Comissão 3.3 - Manejo e conservação do solo e da água

UPLAND RICE UNDER NO-TILLAGE PRECEDED BY CROPS FOR SOIL COVER AND NITROGEN FERTILIZATION[1]

Edemar Moro[2], Carlos Alexandre Costa Crusciol[3], Heitor Cantarella[4] & Adriano Stephan Nascente[5]

SUMMARY

The grain yield of upland rice under no-tillage has been unsatisfactory and one reason could be the nitrate/ammonium balance in the soil. Cover crops and nitrogen fertilization can be used to change the nitrate/ammonium relation in the soil and improve conditions for the development of upland rice in the no-tillage (NT) system. The aim was to study the effect of cover crops and nitrogen sources on grain yield of upland rice under no tillage. The study was carried out on the Fazenda Experimental Lageado, in Botucatu, State of São Paulo, Brazil, in an Oxisol area under no-tillage for six years. The experiment was arranged in a randomized block split-plot design with four replications. The plots consisted of six cover crop species (*Brachiaria brizantha*, *B. decumbens*, *B. humidicola*, *B. ruziziensis*, *Pennisetum americanum,* and *Crotalaria spectabilis*) and the split-plots of seven forms of N fertilizer management. Millet is the best cover crop to precede upland rice under NT. The best form of N application, as nitrate, is in split rates or total rate at topdressing or an ammonium source with or without a nitrification inhibitor, in split doses. When the cover crops *C. spectabilis*, *B. brizantha*, *B. decumbens*, *B. humidicola,* and *B. ruziziensis* preceded rice, they induced the highest grain yield when rice was fertilized with N as ammonium sulfate source + nitrification inhibitor in split rates or total dose at topdressing.

Index terms: *Oryza sativa*, ammonium, nitrate, millet, *Brachiaria*, *Crotalaria spectabilis*, nitrogen.

---

[1] Part of the Doctoral Thesis of the first author submitted to the College of Agricultural Sciences at São Paulo State University (UNESP). Support by FAPESP. Received for publication on January 11, 2013 and approved on July 24, 2013.

[2] Professor, University of Western São Paulo - UNOESTE. Raposo Tavares Highway, km 572, Campus II , Block B3. Zip Code 19067-175 Presidente Prudente (SP), Brazil. E-mail: edemar@unoeste.br

[3] Professor, Department of Crop Science (Agriculture), College of Agricultural Sciences, São Paulo State University - UNESP. PO Box 237. Zip Code 18603-970 Botucatu (SP), Brazil. Research scholarship from CNPq. E-mail: crusciol@fca.unesp.br

[4] Researcher, Agronomic Institute of Campinas, Center of Soil and Environmental Resources. PO Box 28. Zip code 13012-970 Campinas (SP), Brazil. Research scholarship from CNPq. E-mail: cantarella@iac.sp.gov.br

[5] Researcher, Embrapa Rice and Beans, GO-462 Highway, km 12, Rural Zone. PO Box 179. Zip Code 75375-000 Santo Antônio de Goiás (GO), Brazil. E-mail: adriano.nascente@embrapa.br

RESUMO: *ARROZ DE TERRAS ALTAS NO SISTEMA PLANTIO DIRETO - PLANTAS DE COBERTURA E FONTE DA ADUBAÇÃO NITROGENADA*

O arroz de terras altas não está tendo bom desempenho no sistema de plantio direto (SPD) e uma razão pode ser o balanço nitrato e amônio no solo. O uso de plantas de cobertura e a aplicação de N podem ser utilizados para alterar a relação nitrato/amônio no solo e proporcionar melhores condições para o desenvolvimento de arroz de terras altas no SPD. O objetivo deste trabalho foi estudar o efeito de plantas de cobertura e fontes de N na produtividade do arroz de terras altas em SPD. O experimento foi realizado na Fazenda Experimental Lageado, Botucatu, em Latossolo Vermelho distroférrico, em área com seis anos no SPD. O delineamento experimental foi em blocos casualizados, com parcelas subdivididas e quatro repetições. As parcelas foram constituídas por seis espécies de plantas de cobertura do solo (Brachiaria brizantha, B. decumbens, B. humidicola, B. ruziziensis, Pennisetum americanum *e* Crotalaria spectabilis) *e as subparcelas por sete formas de manejo da adubação nitrogenada. Milheto é a melhor planta de cobertura para anteceder o arroz de terras altas no SPD e a melhor forma de aplicar o N como nitrato é parcelado ou dose total na cobertura, ou amônio com ou sem inibidor de nitrificação parcelado.* C. spectabilis, B. brizantha, B. decumbens, B. humidicola *e* B. ruziziensis *proporcionam as mais altas produtividades do arroz quando o N é aplicado como sulfato de amônio + inibidor de nitrificação parcelado ou aplicação total na cobertura.*

Termos para indexação: Oryza sativa*, amônio, nitrato, milheto, Brachiaria,* Crotalaria spectabilis*, nitrogênio.*

INTRODUCTION

Cover crops are plant species used to cover and protect the soil against erosion and nutrient loss through leaching or runoff (Dabney et al., 2001). They also contribute to carbon sequestration and can improve soil quality and increase the soil organic matter, nutrient cycling and cation exchange capacity (Aranda et al., 2011). Cover crops are very important in the no-tillage (NT) system, a technique used on about 25 million hectares of agricultural production in Brazil (Febrapdp, 2012) and on around 120 million hectares worldwide (FAO, 2006).

In this context, we address rice, which is a staple grain in the diet of half the world's population, produced in both lowland and upland ecosystems (Santos et al., 2006). Upland rice, particularly, is cultivated in Asia, Africa and the Americas by mostly small or subsistence farmers in the poorest regions of the world (Oonyu, 2011). Its importance is increasing, since the water availability for rice irrigation by the flooding method is decreasing in Asia, mainly in China and India, due to the rapid growth of industry and urban centers (Feng et al., 2007).

However, producing upland rice under NT still requires improvements, in view of the low yields in this system (Kluthcouski et al., 2000). One reason for this low grain yield would be the low activity of the enzyme nitrate reductase (NR), inhibiting N nutrition of the rice seedlings in environments with high nitrate concentrations (Malavolta, 1980). Experiments performed by Sá (1999) and D'Andréa et al. (2004) showed that in a NT, the availability of $N\text{-}NO_3^-$ in the soil is higher than under conventional tillage, due to the fact that the levels of soil moisture, nutrients and organic matter are higher under no-tillage, stimulating the microbial activity, especially nitrifying bacteria. Additionally, Holzschuh et al. (2009) reported that upland rice developed better when there were similar amounts of ammonium and nitrate in the early crop stages.

In this regard, according to Pacheco et al. (2011) and Nascente et al. (2013a), the evaluation of cover crops can be useful to improve conditions for NT upland rice. Cover crops can increase the nutrient availability (due to straw decomposition), reduce the possible release of allelopathic substances into the soil and decrease the rate of N immobilization by the soil microbial community (Nascente et al., 2013b).

Therefore, as the low performance of NT upland rice may be due to the predominance of nitrate in the soil, practices that limit nitrification temporarily and/or increase the amount of ammonium in the soil could be a solution to improve the crop development. One of these practices could be crop rotation of cover crops preceding upland rice (Pacheco et al., 2011; Nascente et al., 2013a).

Another possibility would be the use of N sources such as ammonium at rice sowing and/or shortly after emergence. However, as the transformation from $N\text{-}NH_4^+$ to $N\text{-}NO_3^-$ in the soil occurs rapidly (Malavolta, 1980; Crusciol et al., 2011), some steps would be required, especially the use of nitrification inhibitors together with ammonium sources and the cultivation of rice after cover crop with potential for nitrification inhibition.

In the light of this information, the hypothesis of this study was: the low performance of upland rice in NT may be due to the predominance of nitrate in the soil; cover crops can inhibit nitrification and consequently balance the NO_3^-/NH_4^+ ratio in the soil, improving the development of upland rice, raising yields to viable economic levels; and when growing upland rice in NT, the probability of success is greater with ammonium as N source. Therefore, the aim was to study the effect of the interaction of cover crops and N sources on the grain yield of upland rice under no tillage.

MATERIAL AND METHODS

The trial was performed in the 2009/2010 growing season on the Fazenda Experimental Lageado of the College of Agricultural Sciences/UNESP, Botucatu, State of São Paulo, Brazil (22° 51' S latitude, 48° 26' W longitude, 740 m asl). According to the Köeppen classification, the prevailing climate in the region is Cwa, high altitude tropical, with dry winters and hot and rainy summers. During the trial, additional temperature and rainfall data were collected daily (Figure 1).

The soil was an Oxisol (Embrapa, 2006) managed under no tillage for six years. The crop sequence in this pre-experimental period was as follows: soybean/oat; maize/*Brachiaria brizantha;* soybean/oat; common bean/oat; soybean/fallow and corn in the summer/beginning of the experiment.

The experiment was arranged in randomized blocks, in a split plot design with four replications. The plots consisted of six species of cover crops (*Brachiaria brizantha*, *B. decumbens*, *B. humidicola*, *B. ruziziensis*, *Pennisetum americanum,* and *Crotalaria spectabilis*) and split plots (experimental unit) and seven forms of N fertilizer management, applied 0 and 30 days after emergence (DAE) of the rice seedlings [Control: no N fertilization; Calcium nitrate, NO (40+40 kg ha^{-1}); NO (0+80 kg ha^{-1}); Sulfate ammonium, NH (40+40 kg ha^{-1}); NH (0+80 kg ha^{-1}); Ammonium sulfate + dicyandiamide (DCD), NHI (40+40 kg ha^{-1}); and NHI (0+80 kg h^{-1})]. *Brachiaria* species were used in view of their ability to inhibit nitrification. Millet was used because it is the species most commonly used as straw source in the Cerrado, and crotalaria is being increasingly used, mainly due to its ability to reduce nematodes.

Prior to the experiment, the soil (layer 0-20 cm) was analyzed for the chemical properties: organic matter 34 g dm^{-3}; pH($CaCl_2$) 5.8; P(resin) 35 mg dm^{-3}; S 40 mg dm^{-3}; H+Al, K, Ca and Mg 6.36, 3.6, 43.0 and 34.0 mmol$_c$ dm^{-3}, respectively, V 73 %. Fe, Cu, Mn, Zn and B, respectively, 6.0, 7.5, 105, 2.3 and 0.22 mg dm^{-3}; and NH_4^+ and NO_3^-, respectively 6.0 and 15.7 mg dm^{-3}.

Spontaneous vegetation was desiccated with Glyphosate (2,000 g ha^{-1} active ingredient, acid equivalent) and cover crops were sown with a planter tractor implement (model Personale DRILL-13, Semeato). The seeding rate and row spacing were according to the recommendations for each species. The cover crops were sown on April 2009 and desiccated in October 2009 (150 DAE) with Glyphosate (2,000 g ha^{-1} acid equivalent). Prior to fertilization, the cover crop dry matter was determined, as well as the accumulated amount of N and concentration of N-NH_4^+ and NO_3^- in the straw (Table 1).

After 30 days, the concentration of N-NO_3^-, N-NH_4^+ and total N in the soil was determined according to Silva (1999), in the 0-5 and 5-20 cm layers (Table 2), and rice cultivar IAC 202 was sown, on December 10, 2009, in rows spaced 0.34 m apart, at a density of 80 seeds per meter, with the same planter model for NT systems, in experimental units of 7 x 4.5 m. The fertilizer was applied at sowing according to the method proposed by Raij et al. (1997).

The eight central rows of each experimental unit were considered, disregarding 1.0 m at either end of each plant row for data collection. In the rice plants, N concentrations (ammonium, nitrate, total) sampled 42 DAE were evaluated according to Silva (1999). Rice leaves were sampled in the morning between 8:00 and 10:00 am.

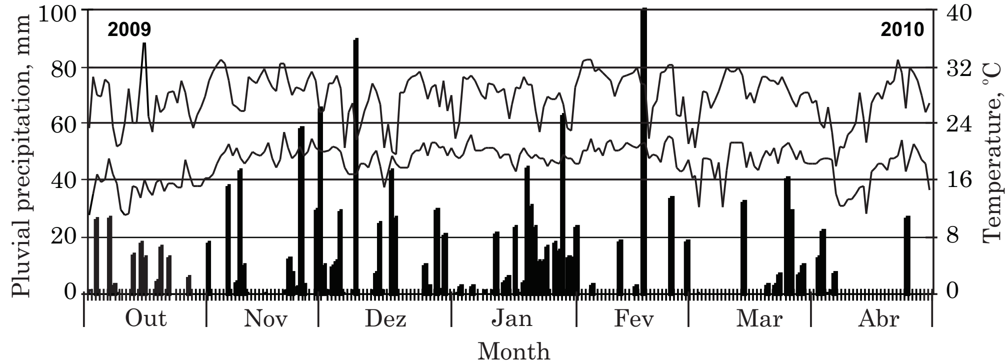

Figure 1. Precipitation (▌), maximum (▬) and minimum (▬) temperatures during the experiment.

Table 1. Dry matter (DM), nitrogen (N) concentration and content, and ammonium ($N\text{-}NH_4^+$) and nitrate ($N\text{-}NO_3^-$) concentration in cover crops before fertilization

Specie	DM	N concentration	N content	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$
	kg ha^{-1}	g kg^{-1}	kg ha^{1}	g kg^{-1}	
Pennisetum americanum	10,660	11.4	122	0.30	1.00
Crotalaria spectabilis[(1)]	8,700	25.3	220	0.26	0.31
Brachiaria brizantha	12,540	14.6	183	0.28	0.86
Brachiaria decumbens	14,620	11.2	164	0.29	0.56
Brachiaria humidicola	12,470	14.5	181	0.28	0.57
Brachiaria ruziziensis	7,030	15.6	110	0.26	1.28

(1) Management practices were applied to *Crotalaria spectabilis* in the early stage of grain filling.

The number of panicles per square meter was obtained by counting panicles contained in 4 m in the assessed area of each split plot. From this result, the number of panicles m^{-2} was calculated. The total number of spikelets per panicle was obtained from 15 panicles per split plot. The spikelet fertility was determined by the ratio of the number of filled spikelets by the total number of spikelets per panicle x 100. The 1,000-grain-weight was obtained by weighing four samples of 1,000 grains per split plot. The grain yield was obtained by sampling of panicles of the usable area of each experimental unit and then the material was threshed and cleaned. After this operation, the weight of grain harvested was determined and extrapolated to Mg ha^{-1} at 130 g kg^{-1} wet basis. The data were subjected to analysis of variance, and means were compared by the LSD test ($p \leq 0.05$).

RESULTS AND DISCUSSIONS

A higher amount of biomass from the cover crops ranging from 7,030 to 10,660 was observed (Table 1). According to Pacheco et al. (2011) and Nascente et al. (2013a,b), these cover crops are well-known for producing high amount of biomass, which is very important for regions such as the Cerrado, where soil fertility is low. Cover crops during straw degradation could release nutrients to the soil and increase the soil fertility. Corroborating this information, it was stated that all cover crop species contained significant foliar amounts of nitrate and ammonium. As a result, increased soil concentrations of ammonium and nitrate were observed for all cover crops, higher than those measured in the beginning of the experiment (Table 2).

Ammonium levels in rice plants were influenced by cover crops and N management (Table 3). The split application of $N\text{-}NH_4^+$ with nitrification inhibitor (DCD) resulted in the highest values, differing from split application of $N\text{-}NO_3^-$, and from NH_4^+ with or without protection (DCD) in a single application. Therefore, it appears that the split N application was more suitable for rice, and results were best when using the N source ammonium. When fertilizing with a nitrate source, split applications were not efficient, possibly due to lower the "ability" of upland rice to metabolize greater amounts of nitrate in the early developmental stages (Malavolta, 1980). The results of N fertilization in a single dose 30 DAE suggest that in this stage, rice plants have a greater ability to metabolize N in nitrate form. Regarding the ammonium source, it seems clear that split applications obtained better results because it is likely that in early developmental stages upland rice plants "preferred" this N source (Soares, 2004).

Of the cover crops, *C. spectabilis* induced the greatest ammonium accumulation in upland rice plants, differing from millet, *B. decumbens* and *B. humidicola* (Table 3). This can be explained by the fact that *C. spectabilis* is a legume, with normally high foliar N levels (Table 1).

Regarding nitrate, it was found that N application without splitting (80 kg ha^{-1}), 30 DAE resulted in the highest concentration in rice shoots (Table 3), when preceded by millet and *Crotalaria spectabilis*. Cazetta et al. (2008), Pacheco et al. (2011) and Nascente et al. (2013b) observed that millet recycles significant N amounts and emphasize the importance of growing cover crops in NT areas. In a comparison of the *Brachiaria* species, the highest nitrate concentration in rice shoots was observed when grown after *B. ruziziensis*.

The total N concentration in upland rice plants was influenced by cover crops and N fertilization management (Table 3). Thus, it appears that the levels were highest after the single application of 80 kg ha^{-1}, regardless of the source (NO, NH and NHI). The single application (30 DAE) a few days before sampling (42 DAE) explains these results. In cover crops, *C. spectabilis* provides the highest value, differing from *B. decumbens*, *B. humidicola* and *B. ruziziensis* (Table 3). These results can be explained because *C. spectabilis* is a legume cover crop, and it would have accumulated 220 kg ha^{-1} N at the time of chemical cover crop management (Table 1).

It is noteworthy that the highest levels of total N in rice plants with an application of 80 kg ha^{-1} 30 DAE, may be due to the fact that the experiment was

Table 2. Ammonium (NH_4^+), nitrate (NO_3^-), and total nitrogen (TN) concentration in the two soil layers as affected by cover crops, evaluated immediately before upland rice sowing

Cover crop	Soil layer					
	0-5 cm			5-20 cm		
	NH_4^+	NO_3^-	TN	NH_4^+	NO_3^-	TN
	mg kg^{-1}		g kg^{-1}	mg kg^{-1}		g kg^{-1}
Pennisetum americanum	12.09	14.25	1.79	10.24	14.60	1.45
Crotalaria spectabilis	12.65	15.12	1.97	8.49	16.47	1.56
Brachiaria brizantha	11.72	16.48	2.02	10.63	13.79	1.61
Brachiaria decumbens	13.70	22.17	2.18	11.14	15.19	1.56
Brachiaria humidicola	14.24	20.41	2.11	8.39	14.34	1.66
Brachiaria ruziziensis	12.30	19.14	1.98	11.12	17.38	1.60

Table 3. Ammonium, nitrate, and total nitrogen concentration in upland rice shoots, 42 days after emergence, as affected by cover crops and nitrogen sources under no-tillage

N management	Cover crop(1)						Mean
Source/temporary distribution	Millet	Crot	Briz	Decu	Humi	Ruzi	
			N-NH_4^+ (mg kg^{-1})				
Control	0.27 bcAB	0.30 bA	0.24 cB	0.26 abB	0.26 abcB	0.27 abAB	0.27 ab
NO-40+40	0.27 bcA	0.27 bcA	0.25 cA	0.26 abA	0.23 cA	0.26 abA	0.26 b
NO-00+80	0.33 aA	0.27 bcB	0.32 aA	0.20 cC	0.24 bcB	0.25 bB	0.27 ab
NH-40+40	0.23 cCD	0.36 aA	0.30 abB	0.21 cD	0.23 cCD	0.27 abBC	0.27 ab
NH-00+80	0.24 bcB	0.25 cB	0.25 cAB	0.26 abAB	0.26 abcAB	0.30 aA	0.26 b
NHI-40+40	0.28 bA	0.28 bcA	0.27 bcA	0.28 aA	0.28 abA	0.29 abA	0.28 a
NHI-00+80	0.23 cB	0.26 cAB	0.23 cB	0.23 bcB	0.30 aA	0.27 abAB	0.25 b
Mean	0.26 B	0.28 A	0.27 AB	0.24 C	0.26 B	0.27 AB	-
			N-NO_3^- (mg kg^{-1})				
Control	0.22 cA	0.18 eAB	0.14 cB	0.11 eB	0.12 eB	0.12 cB	0.15 f
NO-40+40	0.69 bA	0.61 cdB	0.41 bC	0.27 dD	0.28 dD	0.60 bB	0.48 e
NO-00+80	0.87 aB	1.03 aA	0.52 aD	0.60 bCD	0.53 abD	0.62 bC	0.70 b
NH-40+40	0.68 bA	0.65 cA	0.51 aB	0.62 abA	0.43 cC	0.63 bA	0.59 c
NH-00+80	0.93 aB	1.06 aA	0.58 aD	0.69 aC	0.47 bcE	0.65 bCD	0.73 a
NHI-40+40	0.66 bA	0.57 dBC	0.53 aC	0.40 cD	0.52 abC	0.61 bAB	0.55 d
NHI-00+80	0.92 aA	0.80 bB	0.52 aD	0.62 abC	0.57 aCD	0.73 aB	0.69 b
Mean	0.71 A	0.70 A	0.46 C	0.47 C	0.42 E	0.57 B	-
			Total N (g kg^{-1})				
Control	21.2 dA	23.2 cA	23.2 cA	21.5 dA	23.3 dA	20.7 cA	22.2c
NO-40+40	30.1 bcA	29.7 bA	29.3 bA	28.6 bcA	28.8 bcA	29.2 abA	29.3b
NO-00+80	32.7 abA	34.2 aA	32.3 aA	30.4 abA	30.1 abcA	30.7 aA	31.7a
NH-40+40	28.3 cA	30.3 bA	27.9 bA	30.0 abA	28.4 cA	27.0 bA	28.7b
NH-00+80	33.3 aA	30.5 bA	32.1 aA	32.8 aA	31.3 abA	31.5 aA	31.9a
NHI-40+40	29.9 cA	29.4 bA	30.1 abA	27.0 cA	28.3 cA	30.0 aA	29.0b
NHI-00+80	33.5 aA	33.4 aA	32.3 aA	32.7 aA	32.2 aA	31.8 aA	32.7a
Mean	29.9 AB	30.1 A	29.6 AB	28.9 B	28.9 B	28.7 B	-

(1) Millet - *Pennisetum americanum*, Crot - *Crotalaria spectabilis*, Briz - *Brachiaria brizantha*, Decu - *B. decumbens*, Humi - *B. humidicola* and Ruzi - *B. ruziziensis*. Control (without N application), NO: calcium nitrate, NH:ammonium sulfate, NHI: ammonium sulfate + nitrification inhibitor (DCD), 40+40 - 40 kg ha^{-1} N applied 0 DAE of rice and 40 kg ha^{-1} applied 30 DAE, 80 kg ha^{-1} N applied 30 DAE. Means followed by the same letter, lowercase in columns and uppercase in rows, do not differ by the LSD test ($p \leq 0.05$).

carried out after six years of a NT system, with soil ammonium and nitrate levels of 6.0 and 15.7 mg dm^{-3}, respectively (0-20 cm layer), where growing cover crops had been groan with high levels of N (Tables 1 and 2). These high nutrient levels may have possibly nurtured the plant prior to fertilization. In this sense, the history of the area, cover crops used and N levels in the soil must be taken into consideration, for adequate recommendations of N fertilization applied to the soil and consequently to the plant.

The number of panicles was influenced by cover crops and N fertilization management (Table 4). All sources of N fertilization produced higher values than the control. The increase in the number of panicles m^{-2} due to N fertilization was observed by Cazetta et al. (2008) and Nascente et al. (2011). Regarding the cover crops, millet and *C. spectabilis* induced the highest number of panicles m^{-2}, possibly because they produced the highest N levels in rice plants (Table 3). Among *Brachiaria* species, the highest number was observed in plots with *B. ruziziensis*, especially when N was supplied as ammonium.

Regarding the number of spikelets per panicle, all sources of N fertilization outperformed the control, with a slight advantage for management NHI-00+80. *B. decumbens* produced the largest number of spikelets (Table 4). This result can be partly explained by the lower number of panicles m^{-2}. Thus, due to less competition for space, it is likely that the plants produced larger panicles and consequently a larger number of spikelets (Santos et al., 2006). Cazetta et al. (2008) observed little influence of the cover crops on the number of spikelets.

Spikelet fertility was little influenced by the N management and cover crops (Table 4). Arf et al. (2003) and Farinelli et al. (2004) also found no effect of N fertilization on spikelet fertility. However, Bordin et al. (2003) observed higher spikelet fertility in rice grown after wild bean (*Canavalia brasiliensis*), *C. spectabilis* and millet.

In terms of 1,000-grain-weight, results were best in the control and N fertilized shortly after germination (Table 4). Cazetta et al. (2008) reported that this parameter is influenced by the cultivar, N fertilization distribution and level of available water. Of the cover crops, millet produced the highest 1,000-grain-weight. The number of rice panicles was highest under millet straw. At a high number of rice panicles, the tendency is to reduce the panicle size, resulting in fewer spikelets, allowing greater grain filling and, consequently, higher grain weight (Santos et al., 2006), as observed in this trial. Bordin et al. (2003) also found superiority of millet for this characteristic in different cover crops.

The rice grain yield was influenced by the preceding cover crops and N fertilization management (Table 4). The highest yield was obtained with split application of N as ammonium (40 kg ha^{-1} applied twice) with inhibitor, which differed significantly from the others, with the exception of nitrate application (40+40 kg ha^{-1}).

This indicates the importance of N fertilization for rice, since the average yield in the treatment where N was omitted was the lowest (4.0 Mg ha^{-1}), i.e., 1.4 Mg ha^{-1} lower than the highest yield (Table 4). These results confirm those reported by Bordin et al. (2003), Farinelli et al. (2004), Crusciol et al. (2011) and Nascente et al. (2011), of significant increases in rice yield by N fertilization. Regarding the optimal distribution of N fertilization, it was observed that the total application at topdressing was not the most effective, whereas the split application, which resulted in higher yields, was more effective. In addition, later fertilization at higher N concentrations can increase susceptibility to blast (Freitas et al., 2010).

Millet was the cover crop that produced the highest upland rice grain yield (6.8 Mg ha^{-1}), which differed from the other cover crops (Table 5). In the split application of N as ammonium, the yield was even higher (7.6 Mg ha^{-1}) and statistically different from all other cover crops. Our data were consistent with Crusciol et al. (2011), Pacheco et al. (2011) and Nascente et al. (2013a, b), who also reported a higher grain yield of upland rice mulched with millet straw. These authors attributed the results to a rapid degradation of millet residue intensifying nutrient cycling. Moreover, this rapid straw decomposition decreases the possibility of the release of allelopathic substances after desiccation (Souza et al., 2006).

Regarding the interaction between sources and distribution of N application x cover crops it was observed that millet preceding rice induced the highest grain yield, with all sources and distribution of N application (Table 4). For all cover crops, the best temporary distribution of N fertilization was half the dose (40 kg ha^{-1}) at sowing and half the dose (40 kg ha^{-1}) at topdressing, when using the N source NHI-ammonium sulfate + nitrification inhibitor and applying the entire N rate (80 kg ha^{-1}) with the same source at topdressing, with the only exception millet. In this sense, it can be inferred that no-tillage cover crops were more limiting to the success of upland rice than the N source in all treatments, since, on average, the highest yield was similar for all cover crops, under both N sources (5.2 Mg ha^{-1} for nitrate and 5.1 Mg ha^{-1} for ammonium). The only exception was *C. spectabilis*, which produced the highest rice grain yield in the control treatment (without N). On the other hand, the cover crops provided significant differences ranging from 3.5 Mg ha^{-1} (after *C. spectabilis*) to 7.6 Mg ha^{-1} (after millet). Our data indicate that high grain yields of no-tillage upland rice can be obtained when millet is the preceding cover crop and N applied as nitrate in split rates or the total dose at topdressing or ammonium source in split rates or ammonium source + nitrification inhibitor in split rates.

The grain yield of rice is determined by four components: number of panicles m^{-2}, number of spikelets per panicle, spikelet fertility and 1,000-grain-

Table 4. Yield components of upland rice as affected by cover crops and nitrogen sources under no-tillage

N management	Cover crop[(1)]						Mean
Source/temporary distribution	Millet	Crot	Briz	Decu	Humi	Ruzi	
				Panicles (number m^{-2})			
Control	0.27 bcAB	0.30 bA	0.24 cB	0.26 abB	0.26 abcB	0.27 abAB	0.27 ab
Control	276 cAB*	310 aA	219 dC	264 cB	228 bC	251 bBC	258 b
NO-40+40	366 aA	336 aAB	330 abBC	307 aBC	299 aC	314 aBC	325 a
NO-00+80	321 bAB	331 aAB	297 bcB	312 aAB	312 aAB	335 aA	318 a
NH-40+40	352 abA	340 aA	342 aA	304 abBC	280 aC	320 aAB	323 a
NH-00+80	331 bA	325 aAB	324 abcAB	301 abAB	292 aB	316 aAB	315 a
NHI-40+40	354 abA	340 aAB	319 abcB	269 bcC	282 aC	331 aAB	316 a
NHI-00+80	343 abA	318 aAB	292 cB	326 aAB	311 aAB	318 aAB	318 a
Mean	335 A	329 AB	303 CD	298 CD	286 D	312 BC	-
				Spikelets (number/panicle)			
Control	119 dC	120 bC	136 cBC	157 dAB	137 cABC	161 cA	138 c
NO-40+40	144 bcC	142 abC	170 abB	217 aA	182 abB	184 abcB	173 ab
NO-00+80	186 aAB	139 abE	178 abABC	197 abA	173 abBC	162 cCD	173 ab
NH-40+40	151 bC	138 abC	160 bBC	185 bcA	182 abAB	194 aA	168 ab
NH-00+80	125 cdC	152 aB	187 aA	170 cdAB	158 bcB	169 bcAB	160 b
NHI-40+40	146 bcB	140 abB	161 bB	187 bcA	161 bcB	186 abA	164 ab
NHI-00+80	185 aB	124 bC	171 abB	220 aA	188 aB	168 bcB	176 a
Mean	151 C	136 D	166 B	190 A	169 B	175 B	
				Spikelet fertility (%)			
Control	80.0 bcA	82.0 abA	83.5 aA	83.5 abA	82.0 aA	81.1 abA	82ab
NO-40+40	83.7 abA	84.6 aA	83.7 aA	83.7 abA	83.3 aA	83.8 aA	84a
NO-00+80	82.4 abA	81.6 abA	79.5 abA	79.8 bA	81.7 aA	80.0 abA	81ab
NH-40+40	82.8 abA	79.5 cdAB	77.2 bB	82.8 abA	80.2 aAB	78.5 bAB	80b
NH-00+80	76.6 cBC	75.0 cC	82.7 aA	84.7 aA	82.2 aA	81.1 abAB	80b
NHI-40+40	83.2 abA	80.0 abA	83.0 aA	84.1 abA	83.9 aA	79.3 abA	82ab
NHI-00+80	86.0 aAB	81.5 abBC	80.3 abC	86.9 aA	83.8 aABC	82.3 abABC	83a
Mean	82 AB	81 B	81 B	84 A	82 AB	81 B	
				1,000 grain-weight (g)			
Control	22.8 aA	20.8 bB	21.4 aAB	20.1 aB	21.2 aB	20.7 aB	21.2 a
NO-40+40	21.7 abcAB	22.7 aA	19.6 bcC	19.9 aC	20.4 abBC	20.5 abBC	20.8 a
NO-00+80	19.9 dAB	19.8 abAB	19.4 cAB	19.5 aAB	18.6 cB	20.3 abA	19.6 b
NH-40+40	22.5 abA	19.8 abBC	19.6 bcBC	20.3 aBC	20.8 abB	19.1 bC	20.4 ab
NH-00+80	21.1 bcdA	18.4 cC	19.2 cBC	20.0 aAB	20.2 abAB	19.3 abBC	19.7 b
NHI-40+40	21.8 abcA	19.8 abB	21.0 abAB	20.2 aB	20.4 abAB	20.3 abAB	20.6 ab
NHI-00+80	20.9 cdA	19.3 abB	19.2 cB	19.4 aAB	19.4 bcAB	20.0 abAB	19.7 b
Mean	21.5 A	20.1 B	19.9 B	19.9 B	20.1 B	20.0 B	
				Grain yield (Mg ha^{-1})			
Control	5.1 dA	4.6 aA	2.7 dD	2.9 cdBC	3.6 cB	4.9 cA	4.0 c
NO-40+40	7.4 aA	3.5 cC	4.3 bcB	4.8 aB	5.0 aB	6.3 abB	5.2 ab
NO-00+80	7.4 aA	4.4 abC	3.9 bcC	4.2 abC	4.1 bcC	5.1 cB	4.9 bc
NH-40+40	7.6 aA	3.8 bcD	4.1 bcCD	4.2 abCD	4.7 abC	6.3 abB	5.1 b
NH-00+80	6.6 bcA	4.8 aB	3.9 cC	3.6 bcC	4.1 bcBC	6.0 bA	4.9 bc
NHI-40+40	7.3 abA	4.3 abC	5.3 aB	4.4 aC	4.5 abBC	6.8 aA	5.4 a
NHI-00+80	5.9 cA	4.3 abB	4.7 abB	4.4 aB	5.0 aB	6.2 abA	5.1 b
Mean	6.8 A	4.2 C	4.1 D	4.1 D	4.4 C	6.0 B	

[(1)] Millet - *Pennisetum americanum*, Crot - *Crotalaria spectabilis*, Briz - *Brachiaria brizantha*, Decu - *B. decumbens*, Humi - *B. humidicola* and Ruzi - *B. ruziziensis*. Control (without N application), NO: calcium nitrate, NH:ammonium sulfate, NHI: ammonium sulfate + nitrification inhibitor (DCD), 40+40 - 40 kg ha^{-1} N applied 0 DAE of rice and 40 kg ha^{-1} applied 30 DAE, 80 kg ha^{-1} N applied 30 DAE. Means followed by the same letter, lowercase in columns and uppercase in rows, do not differ by the LSD test ($p \leq 0.05$).

weight (Santos et al., 2006). In this context, the superiority of millet observed in this study was due to the larger number of panicles per m^2 and higher 1,000-grain-weight (Table 4).

It is noteworthy that with the exception of *B. ruziziensis* (6.0 Mg ha^{-1}) all other *Brachiaria* resulted in lower rice grain yields, differing from *B. ruziziensis* and also millet (Table 4). These results suggest that there may be some allelopathic effect of these plants that prevent rice development. Souza Filho et al. (1997), Martins et al. (2006) and Souza et al. (2006) reported allelopathic effects caused by *Brachiaria* species. These authors assume that these effects may reduce the crop germination and plant development, affecting yields. However, although rice poduced low grain yield when preceded by certain cover crops, as corroborated by other authors (Kluthcouski et al., 2000), our results are interesting, once millet seems to increase the rice grain yield and could be an alternative as a cover crop preceding upland rice in the no-tillage system.

CONCLUSIONS

1. Millet is the best-suited cover crop to precede upland rice under no-tillage. The best distribution of N application, as nitrate, is in split rates or total rate at topdressing or an ammonium source with or without a nitrification inhibitor, in split doses;

2. The cover crops *Crotalaria spectabilis*, *Brachiaria brizantha*, *B. decumbens*, *B. humidicola* and *B. ruziziensis* cultivated in intercropping or in crop rotation preceding upland rice produced highest rice grain yields when N was applied as ammonium sulfate (source) + nitrification inhibitor, in split rates or total dose at topdressing.

ACKNOWLEDGEMENTS

The authors are indebted to the São Paulo Research Foundation (FAPESP) for the financial support and to the National Council for Scientific and Technological Development (CNPq) for an award for excellence in research of the second and third authors.

LITERATURE CITED

ARANDA, V.; AYORA-CAÑADA, M.J.; DOMINGUEZ-VIDAL, A.; MARTÍN-GARCÍA, J.M.; CALERO, J.; DELGADO, R.; VERDEJO, T. & GONZÁLEZ-VILA, F.J. Effect of soil type and management (organic vs. conventional) on soil organic matter quality in olive groves in a semi-arid environment in Sierra Mágina Natural Park (S Spain). Geoderma, 164:54-63, 2011.

ARF, O.; RODRIGUES, R.A.F.; CRUSCIOL, C.A.C.; SA, M.E. & BUZETTI, S. Manejo do solo e adubação nitrogenada para cultivares de arroz de terras altas irrigadas por aspersão. Sci. Agric., 60:348-352, 2003.

BORDIN, L.; FARINELLI, R.; PENARIOL, F.G. & FORNASIERI FILHO, D. Sucessão de cultivo de feijão-arroz com doses de adubação nitrogenada após adubação verde, em semeadura direta. Bragantia, 62:417-428, 2003.

CAZETTA, D.A.; ARF, O.; BUZETTI, S.; SA, M.E. & RODRIGUES, R.A.F. Desempenho do arroz de terras altas com a aplicação de doses de nitrogênio e em sucessão às culturas de cobertura do solo em sistema de plantio direto. Bragantia, 67:471-479, 2008.

CRUSCIOL, C.A.C.; GARCIA, R.A.; CASTRO, G.S.A. & ROSOLEM, C.A. Nitrate role in basic cation leaching under no-till. R. Bras. Ci. Solo, 35:1975-1984, 2011.

D'ANDRÉA, A.F.; SILVA, M.L.N.; CURI, N. & GUILHERME, L.R.G. Carbon and nitrogen storage, and inorganic nitrogen forms in a soil under different management systems. Pesq. Agropec. Bras., 39:179-186, 2004.

DABNEY, S.M.; DELGADO, J.A. & REEVES, D.W. Use of winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal., 7:1221-1250, 2001.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro, 2006. 306p.

FARINELLI, R.; PENARIOL, F.G.; FORNASIERI FILHO, D. & BORDIN, L. Características agronômicas de arroz de terras altas sob plantio direto e adubação nitrogenada e potássica. R. Bras. Ci. Solo, 28:447-454, 2004.

FEDERAÇÃO BRASILEIRA DE PLANTIO DIRETO NA PALHA - FEBRAPDP. Evolução do plantio direto no Brasil. Available at: <http://www.febrapdp.org.br/arquivos/EvolucaoAreaPDBr72A06.pdf>. Accessed: Mar. 31, 2012.

FENG, L.P.; BOUMAN, B.A.M.; TUONG, T.P.; CABANGON, R.J.; LI, Y.L.; LU, G.A. & FENG, Y.H. Exploring options to grow rice under water-short conditions in northern China using a modeling approach. I: Field experiments and model evaluation. Agric. Water Manage., 88:1-13, 2007.

FOOD AND AGRICULTURE ORGANIZATION - FAO. World reference base for soil resources. Rome: FAO, 2006. Available at: <http://www.fao.org/docrep/W8594E/W8594E00.htm>. Accessed: Mar. 13, 2012.

FREITAS, J.G.; MALAVOLTA, V.M.A.; SALOMON, M.V.; CANTARELLA, H.; CASTRO, L.H.S.M. & AZZINI, L.E. Adubação nitrogenada e incidência de brusone em arroz de sequeiro. Bragantia, 69:173-179, 2010.

HOLZSCHUH, M.J.; BOHNEN, H.; ANGHINONI, I.; MEURER, E.J.; CARMONA, F.C. & COSTA, S.E.V.G.A. Rice growth as affected by combined ammonium and nitrate supply. R. Bras. Ci. Solo, 33:1323-1331, 2009.

KLUTHCOUSKI, J.; FANCELLI, A.L.; DOURADO NETO, D.; RIBEIRO, C.M. & FERRARO, L.A. Manejo do solo e o rendimento de soja, milho, feijão e arroz em plantio direto. Sci. Agric., 57:97-104, 2000.

MALAVOLTA, E. Elementos de nutrição mineral de plantas. São Paulo: Agronômica Ceres, 1980. 251p.

MARTINS, D.; MARTINS, C.C. & COSTA, N.V. Potencial alelopático de soluções de solo cultivado com *Brachiaria brizantha*: Efeitos sobre a germinação de gramíneas forrageiras e plantas daninhas de pastagens. Planta Daninha, 24:61-70, 2006.

NASCENTE, A.S.; KLUTHCOUSKI, J.; RABELO, R.R.; OLIVEIRA, P.; COBUCCI, T. & CRUSCIOL, C.A.C. Produtividade do arroz de terras altas em função do manejo do solo e da época de aplicação de nitrogênio. Pesq. Agropec. Trop., 41:60-65, 2011.

NASCENTE, A.S.; CRUSCIOL, C.A.C.; STONE, L.F. & COBUCCI, C. Upland rice yield as affected by previous summer crop rotation (soybean or upland rice) and glyphosate management on cover crops. Planta Daninha, 31:147-155, 2013a.

NASCENTE, A.S.; CRUSCIOL, C.A.C. & COBUCCI, T. The no-tillage system and cover crops Alternatives to increase upland rice yields. Eur. J. Agron., 45:124-131, 2013b.

OONYU, J. Upland rice growing: A potential solution to declining crop yields and the degradation of the Doho wetlands, Butaleja district-Uganda. Afr. J. Agric. Res., 6:2774-2783, 2011.

PACHECO, L.P.; BARBOSA, J.M.; LEANDRO, W.M.; MACHADO, P.L.O.A.; ASSIS, R.L.; MADARI, B.E. & PETTER, F.A. Produção e ciclagem de nutrientes por plantas de cobertura nas culturas de arroz de terras altas e de soja. R. Bras. Ci. Solo, 35:1787-1800, 2011.

RAIJ, B.van; CANTARELLA, H.; QUAGGIO, J.A. & FURLANI, A.M.C. Recomendações de adubação e calagem para o Estado de São Paulo. 2.ed. Campinas, IAC, 1997. 285 p. (Boletim Técnico, 100)

SÁ, J.C.M. Manejo da fertilidade do solo no sistema plantio direto. In: SIQUEIRA, J.O.; MOREIRA, F.M.S.; LOPES, A.S.; GUILHERME, L.R.G.; FAQUIN, V.; FURTINI NETO, A.E. & CARVALHO, J.G., eds. Inter-relação fertilidade, biologia do solo e nutrição de plantas. Viçosa, MG, SBCS/UFLA/DCS, 1999. p.267-319.

SANTOS, A.B.; STONE, L.F. & VIEIRA, N.R.A. A cultura do arroz no Brasil. 2.ed. Santo Antônio de Goiás, Embrapa Arroz e Feijão, 2006. 1000p.

SILVA, F.C. Manual de análises químicas de solos, plantas e fertilizantes. Rio de Janeiro, Embrapa Solos, 1999. 370 p.

SOARES, A.A. Desvendando o segredo do insucesso do plantio direto do arroz de terras altas. Inf. Agropec., 25:61-69, 2004.

SOUZA FILHO, A.P.S.; RODRIGUES, L.R.A. & RODRIGUES, T.J.D. Potencial alelopático de forrageiras tropicais: efeitos sobre invasoras de pastagens. Planta Daninha, 15:53-60, 1997.

SOUZA, L.S.; VELINI, E.D.; MARTINS, D. & ROSOLEM, C.A. Efeito alelopático de capim-braquiária (*Brachiaria decumbens*) sobre o crescimento inicial de sete espécies de plantas cultivadas. Planta Daninha, 24:657-668, 2006.