves were collected per plot and dried in a Willey mill and then submitted to sulfur digestion according to the methodology of Malavolta et al. (1997);
- Number of grains per spike: The number of grains in 20 ears collected in the useful area of each plot at the time of harvest were counted and averaged per spike;
- Mass of one thousand grains: Two samples of one hundred grains in each plot were weighed, with values extrapolated to one thousand grains and corrected to 13 % moisture (w.b.);
- Hectoliter weight: Using two samples per plot the hectoliter mass balance was determined, correcting for 13 % moisture (w.b.);
- Grain yield: Area of the plants in each plot were hand harvested and threshed mechanically. The grain mass and the transformed data were then determined in kg ha^{-1}, correcting for 13 % moisture (w.b.).

Statistical analysis

The results were submitted to analysis of variance (ANOVA) and when the significance was verified by the F test, the means were compared by Tukey test ($p < 0.05$) for cover plants and the regression analysis for N doses (Pimentel-Gomes and Garcia, 2002). Statistical analysis was performed using SISVAR software (Ferreira, 2011).

Conclusion

Plant residues of maize + *Cajanus cajan* and maize + *Urochloa ruziziensis* from the 2013/14 and 2015/16 growing seasons provided an increase in the yield of wheat cultivated in the winter of 2015 and 2017, respectively, and the yield was higher than that in other treatments and matched the productivity obtained in the maize + *Canavalia ensiformis* treatment. The doses 74 and 86 kg ha^{-1} of N under cover, in 2015 and 2017, respectively, provided the maximum yield of wheat grains.

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