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RESEARCH ARTICLE

Biomass and Nutrient Accumulation by Cover Crops and Upland Rice Grown in Succession Under No-Tillage System as Affected by Nitrogen Fertilizer Rate

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Abstract

Cover plants are intended to cover the soil, protecting it from erosion, nutrient leaching, and providing nutrients through recycling or biological fixation. The objectives of this study were to evaluate the dry biomass productivity and total accumulation of nutrients in the cover crops shoots and in the upland rice grown in succession; and evaluate the effect of the isolated and combined use of cover crops and urea on upland rice crop, grown under no-tillage system. The field experiment was conducted at Selvíria-MS, Brazil, in an Oxisol (Rhodic Haplustox), cerrado (savannah) phase. The experimental design was randomized blocks, in a 5x3 factorial scheme. The treatments were four cover crops species: sunn hemp (*Crotalaria juncea* L.), pigeon pea (*Cajanus cajan* L.), green velvet bean (*Mucuna prurens*), millet (*Pennisetum glaucum* L.), and spontaneous vegetation (fallow in off-season) combined with 20 kg N ha^{-1} applied at sowing, 20 kg N ha^{-1} applied at sowing + 60 kg N ha^{-1} at plus topdressing, and without mineral N fertilizer application. The millet recycled large amounts of K, Mg, S, and micronutrients, but negatively influenced the rice grain yield grown in succession. There was no response to topdressed mineral N fertilizer when the crop was grown in rotation to legume cover crops. Upland rice under no-tillage showed a positive response to the N fertilization at seeding and when it is grown in rotation with the use of millet or fallow in the off-season. Upland rice also showed a response to N fertilization applied at topdressing.

Key words : *Oryza sativa*, grasses, legumes, mineralization, nutrient cycling, urea

Introduction

The Food and Agriculture Organization (FAO) has shown great concern for stocks and high food prices in the world, which can exacerbate the problem of hunger, especially for the population close to the poverty line. Rice is one of the most important crops to world food security; being the staple food for about 2.4 billion people and, according to estimates, by 2050 there will be twice the demand (FAO 2017).

Brazil is the world's largest producer of upland rice and the ninth largest producer of grain, considering both cropping systems (irrigated and upland), with grain production 12.06 million tons in 2017/2018, of which 1.3 million tons cultivated in the irrigated systems and 10.6 with irrigated planting (CONAB 2019).

Most upland rice fields are located in the Brazilian Cerrado (Savannah) region, where soils have low fertility (CONAB 2019). Among the nutrients, the N is the nutrient that affects the productivity of this crop most often, with its dynamics in the soil-plant system changed by the management used. However, the naturally available quantity in the soil is usually insufficient to meet the demand of this crop, which makes supplementation with N fertilizer crucial for obtaining satisfactory yields, which represents a significant portion of

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the production cost (Fageria et al. 2010). Thus, the rational use of N fertilizers associated with better use of N released by crop residues is an important aspect for the rice production in a farming system, considering economic sustainability and is ecologically correct (Carvalho et al. 2011; Fageria et al. 2011; Guimarães et al. 2018).

No-tillage or reduced tillage establishment is used widely for many crops worldwide and this technology has potential to allow saving time, energy, water, and labor during rice establishment (Singh et al. 2014). The use of the no-tillage system and cover crops that maintain soil moisture would prove advantageous in the move toward sustainable agriculture. However, upland rice develops better in plowed soil, and it has been reported that this crop does not perform well under no-tillage (Nascente et al. 2013a, b).

Nitrogen is one of the most yield-limiting nutrients in crop production in all agroecological regions of the world (De Bruijn 2015). The main reasons for N deficiency in annual crops are its low recovery efficiency. In cereals, N recovery efficiency at the global level is reported to be less than 40% (Raun et al. 2002). The low recovery efficiency of N is associated with its loss by leaching, denitrification, volatilization, and soil erosion (Fageria and Baligar 2005; Silva et al. 2016). N has significantly increased rice yield by improving yield components like panicle number, thousand grain weights, and reduced grain sterility, as well. N has also improved grain harvest index, N harvest index, and plant height, which are positively associated with grain yield (Fageria et al. 2011; Guimarães et al. 2018).

Nitrogen fertilization stands out as one of the management practices that provides better results on rice productivity. Traditionally, mineral fertilizers are a major source of N to the crop. However, the increasing concern on the sustainability of production systems has stimulated the search for alternative nutrient sources, enabling full or partial replacement of this input. Due to its capability to fix, symbiotically, the atmospheric N, legumes are considered promising alternatives to meet this demand (Carvalho et al. 2011; Muraoka et al. 2002; Scivittaro et al. 2004; Silva et al. 2016). However, in the Cerrado the grasses have been used more as cover crops, especially millet and Brachiaria. This is due to its greater resistance to drought, higher biomass, slower decomposition, and lower cost of seeds (Boer et al. 2008; Guimarães et al. 2018; Silva et al. 2006a, 2008; Teixeira et al. 2009; Torres et al. 2008).

Most studies which perform the combination of cover crops with mineral N sources are a synergistic effect on the use of these N sources - priming effect (Muraoka et al. 2002; Scivittaro et al. 2004). This is because the cover crop residues are incorporated into the soil as well as N, other nutrients and organic compounds, which favor the development of the root system and the biological activity, mediating the mineralization process of organic forms (Silva et al. 2006b).

Cover crops or green manures play an important role in nutrient cycling in the soil, both those added through mineral fertilizers or from the mineralization of soil organic matter (SOM). Compared to mineral fertilizer, N recovery of hedge plants has been low for the first crop in succession, rarely exceeding 20% (Acosta et al. 2011; Silva et al. 2006b), which indicates the great permanence part of N in the soil and can provide a residual effect to subsequent crops and increase the storage of organic soil N (Silva et al. 2006a). However, studies show that species of cover crops can provide the equivalent effect of high doses of mineral N (Acosta et al. 2011; Muraoka et al. 2002).

Muraoka et al. (2002), using the crotalaria-juncea legumes and velvet bean as green manure for upland rice, obtained an equivalent effect to the fertilization with 40 kg N ha^{-1} as urea, which shows that these pulses are an important alternative N and another nutrient source to plants.

The objectives of this study were to evaluate the dry biomass productivity and total accumulation of nutrients (N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn) in the cover crop shoots and in the upland rice (straw and grain) grown in succession; and evaluate the effect of the isolated and combined use of cover crops and urea on plant height, yield components, dry matter, and total nutrient accumulation by upland rice and in the industrial quality of rice grain grown under a no-tillage system.

Material and Methods

The field study was carried out at the Experimental Farm of Faculty of Engineering, Sao Paulo State University, located in Selvíria-MS, Brazil (51º 22' W and 20º 22' S, 335 m of altitude). The soil is classified as Dystropherric Typic Rhodic Haplustox soil (Soil Survey Staff 2010) and *Latossolo Vermelho Distroférrico*, loamy, cerrado (savanah) phase (Santos et al. 2018). The experimental area has a history of 19 years under conventional tillage and the last 11 years in a no-tillage system. The local climate is Aw based on the Köppen classification system (Alvares et al. 2013).

The initial chemical characteristics of the soil, analyzed according to methods described by Raij et al. (2001) for the layers of 0-0.10 and 0.10-0.20 m were respectively: pH ($CaCl_2$) 4.9 and 4.7; total N 1.0 and 0.8 g kg^{-1}; organic matter 26.0 and 22.0 g dm^{-3}; P (resin extractable) 30 and 25 mg dm^{-3}; Ca^{2+} 32 and 20 mmol$_c$ dm^{-3}; Mg^{2+} 18 and 12 mmol$_c$ dm^{-3}; K^+ 2.0 and 2.6 mmol$_c$ dm^{-3}; S 4.0 and 3.5 mg dm^{-3}; H+Al 31 and 38 mmol$_c$ dm^{-3}; CEC 83.0 and 72.6 mmol$_c$ dm^{-3}; base saturation 62.7 and 47.7%.

The experimental design was randomized blocks with 15 treatments and four replications, in a 5x3 factorial outline. The treatments were four cover crop species, including: (1) sunn hemp (*Crotalaria juncea* L.), (2) pigeon pea (*Cajanus cajan* L.), (3) green velvet bean (*Mucuna prurens*), (4) millet (*Pennisetum glaucum* L.), (5) spontaneous vegetation (fallow ground in off-season), combined with or without mineral N fertilizer application as urea to upland rice grown in succession to cover crops. N fertilizer was applied at sowing (20 kg N ha^{-1}), and at sowing (20 kg N ha^{-1}) plus topdressing (60 kg N ha^{-1}), besides a control (without N application).

The field experiment comprised two phases: initially (winter/spring season) in the first phase cover crops were sown 0.40 m between rows for legume species (sunn hemp, pigeon pea, and velvet bean) and 0.25 m for millet and an area left with spontaneous vegetation during the fallow ground off-season. In the second phase (spring/summer season), on soil with cover crops residues an upland rice crop was grown under a no-tillage system.

The cover crops and spontaneous vegetation were cut mechanically with a straw crusher and glyphosate herbicide applied at 70 days after sowing (DAS) with crop residues left on the soil surface and used as mulch in the field. The shoot biomass yield of sunn hemp, green velvet bean, pigeon pea, millet, and spontaneous vegetation (fallow in the off season) were determined in four samples of 0.25 m^2, sampled in the floor area of the plots the day before the mechanical management of plants. The samples were dried in an oven at 65 °C for 4 days, the data transformed in t ha^{-1} of dry matter. In this material, sub-samples were taken ground in a Wiley mill, and macro (N, P, K, Ca, Mg, and S) and micronutrients (Cu, Fe, Mn, and Zn) contents were determined according to Malavolta et al. (1997).

In succession to cover crops, the rice crop (cv. IAC 202) was sown mechanically (second phase), in spacing of 0.35 m between rows at a density of approximately 200 seeds per m^2. Basal phosphorus and potassium fertilizer were applied 40 kg ha^{-1} P_2O_5 as triple superphosphate and 40 kg ha^{-1} K_2O as potassium chloride. N fertilizer, as urea, was applied manually after sowing (20 kg N ha^{-1}). N topdressing (60 kg ha^{-1} N) was applied between rows at the initiation of panicle differentiation stage. Supplementary irrigation was done, by conventional sprinkling whenever a water deficiency occurred.

To evaluate nutritional status of rice plants, 30 leaves were collected from each plot, at the flowering stage, according to the methodology described by Raij et al. (1996). The procedures and analytical methods were similar to those described above for cover crops.

The plant height was determined by measuring, with a ruler, the distance between rot collar and the summit of the highest panicle in 20 rice plants per each plot, in the nine stages of the vegetative cycle (IRRI 2002). The number of panicles m^{-2} was determined by direct counting of panicles harvested in four subsamples of 0.25 m^2 floor area demarcated in the plots.

Rice plant shoots (grain and straw) were harvested manually at 113 DAS in the useful area of each plot, in the stage when the upper 2/3 of grain from 50% of panicles had become stiff and the lower third, semi-hard, by cutting the plant close to the ground. Subsequently, the panicles were separated to evaluate the grain yield and straw biomass. Following this, the grains were shade dried and cleaned, separating the straw and the grains with the aid of a sieve, through manual cleaning, and data processed in kg ha^{-1} grain, 13% humidity. To determine the total accumulation of nutrients (N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn) in straw and rice grain subsamples were taken from respective parts of the plant for the analysis as described previously for cover crops.

The mass of 1,000 grains were determined by averaging the mass in grams, of four lots of 1,000 threshed grains of each plot at random. The hectoliter mass was evaluated in two samples using a container with a volume of 0.25 L filled with rice grain, which was then weighed on a precision balance, correcting the grain moisture content to 13% (wet basis). The total number of grains per panicle was checked by counting the grains of 20 panicles collected at harvest. For the number of filled or void grains per panicle full and void grains were counted after their separation by air flow.

Grain yield in benefit was obtained 60 days after storage from each plot, one sample of 100 g of hulled rice grains was collected, and a Suzuki proof mill model MT was used for 1 minute; then the polished grains were weighed and the found values were considered the milling yield percentage. Later, the polished grains were placed in a "trieur" 2 and the grains separated for 30 s. The grains that remained in the "trieur" were weighed to determine the percentage of undamaged grains and broken rice grains.

The data were analyzed statistically by *F* test, with comparison of means by Tukey test at the 0.05 probability level. The statistical analyses were carried out using the SAS package 8.02 (SAS Institute 2001).

Results and Discussion

Characterization of ground cover species

At 70 days after sowing (DAS), dry biomass productivity of cover crops followed the decreasing order: sunn hemp > mille t > pigeon > velvet bean green > spontaneous vegetation (Table 1). Bordin et al. (2003) had lower values for sunn hemp and higher for millet (9:58 t ha^{-1}), also cut at 70 DAS. Cazetta et al. (2008), in two crops, obtained at 60 DAS, dry matter productivity values were lower for sunn hemp, pigeon pea, and fallow, and higher for velvet bean and to millet.

Except for S, sunn hemp accumulated the largest amount of other macronutrients (Table 1), but no significant difference in the millet for the quantities of K and Mg. This result was observed mainly due to its higher dry biomass production of this species compared to others cover crops. It was observed that only the shoot part of legumes covers crops added to the soil: 196.9; 142.9, and 109.5 kg N ha^{-1}, respectively, for sunn hemp, pigeon pea, and green velvet bean, showing thus the great potential for supplying this nutrient to crops grown in rotation.

The sunn hemp and millet were the species that have accumulated a larger amount of P in the shoot part, whose quantity of this nutrient recycled ranged from 5 kg ha^{-1} by spontaneous vegetation to 20 kg ha^{-1} by sunn hemp (Table 1). Studies have shown that plant species with a greater ability to cycle P are able to recover from low availability fractions and thus reduce the need for the addition of high amounts of

Table 1. Dry biomass and macro and micronutrient accumulation in shoots of cover crops and spontaneous vegetation (fallow), 70 days after sowing, Selvíria-MS[(*)].

Cover crop	Biomass	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
	t ha^{-1}	kg ha^{-1}						g ha^{-1}			
Sunn hemp	11.3a	196.9 a	20.0 a	232.3 a	54.6 a	26.9 a	13.7 b	76 a	2376 bc	388 ab	210 a
Pigeon pea	6.1 c	142.9 b	15.3 c	139.9 b	40.0 b	14.4 b	9.6 c	62 ab	2761 b	321 ab	137 ab
Velvet bean	4.0 d	109.5 c	11.4 d	103.5 bc	33.0 bc	12.5 bc	8.1 d	56 b	3729 a	286 b	114 ab
Millet	7.4 b	83.9 d	17.1 b	226.1 a	31.1 c	24.4 a	16.8 a	63 ab	3627 a	565 a	191 a
Fallow	3.1 e	36.0 e	5.0 e	59.4 c	16.5 d	9.9 c	5.8 e	22 c	2057 c	322 ab	65 b
C.V. (%)	15.5	4.9	2.1	11.4	4.9	7.7	2.3	12.4	42.5	24.7	26.5

(*) Values followed by same letters in columns are not significantly different ($P < 0.05$) amongst themselves by Tukey's test.

phosphate fertilizers to the soil (Carvalho et al. 2008; Ryan et al. 2007).

The K recycled by sunn hemp and the millet were higher than for N (Table 1). But the pigeon pea and green velvet bean accumulated very close amounts of both nutrients. In this aspect, considering that most of the K contained in the plant residues are released in less than 30 days after application (Malavolta et al. 1997), the management time of cover crops in relation to the sowing of commercial crop it is also important, considering better synchronization between demand/release.

The cover crops also recycled considerable amounts of Cu, Fe, Mn, and Zn (Table 1). Studies have shown that regular addition of cover crops residues enhances the stability of soluble forms of cationic micronutrients in the soil solution (Pegoraro et al. 2006). The cover crops of plants have different nutrient recycling capabilities and, in the case of biological nitrogen fixation (BNF), it depends on the nutrient content in plant tissue and the amount of dry biomass produced, which in turn influences the edaphic conditions, and climate, as well as the handling time (Amabile et al. 1999; Perin et al. 2004). Studies carried out by Silva et al. (2006b) found that sunn hemp accumulated a higher amount of biomass and N, corresponding to approximately 2.7 and 5.8 times more, respectively, than millet and spontaneous vegetation. In addition to N, cover crops recycled considerable amounts of other nutrients, which sunn hemp accumulated a higher amount of macro and micronutrients, except Fe and Mn. Alcantara et al. (2000) evaluating the performance of sunn hemp and pigeon pea, observed a higher dry matter yield of shoot in the pigeon pea, corresponding to more than twice that produced by the sunn hemp, as well as larger amounts of accumulated nutrients, especially N, P, and K.

In general, the production of biomass of cover crops varies with genotype, sowing date, management practices, soil and climatic conditions, growing season, as well as plant population. Thus, it is necessary to study the adaptation of different species on a regional scale. In this context, Amabile et al. (1999) observed that the rates and the absorbed N, P, and K are both influenced by sowing time of cover crops; however, there was no effect of row spacing and plant population. Therefore, the selection of cover crops to provide nutrients must also consider the time of sowing. In general, biomass production and nutrient uptake is an intrinsic characteristic of each cover crop species (Carvalho et al. 2011). However, biomass production of cover crops is also influenced by environmental conditions, soil fertility, and crop management practices (Perin et al. 2004; Silva et al. 2006b).

In this sense, it is necessary to also rethink the sequence of crops within the different production systems. Growing cover crops in the off season should not compete with crops of economic interest but modify the physical, chemical, and biological conditions of the soil to reduce costs and / or increase productivity. In addition, in general, little emphasis has been given to breeding studies of cover crops to adapt to the harsh conditions of soil, climate, and growing seasons, as well as for increasing the absorption of nutrients and biomass production.

Production components and rice yield

Nitrogen rate proportionated a significant influence on leaf N, Mg, and Cu contents at the flowering time of rice (Table 2). Different species of cover crops also influenced the levels of these same nutrients, as well as the S content. However, there was no significant interaction between cover crops and N rates for the nutritional status of the crop at flowering. It appears that the N content in rice leaf in legumes succession treatments, ranged within the range (27-35 g kg^{-1}) described as suitable for Raij et al. (1996). This fact shows that the legume residues provide the nutrient and favor its absorption compared to the use of millet, which due to its high C/N ratio, its residues were probably mineralized more slowly, thus immobilizing part of the N from the soil and the mineral fertilizer, as well as that of the mineralized residue itself (remobilization).

Regarding the applied N, the lowest leaf N content in rice was observed in treatments without the application of this nutrient (Table 2). The Mg, S, and Cu contents are within the appropriate ranges, which are 1.5 to 5.0; 1.4 to 3.0 g kg^{-1}, and 3 to 25 mg kg^{-1} of dry matter, respectively (Raij et al. 1996). The other macronutrients (P, K, and Ca) and Mn and Zn micronutrients were not affected by treatments and also, were within the range considered appropriate for rice crops (Raij et al. 1996) regardless of the cover crop species and the

Table 2. Nitrogen (N), magnesium (Mg), sulfur (S), and copper (Cu) in upland rice diagnostic leaves at the flowering time, grown with different N rates applied at sowing (Sow) and topdressing (Top), in succession to cover crops, Selvíria- MS(*).

Crop succession	N	Mg	S	Cu
	------------------------------ g kg^{-1}	------------------------------		mg kg^{-1}
Sunn hemp/rice	28.06 a	2.36 a	2.33 ab	9.23 a
Pigeon pea/rice	27.53 a	2.22 ab	2.32 ab	8.79 ab
Velvet bean/rice	27.64 a	2.31 ab	2.39 ab	9.33 a
Millet/rice	24.54 b	2.19 ab	2.26 b	7.92 b
Fallow/rice	23.95 b	2.10 b	2.42 a	7.77 b
		N rate (kg ha^{-1})		
0	22.79 c	2.06 b	2.30 a	7.75 b
20 Sow.	26.74 b	2.17 b	2.35 a	8.51 b
20 Sow. + 60 Top.	29.52 a	2.48 a	2.39 a	9.56 a
CV (%)	4.3	5.5	9.8	6.4

(*) Values followed by same letters in columns are not significantly different ($P < 0.05$) amongst themselves by Tukey's test.

Table 3. Rice grain yield as affected by nitrogen rates, applied at sowing (Sow) and topdressing (Top), and cover crops species, Selvíria, MS, Brazil(*).

N rate (kg ha^{-1})	Rice grain yield (kg ha^{-1})				
	Sunn hemp	Pigeon pea	Velvet bean	Millet	Fallow
0	4303 Ab	4517 Ab	4688 Ab	3086 Bc	2950 Bc
20 Sow.	5305 Aa	5153 Aa	5426 Aa	3951 Bb	4161 Bb
20 Sow. + 60 Top.	5881 Aa	5333 Aa	5699 Aa	5215 Aa	5175 Aa

(*) Values followed by same letters, capital in row and lower case in columns, do not differ ($P < 0.05$) amongst themselves by Tukey's test.

applied N rate. Since the iron (Fe) content was, on average 52 mg kg^{-1}, slightly below that considered adequate, 70-200 mg kg^{-1} (Raij et al. 1996).

There was a significant effect on the isolated N application and use of species of cover crops on plant height and number of panicles per m^2 (Fig. 1). As for the productivity of rice grains, a significant interaction between the factors N and cover crops (Table 3). The hectoliter weight, with a mean value of 54.78 g, was not influenced by the treatments, which indicates that the number of panicles, spikelet, and grains per panicle were the components that most influenced the grain yield. The coefficients of variation were 10.7, 5.1, and 14.1%, respectively, for the number of panicles per m^2, hectoliter weight, and grain yield.

Regardless of N rate, the larger plant height was observed when the rice was grown in rotation with the plants in leguminous cover, compared to using millet or untreated (Fig. 1A). In relation to mineral N, the higher plant height was in treatments with the higher N rate (Fig. 1B), but without significant difference of the treatments that received 20 kg N ha^{-1} at sowing, while the lower height is found in treatments where this nutrient was not applied. This effect occurs due to the N part of the chlorophyll molecule and to act in the process of photosynthesis and cell division and expansion because, according to Marschner (1995) in cereals, with the application of high nitrogen rate before growth point turn into reproductive structure, increases the production of phytohormones, particularly auxin, stimulating the division and cell expansion process, which increases the stem elongation and consequently the height of the plant.

Regarding the number of panicles per m^2, the highest values were observed in the treatments with pigeon pea grown previously (Fig. 1C), but with significant differences only to the treatments that had millet as previous crop. In relation to N fertilization, there was a positive influence on the number of panicles per m^2, both with the application of N at seeding only and at sowing + topdressing (Fig. 1D). The largest number of panicles per m^2 occurred in treatments with legume cover plant, as well as those with the application of N, which indicates that an adequate supply of this nutrient promotes the development of tillers and consequently the number of panicles. Boldieri1 et al. (2010), evaluating response of different rice cultivars to N fertilization, among them the IAC 202, found positive linear response and the supply of nutrients to the number of panicles per area. Guimarães and Stone (2003) also observed an increase in the number of panicles per area with increased N fertilization. Cazetta et al. (2008), using the same species of this study, in succession to sorghum, found in treatments with grown sorghum and millet grown previously, lower values of number of panicles per m^2; however, no significant difference from other species. Also, N fertilization positively influenced the number of panicles per m^2. This component characteristic defined genetically and influenced by environmental factors, in this case

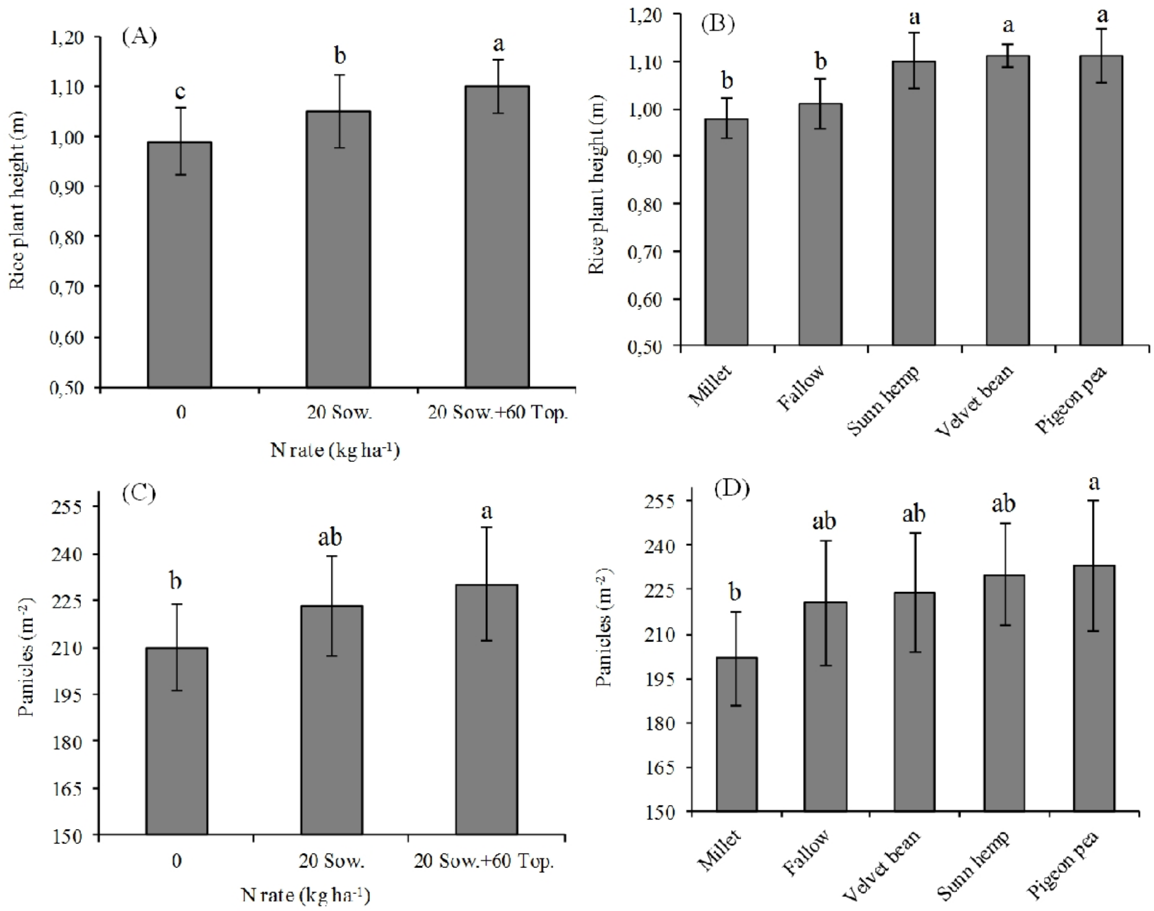

Fig. 1. Rice plant height (A and B) and number of panicles per m^2 (C and D) as affected by cover crops (sunn hemp, pigeon pea, green velvet bean, millet, and fallow) and of nitrogen fertilizer applied at sowing (Sow) and topdressing (Top), Selvíria-MS. Means followed by different lowercase letters above the columns differ by 5% Tukey's test.

the appropriate N rate application associated with the use of cover crops.

The mass of 1000 grains did not differ statistically due to previously grown different cover crops, as well as to applied N rates, with values: 25.22; 24.26; 24.15; 24.06, and 23.67 grams, respectively, with the use of sunn hemp, green velvet bean, pigeon pea, millet, and fallow. In relation to N rates, the values were: 24.05; 24.58, and 24.30 g, respectively, for the treatments without N, 20 kg N ha^{-1} at sowing and 80 kg N ha^{-1} (20 kg N ha^{-1} sowing + 60 kg N ha^{-1} topdressing). The mass of grain is a stable varietal character that depends on the size of the shell, determined during the 2 weeks prior to anthesis, and the development of caryopsis after flowering; therefore, it depends on the translocation of carbohydrates in the first 7 days, to fill the fruit in the sense of its length, and seven days later, the width and thickness (Alvarez et al. 2005; Machado 1994). This component is little influenced by climate and nutrition-related factors (Alvarez et al. 2007; Arf et al. 2005).

In rice, grain yield of a given cultivar is determined by four components: i) number of panicles per m^2; ii) number of spikelets per panicle; iii) percentage of fertile spikelets, and iv) the 1,000 seeds (Arf et al. 2015; Hernandes et al. 2010).

In the present study, based on the results of production components, the highest grain yield in treatments with the use of legumes species and N application (Table 3) was due to the greater number of panicles per square meter, since this component was higher in those treatments (Figs. 1C and 1D) and probably the largest number of spikelets per panicle and percentage of fertile spikelets.

The largest productivity of rice grains, in the treatments without applied N or those with application only at sowing were obtained with use of legumes as cover crops in rotation, compared to using millet or fallow in the off season (Table 3). Since the application of N at sowing + topdressing provided similar grain yield, regardless of the predecessor cover crop. This fact shows that the application of N at sowing plus topdressing 60 kg N ha^{-1} was sufficient to supply this nutrient to treatment with the use of millet or fallow. However, rice productivity in these treatments was similar to the treatment with the use of leguminous crops and N application only at the sowing. This phenomenon shows that when legumes are used as cover crops in rotation to the upland rice under no-tillage, topdressing N fertilization may not be necessary, oppositely when using millet or fallow in the off season.

In general, the rice grain yield in treatments without N

Table 4. Numbers of total grains, grains filled and voids per panicle and grain yield in benefit (hulling), total, whole and broken, obtained in upland rice grown with different nitrogen rate applied at sowing (Sow) and plus topdressing (Top), under no-tillage system, in succession with cover crops, Selvíria-MS(*).

Crop succession	Number of grains per panicle			Grain yield in benefit (hulling)		
	Total	Filled	Voids	Total	Whole	Broken
				%		
Sunn hemp/rice	227.5 ab	202.5 ab	25.3 a	63.9 a	49.0 a	14.9 a
Pigeon pea/rice	219.0 ab	197.5 ab	25.0 a	63.8 a	48.4 ab	15.4 a
Velvet bean/rice	239.1 a	213.8 a	21.4 ab	63.9 a	46.9 ab	17.0 a
Millet/rice	174.3 c	155.1 c	19.2 b	61.8 a	47.2 ab	14.6 a
Fallow/rice	206.5 b	185.7 b	20.8 ab	61.7 a	43.3 b	16.4 a
			N rate (kg ha^{-1})			
0	201.9 b	182.9 b	19.0 b	61.2 b	46.2 b	15.0 a
20 Sow.	206.4 b	184.3 b	22.1 b	63.2 ab	47.0 ab	16.2 a
20 Sow. + 60 Top.	231.5 a	205.6 a	25.9 a	64.6 a	48.8 a	15.8 a
CV (%)	8.6	8.7	17.9	3.6	5.5	14.9

(*) Values followed by same letters in columns are not significantly different ($P < 0.05$) amongst themselves by Tukey's test.

application but with previous growth of legumes was higher than that with the use of 20 kg N ha^{-1} at sowing with cultivation of millet or fallow (Table 3). The predecessor grown legume cover crop associated with the application of 20 kg N ha^{-1} at sowing, provided superior productivity to that with the application of N at sowing and topdressing and use of millet or fallow; therefore, legumes provided equivalent effect to the application of 60 kg N ha^{-1} as urea. Muraoka et al. (2002), using sunn hemp and velvet bean as cover crops, reported an equivalent effect to the fertilization of 40 kg N ha^{-1} as urea.

Fageria et al. (2011) observed that grain yield, yield components, and growth characteristics of upland rice grown on Brazilian Oxisol were significantly influenced by N sources and N rates. Most of the responses related to these plant parameters were quadratic in fashion. At higher and lower N rate ammonium sulfate produced higher grain yield and most of the plant growth and yield components. At the intermediate N rate (125 to 275 mg N kg^{-1}) urea was slightly better compared to ammonium sulfate for grain production. The contribution of yield components and other plant growth characters was in the order of shoot dry weight > plant height, panicle number > root dry weight, grain harvest index.

The rice straw yield (shoot except grains) was 6.80; 6.58; 6.43; 5.31, and 5.04 t ha^{-1}, respectively, for the crop grown in succession to sunn hemp, pigeon pea, green velvet bean, millet and fallow. In relation to N rates, it was 5.71; 5,97e 6.42 t ha^{-1}, respectively, for the rate of 0, 20 and 80 kg N ha^{-1}. Thus, considering the average grain yield, which was 4,722 kg ha^{-1} (Table 3), the ratio grain / straw, was 0.74. These values are close to those obtained by Souza et al. (2010), in a study with doses of lime and N in soil with similar characteristics to the one used in this study, also using the IAC 202 cultivar.

The largest number of rice grains per panicle was obtained in treatments in succession to legumes compared to millet, which also provided a smaller number of filled grains per panicle (Table 4). The total grain yield in hulling, as well as the percentage of broken grains was not affected by cover crop specie. However, the use of sunn hemp provided greater proportion of whole grains compared to the use of fallow between crops. As for the N, of the higher dose resulted in greater number of grains per panicle; however, as shown in Table 3, it did not imply a higher yield, compared to treatments in succession legumes and receiving only 20 kg N ha^{-1}. This fact is possibly because this variable is also conditioned by the number of panicles per area. About grain yield in benefit (hulling), the N rate had little influence on this variable. Similar results with respect to rice industrial yield were also observed by Cazetta et al. (2008). Arf et al. (2005) also found no effect of N application time in these variables. These results allow us to infer that these variables are characteristics more influenced by genetic makeup of the plant, with little influence of nitrogen fertilization. Guimarães et al. (2018), also under cerrado conditions, observed that cover crops did not influence the income of whole grains and broken grain; however, showed significant effect on the mass of 1.000 grain, grain yield, and income of grain in the benefit.

The largest amount of N and K returned to the soil by rice straw occurred with previous grown of legumes, when compared to grown in succession to millet or fallow ground in off season (Table 5), similar to the amount of N exported in the grains, although in succession to sunn hemp or pigeon did not differ significantly from the use of millet or fallow ground.

The increase in the N rate promoted increased of N and K absorption, as well as the export of N in rice grains (Table 5). Regardless of N rate or cover crop specie used, most fraction of the absorbed N, on average 58% (53 kg ha^{-1}), was exported to the grains, and 42% (38,5 kg ha^{-1}) remained in rice straw.

Table 5. Amount of macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Cu, Fe, Mn, and Zn) in rice (straw and grain), at harvest time, grown with different nitrogen rates applied at sowing (Sow) and plus topdressing (Top), in succession cover crops, Selvíria-MS(*).

Crop succession	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
	Straw									
	kg ha^{-1}						g ha^{-1}			
Sunn hemp/rice	43.6 ab	7.2 a	155.0 ab	16.6 a	16.5 a	7.2 a	50 ab	1294 a	3693 a	172 a
Pigeon pea/rice	38.3 bc	5.5 b	162.6 a	16.2 a	17.1 a	7.6 a	54 a	1124 b	2822 b	167 a
Velvet bean/rice	43.8 a	5.2 b	144.7 b	12.8 b	11.6 b	7.7 a	46 bc	1205 ab	2083 d	120 b
Millet/rice	34.0 c	6.4 a	113.2 c	10.2 c	10.3 bc	6.1 b	41 cd	1156 ab	2466 bc	163 a
Fallow/rice	33.0 c	5.1 b	111.6 c	9.2 c	9.3 b	5.6 b	38 d	1068 b	2189 cd	120 b
	N rate (kg ha^{-1})									
0	35.6 c	5.4 b	121.8 c	10.7 c	10.4 b	6.1 b	45 a	769 c	2794 a	141 b
20 Sow.	37.0 b	5.8 b	138.1 b	15.6 a	14.7 a	6.6 b	45 a	1314 b	2547 b	160 a
20 Sow.+60 Top	47.0 a	6.4 a	152.2 a	12.6 b	13.8 a	7.8 a	47 a	1425 a	2610 ab	144 ab
CV (%)	8.0	7.5	7.1	6.7	6.3	6.8	7.0	7.2	7.9	9.3
Crop succession	Grain									
	kg ha^{-1}						g ha^{-1}			
Sunn hemp/rice	56.6 ab	18.8 a	18.7 a	2.2 bc	8.2 bc	4.5 a	22 a	231 ab	485 a	138 a
Pigeon pea/rice	57.1 ab	13.0 b	17.7 a	1.8 c	7.1 c	4.7 a	20 a	190 b	363 b	120 a
Velvet bean/rice	60.0 a	12.7 b	19.1 a	2.6 b	9.5 ab	5.0 a	20 a	271 a	404 ab	128 a
Millet/rice	46.7 b	11.2 b	15.4 a	3.5 a	11.3 a	3.9 a	18 a	236 ab	354 b	110 a
Fallow/rice	46.1 b	11.1 b	15.9 a	2.6 b	8.9 bc	4.0 a	18 a	210 b	370 b	108 a
	N rate (kg ha^{-1})									
0	40.1 c	10.7 a	14.9 b	1.7 c	6.6 c	3.4 c	16 b	176 c	356 b	107 b
20 Sow.	53.4 b	11.8 a	14.7 b	2.4 b	8.7 b	4.4 b	18 b	219 b	328 b	124 ab
20 Sow. + 60 Top	66.5 a	14.6 a	22.6 a	3.5 a	11.7 a	5.6 a	25 a	288 a	501 a	130 a
CV (%)	12.3	13.0	12.7	13.4	13.7	13.3	13.5	13.6	11.9	13.4

(*) Values followed by same letters in columns are not significantly different ($P < 0.05$) amongst themselves by Tukey's test.

As for the K, on average 89% (137 kg ha^{-1}) remained in rice straw. Thus, considering that most of K contained in the vegetable residues is released relatively quickly, because this nutrient is not part of cellular compound (Malavolta et al. 1997) and is susceptible to leaching, it is necessary the adoption of management practices that maintain this nutrient in the soil layer explored by the crop roots. In this respect, the cover crops grown during off-season promotes efficient recycling of this nutrient, with the potential for some species, even higher than of N, exceeding 200 kg ha^{-1} (Silva et al. 2006b), such as the sunn hemp and millet in this study (Table 1).

In general, the amount of macronutrients accumulated in rice straw followed the decreasing order: K, N, P, Ca, Mg, and S, while the accumulated in the grain followed the order: N, K, P, Mg, S, and Ca. As for the micronutrients, there was a similar partition of the total accumulated between straw and grains, whose order was: Mn, Fe, Zn, and Cu.

Except for S and Cu in grains, different cover crops influenced the accumulation of other macro and micronutrients in the rice shoot (straw and grain) (Table 5). However, in general, legumes used as cover crops provided greater accumulation of most nutrients in rice straw and grains, compared to millet. With respect to applied N rates, except for amount of Cu and Mn in straw and P in grains, amount of nutrient accumulation in shoots of rice (straw and grain) was positively influenced by the application of this nutrient.

In general, the amount of macronutrients accumulated in rice straw followed the decreasing order: K > N > P > Ca = Mg > S, while the accumulated in the grain followed the order: N > K > P > Mg > S > Ca. As for the micronutrients, there was a similar partition of the total absorbed between straw and grain, whose order was: Mn > Fe > Zn > Cu.

It is also noteworthy that the values of the in this study are underestimated, because it was not considered N in the root system of different cover crop species, which is therefore an underestimate of the amount of nutrients additional to the soil by plant residues. Likewise, it was also not accounted the amount of nutrients accumulated in the rice root system. Studies have shown that the root system of cover crops and commercial crops are also potential sources of nutrients, especially N, to crops grown in succession (Araújo et al. 2004; Silva et al. 2008). Also, there are reports that much of the N from crop residues remains the crop root system (Azam et al. 1995; Silva et al. 2008).

The results of this study show that the use of leguminous cover crops in rotation has the potential to increase the supply of nutrients for the subsequent crop, reducing the necessary doses of fertilizer and increase the productivity of upland rice in no-tillage, which is important consideration in Brazil where resources are limited and there is a need to improve both productivity and environmental sustainability.

Conclusion

The sunn hemp and millet produced the higher amount of dry matter compared to other cover crops and spontaneous vegetation (fallow in the off season).

Nitrogen and potassium were macronutrients accumulated in larger amounts, regardless of cover crops, as for micronutrients, stood out iron and manganese.

The number of panicles per area and grains per panicle were the plant components that most contributed to the increase in rice grain yield.

Grain yield in processing was not influenced by different cover crop and the nitrogen fertilizer used for rice cultivation.

The cover crop specie and nitrogen fertilizer influenced the plant straw biomass accumulation and rice grains yield, as well as the absorption of most nutrients.

Most potassium (89%) and much nitrogen (42%) absorbed by the rice crop will potentially return to the soil through rice straw organic matter.

There was no response to nitrogen topdressing by rice, when grown after legume cover crops, which provided equivalent effect to the application of 60 kg ha^{-1} N as urea.

The upland rice under no-tillage system, responded to nitrogen fertilization at seeding grown in succession to millet or ground fallow, there was also a response to N application in topdress.

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Conflict of interest

The authors declare that there is no conflict of interest.

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