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Performance of Flooded Rice Grown in Succession to Winter Cover Crops

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ABSTRACT: Mean grain yield of flooded rice in southern Brazil has increased in recent years due to the use of high-yield cultivars and improvement of crop management practices. Nevertheless, stagnation in grain yields has been observed in some rice-producing regions. Adoption of conservation tillage systems based on cover crops may be a strategy to increase rice grain yield potential. The objective of the present study was to evaluate the effect of winter cover crops on initial establishment, development, and grain yield of flooded rice (*Oryza sativa* L.) grown under different fertilization levels and no-tillage. A field experiment was carried out for three consecutive years (2010/11, 2011/12, and 2012/13) in Cachoeirinha, Rio Grande do Sul, South Brazil. Treatments included three winter cover crops [ryegrass (*Lolium multiflorum* Lam.), native serradella (*Ornithopus micranthus* Benth.), and a ryegrass-serradella mixture] and fallow, and three fertilization levels for rice grown in succession. More than 3 Mg ha^{-1} of serradella aboveground residue or 4 Mg ha^{-1} of ryegrass residue limited rice emergence in the first year when rainfall in the sowing-emergence period was higher than in the second and third years. In contrast, a large amount of residue (serradella >2 Mg ha^{-1}; ryegrass >3 Mg ha^{-1}) was beneficial to rice emergence when rainfall was low in the sowing-emergence period of the second and third years. The serradella cover crop increased rice aboveground biomass at anthesis by 22 % compared to the ryegrass cover crop. Furthermore, rice grain yield was 15 % higher in succession to serradella than to ryegrass in the third year. Continuous cultivation of flooded rice in succession to ryegrass over three years reduced grain yield by around 1.4 Mg ha^{-1}, regardless of fertilization level. Fertilization for very high production expectations increased rice grain yield in all years, especially in the second year, when solar radiation was higher than normal. The use of winter cover crops affected plant emergence, aboveground biomass, and grain yield of flooded rice. Rice grain yield increased with increases in fertilization level, and this response was not affected by the previous cover crop.

Keywords: grain yield, plant development, fertilizer rate, fertilization response.

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INTRODUCTION

Flooded rice (*Oryza sativa* L.) has great economic and social importance in southern Brazil. In the state of Rio Grande do Sul (RS), 5.4 million hectares are known as "lowland soils", and around one million hectares are annually cultivated with flooded rice. This state is the largest producer of rice in Brazil, accounting for nearly 69 % of national production (Conab, 2016); mean grain yield is 7.8 Mg ha^{-1} (IRGA, 2016). On rice farms of southern Brazil, rice residue is generally used as winter feed for beef cattle, but many rice fields are not used in winter and remain fallow (Correia et al., 2013).

Although much of the recent increase in grain yield of flooded rice in southern Brazil is attributed to high-yield cultivars and improved crop management practices (Menezes et al., 2012), other factors, such as the cultivation of winter cover crops, have also contributed to that increase. However, some cover crops do not easily adapt to lowland areas, where flat topography and low soil permeability may cause water stress (Menezes et al., 2001), especially in winter, when high rainfall may occur. Therefore, evaluation of winter cover crops adapted to poorly drained soils is crucial for grain yield increases and the sustainability of flooded rice-producing systems. Ryegrass (*Lolium multiflorum* Lam.) and native serradella (*Ornithopus micranthus* Benth.) can be grown in autumn-winter in these areas, given their adaptation to poorly drained soils (Menezes et al., 1994). Ryegrass may produce high aboveground biomass yield when properly fertilized, recycling nutrients and adding residue to the soil (Marchesi et al., 2011). Native serradella can benefit flooded rice grown in succession by fixing atmospheric N_2 and increasing soil N availability. The availability of P, K, Ca, and Mg is also believed to increase by nutrient recycling.

The adoption of conservation tillage systems based on cover crops may be an effective strategy to achieve higher rice grain yields in lowland areas (Koutroubas and Ntanos, 2003) by improving soil physical, chemical, and biological properties, as well as by reducing weed infestation, especially in red rice (*Oryza sativa* L.) (Agostinetto et al., 2001). However, the effects of winter cover crops on the subsequent rice grown in lowland areas have not been extensively studied and are still poorly understood. Thus, the low rate of cover crops use in these areas indicates a lack of knowledge in relation to their potential contribution to the sustainability of rice-producing systems.

Our hypothesis is that the agronomic performance and the response of flooded rice to different fertilization levels can be improved by the previous cover crop. The objective of the present study was to evaluate the effect of winter cover crops on initial establishment, development, and grain yield of rice grown under different fertilization levels.

MATERIALS AND METHODS

Field experiment

A field experiment was conducted at the *Instituto Rio Grandense do Arroz* in Cachoeirinha, RS, Brazil, over three growing seasons (2010/11, 2011/12, and 2012/13) in a soil classified as *Gleissolo Háplico Ta Distrófico* (Santos et al., 2013), which correspond to Gleysols (WRB, 2014) with sandy loam texture. Regional climate is humid subtropical (Cfa, according to the Köppen classification system). The experimental site was cultivated with soybean in the summer of 2008/09 and was left fallow in 2009/10. In 2010, the 0.00-0.20 m soil layer contained 160 g kg^{-1} of clay, pH(H_2O) of 5.2, 23.2 mg dm^{-3} of P (Mehlich-1), 105 mg dm^{-3} of K (Mehlich-1), 8.0 $cmol_c$ kg^{-1} of $CTC_{pH\ 7.0}$, and 18 g kg^{-1} of organic matter [methods described by Tedesco et al. (1995)].

A randomized block split-plot experimental design was used with four replicates. Cover crops were assigned to the main plots and fertilization levels to the split-plots. Each main plot measured 100 m^2 (10 × 10 m) and each split-plot 30.6 m^2 (10 × 3.06 m), with row spacing of 0.17 m. Treatments consisted of three winter cover crops [ryegrass (*Lolium multiflorum* Lam.), native serradella (*Ornithopus micranthus* Benth.), and a ryegrass-serradella mixture] and fallow, with three fertilization levels on rice grown in succession (without fertilization and fertilization for medium and very high expected yield) (Sosbai, 2014). The medium fertilization level consisted of the application of 8 kg ha^{-1} of N, 34 kg ha^{-1} of P_2O_5, and 54 kg ha^{-1} of K_2O (as 4-17-27 NPK formula) at sowing, plus 90 kg ha^{-1} of N (as urea) in two topdressed applications (1/3 at the V_3 stage, three fully developed leaves on the main stem; and 2/3 at the V_8, eight fully developed leaves). For the very high fertilization level, those rates were doubled.

Cover crops were always sown in April. Urea-N was applied as topdressing only for ryegrass (half at tillering and half 20 days later), at rates of 50 kg ha^{-1} N in the first year and 75 kg ha^{-1} N in the second and third years to achieve aboveground biomass of 4 Mg ha^{-1} (CQFS-RS/SC, 2004). No fertilizer was applied at sowing of cover crops. The ryegrass and native serradella sowing rate was 20 and 6 kg ha^{-1} in the first year and 40 and 12 kg ha^{-1} in the second and third years, respectively. The sowing rate for the serradella-ryegrass mixture in the first year was 6 and 10 kg ha^{-1} for serradella and ryegrass, respectively, and twice these amounts in the following years to prevent problems related to germination and plant establishment that could be caused by rice straw. Glyphosate herbicide [4 L ha^{-1} of N-(phosphonomethyl) glycine] active ingredient (a.i.) was applied on ryegrass and on the fallow treatment at 72 (first year) and 52 (second and third years) days before rice sowing. On the serradella and serradella-ryegrass mixture, glyphosate was applied at 21, 23, and 12 days before rice sowing in the first, second, and third years, respectively. Different intervals between herbicide application and rice sowing were chosen in order to maximize nitrogen availability from the serradella residue, which has a low C:N ratio (12:1 in 2010/11 and 11:1 in 2011/12), as well as to minimize N immobilization by ryegrass residue of high C:N ratio (42:1 in 2010/11 and 44:1 in 2011/12). In 2012/13, the C:N ratio of cover crop residues was not evaluated. For determination of C:N ratio, organic carbon content was analyzed by the dry combustion method (Nelson and Sommers, 1996), while N content was determined by the semi-micro Kjeldahl method (Tedesco et al., 1995).

The cultivar IRGA 424 was sown on 12 Nov 2010, 3 Nov 2011, and 27 Oct 2012 at a seed rate of 100 kg ha^{-1}, under no-tillage. Flooding with 0.05 m water began after N topdressing, at the V_3 stage to the R_7 stage (one grain of the main stem panicle with a yellow hull). Crop management practices (weed, pest, and disease control) were performed according to recommendations for southern Brazil (Sosbai, 2014).

Cover crops and rice parameters

Aboveground biomass of winter cover crops was measured at flowering in 0.5 m^2 one day before glyphosate application. The biomass was dried at 60 °C. The aboveground biomass in the fallow treatment was not evaluated since the plots were maintained free of spontaneous vegetation by herbicide application.

The initial density of rice plants was counted at the V_3 growth stage (beginning of tillering) in 0.34 m^2 per split-plot. The rice aboveground biomass at the R_4 growth stage (anthesis) was evaluated in 0.17 m^2 per split-plot. The aboveground N accumulation at R_4 was calculated by multiplying aboveground biomass and N content (Tedesco et al., 1995). Rice grain yield was determined in 16.8 m^2 and corrected for moisture content of 0.13 kg kg^{-1}. Number of panicles was determined in 0.34 m^2 in each split-plot. Number of grains per panicle was estimated by dividing total number of grains by total number of panicles sampled in 0.34 m^2. Total number of grains was estimated by dividing total grain weight by individual grain weight. Grain weight was determined by weighing three samples of 100 grains.

Solar radiation data during the growing season were obtained from a meteorological station located near the experimental site. These data were related to rice growth stages determined by the Counce scale (Counce et al., 2000) and compared to the climate normal for the period 1975-2002 (Inmet, 2013).

Statistical analysis

Data were analyzed by analysis of variance (Anova). When differences for main effects (cover crop and fertilization level) and interaction between both factors were significant by the F-test ($p<0.05$), treatment means were compared by Tukey's test at a 5 % significance level using the Mixed procedure of SAS - Statistical Analysis Software (SAS, 2008).

RESULTS

Global solar radiation in the first year (2010/11) was greater than climate normal between the sowing and V_8 stage, while it was approximately 21 % lower between the V_8 and harvest (V_9) stage (Figure 1). In the second year (2011/12), solar radiation was higher than climate normal during rice development, especially between sowing and the V_3 stage and between the V_8 and harvest stage. The V_8 growth stage corresponds to the second top-dressed N fertilization. In the third year (2012/13), global solar radiation was greater than climate normal during most of the growing season, except between R_4 and R_9 (Figure 1).

Aboveground biomass of cover crops was similar across species in the first two years, but in the third year, ryegrass produced the most biomass and serradella the least (6.59 vs. 2.56 Mg ha^{-1}) (Table 1). Cover crop biomass was not affected by fertilization level in any year ($p>0.10$).

A significant effect of cover crops on rice plant density was observed in the first and second years (Table 2). In the first year, it was higher after fallow; in the second year, after the serradella-ryegrass mixture. In the third year, it was not affected by cover crops. Fallow resulted in the highest rice population in the first year, but it was responsible, together with ryegrass, for the lowest population in the second year. The fertilization level had no effect on the rice plant population in any year ($p>0.10$).

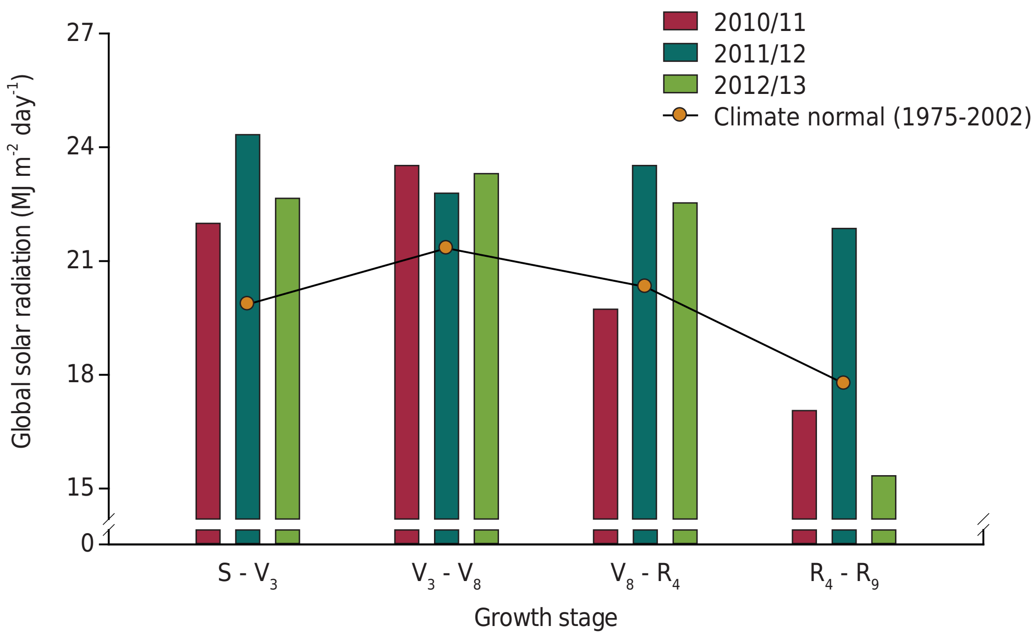

Figure 1. Global solar radiation at different rice growth stages and growing seasons and the climate normal (1975-2002) in Cachoeirinha, RS, Brazil. Source: Cargnelutti Filho et al. (2004) and Inmet (2013). S = sowing; V_3 = three fully-developed leaves on the main stem; V_8 = eight fully-developed leaves on the main stem; R_4 = anthesis; R_9 = harvest (Counce et al., 2000).

Rice aboveground biomass at anthesis varied among cover crops and fertilization levels in the first two years (Table 3). In the first year, considering the very high fertilization level, biomass was higher in succession to serradella than in succession to fallow, whereas in the second year, it was highest in succession to ryegrass. In contrast, rice biomass was lower in succession to ryegrass than in succession to serradella in the treatment without fertilization. In general, lower aboveground biomass was observed in the second year for all fertilization levels (Table 3). In the third year, only the main effects of cover crops and fertilization levels were significant ($p<0.05$). Rice fertilized for a very high expected yield produced more biomass than without fertilization (14.08 vs. 8.42 Mg ha^{-1}), while it was higher in succession to serradella than in succession to ryegrass and the serradella-ryegrass mixture (22 and 14 % higher, respectively) (Table 3).

Table 1. Aboveground biomass yield of winter cover crops in three growing seasons

Growing season	Cover crop				CV
	Serradella	Ryegrass	Mixture[(1)]	Fallow	
	Mg ha^{-1}				%
2010/11	3.71 a[(2)]	4.63 a	4.02 a	-	20.0
2011/12	2.33 a	3.10 a	2.69 a	-	14.4
2012/13	2.56 c	6.59 a	3.39 b	-	7.5

CV: coefficient of variation; - : not evaluated. [(1)] Serradella-ryegrass mixture. [(2)] Means followed by the same letter in the row do not differ significantly by Tukey's test ($p<0.05$).

Table 2. Plant density of rice grown in succession to cover crops in three growing seasons

Growing season	Cover crop				CV
	Serradella	Ryegrass	Mixture[(1)]	Fallow	
	plants per m^2				%
2010/11	225 b[(2)]	250 b	242 b	312 a	15.0
2011/12	167 ab	154 b	197 a	157 b	22.8
2012/13	271 a	273 a	255 a	283 a	19.0

CV: coefficient of variation. [(1)] Serradella-ryegrass mixture. [(2)] Means followed by the same letter in the row do not differ significantly by Tukey's test ($p<0.05$).

Table 3. Aboveground biomass yield of rice at anthesis grown in succession to different cover crops and at different fertilization levels

Cover crop	Fertilization level			Mean	CV
	Without fertilization	Medium expected response	Very high expected response		
					%
2010/11 growing season (Mg ha^{-1})					
Serradella	10.31 Ac[(1)]	12.06 Ab	14.60 Aa	12.32	
Ryegrass	10.34 Ab	11.54 Aab	12.81 ABa	11.57	
Mixture[(2)]	9.74 Ab	11.69 Aa	13.18 ABa	11.54	9.1
Fallow	11.08 Ab	12.87 Aa	11.85 Bab	11.93	
Mean	10.37	12.04	13.11		
2011/12 growing season (Mg ha^{-1})					
Serradella	7.16 Ab	10.51 Aa	12.21 Ba	9.96	
Ryegrass	5.25 Bc	10.00 Ab	14.71 Aa	9.98	
Mixture	6.62 ABc	10.15 Ab	13.28 ABa	10.02	12.0
Fallow	6.51 ABc	9.17 Ab	11.69 Ba	9.12	
Mean	6.38	9.96	12.97		
2012/13 growing season (Mg ha^{-1})					
Serradella	9.61	13.57	15.18	12.79 A	
Ryegrass	7.95	9.99	13.48	10.47 B	
Mixture	8.42	11.98	13.18	11.19 B	13.5
Fallow	7.68	11.58	14.47	11.25 AB	
Mean	8.42 c	11.78 b	14.08 a		

CV: coefficient of variation. [(1)] Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ significantly by Tukey's test ($p<0.05$). [(2)] Serradella-ryegrass mixture.

The aboveground N accumulated at anthesis significantly increased with the increasing fertilization level and was 38, 45, and 44 % higher in the first, second, and third years, respectively, for the very high level of fertilization compared to no fertilization (Table 4). Nitrogen accumulation was not affected by cover crops in any year (p>0.10) (data not shown).

Regarding yield components, only the number of panicles per square meter was affected by treatments (Table 5). This component increased along with the increase in fertilization level in the second and third years, while in the first year, it increased only up to fertilization for the medium yield response. In comparison to the unfertilized treatment, the number of panicles per square meter increased 20, 39, and 17 % in the first, second, and third years, respectively, for fertilization for a very high expected yield response (Table 5). Considering cover crops, this same component was higher following serradella in the second year and fallow in the third year, while it was not affected by cover crops in the first year (Table 5). The other yield components evaluated were not affected (p>0.10) (data not shown).

Table 4. Aboveground nitrogen accumulation in rice at anthesis grown with different fertilization levels

Growing season	Fertilization level			CV
	Without fertilization	Medium expected response	Very high expected response	
	kg ha^{-1}			%
2010/11	104 c[1]	132 b	169 a	19.9
2011/12	89 b	114 a	162 a	21.1
2012/13	83 c	118 b	149 a	11.8

CV: coefficient of variation. [1] Means followed by the same letter in the row do not differ significantly by Tukey's test (p<0.05).

Table 5. Number of panicles per area in rice grown in succession to different cover crops and at different fertilization levels

Cover crop	Fertilization level			Mean	CV
	Without fertilization	Medium expected response	Very high expected response		
	2010/11 growing season (No. panicles m^{-2})				%
Serradella	632	722	599	651 A[1]	
Ryegrass	491	616	621	576 A	
Mixture[2]	524	646	668	612 A	13.5
Fallow	566	646	760	657 A	
Mean	553 b	657 a	662 a		
	2011/12 growing season (No. panicles m^{-2})				
Serradella	583	738	735	685 A	
Ryegrass	476	595	702	591 B	
Mixture	519	650	764	645 AB	13.7
Fallow	493	667	677	612 B	
Mean	518 c	663 b	720 a		
	2012/13 growing season (No. panicles m^{-2})				
Serradella	583	518	578	563 B	
Ryegrass	508	593	637	579 AB	
Mixture	548	587	657	597 AB	13.8
Fallow	556	653	703	637 A	
Mean	549 b	590 b	644 a		

CV: coefficient of variation. [1] Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ significantly by Tukey's test (p<0.05). [2] Serradella-ryegrass mixture.

The effect of fertilization levels and cover crops on rice grain yield varied among the crop years (Table 6). Yield was not affected by cover crop in the first year, whereas in the third year, the lowest grain yield was observed after ryegrass. The effect of fertilization level was similar in the first and third years and the highest yield was observed under fertilization for a very high expected yield response, and the lowest yield was observed in the treatment without fertilization. In the second year, there was a significant interaction of fertilization level and cover crop (Table 6). Under fertilization for a medium expected yield response, significant differences between cover crops were found, and fallow resulted in the highest rice grain yield, whereas the ryegrass and mixture cover crop treatments resulted in lower rice yields in succession. In general, in the third year, lower grain yields were observed for all treatments, especially in succession to ryegrass.

DISCUSSION

Aboveground biomass of winter cover crops and rice establishment

In the first year, biomass was considered high according to the classification proposed by Amado et al. (2000) (>3 Mg ha^{-1} for legumes and >4 Mg ha^{-1} for Poaceae), whereas in the second and third years, biomass yields were medium (2-3 Mg ha^{-1} for legumes and 2-4 Mg ha^{-1} for Poaceae), except for ryegrass in the third year, which was considered high (Table 1). Winter cover crops with medium or high aboveground biomass could intensify nutrient cycling and increase nutrient availability to rice grown in succession. The decrease in aboveground biomass observed in the second year compared to the first may be explained by the large amount of rice straw on the soil surface (>10 Mg ha^{-1}), which may negatively affect seed-soil contact, emergence, and seedling establishment. The differences observed are related to the intrinsic characteristics of the species used in the present study. Ryegrass has better establishment and higher aboveground biomass than serradella, and their mixture is at an intermediate level. Similar aboveground biomass yields were recorded in

Table 6. Grain yield of rice grown in succession to different cover crops and at different fertilization levels

Cover crop	Fertilization level			Mean	CV
	Without fertilization	Medium expected responses	Very high expected responses		
		2010/11 growing season (Mg ha^{-1})			%
Serradella	9.90	10.87	10.88	10.55 A	
Ryegrass	8.56	10.00	10.34	9.63 A	
Mixture[(2)]	9.54	10.04	11.31	10.30 A	5.2
Fallow	9.68	10.26	10.99	10.31 A	
Mean	9.42 c	10.29 b	10.88 a		
		2011/12 growing season (Mg ha^{-1})			
Serradella	8.32 Ac[(1)]	10.99 ABb	12.71 Aa	10.68	
Ryegrass	7.64 Ac	9.65 Bb	12.60 Aa	9.96	
Mixture	8.41 Ac	10.15 Bb	12.18 Aa	10.24	5.3
Fallow	8.16 Ac	11.58 Ab	12.43 Aa	10.72	
Mean	8.13	10.59	12.48		
		2012/13 growing season (Mg ha^{-1})			
Serradella	8.31	9.95	10.73	9.66 A	
Ryegrass	7.30	8.19	9.14	8.21 B	
Mixture	8.45	9.53	10.42	9.47 A	7.1
Fallow	7.58	10.03	10.96	9.52 A	
Mean	7.91 c	9.42 b	10.31 a		

CV: coefficient of variation. [(1)] Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ significantly by Tukey's test ($p<0.05$). [(2)] Serradella-ryegrass mixture.

previous experiments carried out in the same location with serradella (Vieira et al., 2007) and ryegrass (Marchesi et al., 2011; Correia et al., 2013). For ryegrass, N fertilization is necessary to achieve medium to high aboveground biomass production, especially in lowland soils with low organic matter content (Menezes et al., 2012). In the present study, ryegrass was fertilized with N in all years, resulting in medium to high aboveground biomass production. However, N fertilization may increase production costs, which may limit the use of ryegrass as a cover crop preceding rice cultivation.

The results show that an annual addition of around 15.0 Mg ha^{-1} of residue (rice and cover crop) is possible when flooded rice is cultivated in succession to cover crops, which may contribute to positive carbon balance and increase soil carbon storage. In fact, the adoption of a no-tillage system with winter cover crops may add between 0.53 and 1.47 Mg ha^{-1} year^{-1} of carbon to soil (Rice and Reed, 2007). Although the cultivation of winter cover crops has numerous benefits, including carbon supply to soil and nutrient cycling, the presence of large amounts of residue on the soil surface may affect seedling establishment of rice grown in succession.

The rice plant population was affected by cover crops in the first and second years, whereas there was no effect in the third year. The lowest values were observed in the second year (Table 2). In the first year, higher rainfall (46 mm) between rice sowing and emergence was observed, compared to the second and third years (8 and 13 mm, respectively), thus the fallow treatment resulted in the highest plant population. In this case, the large amount of straw from cover crops was a physical obstacle to soil moisture loss, and this decreased rice seedling emergence. Similar results were found in a study conducted at the same site and in the same growing season, i.e., initial plant density was greater when rice was sown after fallow than under three types of ryegrass straw management (Marchesi et al., 2011). Some practical strategies may minimize such limitations, like early herbicide application on cover crops and proper drainage, which were carried out in the present study. Conversely, rainfall in the sowing-emergence period of the second year was lower than in the first year, reducing soil moisture and the rice population in succession to fallow compared to cover crops. In this case, the presence of straw was beneficial since it maintained soil moisture for a longer period. This effect was probably less important for rice grown in succession to ryegrass, due to the longer period (52 days) between crop desiccation and rice sowing, which may have reduced the amount of straw and increased moisture loss from the soil. Rainfall in the third year in sowing-emergence was higher than in the second year, although lower than in the first year. The higher aboveground biomass of cover crops combined with the higher rainfall maximized soil protection and reduced moisture loss, resulting in uniform rice emergence. The interval between herbicide application on cover crops and the time of rice sowing was the same in the second and third years. Thus, the differences lie in the aboveground biomass production, especially for ryegrass, without the same negative affect observed in the second year on the rice plant population. Although significant differences in rice plant density were observed, values were within the recommended interval, i.e., 150 to 300 plants per m^2 (Sosbai, 2014) (Table 2). Previous studies conducted at the same site with ryegrass and *Lotus corniculatus* (Jandrey, 2009; Vieira et al., 2011; Correia et al., 2013), as well as with serradella (Jandrey, 2009), showed no significant differences in initial seedling establishment as a function of cover crop and the aboveground biomass produced.

Rice aboveground biomass and nitrogen accumulation

Significant differences were found in biomass at anthesis in all years. The lowest values were observed in the second year, especially when rice was grown without fertilization (Table 3). Higher aboveground biomass was observed in succession to serradella, especially without fertilization, indicating the positive effect of this cover crop on rice with limited nutrient availability. The higher amount of N in the legume biomass and its rapid availability to the following crop due to its low C:N ratio reduce the need for another source of N to maximize the grain yield of the crop grown in succession (Amado et al., 2002). For N accumulation, only the main effect of the fertilization level was observed (Table 4). Increased fertilization over the three years provided higher N, P, and K availability for rice. Higher N accumulation in aboveground biomass was observed in the first year than in the other two years, especially without fertilization (an increase of 38, 45, and 44 % in the first, second, and third years, respectively). As seen in rice aboveground biomass and N accumulation, lower values in the treatment without fertilization may be indicative of reduced soil nutrient availability over the years. Thus, continuous rice cultivation in the same area without adequate nutrient replacement by fertilization may have decreased soil fertility.

Rice grain yield and yield components

Grain yield ranged from 9.42 to 10.88 Mg ha^{-1} in the first year, from 7.64 to 12.71 Mg ha^{-1} in the second year, and from 7.91 to 10.31 Mg ha^{-1} in the third year (Table 6). In the first year, grain yield was significantly affected by the fertilization level, but not by the cover crop. This response may be related to previous management of the experimental site, which was cultivated with soybean in the 2008/09 growing season. Therefore, the presence of legumes in the previous growing season may have increased soil nutrient availability and reduced the effect of cover crops on rice grain yield in the first year, even in the treatments without fertilization or fertilization for an expected medium yield response. For corn cultivated in rotation with soybean, a reduction of 20 % in the N rate applied is suggested (CQFS-RS/SC, 2004). In lowland soils, however, these effects are poorly understood and may be different from those verified in well-drained soils. According to Rosa et al. (2011), the alternation between cycles of flooding and drainage in lowland soils may result in different decomposition dynamics of organic matter compared to oxidized soils.

In the first year, the highest grain yield was observed for the very high fertilization level (10.88 Mg ha^{-1}). However, the limitation on grain yield may have resulted from lower solar radiation in the reproductive growth stage (Figure 1), since sowing occurred at the end of the recommended period, i.e., on November 13. In the second year, a significant interaction of the cover crop and the fertilization level was observed for grain yield, while only main effects of treatments were found for number of panicles per m^2 (Tables 5 and 6). Higher grain yield and number of panicles per m^2 were observed in the second year, especially when rice was grown at a very high fertilization level. This increased response to fertilization was promoted by more favorable weather conditions during the second year, especially higher global solar radiation (Figure 1). Higher nutrient availability and solar radiation are key factors in increasing N uptake and assimilation, since incorporation of this nutrient in proteins depends on photoassimilates to provide energy and carbon skeletons (Bredemeier and Mundstock, 2000). In the third year, a response similar to the first year was found, i.e., the highest values were observed under fertilization for a very high expected yield response (Tables 5 and 6). However, a limitation on grain yield was observed (10.31 Mg ha^{-1} at a very high level of fertilization), which may be related to lower solar radiation during grain filling (Figure 1) and reduced nutrient uptake. Although differences in number of panicles per m^2 occurred among the treatments with different cover crops and fertilization levels (Table 5), mean values in all years were similar (624, 633, and 594 panicles per m^2 in the first, second, and third years, respectively). These mean values are adequate for high grain yield potential of flooded rice genotypes grown in southern Brazil (Sosbai, 2014).

The same effect observed for rice aboveground biomass and N accumulation was observed for grain yield over the years, i.e., continuous cultivation in the same area without fertilization reduces rice development and grain yield. Rice grain yield decreased 1.29 and 1.51 Mg ha^{-1} in the second and third years, respectively, compared to the first year, considering mean grain yield of the treatment without fertilization of all cover crops (Table 6). Therefore, a fertilization program that is both economically and environmentally adequate is essential for improving soil quality and sustaining crop diversification in lowland areas. This trend was observed in general for all fertilization levels in the present study (Table 6). In the third year, rice grain yield was 1.42 Mg ha^{-1} lower than in the first year for ryegrass. In a study conducted at the same site, Correia et al. (2013) observed a decrease of 2.60 Mg ha^{-1} of rice grain yield in succession to ryegrass for two successive years without fertilization. Even when rice was in succession to serradella, a decrease in grain yield of 0.89 Mg ha^{-1} from the first to the third year was observed, although this decrease was less than after ryegrass. These differences may result from N addition to the soil-plant system due to N_2 symbiotic fixation by serradella even in soils subjected to flooding conditions, as well as from N immobilization by ryegrass residues with a high C:N ratio (Menezes et al., 2001; Silva et al., 2006). Furthermore, the possible presence of phytotoxic compounds (organic acids) derived from decomposition of large amounts of ryegrass straw may limit the development of rice grown in succession (Camargo et al., 2001).

CONCLUSIONS

More than 3 Mg ha^{-1} of serradella aboveground residue or 4 Mg ha^{-1} of ryegrass residue was harmful to rice emergence in the first year when rainfall between sowing and emergence was higher than in the second and third years. However, a large amount of residue (>2 Mg ha^{-1} for serradella and >3 Mg ha^{-1} for ryegrass) was beneficial to rice emergence when rainfall was lower between sowing and emergence in the second and third years. The serradella cover crop increased rice aboveground biomass at anthesis compared to the ryegrass cover crop. Rice grain yield was higher in succession to serradella than ryegrass in the third year. Continuous cultivation of flooded rice in succession to ryegrass over three years reduced grain yield by around 1.4 Mg ha^{-1}, regardless of the fertilization level. Fertilization for a very high expected yield response increased rice grain yield in all years, especially in the second year when solar radiation during the plant cycle was higher than climate normal. The use of winter cover crops affected plant emergence, aboveground biomass, and grain yield of flooded rice. Rice grain yield increased with an increase in fertilization level, and this response was not affected by the previous cover crop.

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