

# Cover crops affecting levels of ammonium and nitrate in the soil and upland rice development

## Plantas de cobertura afetando os níveis de nitrato e amônio no solo e o desenvolvimento do arroz de terras altas

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### Abstract

The use of cover crops in no-tillage systems (NTS) increases the levels of organic matter and could increase the nitrogen content of the soil, contributing to reduce fertilizers costs. The knowledge of these processes is fundamental for deciding whether cover crops can be effectively incorporated into the agricultural production system. The objective of this study was to evaluate the effect of cover crop species on the levels of nitrate and ammonium in the soil in early upland rice development, as well upland rice yield. A field experiment was performed and treatments consisted of growing rice on five cover crops (*Panicum maximum*, *Brachiaria ruziziensis*, *Brachiaria brizantha*, millet and fallow) in an NTS and two control treatments (*Brachiaria brizantha* and fallow) under a conventional tillage system, CTS, (one plowing and two disking). The experimental design was a complete randomized block with three replications. The soil samples were collected during a period of six weeks (0, 7, 14, 21, 28 and 35 days in relation to upland rice sowing). The cover crops *Brachiaria brizantha*, *Panicum maximum* and *Brachiaria ruziziensis* in the NTS and *B. brizantha* fallow incorporated into the CTS favored higher levels of nitrate in the soil. In contrast, *B. brizantha* and fallow in the CTS and millet and *P. maximum* in the NTS favored the buildup of high levels of ammonium in the soil. The treatments under the plowed cover crops millet and fallow allowed for a higher upland rice yield. The tillage system and nature of the cover crops could be used to achieve the desired levels and forms of nitrogen in soil.

**Key words:** *Brachiaria brizantha*, *Brachiaria ruziziensis*, *Panicum maximum*, millet, fallow, soil management

### Resumo

O uso de plantas de cobertura no sistema plantio direto (SPD) aumenta os níveis de matéria orgânica e pode ajudar a aumentar os teores de nitrogênio no solo contribuindo para reduzir os custos de fertilizantes. O conhecimento desse processo é fundamental para que as plantas de cobertura possam ser efetivamente incorporadas aos sistemas de produção agrícola. O objetivo deste estudo foi avaliar o efeito de espécies de plantas de cobertura nos níveis de nitrato e amônio no solo durante o desenvolvimento inicial do arroz de terras altas, bem como a produtividade do arroz. Um experimento de campo foi realizado e os tratamentos consistiram de cultivo de arroz sobre cinco plantas de cobertura (*Panicum maximum*, *Brachiaria ruziziensis*, *Brachiaria brizantha*, milheto e pousio) no SPD e mais dois tratamentos controle (*Brachiaria brizantha* e pousio) no sistema de plantio convencional, PC (uma aração e duas gradagens). O delineamento experimental foi em blocos completos casualizados com três repetições. As amostras de solo foram coletadas por seis semanas (0, 7, 14, 21, 28 e 35 dias em relação à semeadura do

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arroz). As culturas de cobertura *B. brizantha*, *Panicum maximum* e *B. ruziziensis* no SPD e *B. brizantha* incorporada e pousio incorporado no PC tiveram os níveis mais elevados de nitratos no solo. Por outro lado, *B. brizantha* e pousio no PC e milheto e *P. máximo* no SPD tiveram os níveis mais elevados de amônio no solo. Tratamentos com a planta de cobertura milheto e pousio incorporado proporcionaram as maiores produtividades do arroz. Sistema de cultivo e espécies de plantas de cobertura podem ser usadas para atingir os níveis desejados e a forma de nitrogênio no solo.

**Palavras-chave:** *Brachiaria brizantha*, *Brachiaria ruziziensis*, *Panicum maximum*, milheto, pousio, manejo do solo

## Introduction

In the last fifteen years, the number of crops cultivated worldwide under a no-tillage system (NTS) has grown impressively. This number was approximately 5 million ha in 1987 (80% of the area was in the USA) and grew to almost 117 million ha in 2007-08. The higher increase in NTS has taken place in Latin America (58 million ha), the USA and Canada (40 million ha) and Australia (17 million ha) (FAO, 2012).

An important point to be considered is the nature of the cover crop used (DABNEY; DELGADO; REEVES, 2001; FILIZADEH; REZAZADEH; YOUNESSI, 2007; YAHUZA, 2011). The correct identification of cover crop can provide many benefits to the agricultural system (NASCENTE; CRUSCIOL, 2012; NASCENTE; CRUSCIOL; COBUCCI, 2013a). In this regard, the decomposition of cover crops present on the ground may provide a greater availability of nutrients, lower release of possible allelopathic substances to the soil, and, especially, lower levels of nitrogen immobilization by the microbial community in the soil when the nitrogen demand of the crops is high (CRUSCIOL et al., 2012; DIECKOW et al., 2006; LAL, 2004).

It is necessary to study the decomposition of straw in order to provide crops with their nutrient plant demand at the right time. Nitrogen is one of the most dynamic nutrients in the NTS (D'ANDRÉA et al., 2004; SAITO et al., 2005). The buildup of high levels of N in the soil before crop demand could lead to nitrate loss through leaching or denitrification (MALAVOLTA, 1980). On the other hand, a delay in the release of N from decomposing crop residues could lead to losses in crop yields (VEIGA;

REINERT; REICHERT, 2010). The amount of nitrogen that will be effectively used by the crop in the succession of cover crops will depend on the timing between the decomposition rate of the cover crop residue and the crop demand (KLIEMANN; BRAZ; SILVEIRA, 2006). Therefore, the cycling of nutrients by cover crops could allow for a better use of soil nutrients, thereby leading to a substantial reduction in the input cost of adding costly fertilizer (ARANDA et al., 2011; BASTIDA et al., 2008; CECCANTI; MASCIANDARO; MACCI, 2007).

The knowledge of these various processes is fundamental for deciding whether cover crops can be effectively incorporated into the agricultural production system (NASCENTE et al., 2011). This knowledge would include knowing the quantities and times of N release and the availability to meet the crop demand. Moreover, such an understanding will determine the amount of additional fertilizer needed (AITA; PORT; GIACOMINI, 2006). However, in Brazil, information is lacking under field conditions on the dynamics of cover crop decomposition and rate and the form of N released from cover crop residues (KLIEMANN; BRAZ; SILVEIRA, 2006).

In addition, upland rice is cultivated in Asia, Africa and the Americas mostly by small or subsistence farmers in the poorest regions of the world (AFRICA RICE CENTER, 2005; CGIAR, 2006; OONYU, 2011). However, the reduction of available water resources due to the demands of the industry and population, mainly in Asia, and the search for alternatives to produce rice while allowing a greater economy of water has been in demand (FENG et al., 2007; QU et al., 2008; NASCENTE; CRUSCIOL; COBUCCI, 2013a).

Some alternatives include growing rice under aerobic conditions, irrigated or not, as well as the use of cover crops to seek a greater soil moisture conservation (BOUMAN et al., 2007; TAO et al., 2006; NASCENTE et al., 2013b). In this regard, the development of technologies that helps to increase the yield of rice on the upland environment, besides producing food and saving more water, could allow for an increase in the revenue of many farmers who depend on this grain to subsist (CGIAR, 2006).

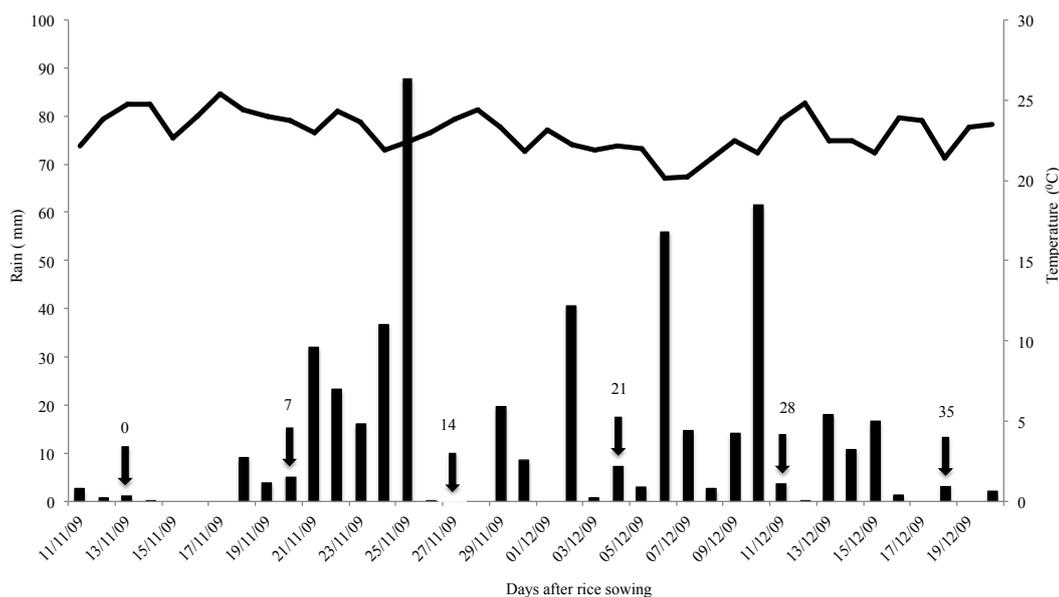
The objective of this study was to evaluate the effect of cover crop species on the levels of nitrate and ammonium in the soil under no-tillage and conventional tillage systems, as well as upland rice yield.

## Materials and methods

### Site descriptions

The field experiment was conducted in Santo Antônio de Goiás, GO (16°27' latitude, 49°17' longitude and 823 m local elevation). The regional climate is tropical savanna, Aw according to the Koppen classification. There are two well-defined seasons, normally dry from May to September (autumn/winter) and rainy from October to April (spring/summer), usually the growing season. The long-term annual average rainfall is between 1500 mm and 1700 mm, and the long-term annual average temperature is 22.7°C, varying annually between 14.2°C and 34.8°C. In addition, climatic data were evaluated during the experiment period (Figure 1).

**Figure 1.** Rain and temperature at the experimental site during the first six weeks of rice growth. Arrows show sampling times, and the labels are days after sowed rice in each sampling.



**Source:** Elaboration of the authors.

The soil was a Rhodic Ferralsol (FAO, 1998) in a gently undulating topography. The soil texture was clayey (540 g kg<sup>-1</sup> clay, 110 g kg<sup>-1</sup>, and 350 g kg<sup>-1</sup> sand). The research was conducted in an area that had been in NTS for eight years (2001-02 - 2008-09) in rotations with corn (2001-02, 2003-04, 2005-

06 and 2007-08), soybean (2002-03, 2004-05 and 2006-07) and upland rice (2008-09) in the summer and fallow in the winter.

Regarding the soil analysis, for the chemical analysis of the soil before the installation of the

experiment, 48 samples were collected in each of the following layers: 0-0.05 m, 0.05-0.10 m and 0.10-0.20 m depths (Table 1). P and K were extracted by Mehlich 1 extracting solution (0.05 M HCl in 0.0125 M H<sub>2</sub>SO<sub>4</sub>). From the extracted solution, phosphorus was measured colorimetrically and K

by flame photometry. Ca, Mg, and Al were extracted with 1 M KCl. Aluminum was collected by titration with NaOH and Ca and Mg by titration with EDTA from the extracted solution. The micronutrients were measured on a portion of the extract for P by atomic absorption spectrophotometry.

**Table 1.** Soil chemical properties at the experimental area, 2009.

Depth (cm)	pH water	Ca .....cmol <sub>c</sub> dm <sup>-3</sup> .....	Mg	Al	P	K	Cu	Zn	Fe	Mn	M.O. g dm <sup>-3</sup>
							.....mg dm <sup>-3</sup> .....				
0 – 5	5.7	2.8	1.4	0.0	14.6	191.9	1.5	4.9	30.6	25.2	23.0
5 – 10	5.7	2.1	0.8	0.0	15.4	144.9	1.8	4.4	32.2	20.9	17.5
10 – 20	5.5	1.8	0.5	0.1	15.9	107.7	1.9	4.0	32.3	18.4	13.5

**Source:** Elaboration of the authors.

#### Experimental design and treatments

The experimental design was randomized blocks with five cover crops + two control treatments with three replications, totaling 21 plots. Each plot measured 6.0 m x 10 m. The cover crops used to grow rice in the no-tillage system were as follows: 1 – fallow (spontaneous vegetation, predominantly *Bidens pilosa*, *Commelina benghalensis*, *Conyza bonariensis* and *Cenchrus echinatus*); 2 - *Panicum maximum*; 3 - *Brachiaria ruziziensis*; 4 - *Brachiaria brizantha*; and 5 - millet (*Pennisetum glaucum*). Beside these treatments, two additional treatments considered controls were included in growing rice in the conventional tillage system (CTS), 1 plowing and 2 disking: 6 – *B. brizantha* and 7 – fallow (spontaneous vegetation) incorporated 30 days before rice sowing.

#### Crop management

The cover crops were sowed in the off-season (March 2009). For this sowing, tropical forages were planted in 0.20 m rows using a mechanical planter set to distribute 10 kg seeds ha<sup>-1</sup> with at least 30% viable seed germination without fertilization. In the following summer (November 2009), the cultivar

of upland rice (*Oryza sativa* L.) BRS Sertaneja was sowed, spaced 0.35 m apart with a population of 60 plants per meter, using the fertilization of 20 kg ha<sup>-1</sup> N as urea, 120 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> as triple super phosphate and 60 kg ha<sup>-1</sup> K<sub>2</sub>O as potassium chloride and, for topdressing fertilization, 45 kg N ha<sup>-1</sup> as urea one day after the upland rice was seeded and later, at the beginning of the tillering stage, 45 kg N ha<sup>-1</sup> as urea. Culture management was performed according to rice needs.

Herbicide was applied to all cover crops of the NTS treatments 30 days before and on the upland rice sowing day right before the sowing operation. The herbicide glyphosate was used at a 1.8 kg ha<sup>-1</sup> acid equivalent. For this application, a boom sprayer was used with a spray volume of 200 liters ha<sup>-1</sup>. The environmental conditions during pulverization were weak winds, a temperature of approximately 25°C and relative humidity around 80%. This operation was performed after drying the dew on the cover crop leaves.

#### Soil sampling

The soil sampling was performed with an auger on the upland rice sowing day (30 days after

cover crop desiccation) and five additional times (7, 14, 21, 28 and 35 days) in all treatments and replications following the method suggested by Aita, Port and Giacomini (2006), Pacheco (2009), and Oliveira (2010). Thus, eight sub-samples were collected in each composite sample from each plot at a depth 0-10 cm, which were homogenized by hand, labeled, wrapped in plastic bags, kept in a cooler with ice and sent to the lab for analysis.

#### *N-NH<sub>4</sub><sup>+</sup> and N-NO<sub>3</sub><sup>-</sup> evaluation*

The analyses of mineral N were performed the same day of soil sample collection. From each soil sample, a representative aliquot of 20 g was removed and mixed with 60 ml of extraction solution KCl 2 mol L<sup>-1</sup>. (BREMNER, 1965). After shaking for an hour and decanting the solid material, the supernatant was filtered using filter paper. This supernatant was used to quantify the levels of nitrate and ammonium.

For this experiment, the method proposed by Griess (1879) was used in which nitrate was quantified indirectly in the form of the nitrite ion after the reaction with sulphanilamide and N- $\alpha$ -naphthalene diamine. The ammonium was measured according to the methodology of Berthelot (1859). Both mineral nitrogen sources were measured by spectrophotometry coupled to an FIA ("Flow Injection Analysis") following the methodology used by Gine et al. (1980).

Parallel to the determination of mineral N, the moisture from the soil samples was determined by weighing immediately after soil sampling and then drying in an oven at 105°C for 72 h, weighing again to calculate the dry weight, and aiming at presenting the results of ammonium and nitrate on a dry basis. The amounts of N-NH<sub>4</sub><sup>+</sup> and N-NO<sub>3</sub><sup>-</sup> were expressed in mg kg<sup>-1</sup> dry soil, considering the concentration of these forms of N in the layer evaluated. The soil pH in water was already measured using a pH meter during the N-NH<sub>4</sub><sup>+</sup> and N-NO<sub>3</sub><sup>-</sup> evaluations.

#### *Dry matter cover crop degradation*

At the beginning of rice development (30 days after cover crop desiccation) and every 7 days (same day sampling of ammonium and nitrate in the soil) a total of seven assessments (0, 7, 14, 21, 28 and 35 days after rice sowing) were collected, and the dry matter of the cover crops was evaluated. The samples were taken using a hollow metallic square of 1.0 m x 1.0 m (1.0 m<sup>2</sup>) thrown at random in each plot. All plant material was collected using the methodology proposed by Crusciol and Soratto (2009) and Nascente, Pereira and Medeiros (2004). The plant samples were placed in paper bags and dried in an oven with forced ventilation at 65°C until constant weight of plant dry matter.

To evaluate cover crop degradation, an exponential mathematical model was used (OLIVEIRA, 2010; PACHECO, 2009; THOMAS; ASAKAWA, 1993) with the formula

$$y = y_0 \cdot e^{(-kt)}, \text{ equation (1)},$$

where y is the fraction of initial residue existing at time t, y<sub>0</sub> is the proportion of potentially decomposable residue and k is the constant of decomposition of the residue. With the data, a graphic of the dry matter degradation of each species of plant cover was made.

#### *Upland rice yield*

The manual harvest of upland rice was conducted when approximately 90% of panicles had grains of typical mature coloration. Therefore, the grain yield was measured (unhulled grain weight collected at three central rows of five meters in each split-plot, eliminating 2.5 meters on each side of the plots from the usable areas, correcting their moisture content to 130 g kg<sup>-1</sup> and converting to kg ha<sup>-1</sup>).

#### *Statistical analysis*

All data were analyzed using the Statistical Software Package SAS (SAS INSTITUTE, 1999).

The cropping system (five cover crops + two control, totaling seven treatments) and sampling day (0, 7, 14, 21, 28 and 35 days after upland rice sowing) were considered fixed effects. Two error terms were considered in the analysis of the data, one associated with the cropping system and the other associated with the sampling day and the interaction (cropping system x sampling day). Mean separations were conducted using the LSD test. The effects were considered statistically significant at  $P \leq 0.05$ , as by Aita, Port and Giacomini (2006), Nascente, Crusciol and Cobucci (2013a) and Nascente et al. (2013b). If necessary, a polynomial

regression analysis was also performed for cover crop degradation and mineral N data for each type of straw depending on the sampling day.

## Results and Discussions

### Nitrate

Regarding nitrate, there were effects of the cover crops, sampling day and interaction (Table 2). The application of urea 1 day after upland rice sowing favored increased levels of nitrate in the soil in all plots, which was observed in the subsequent sampling (7 days) (Figure 2).

**Table 2.** Variance analyses of nitrate, ammonium, the nitrate ammonium rate, pH and rice yield under soil cultivated with cover crops.

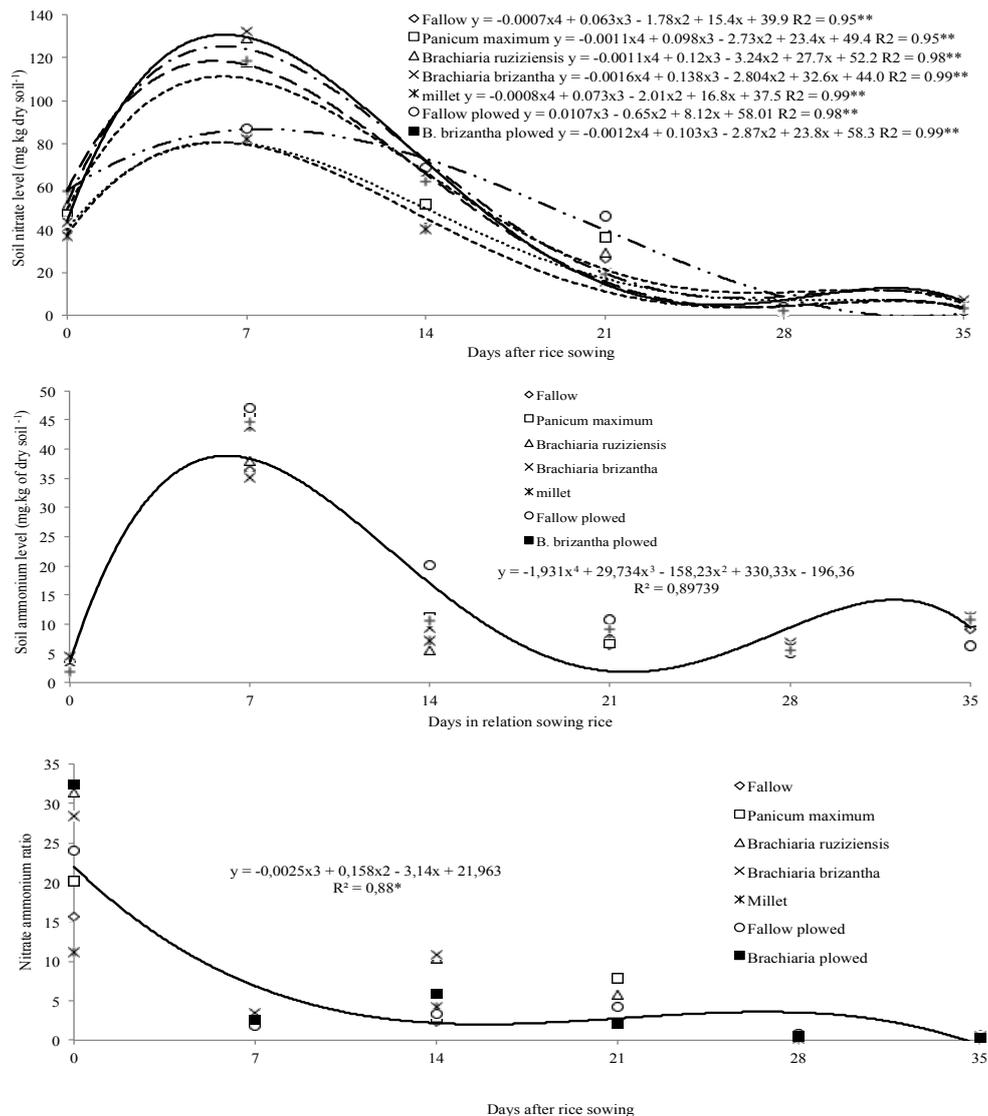
Variable	Nitrate	Ammonium	$\text{NO}_3^-/\text{NH}_4^+$	pH	Rice Yield
Cover crop (C)	<0.001	0.5467	0.8786	<0.001	<0.001
Sampling day (D)	<0.001	<0.001	<0.001	<0.001	-
C*D	0.0423	0.8793	0.7584	<0.001	-

**Source:** Elaboration of the authors.

Additionally, Oliveira (2010) and Pacheco (2009) found increased levels of nitrate in the soil after the application of nitrogen fertilizers; this result can be explained by the input of nitrogen to the soil (FAGERIA; MOREIRA; COELHO, 2011). In this sense, after urea application, an increase of ammonium in the soil was expected. However, in the soil, urea is hydrolyzed by the action of urease in two or three days, producing ammonium carbonate, and then  $\text{NH}_3$ ,  $\text{CO}_2$  and water (FAGERIA, 2009). Ammonia ( $\text{NH}_3$ ), depending on the pH and soil

moisture, can be lost by evaporation. However, part of this molecule is converted to  $\text{NH}_4^+$ . In this aerobic environment, the metabolism from ammonium to nitrate through the intermediate form nitrite, in a process called nitrification, is rapid (FAGERIA; MOREIRA; COELHO, 2011). Therefore, as the second sampling was performed six days after urea application, it was possibly too late to measure ammonium before it changed to nitrate (MALAVOLTA, 1980).

**Figure 2.** Nitrate, ammonium and nitrate/ammonium in the soil under cover crops in tillage and no-tillage systems in the first six weeks of rice growing.



Source: Elaboration of the authors.

The soil level of nitrate was different among the cover crops used (Table 3). The amount of nitrate was lower in the cover crops millet and fallow, and these crops were different from all other cover crops, mainly in the first three weeks of rice development (Figure 3). A sharp drop in the soil nitrate levels was also observed for all cover crops after the third sampling (14 days). This drop occurred partly because of the root development of the upland rice plants, as they absorb nitrogen from the soil as they grow (FAGERIA, 2009; MALAVOLTA, 1980).

However, this result also reflects the large amount of rainfall that had occurred in the experimental area (Figure 1). One day before the fourth soil sampling, there was 40.6 mm of rain, and between the fifth and sixth samplings, 160 mm of rainfall water accumulated, 61.40 mm of which fell down in the night prior to this fifth soil sampling. According to D'Andréa et al. (2004), nitrate is easily leachable and this leaching is directly related to the volume of water precipitated. This relationship is because there is a predominance of negative charges in the

soil and NO<sub>3</sub><sup>-</sup> has a low chemical interaction with the soil minerals, therefore causing the easy loss of this anion following the downward flow of water that percolates through the soil profile (FAGERIA, 2009).

At an average of six weeks, the nitrate levels were higher in plots with *P. maximum* (44.02 mg kg dry soil<sup>-1</sup>), *B. ruziziensis* (42.26 mg kg dry soil<sup>-1</sup>),

<sup>1</sup>) and *B. brizantha* (45.59 mg kg dry soil<sup>-1</sup>) in the NTS and *B. brizantha* plowed (44.03 mg kg dry soil<sup>-1</sup>) and fallow plowed (44.47 mg kg dry soil<sup>-1</sup>) in the conventional tillage system (Table 3). In the conventional tillage system, it is usual to find a larger amount of nitrate, which may be related to the increased mineralization of organic matter in this type of soil management after plowing (FAGERIA, 2009; VEIGA; REINERT; REICHERT, 2010).

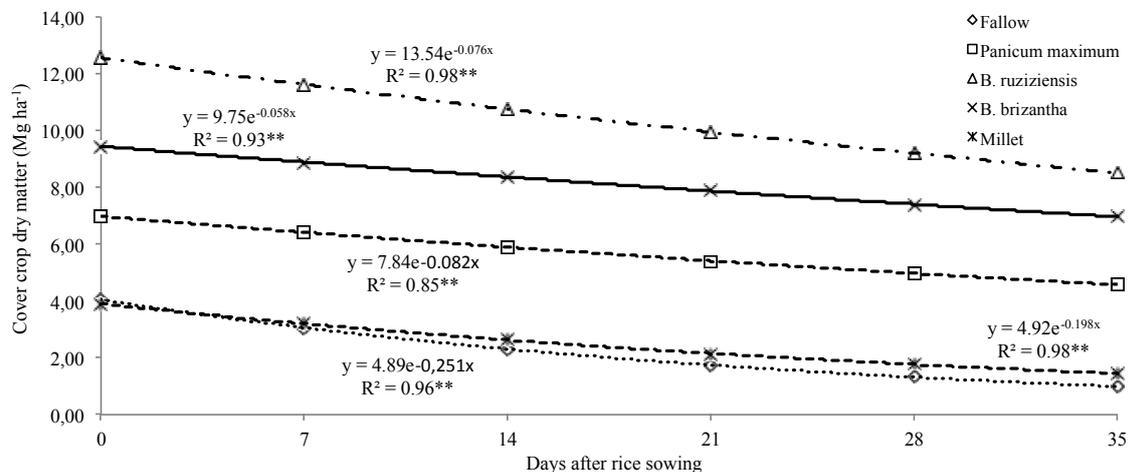
**Table 3.** Levels of nitrate and ammonium (average of the first 6 weeks of upland rice development) at depths from 0 to 10 cm and rice yield under soil with rice cover crops in tillage and no-tillage systems.

Treatments	Nitrate -----mg kg dry soil <sup>-1</sup> -----	Ammonium	Rice yield kg ha <sup>-1</sup>
Fallow	32.98 b	12.00 b	3,460 b
<i>Panicum maximum</i>	44.02 a	14.10 a	2,857 cd
<i>Brachiaria ruziziensis</i>	42.26 a	11.90 b	2,177 d
<i>Brachiaria brizantha</i>	45.59 a	12.26 b	2,356 d
Millet	30.24 b	13.57 a	4,263 a
Fallow plowed	44.47 a	15.32 a	3,774 ab
<i>Brachiaria brizantha</i> plowed	44.03 a	13.74 a	2,616 cd
Average	40.40	12.91	2,287

\* Same lower case letters vertically do not differ by the LSD test at p < 0.05.

Source: Elaboration of the authors.

**Figure 3.** Cover crop dry matter degradation after rice sowing and regression analysis. \*\* Significant by the F test at p < 0.01.



Source: Elaboration of the authors.

### Cover crop degradation

Regarding the cover crops in NTS, the results corroborate with those obtained by Boer et al. (2007), D'Andréa et al. (2004), Pacheco (2009) and Rosolem, Werle and Garcia (2010), who found a large amount of nitrate in the NTS. According to these authors, during straw degradation, ammonium is produced first, but due to the humidity, temperature stability, pH and the presence of oxygen, the activity of bacteria that transform ammonium to nitrate faster than in conventional tillage is favored. Beside this favoritism, large amounts of cover crop dry matter are produced in NTS (Figure 3) and, after herbicide application in those plants, most likely due to high temperatures and humidity, straw degradation is favored, increasing the levels of nitrogen in the soil. According to Boer et al. (2007) and Rosolem, Werle and Garcia (2010), the high N mineralization rate is also correlated to the rapid plant residue decomposition (Figure 2). Similar results were obtained by Oliveira (2010), where *B. brizantha* straw favored increased levels of nitrogen in the soil in NTS. These results demonstrate that the use of cover crops with large biomass production could lead to an increase in the nitrogen content of the soil that can be used by the crops that follow.

As for millet and fallow, the straw values of nitrate were lower than the other treatments, differing by the "LSD" test (Table 3). This difference seems again to be related to the amount of dry matter produced by the covers. Millet and fallow produced the lowest amount of biomass and also favored the lowest levels of these ions in the soil (Table 3 and Figure 3).

### Ammonium

It was also found that the levels of ammonium after nitrogen fertilization (1 day after upland rice sowing) increased in the soil (Figure 2). A regression analysis showed no interaction between the cover crops and sampling time (Table 2). On average, fallow (12.00 mg kg dry soil<sup>-1</sup>), *B. ruziziensis* (11.90 mg kg dry soil<sup>-1</sup>) and *B. brizantha* (12.26 mg kg

dry soil<sup>-1</sup>) in NTS were significantly different from millet (13.57 mg kg dry soil<sup>-1</sup>) in NTS and fallow plowed (15.32 mg kg dry soil<sup>-1</sup>) (Table 3). It was also observed that the crop covers *B. brizantha* and fallow in the conventional tillage system and millet and *P. maximum* in the NTS had, on average, the largest ammonium values and did not differ from each other by the LSD test but differed from the other cover crops. These results can be explained by the conventional tillage system favoring organic matter mineralization and by ammonium being the first nitrogen compound generated (FAGERIA, 2009). Beside this result, *Panicum maximum* and millet showed a rapid degradation and also the fastest delivery of this ion to the soil (Figure 2).

Additionally, the amount of nitrate was much larger than that of ammonium (Table 3). This result is typical of well-drained soils, such as the Brazilian Cerrado (FAGERIA, 2009). Normally, the average concentrations of NH<sub>4</sub><sup>+</sup> found in agricultural soils are smaller than those of NO<sub>3</sub><sup>-</sup> (MARSCHNER, 1995; OWEN; JONES, 2001; POLETTI; GROHS; MUNDSTOCK, 2008), which occurs mainly due to limitations in ammonium diffusion (SCHJOERRING et al., 2002) and to the rapid oxidation from NH<sub>4</sub><sup>+</sup> to NO<sub>3</sub><sup>-</sup> by nitrifying bacteria (NORTON, 2000).

### pH

After nitrogen fertilization with urea (day 1), there was a reduction in the soil pH in all of the plots, which was observed in two subsequent samples at 7 and 14 days after rice sowing in all treatments, compared with day 0 (Table 4). This increased acidity is possibly caused by the use of nitrogen fertilizer (urea) when it releases hydrogen ions that contribute to soil acidification (FAGERIA, 2009), as observed in this trial. It was also found that from the fourth sampling, the pH values increased in the soil of all plots. This increase is possibly due to the plants releasing OH<sup>-</sup> bound to H<sup>+</sup> and raising the pH to maintain the internal equilibrium when they absorb nitrate (MALAVOLTA, 1980; MARSCHNER, 1995).

**Table 4.** Values of pH during the first six weeks of rice plant development under cover crops in the no-tillage and conventional tillage systems.

Treatments	Days after rice sowing					
	0	7	14	21	28	35
Fallow	5.94 a B	5.83 abc C	5.48 ab D	5.75 b C	5.94 bc B	6.12 ab A
<i>P. maximum</i>	5.88 ab B	5.78 abc B	5.34 b D	5.61 c C	5.87 c B	6.04 bcd A
<i>B. ruziziensis</i>	5.74 bc B	5.92 ab A	5.44 ab C	5.56 c C	5.88 c A	5.97 cd A
<i>B. brizantha</i>	5.96 a A	5.83 abc A	5.37 b B	5.50 c B	5.84 c A	5.94 d A
Millet	6.02 a AB	5.93 a B	5.42 b C	5.93 a B	6.05 ab AB	6.17 ab A
Fallow plowed	5.70 c B	5.70 c B	5.30 b C	5.57 c B	6.13 a A	6.15 bc A
<i>B. brizantha</i> plowed	5.97 a BC	5.73 bc CD	5.67 a D	5.87 ab BC	6.07 ab AB	6.27 a A

\*Same upper case letter horizontally or lower case letter vertically do not differ at  $p < 0.05$  by the LSD test.

Source: Elaboration of the authors.

### Upland rice yield

It could be seen that millet in the no-tillage system allowed for the statistically highest upland rice yield and was similar to fallow plowed and differed from all other treatments (Table 3). This result may have occurred because upland rice crop seems to “prefer” ammonium nitrogen or the lowest nitrate ammonium rate in the first weeks of its development (MALAVOLTA, 1980). Millet, in this regard, for almost all six samplings, stood out as having the lowest values of nitrate (Table 3 and Figure 2). These data are extremely important because again, upland rice plants are different from most agricultural crops because it comes from a hydrophilic environment (MALAVOLTA, 1980; FAGERIA; MOREIRA; COELHO, 2011), which prevails ammonium (HOLZSCHUH et al., 2009; SCHJOERRING et al., 2002; WANG et al., 1993). Therefore, upland rice has difficulty in synthesizing nitrate in its first month of development due to a lack of the nitrate reductase enzyme. This fact may explain the low initial rice development when only  $\text{N-NO}_3^-$  prevails in the environment with a reflex in rice yield (HOLZSCHUH et al., 2009; MALAVOLTA, 1980), as observed under *B. brizantha*, *B. ruziziensis* and *Panicum maximum*.

Kronzucker et al. (1998) and Wang et al. (1993) showed that upland rice plants develop better when

higher levels of  $\text{N-NH}_4^+$  are available in its early development. However, Holzschuh et al. (2009) warn that only ammonium in the environment can be prejudicial for rice plants. Therefore, cover crops that can provide larger amounts of  $\text{N-NH}_4^+$  or a lower nitrate ammonium rate in the early development of upland rice may provide a good strategy to allow this crop in NTS. Millet, in this regard, seems to be the best option (Figure 2), allowing the highest upland rice yield in this trial (Table 3).

In this regard, upland rice is grown worldwide on irrigated land (QU et al., 2008). However, the reduction of available water resources due to the demands of industry and the population requires the search for alternatives that allow a greater economy of water (FENG et al., 2007; QU et al., 2008). Some alternatives include growing rice under aerobic conditions, irrigated or not, and also the use of cover crops, seeking a greater conservation of soil moisture (BOUMAN et al., 2007; TAO et al., 2006). Upland rice is cultivated in Asia, Africa and the Americas mostly by small or subsistence farmers in the poorest regions of the world (AFRICA RICE CENTER, 2005; OONYU, 2011). Therefore, development of technologies that help to increase the yield of rice on upland environments, besides producing food and saving more water, could allow for an increase in the revenue of many farmers who depend of this grain to subsist (CGIAR, 2006).

In this study, it could be observed that plowed millet and fallow had the statistically highest upland rice yields. However, plowed fallow that causes soil disturbances and is therefore not eligible for the no-tillage system does not seem to be a good option. On the other hand, the worst rice yields were found under cover crops *Brachiaria brizantha*, *Panicum maximum* and *Brachiaria ruziziensis* in the NTS (2356, 2857 and 2177 kg ha<sup>-1</sup>, respectively). Moreover, those grasses may have some allelopathic effect that hampers aerobic rice plant development. Martins, Martins and Costa (2006), Souza Filho, Rodrigues and Rodrigues (1997), and Souza et al. (2006) reported allelopathic effects caused by species of *Brachiaria* in rice. Therefore, from the data obtained, *Brachiaria brizantha*, *B. ruziziensis* and *Panicum maximum*, despite their importance in NTS for producing large amounts of biomass (Figure 3), do not seem to be the ideal cover crop for upland rice. However, in an agricultural system, we could infer that before upland rice, it is important to introduce millet. After upland rice harvesting, perennial forage, such as *Panicum maximum*, *Brachiaria brizantha* or *B. ruziziensis*, could be introduced to achieve a great amount of cover crop in the beginning of the following rainy season and to cultivate another cash crop. Allen et al. (2005) observed a higher cotton yield under forage species than cotton monoculture. Kluthcouski et al. (2000) obtained higher corn, soybean and common bean yields using straws of *Panicum maximum* and *B. brizantha*. Crusciol et al. (2010) also had better results with a soybean crop on *Brachiaria* straw. Nascente and Crusciol (2012) had the highest soybean yield under *Brachiaria brizantha*, *B. ruziziensis*, *Panicum maximum* and millet under NTS that differed from plowed fallow.

## Conclusions

The cover crops *Brachiaria brizantha*, *Panicum maximum* and *Brachiaria ruziziensis* in the NTS and *B. brizantha* and fallow incorporated in the

CTS favored higher levels of nitrate in the soil. On the other hand, *B. brizantha* and fallow in the CTS and millet and *P. maximum* in the NTS favored the buildup of high levels of ammonium in the soil. The treatments under the plowed cover crops millet and fallow allowed for the statistically highest upland rice yield. The tillage system and the nature of cover crops could be used to achieve the desired levels and forms of nitrogen in the soil.

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