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EFFECT OF COVER CROPS ON SOIL ATTRIBUTES, PLANT NUTRITION, AND IRRIGATED TROPICAL RICE YIELD[1]

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ABSTRACT - In flood plains, cover crops are able to alter soil properties and significantly affect rice nutrition and yield. The aims of this study were to determine soil properties, plant nutrition, and yield of tropical rice cultivated on flood plains after cover crop cultivation with conventional tillage (CT) and no-tillage system (NTS) at low and high nitrogen (N) fertilization levels. The experimental design was a randomized block in a split-split-plot scheme with four replications. In the main plots were cover crops [sunhemp (*Crotalaria juncea* and *C. spectabilis*), velvet bean (*Mucuna aterrima*), jackbean (*Canavalia ensiformis*), pigeon pea (*Cajanus cajan*), Japanese radish (*Raphanus sativus*), cowpea (*Vigna unguiculata*)] and a fallow field. In the subplots were the tillage systems (CT or NTS). The nitrogen fertilization levels in the sub-subplots were (10 kg N ha^{-1} and 45 kg N ha^{-1}). All cover crops except Japanese radish significantly increased mineral soil nitrogen and nitrate concentrations. Sunhemp, velvet bean, and cowpea significantly increased soil ammonium content. The NTS provides higher mineral nitrogen and ammonium content than that by CT. Overall, cover crops provided higher levels of nutrients to rice plants in NTS than in CT. Cover crops provide greater yield than fallow treatments. Rice yield was higher in NTS than in CT, and greater at a higher rather than lower nitrogen fertilization level.

Keywords: Nitrogen. No-till. Tropical lowland.

PLANTAS DE COBERTURA AFETANDO ATRIBUTOS DE SOLO, NUTRIÇÃO E PRODUTIVIDADE DO ARROZ IRRIGADO TROPICAL

RESUMO - O uso de plantas de cobertura pode alterar atributos do solo e afetar significativamente a nutrição das plantas e produtividade do arroz cultivado em planícies inundáveis. Este trabalho teve como objetivo determinar atributos do solo, nutrição de plantas e produtividade do arroz irrigado tropical em planícies irrigáveis por inundação após o cultivo de plantas de cobertura, no preparo convencional do solo (PC) ou sistema plantio direto (SPD) em baixa e alta adubação com N. O delineamento experimental foi em blocos casualizados, no esquema de parcelas sub-subdivdidas, com quatro repetições. Nas parcelas estavam as coberturas vegetais [*Crotalaria juncea*, *C. spectabilis*, mucuna preta (*Mucuna aterrina*), feijão de porco (*Canavalia ensiformis*), feijão guandu (*Cajanus cajan*), nabo forrageiro (*Raphanus sativus*), feijão caupi (*Vigna unguiculata*) e pousio], nas subparcelas o sistema de preparo do solo (PC ou SPD) e nas sub-subparcelas a adubação nitrogenada (10 e 45 kg ha^{-1} N). As plantas de cobertura, com exceção do nabo forrageiro, proporcionam incrementos nos teores de N total e nitrato no solo. *C. juncea*, *C. spectabilis*, mucuna preta e feijão caupi proporcionam incrementos nos teores de amônio no solo. O SPD proporciona maiores teores de N total e amônio do que o PC. No âmbito geral, as plantas de cobertura proporcionaram maiores teores de nutrientes nas plantas de arroz no SPD do que no PC. As plantas de cobertura também proporcionaram maior produtividade do arroz em relação ao tratamento pousio. O rendimento do arroz é maior em SPD do que PC, e superior com alto nível de adubação nitrogenada.

Palavras Chaves: Nitrogênio. Plantio direto. Várzea tropical.

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INTRODUCTION

Rice is a dietary staple for half of the world's population (BELLON et al., 2006; KUMAR; LADHA, 2011; NASCENTE; CRUSCIOL; COBUCCI, 2013). In Brazil, rice is cultivated in two distinct ecosystems: (a) irrigated flood plain (IFP) and (b) uplands. The area available for sustainable irrigation in Brazil is 29,564,000 ha, of which IFP constitutes 50.6% (~15,000,000 ha) (MATTOS, 2014). It is estimated that there are about 1,000,000 ha of tropical IFP in the Tocantins-Araguaia Valley of Brazil (COELHO et al., 2006; PELÚZIO et al., 2008; FRAGOSO et al., 2013). In this environment, hydromorphic soils with shallow subsurface horizons or temporary water table elevations predominate. These restrict water percolation are prone to accumulating excess moisture (EMBRAPA, 2013).

In the state of Tocantins, rice sown in the summer is rotated with soybean in the winter and dry seasons. The alternating use of cover crops like soybeans provides significant benefits to tropical floodplain ecosystems. According to Correia et al. (2013), the benefits of using crop rotation and succession systems in rice irrigation zones include nutrient cycling, soil use optimization, soil quality improvement by increasing organic matter, grain yield increase, and augmented crop profitability. These cultivation practices may also decrease fertilizer requirements via nutrient release from cover crop straw (VERNETTI JÚNIOR; GOMES; SCHUCH, 2009; NASCENTE et al., 2014).

Nascente and Crusciol (2015) reported that the use of cover crops contributed to the increase in soil organic matter content. Cover plants can also significantly affect soil N and improve the crop development environment (NASCENTE et al., 2016). The use of legumes as cover crops can provide N to the soil, help reduce the requirement for N fertilization (FAGERIA, 2014), and lower production costs (FAGERIA; STONE, 2003). There are, however, very few studies on the use of cover crops or their N inputs on irrigated tropical flood plains.

The hypothesis is that cover crops significantly affect soil attributes, and their impact is reflected in improved nutrition and grain yield in rice cultivated on IFP. In a no-tillage system (NTS), straw is maintained on the soil surface. It increases soil fertility and improves rice development more effectively than conventional tillage (CT) system (one plowing and two diskings). The NTS also permits the application of lower rates of N because it releases high levels of organic matter and nutrients to the soil. Therefore, with its reduced N inputs, NTS realizes soil attributes and grain yield comparable to those attained with the higher N dosages used in CT.

The objective of this study was to compare the effects of CT and NTS, and high- and low N fertilization levels on soil attributes, nutritional status, and yield of tropical rice grown following cover crops on IFP.

MATERIAL AND METHODS

The experiment was carried out in the city of Lagoa da Confusão, State of Tocantins, Brazil, at 10°49′3478″ S and 49°54′033″ W, and 180 m altitude, in the growing season 2011/12. The climate in the region is classified as Awi (Koppen), with maximum precipitation in the summer and warm, dry winters. The soil is a Plinthaquults according to US taxonomy, and cultivated by CT for five years with an irrigated rice (summer) and soybean (winter) succession.

Prior to experimental setup, the soil was analyzed. The following results were obtained: pH ($CaCl_2$): 4.9; P (Mehlich): 23.7 mg dm^{-3}; organic matter: 54 g dm^{-3}; K: 1.3 $mmol_c$ dm^{-3}; Ca: 37.4 $mmol_c$ dm^{-3}; Mg: 15.1 mmol dm^{-3}; Al: 0 $mmol_c$ dm^{-3}; CEC: 91 mmol cm^{-3}, base saturation: 59%. Sand, silt and clay: 60%, 6%, and 34%, respectively.

The experimental design was a completely randomized block with spli-split-plots and four replications. The main plots had the following cover crops: *Crotalaria juncea*, *Crotalaria spectabilis*, black mucuna (*Mucuna aterrima*), pigeon pea (*Canavalia ensiformis*), guandu bean (*Cajanus cajan*), forage turnip (*Raphanus sativus*), caupi bean (*Vigna unguiculata*), and fallow. Either NTS or a CT was used in the subplots. Further, in the sub-subplots, the nitrogen (N) fertilization level was either high (45 kg ha^{-1}) or low (10 kg ha^{-1}). The main plots measured 80 m², the subplots 40 m², and the sub-subplots 20 m². It was considered a 3 m² in the center of the experimental units for harvesting. The cover crops were sown to a depth of 5 cm using a fertilizer sowing machine (without fertilizer) on June 10, 2011, during the summer season, after rice cultivation. Twenty-five, 12, 60, 100, 30, 12, and 40 kg seeds ha^{-1} of *Crotalaria juncea*, *C. spectabilis*, black mucuna, pigeon pea, guandu bean, forage turnip, and caupi beans were sown respectively. All seeds were planted 45 cm apart in rows except for forage turnip seeds, which were sown used 17-cm rows. All plants were irrigated by sub-irrigation. After 135 days, the average total dry matter (root + shoot) was 3567 kg ha^{-1} for *C. juncea*, 4565 kg ha^{-1} for *C. spectabilis*, 1848 kg ha^{-1} for black mucuna, 2298 kg ha^{-1} for pigeon pea, 2944 kg ha^{-1} for guandu bean, 1897 kg ha^{-1} for forage turnip, and 2322 kg ha^{-1} for cowpea.

Eleven days before rice sowing, each plot was divided into two subplots according to soil management type (CT or NTS). In the CT plot, a leveling grid with 22″ disks was used to incorporate the organic residues down to a depth of ≤10 cm. For the NTS plot, plants were desiccated with glyphosate at 960 g a.i. ha^{-1} and 2,4-D at 640 g a.i. ha^{-1}.

The subplots were themselves divided into sub-subplots partitioned into low N (10 kg ha^{-1} applied at sowing), and high N (45 kg ha^{-1} total: 10 kg ha^{-1} applied at sowing, and 30 kg ha^{-1} applied as topdressing 25 d after rice emergence). The nitrogen source was urea.

The rice crop was planted on December 3, 2011, by using a no-tillage seeder machine, with a distance of 0.17 m between rows. The cultivar used was IRGA 424, a variety commonly used by local growers. It has a life cycle of ~117 d and was sown at a seed density of 85 kg ha^{-1}. Sowing fertilization was performed according to crop needs and soil analysis, as recommended by Fageria (2006). A total of 90 kg ha^{-1} P_2O_5 (triple superphosphate) was applied to the sowing row. A total of 70 kg ha^{-1} K_2O (potassium chloride) was used. One-third of it was applied in the sowing row and the remainder 40 d after sowing.

After 10 d soil management and the day before rice sowing, soil samples were drawn for nitrogen analysis. In each sub-subplot, eight separate samples were collected with a Dutch augur at a depth range of 0–10 cm and pooled to form one composite sample. The samples were immediately frozen. Total nitrogen, ammonium, and nitrate were measured. The total nitrogen was determined by the Kjeldahl method. N-NO_3^- and N-NH_4^+ were determined by colorimetry (MONIZ; JORGE; VALADARES, 2009).

At 80 d after rice emergence, leaf samples were collected at the full flowering stage to determine leaf nutrient content. Each sample consisted of fifty flag leaves per sub-subplot. The material was oven dried at 65°C for 72 h, ground, and submitted for laboratory analysis. The material was digested with nitroperchloric acid. Phosphorus was determined by colorimetry, calcium and magnesium by atomic absorption spectrophotometry, potassium by flame emission photometry, and sulfur by turbidimetry (MONIZ; JORGE; VALADARES, 2009).

At 115 d after sowing, when the rice was physiologically mature, biometric parameters were determined. Plant height (m) between the soil surface and the upper end of the highest panicle was measured for ten plants selected at random. The number of tillers per plant was determined for all the plants on 1 m of row. The number of panicles per m^2 was determined by counting the number of panicles in the central 3 m^2 area of each sub-subplot. Grain yield was determined by weighing the grains harvested from each sub-subplots, correcting the moisture content to 13%, and converting to the weight to kg ha^{-1}.

All data were subjected to ANOVA by the F-test using ASSISTAT software, v. 7.6 beta (SILVA; AZEVEDO, 2009). Means were subjected to the Scott–Knot test at 5% probability.

RESULTS AND DISCUSSION

Mineral forms of N in the soil

There was no interaction between cover crop and soil management type for total N, ammonium, and nitrate (Table 1). The average total N for all legume species was 4250 mg kg^{-1}, 42.5% higher than the control (fallow). Forage turnip had the same total N content as the fallow control.

Table 1. Nitrogen content (total N), ammoniacal nitrogen (N NH_4^+), and nitrate nitrogen (N NO_3^-) in the soil as functions of cover crop and soil management.

Cover crop	Total N	N NH_4^+	N NO_3^-
	mg kg^{-1}		
Crotalaria juncea	4535 a[+]	32.5 a	16.0 a
Crotalaria spectabilis	4446 a	30.8 a	15.6 a
Black mucuna	4522 a	31.2 a	15.3 a
Pigeon pea	3927 a	27.2 b	13.5 a
Guandu bean	3820 a	26.0 b	13.0 a
Cowpea	4156 a	29.8 a	14.8 a
Forage turnip	2944 b	23.2 b	10.6 b
Fallow	2983 b	20.5 b	9.6 b
Soil management			
No-tillage system	4123 a	29.29 a	14.12 a
Conventional tillage	3710 b	26.00 b	13.01 a

[+]Means followed by the same letter in the column do not significantly differ from each other according to the Scott–Knott test ($p < 0.05$). *, **, and ns: significant ($p < 0.05$), ($p < 0.01$), and not significant for the F-test, respectively.

Biological N fixation by bacteria symbiotic with the legumes probably increased soil N (FAGERIA; SANTOS, 2007; FAGERIA, 2014; NASCENTE et al., 2016). Nitrogen is made available in the soil from the mineralization of organic matter by soil microbes. They convert organic N to ammonium ion (NH_4^+) and oxidize the latter to nitrate (NO_3^-) (MARY et al., 1996). It is known that legumes increase soil N levels in other conditions as well. Legumes also increase total N more than those of the mineral (ammoniacal and nitric) forms. Mclaren and Cameron (1996) and Fageria, Santos and Oliveira (2013) report that more than 94% of the soil N is bound in plant residue, microbial mass, and humus.

The ammoniacal N content in the soil was equivalent in crotalaria, black mucuna, and cowpea (32.5 mg kg^{-1}, 30.8 mg kg^{-1}, and 31.2 mg kg^{-1}, respectively; Table 1). The ammoniacal N content in the soil under pigeon pea, guandu bean, forage turnip, and fallow were, on average, 30% less than the above. Both nitric- and total N values were the highest where legumes were grown, but were 45% lower than these in the soil under forage turnip and fallow.

For all treatments, soil ammonium levels were higher than those of nitrate (Table 1). This observation can be explained by the fact that *Nitrosomonas* spp. and *Nitrobacter* spp., which oxidize ammonia to nitrite and then nitrite to nitrate, flourish when soil pH is corrected and soil is aerated (POUDEL; HORWATH; LANINI, 2002). Soils with pH < 5.0, such as those in the experimental area, transform ammonium to nitrate more slowly than that by highly alkaline soils (SILVA; VALE; GUILHERME 1994).

Soil management influenced the levels of total N and ammoniacal N in 10 and 11%, respectively, but was not significant for the nitrate content (Table 1). The incorporation of residues into conventionally prepared soil greatly accelerates organic matter decomposition (THONNISSEN et al., 2000). Most of the N is released at the start of decomposition and coincides with low crop N demand during the early stages of plant development. If mineral N is available early, some of it may be lost to NO_3^- leaching (ROSECRANCE et al., 2000). As this present study demonstrated, in the NTS, where plant residues are left on the soil surface and are not incorporated into it, both the soil organic matter and total N content are significantly higher than those of the CT system. Ammonium is the first compound produced by bacteria that transform organic matter (FAGERIA, 2014) and pH < 5 is not conducive to the conversion of ammonium into nitrate. Therefore, as the present study indicated, it was more probable to detect higher values of ammonium in the NTS than the CTS.

Rice plant nutrient content

Leaf nutrient content analysis revealed a triple interaction among the factors for N content (Table 2). Phosphorus was significantly affected by soil management type, and there was an interaction between cover crops and nitrogen fertilization level (Table 3). Potassium was significantly affected by both cover crop and soil management type, and there was no interaction (Table 4). Neither calcium nor magnesium was affected by the factors evaluated. Sulfur was significantly affected by both cover crop type and nitrogen fertilization level (Table 4).

Table 2. Triple interaction (cover crops, soil management type, and nitrogen fertilization level) with leaf nitrogen content.

Low N (10 kg ha^{-1})		
	Soil management	
Cover crop	No-tillage system	Conventional tillage
	--------------------g kg^{-1} ---------------	
Crotalaria juncea	20.23 aA*	15.93 bB
Crotalaria spectabilis	18.24 bA	15.23 bB
Black mucuna	17.90 bA	17.43 aA
Pigeon pea	16.56 cA	14.91 cB
Guandu bean	19.77 bA	15.76 bB
Cowpea	15.33 cA	16.32 bB
Forage turnip	14.53 dA	15.33 bA
Fallow	14.70 dA	14.17 cA
High N (45 kg ha^{-1})		
	Soil management	
Cover crop	No-tillage system	No-tillage system
	--------------------g kg^{-1} ---------------	
Crotalaria juncea	17.37 cA	16.84 bA
Crotalaria spectabilis	25.15 aA	23.05 aB
Black mucuna	23.33 aA	18.81 bB
Pigeon pea	18.92 bA	18.84 bA
Guandu bean	23.34 aA	16.60 bB
Cowpea	17.15 cA	16.14 bA
Forage turnip	20.18 bA	15.65 cB
Fallow	15.97 eA	14.33 cA

*Means followed by the same letter, whether lowercase in columns or upper case in rows, do not differ significantly according to the Scott–Knott test at $0.01 \le p < 0.05$.

Table 3. Double interaction (cover crops and nitrogen fertilization levels) and isolated effect of soil management on leaf phosphorus content.

Cover crop	Level of N fertilization	
	Low Nitrogen	High Nitrogen
	-------------------------g kg^{-1}--------------------------	
Crotalaria juncea	1.06 aA*	0.98 bA
Crotalaria spectabilis	1.08 aA	1.23 aA
Black mucuna	1.02 aB	1.23 aA
Pigeon pea	0.81 bB	1.12 aA
Guandu bean	1.01 aB	1.18 aA
Cowpea	0.87 bB	1.13 aA
Forage turnip	0.88 bB	1.07 bA
Fallow	0.85 bA	0.99 bA
Soil management	**Phosphorus Content**	
	--------------g kg^{-1}-------------	
Conventional tillage	0.987 b	
No-tillage system	1.071 a	

*Means followed by the same letter, whether lowercase in columns or upper case in rows, do not differ significantly according to the Scott–Knott test at $0.01 \leq p < 0.05$.

Table 4. Rice leaf K and S content as functions of cover crop, soil management type, and nitrogen fertilization level.

Cover crop	Potassium content	Sulfur content
	---------------------------------g kg^{-1}-----------------------------	
Crotalaria juncea	8.16 a*	0.61 a
Crotalaria spectabilis	9.03 a	0.68 a
Black mucuna	8.28 a	0.53 b
Pigeon pea	8.05 a	0.52 b
Guandu bean	7.79 a	0.54 b
Cowpea	6.87 a	0.64 a
Forage turnip	7.65 a	0.60 a
Fallow	8.22 a	0.45 b
Soil management	**Potassium content**	
	--------------g kg^{-1}-------------	
Conventional tillage	7.49 b	
No-tillage system	8.42 a	
Level of nitrogen fertilization	**Sulfur content**	
	--------------g kg^{-1}-------------	
Low (10 kg ha^{-1} N)	0.534 a	
High (45 kg ha^{-1} N)	0.615 b	

*Means followed by the same letter do not differ significantly according to the Scott–Knott test at $0.01 \leq p < 0.05$.

Rice leaf nitrogen levels were the highest in treatments with low nitrogen fertilization (10 kg ha^{-1} of N) for all cover crop types in the NTS (Table 2). Black mucuna, forage turnip, and fallow provided similar levels of N in both soil management systems. In the NTS, leaf N levels were higher at the highest nitrogen fertilization levels, but *C. spectabilis*, black mucuna, pigeon pea, and forage turnip provided similar leaf N levels in both systems. As shown in Table 1, the NTS produces greater accumulations of organic matter and mineral N in the soil than does the CTS. Therefore, at these higher soil N levels, the rice plants were able to absorb more of the nutrient than those under the CTS at comparable soil N levels.

At low nitrogen fertilization levels, the highest N content was found where *C. juncea* grew under the NTS and black mucuna grew under the CT (Table 2). When a higher amount of N was added to the soil, the highest levels of N were obtained with *C. spectabilis*, black mucuna, and pigeon pea under NTS, and with *C. spectabilis* under CT. At both nitrogen fertilization levels and both soil management types, the fallow (control) treatment provided the lowest N levels to the rice plants. Therefore, the use of cover crops efficiently increases N levels in rice plants.

Although it is not a legume, forage turnip provided higher N content for cultivated rice than did fallow in both soil management types and at all N fertilization levels (Table 2). Despite the fact that the forage turnip did not add N to the soil, it can cycle soil mineral N mineral and reduce leaching (AITA et al., 2004).

P levels in the rice plants were higher in all cases of cover crops at the highest level of N, differing from black mucuna, pigeon pea, guandu bean, cowpea and forage turnip (Table 3). In general, cover crops that produced lower leaf N contents (Table 2) also produced lower leaf P contents. Therefore, there is a correlation between N and P uptake in rice plants. The correlation analysis between these two nutrients was highly significant and positive (r = 0.7515, $p < 0.001$). According to Fageria (2014), N and P are components in several plant structures, and increasing the levels of one nutrient generally implies that the other increases as well. In the NTS, the leaf P content was higher than that in CT. The NTS soil also had higher values of total N and ammonium than those in CT soil. Thus, higher plant N levels also require higher P levels.

Cover crops did not affect rice K content (Table 4). After cover crop management and the onset of straw degradation, K leached into the soil because this nutrient does not constitute any part of the plant structure. In fact, K is the nutrient most readily released to the soil (FAGERIA; SANTOS, 2007). Potassium is highly mobile at all concentrations in all plant cells and tissues (CALONEGO; FOLONI; ROSOLEM, 2005). Rosolem, Calonego and Foloni (2003) subjected the residues of six cover crop species to various amounts of rainfall and observed considerable leaching of K, with values ranging from 7-24 kg ha^{-1}. Soil K leaches readily (CALONEGO; FOLONI; ROSOLEM, 2005). It is, therefore, likely that nutrients were released from the cover crop straws and some of the K leached. For this reason, there were no significant differences among the treatments in terms of rice leaf K content. In fact, the K values were higher in plants grown under NTS than in those grown under CT. CT promotes K leaching because, unlike NTS, this soil management involves plowing and residue degradation.

The sulfur content was higher in *C. spectabilis*, which did not differ from the cowpea, *C. juncea* and forage turnip (Table 4). *C. spectabilis*, *C. juncea*, and cowpea provided the greatest increase in total soil N and ammonium content. Sulfur forms an integral part of the plant structure, because it is a constituent of cystine, cysteine, and methionine. These amino acids account for ~90% of the total plant S. Sulfur also participates in plant enzymatic processes and redox reactions (MALAVOLTA; VITTI; OLIVEIRA, 1997). Therefore, there probably is a relationship between nitrogen and sulfur in plants. In the present study, a strong correlation was found between the levels of N and S in the soil (r = 0.274, $p < 0.001$) and the plant (r = 0.4792, $p < 0.001$).

Diagnosis and Recommendation Integrated System (DRIS) analysis on rice cultivated on IFP indicates that the nutrient balance in rice leaf is 26 g kg^{-1} N, 2.0 g kg^{-1} P, 12.5 g kg^{-1} K, 2.9 g kg^{-1} Ca, 1.5 g kg^{-1} Mg, and 1.8 g kg^{-1} S (GUINDANI; ANGHINONI; NACHTIGALL, 2009). Thus, in the present study, only the Ca and Mg levels were optimal for crop development, and that even the cover crops did not suffice to supply the needs of the rice. Therefore, supplementary fertilizer application is required (MALAVOLTA, 1980).

Morphologic parameters

Cover crops affected all morphological parameters (plant height, tillering, panicle mass, and grain yield) (Table 5). Soil management affected panicle mass and grain yield. Nitrogen fertilization levels affected tillering, panicle mass, and grain yield. There was an interaction between soil management and nitrogen fertilization level for plant height.

When rice was cultivated after *C. spectabilis*, pigeon pea, *C. juncea*, cowpea, and black mucuna, its yield was ~7% greater than that obtained for rice sown after fallow (Table 5). Rice sown after pigeon pea and forage turnip produced plants that were 4.5% and 6% shorter than the plants that grew after *C. spectabilis* cultivation, respectively. The rice that was planted and grew after fallow had about the same height as the plants that grew after pigeon pea and forage turnip cultivation. Cazetta et al. (2008) reported a relative rice height increase following the planting of black mucuna, *C. juncea,* and pigeon pea. This difference may be explained by the fact that the cover crops increased nitrogen availability (ARF et al., 2015a). At low N fertilization levels, rice plants in the NTS were 6.6% taller than those in CT. N directly affects plant height, and more N was available in the NTS than in the CT. On the other hand, despite the greater availability of this nutrient, no differences between treatments were observed. The high-N treatment produced plants that were 8.6% higher than those from the low-N treatment under CT, but the plants had the same height at both N levels under the NTS.

Table 5. Morphological parameters and grain yield in irrigated rice crop as functions of cover crop type, soil management type, nitrogen fertilization level, and double interaction (soil management and nitrogen fertilization level) for plant height.

Cover crop	Plant height	Tillers	Panicle mass	Grain yield
	----- cm -----	No. tillers	----- g -----	- kg ha $^{-1}$ -
Crotalaria juncea	64.25 a*	4.9 a	190 a	7397 a
Crotalaria spectabilis	65.37 a	5.2 a	190 a	7381 a
Black mucuna	63.00 a	4.2 c	184 a	7167 a
Pigeon pea	61.00 b	3.9 c	183 a	6898 a
Guandu bean	64.81 a	4.2 c	177 a	7137 a
Cowpea	63.37 a	5.0 a	192 a	7476 a
Forage turnip	62.56 b	4.6 b	169 a	5654 b
Fallow	60.87 b	3.3 d	145 b	6559 b

Soil management	Tillers	Panicle mass	Grain yield
	No. tillers	----- g -----	- kg ha $^{-1}$ -
No-tillage system	4.34	192 a	7457 a
Conventional tillage	4.53	166 b	6461 b

N fertilization level	Tillers	Panicle mass	Grain yield
	No. tillers	----- g -----	- kg ha $^{-1}$ -
High N	4.92 a	188 a	7299 a
Low N	3.95 b	170 b	6618 b

Soil management	Plant height	
	Low N	High N
	------------------------------- (cm)-------------------------	
Conventional system	59.5 bB	65.1 aA
No-tillage system	63.7 aA	64.1 aA

*Means followed by the same letter do not differ significantly according to the Scott–Knott test at $0.01 \leq p < 0.05$.

The highest numbers of tillers were observed in the rice sown after *C. juncea*, cowpea, and *C. spectabilis* (Table 5). The fallow treatment resulted in rice plants with the lowest numbers of tillers. In the absence of environmental stress, tillering is a very important component of rice yield (ARF et al., 2015a) and is a function of N availability (FAGERIA; BALIGAR, 2005; ARF et al., 2015b). The correlation between rice leaf N content and tillering was significant and positive ($r = 0.409$, $p < 0.001$). Higher tillering was observed in rice plants cultivated with high nitrogen fertilization levels than those treated with low amounts of N. The soil management type did not affect this variable.

Panicle mass was also influenced by cover crop type (Table 5). Rice cultivation after fallow produced the lowest panicle mass and differed significantly from the other treatments. Panicle production per unit area is the main rice production measure, and it is significantly affected by nitrogen fertilization levels (FAGERIA; STONE, 2003; ARF et al., 2015a). In this study, the correlation between panicle mass and grain yield was significant ($r = 0.281$, $p < 0.05$). Both NTS (higher N content; Table 1) and high N fertilization levels produced higher panicle mass values.

Grain yields derived from cowpea (7,476 kg ha^{-1}), *C. juncea* (7,397 kg ha^{-1}), *C. spectabilis* (7,381 kg ha^{-1}), black mucuna (7,167 kg ha^{-1}), guandu bean (7,137 kg ha^{-1}), and pigeon pea (6,898 kg ha^{-1}) were all similar and did not significantly differ from each other (Table 5). Fallow treatment (6,559 kg ha^{-1}) and forage turnip (5,654 kg ha^{-1}) resulted in lower rice yields and differed significantly from the other treatments. Nascente, Crusciol and Cobucci (2013) used grasses as cover crops for upland rice. They reported that millet gave rise to the highest grain yield. Fageria and Santos (2007) observed that planting the cover crop gray mucuna (*Mucuna cinereum*) and mineral fertilization prior to irrigated rice cultivation (in the same conditions as IFP) significantly increased grain yield.

The highest grain yield was obtained under

NTS and at the higher N fertilization level (Table 5). According to Fageria and Santos (2007), nitrogen is the major nutrient responsible for significant rice yield increases. In this study, NTS resulted in better performance of morphological parameters and higher productivity than did CT. This observation does not corroborate the report of Kluthcouski et al. (2000), who found lower productivity of upland rice under NTS than CT and proposed that the crop was not adapted to the NTS. Nevertheless, flooding can alter the response of rice to the NTS since the water and anaerobic conditions change soil structure and permeability (FAGERIA; SANTOS, 2003).

Based on the data obtained in this study, the use of cover crops can increase soil N, improve plant nutrition, and augment rice yield on tropical flood plains. Cover crops significantly improve both soil- and crop quality compared with the fallow treatment.

CONCLUSIONS

Except for forage turnip, all cover crops provided significant increases in total soil N and nitrate content;

Crotalaria juncea, *C. spectabilis*, black mucuna, and cowpea provided significant increases in soil ammonium content;

The no-tillage system provided higher total soil N and ammonium levels than that by conventional tillage;

In general, cover crops provided higher nutrient levels to rice plants under no-tillage systems than conventional tillage;

Cover crops provided higher rice yield than the fallow treatment. Rice grain yield is higher under no-tillage systems than conventional tillage, and at higher N fertilization levels.

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