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Effectiveness of Current Fertilizer Recommendations for Irrigated Rice in Integrated Crop-Livestock Systems

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ABSTRACT: Irrigated rice in the state of Rio Grande do Sul (Brazil) has shown significant growth in yield in recent years due to improved management practices, especially in regard to fertilizer use. However, the response curves that led to the current fertilizer recommendations do not consider integrated systems prevailing in rice-producing regions that have adopted the practice of integrated crop-livestock systems. The aim of the present study was to evaluate the effectiveness of current fertilizer recommendations for irrigated rice in lowland soils in Rio Grande do Sul under integrated crop-livestock systems for different periods of time. The experiments were performed in the 2012/2013 growing season on four farms in the state with different forage species under cattle grazing. In these areas, fertilizer recommendations were made based on previous soil analyses, and treatments consisted of fractions of the currently recommended application rates. At the end of the crop cycle, the percentages of maximum technical efficiency (PMTE) and maximum economic efficiency (PMEE) of NPK fertilizers, and increases in yield and net income provided by PMEE were determined. Rice yield increased and fertilizer response decreased over time in a rice-beef cattle integrated system. The highest incomes with fertilization of irrigated rice occurred at lower application rates than those recommended by soil analysis.

Keywords: economic response to fertilization, lowland soils.

INTRODUCTION

The irrigated rice crop in Rio Grande do Sul, Brazil, has shown a significant yield increase in recent years, mainly due to improvement in some management practices. The average yield of approximately 7.6 Mg ha^{-1} in the 2010/2011 growing season compared to the 5.5 Mg ha^{-1} in the 2001/2002 season (Conab, 2011) is a result of this new panorama, and most of this increase is due to fertilizer recommendations (Sosbai, 2012). The effectiveness of these recommendations, based on a network of experiments performed in many locations, years, and soil types, is considered consistent and of high economic return (Genro Jr et al., 2010).

However, the response curves that led to the current fertilizer recommendations were obtained in tilled soils (tilling performed in the autumn season), without the introduction of winter cover crops, and in a system of rice-fallow-rice succession. Such recommendations, which depend on expected rice response to fertilization, can reach values as high as 150, 70, and 135 kg ha^{-1} of N, P_2O_5, and K_2O, respectively, when these nutrients are in a 'Low' soil fertility class and the expected rice response to fertilization is 'Very high' (Sosbai, 2012). Although this model of rice production is adopted in most of the fields in Rio Grande do Sul, the model does not include the integrated crop-livestock systems (ICLS) that prevail in the rice-growing regions denominated Zona Sul, Campanha, and Fronteira Oeste. In these regions, the adoption of ICLS is common. Areas suitable for rice cropping are used for two to six consecutive years, along with winter and summer forage species when these areas are cultivated again with irrigated rice. In these cases, even though the results of soil analysis indicate application of a certain amount of N-P-K, the current fertilizer recommendation system for irrigated rice may overestimate that amount, which leads to the occurrence of lodging and some diseases - two typical examples of excessive application of N fertilizer, which leads to lower use efficiency and a potential negative impact on the environment.

This limitation of soil analysis as a criterion for irrigated rice fertilization may be due to non-identification of the potential and the kinetics of nutrient release from the plant tissue of previous forage species cultivated, as well as from animal excreta (dung and urine), on the rice cropped in succession. In this context, production (through research) and popularization (through extension) of information become important to ensure more accurate recommendations of fertilizer rates for irrigated rice when this crop is part of an ICLS.

The aim of this study was to evaluate the effectiveness of current fertilizer recommendations for irrigated rice in different soil types of the lowlands of Rio Grande do Sul, Brazil, under integrated crop-livestock systems with rice-livestock (beef cattle) succession for different periods of time.

MATERIALS AND METHODS

The study was carried out in the 2012/2013 growing season on private farms located in four of the six rice-growing regions of Rio Grande do Sul, represented by the municipalities of Dom Pedrito, Uruguaiana, Mostardas, and Camaquã. These locations corresponded to different soil types and different lengths of time under rice cropping (Table 1). Fertilization was performed according to rates recommended by soil analysis and the different yield responses expected from the rice (Sosbai, 2012).

The experimental areas were under bovine (beef cattle) grazing for different lengths of time: two years of grazing in white clover (*Trifolium repens*) in Camaquã; five years of grazing in Italian ryegrass (*Lolium multiflorum*) + white clover in Dom Pedrito; five years of grazing in improved native pasture in Mostardas; and 16 years of grazing in native pasture in Uruguaiana. Prior to rice sowing, the animals were removed from the areas and plant cover was desiccated with broad-spectrum herbicide. Before desiccation, soil samples were collected from the 0.00-0.20 m layer in an area of 384 m^2 (32 × 12 m), representing the experimental area later cultivated with irrigated rice in each of the four different locations. In these samples, the following analyses were performed, according to Tedesco et al. (1995): pH(H_2O), clay content, organic matter, available P and K (Mehlich-1), Ca^{2+} and Mg^{2+} (KCl 1.0 mol L^{-1}), and cation exchange capacity ($CEC_{pH7.0}$) (Table 2). The results of soil analysis were used for fertilizer recommendations for the irrigated rice in the growing season under evaluation (Sosbai, 2012).

In each location (experimental area), five treatments were applied. The treatments were related to the fertilizer recommendation for *High* or *Very High* expected rice yield response, as a function of the cultivar and management practices in use, in accordance with Sosbai (2012). The treatments represented proportional fractions of the official recommended fertilization rate based on soil analyses: T1 – control, non-fertilized; T2 – 25 % of recommended fertilization rate; T3 – 50 % of recommended fertilization rate; T4 – 75 % of recommended fertilization rate; and T5 – 100 % of recommended fertilization rate (Table 3). The cultivars used were IRGA 424 (medium cycle, with very high expected response to fertilization) in Mostardas, Camaquã, and Uruguaiana; and Puitá INTA CL (early cycle, with high expected response to fertilization) in Dom Pedrito.

Table 1. Geographic location and historical use of experimental areas

Experimental area	Rice-growing region	Geographic coordinate	Soil type		Grazing period	Historical use
			USDA[1]	SiBCS[2]		
Camaquã	Planície Costeira Interna	31° 04’ 46” S/51° 42’ 12” W	Albaqualf	*Planossolo Háplico*	2 years	White clover + Italian ryegrass[3]
Dom Pedrito	Campanha	31° 13’ 15” S/54° 46’ 32” W	Aquoll	*Chernossolo Argilúvico*	5 years	White clover + Italian ryegrass[3]
Mostardas	Planície Costeira Externa	30° 30’ 32” S/50° 33’ 56” W	Albaqualf	*Planossolo Háplico*	10 years	Native pasture
Uruguaiana	Fronteira Oeste	29° 49’ 40” S/57° 05’ 60” W	Aquent	*Neossolo Litólico*	16 years	Native pasture

[1] According to USDA (2010). [2] According to Santos et al. (2013). [3] Succession field with native pasture in the summer, after the cycle of winter pastures.

Table 2. Soil clay contents and chemical properties in the different experimental areas

Experimental area	Clay	OM	pH(H_2O)	P	K	Ca^{2+}	Mg^{2+}	$CEC_{pH7.0}$
	g kg^{-1}			mg dm^{-3}		$cmol_c$ dm^{-3}		
Camaquã	150	16	5.4	7.5	35	2.8	1.1	8.9
Dom Pedrito	160	29	6.3	9.7	67	16	1.1	20
Mostardas	130	14	4.5	19	59	1.4	0.7	4.7
Uruguaiana	190	25	5.0	3.9	52	18	6.3	28

Clay: pipette method; OM: organic matter, Walkley-Black method; P and K: extractor Mehlich-1; Ca^{2+} and Mg^{2+}: 1 mol L^{-1} KCl; CEC: cation exchange capapity, extractor 0.5 mol L^{-1} calcium acetate at pH7.0.

Table 3. Amounts of nitrogen, phosphorus, and potassium applied and fertilization cost according to recommendations for the different experimental areas

Experimental area	N	P_2O_5	K_2O	Fertilization cost
	kg ha^{-1}			US\$ 100 kg^{-1}
Camaquã	150	50	105	113.48
Dom Pedrito	110	40	90	113.04
Mostardas	150	50	65	115.65
Uruguaiana	150	60	135	112.61

Fertilizer recommendation according to Sosbai (2012), relative to treatment 5.

Rice sowing occurred from the second half of October to the first half of November 2012, the period recommended when sowing is performed in dry soil, at a density of 100 kg ha^{-1} and row spacing of 17.5 cm. The fertilizers applied in rice sowing (P_2O_5 in the form of triple superphosphate and K_2O in the form of potassium chloride) were broadcast without incorporation in the soil, as indicated by Sosbai (2012), in the fractions related to each treatment. Topdressing was performed with N fertilization (in the form of urea), applied two times: 66 % in the V_3-V_4 stage (immediately after flooding) and 34 % in the V_8 stage (Counce et al., 2000). Pest control was performed according to technical recommendations (Sosbai, 2012). The treatments were distributed in a randomized block design, with three replicates. Each plot was spaced 0.5 m from others and had a total size of 20 m^2 (10 × 2 m).

At the end of the rice cycle, an area of 10 m^2 was sampled to evaluate grain yield. The samples were mechanically threshed and grain weight was determined and corrected to moisture equivalent to 130 g kg^{-1}. The results were subjected to regression analysis, and second degree polynomial equations were used. From these equations, the percentages of maximum technical efficiency (PMTE) and maximum economic efficiency (PMEE) were calculated (Grimm, 1970; Tisdale et al., 1993) in relation to the N-P-K rate combination recommended by Sosbai (2012) in each of the locations evaluated, as well as the yield increase in the percentage of maximum technical efficiency (YIMTE) and maximum economic efficiency (YIMEE). The percentage calculation was defined by the price of the input variable (Table 3) and of rice grain (US$ 266.52 Mg^{-1}) in April 2013. The total cost of fertilization in each location, represented by T5, was also calculated based on fertilizer prices in April 2013 (Table 3). The values considered were US$ 533.91 Mg^{-1} for urea, US$ 595.65 Mg^{-1} for triple superphosphate, and US$ 578.26 Mg^{-1} for potassium chloride (Conab, 2011). Finally, from the total fertilization cost in each location and the PMEE, the net profit considering the percentage of maximum economic efficiency (NPMEE) was calculated.

RESULTS AND DISCUSSION

The response of irrigated rice to fertilization was quadratic but occurred at different magnitudes in the experimental areas (Figure 1). The most expressive increase (30 %) occurred in Camaquã (Figure 1a), the location with the shortest period of grazing (only two years). In this area, the lowest grain yield was also observed (approximately 7.0 Mg ha^{-1}) in the non-fertilized treatment. In contrast, the grain yields of the control treatments in the other locations were always above 9.0 Mg ha^{-1} (Figures 1b, 1c, and 1d). It is important to highlight that in Uruguaiana – the location with the longest period of grazing (16 years) – the grain yield was 12.0 Mg ha^{-1} (Figure 1d).

In the experiment performed in Camaquã, in addition to greater response to fertilization, the percentages of maximum technical efficiency (PMTE) and maximum economic efficiency (PMEE) were higher (Table 4). The grain yield increase by PMEE (YIMEE) in this location reached 2.19 Mg ha^{-1}, which provided a net profit (NPMEE) of almost US$ 500 ha^{-1}, a much higher value than in the other experimental areas (Table 4). In the other locations, the PMEE ranged from 41 to 55 % in relation to the fertilization recommended by Sosbai (2012) as a function of soil analysis (Table 2). The NPMEEs in Dom Pedrito, Mostardas, and Uruguaiana were of inexpressive importance compared to Camaquã, as they were lower than 1.0 Mg ha^{-1}, with net profit lower than US$ 170 ha^{-1}.

In a network of 23 experiments performed in the rice-fallow-rice system, in many types of soil from the lowlands of Rio Grande do Sul, Genro Jr et al. (2010) found an increase in average grain yield in irrigated rice due to fertilization of 3.2 Mg ha^{-1}, and the maximum response reached almost 4.0 Mg ha^{-1} in one of the locations evaluated. However, these authors found that control treatments (non-fertilized) had an average grain yield of 6.5 Mg ha^{-1}, compared to the present study in which the average grain yield in such treatments was 9.7 Mg ha^{-1}. The presence of pasture and especially of grazing animals determine the intensity of nutrient cycling. This occurs due to low removal of nutrients within the animal: 2.8, 1.0, and 0.22 kg of N, P, and K for each 100 kg of live weight (McDonald et al., 1995), and 70 to 90 % of ingested nutrients are returned to the soil in the form of excreta (Haynes and Williams, 1993; Cantarutti et al., 2001). These results are a consistent indication of the beneficial effects that the ICLS provides to the irrigated rice crop. Despite the scarcity of studies focusing on integrated systems, the results of the present study are consistent with those found by Saibro and Silva (1999) in the rice-growing region of the *Planície Costeira Externa*. These authors evaluated the effect of three grazing cycles, performed in different cultivated winter pastures, on irrigated rice performance. The grain yield increase reached 18 % when irrigated rice was preceded by leguminous forage species, compared to rice cultivated under a conventional system. It is important to highlight that this study (Saibro and Silva, 1999) was developed in a period when the average grain yield of irrigated rice in Rio Grande do Sul was below current yields (IRGA, 2014). Furthermore, the period under grazing was shorter, especially compared to Dom Pedrito, Mostardas, and Uruguaiana in the present study (Table 1).

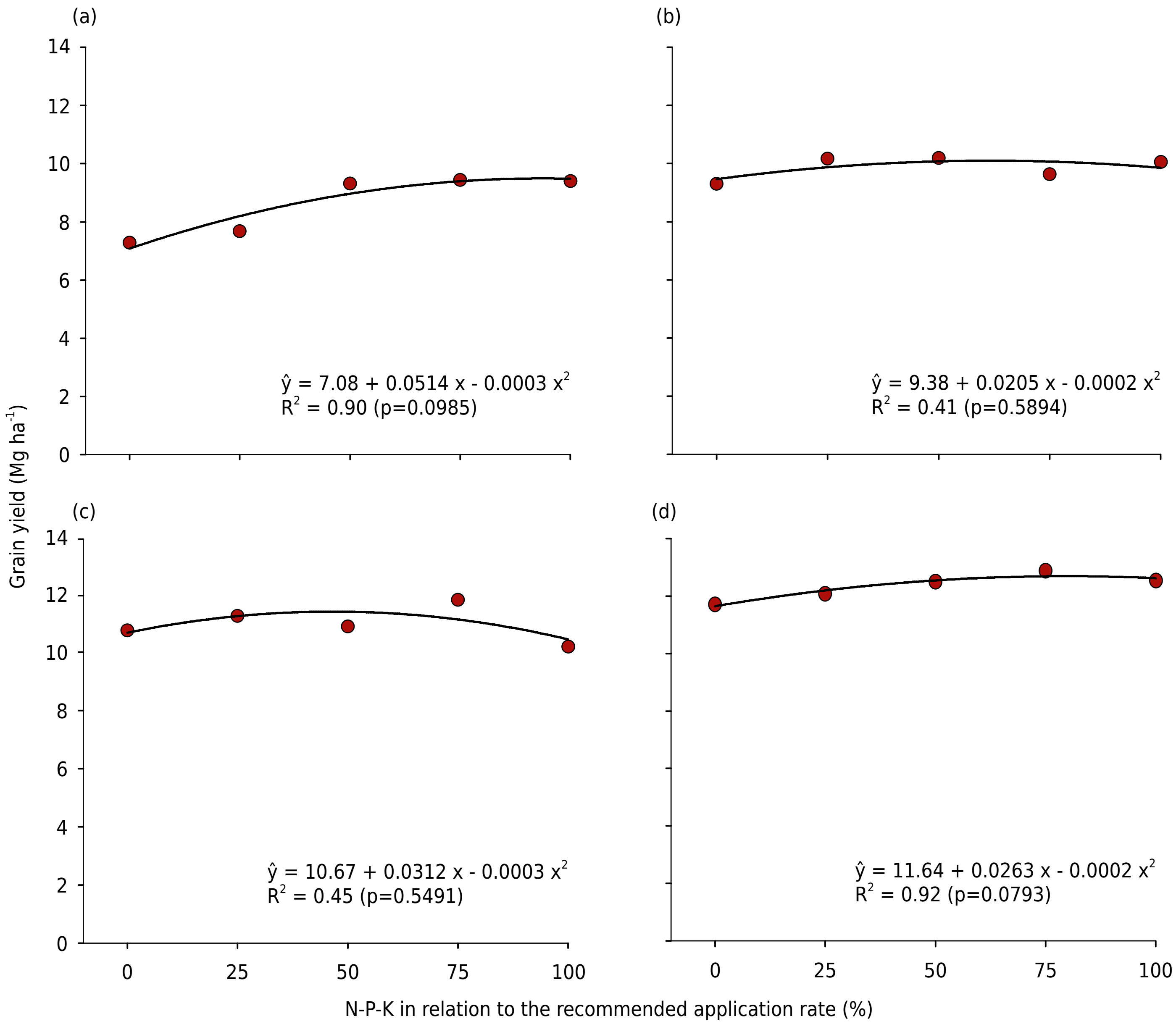

Figure 1. Response of irrigated rice to different fractions of recommended nitrogen (N), phosphorus (P), and potassium (K) application rates in the experimental areas of the municipalities of Camaquã (a), Dom Pedrito (b), Mostardas (c), and Uruguaiana (d), Brazil.

Table 4. Percentages of maximum technical efficiency (PMTE) and maximum economic efficiency (PMEE), yield increase in the percentage of maximum technical efficiency (YIMTE) and maximum economic efficiency (YIMEE), and net profit considering the percentage of maximum economic efficiency (NPMEE) in fertilization of irrigated rice in the different experimental areas

Experimental area	PMTE	PMEE	YIMTE	YIMEE	NPMEE
	%		Mg ha^{-1}		US$ ha^{-1}
Camaquã	85.7	78.6	2.20	2.19	493.48
Dom Pedrito	51.3	40.7	0.53	0.50	88.26
Mostardas	52.0	44.8	0.81	0.80	160.43
Uruguaiana	65.8	55.2	0.86	0.84	162.17

The recommendation for ICLS conducted in subtropical lowland areas is the use of adapted grasses, such as Italian ryegrass (Marchezan et al., 2005), as well as cultivation of other forage species, such as leguminous plants, mainly under intercropping (Gomes et al., 1993). Cultivated pastures constituted by Italian ryegrass + white clover + birdsfoot trefoil (*Lotus corniculatus*) show potential for higher animal productivity in integrated systems of livestock (beef cattle) and irrigated rice, allowing weight gain of more than 500 kg ha^{-1} yr^{-1} and 1.0 kg animal^{-1} d^{-1} (Silva et al., 1997; Marchezan et al., 2002; Marchezan et al., 2005). According to Saibro and Silva (1999), the intercropping of Italian ryegrass and leguminous forages, as occurred in Dom Pedrito and Camaquã (Table 1), can represent an increase of 25 % in the grain yield of irrigated rice, which is followed by a significant decrease in fertilizer application rate. Reis et al. (2008) found that correct fertilization of mixed pastures also allows the absence of response to phosphate and potassium fertilizers for irrigated rice cropped in succession. In production systems without fallow periods between croppings, K uptake by plants remains most of the time in plant tissues, protected from losses by runoff or leaching (Santi et al., 2003). Although the amount of K taken up by plants is high (43 kg Mg^{-1}), the amount removed by grains is low (5 kg Mg^{-1}), i.e., only 12 %, and the remainder returns to the soil (Yoshida, 1981). Thus, the dry matter production of crops, due to improvement in soil fertility, intensifies K recycling.

In a consolidated ICLS, the supply of nutrients is constant due to the different sources of decomposition (plant residues and animal excreta), and its release occurs in different manners in these two sources (Larcher, 2000; Hoffmann et al., 2001). Forage ingestion by animals stimulates the growth of grazed plants, contributing to higher nutrient extraction and recycling due to excretion of dung and urine (Cantarutti et al., 2001). In this sense, the addition of animal and plant residues to the soil establishes a nutrient flow, whose magnitude can promote changes in biological activity and the status of soil aggregation, contributing to improvement of the system (Lovato et al., 2004). Since grasses have a fasciculated and aggressive root system, these plants tend to promote greater soil aggregation and physical protection of organic matter, avoiding its decomposition (Salton et al., 2002). The higher the cultivation time of these species, the higher the beneficial effects on the production system. This is evidenced in the current study, since lower responses to fertilization were found in Dom Pedrito, Mostardas, and Uruguaiana (Figures 1b at 1d; Table 4), where the grazing of forage species ranged from 5 to 16 years (Table 1). In contrast, the highest rice response to fertilization occurred in Camaquã, with only two years of grazing (Figure 1a, Table 4).

Thus, simple soil analysis is not sufficient to indicate the correct fertilizer recommendation for irrigated rice when this crop is within a consolidated ICLS (or under the period of consolidation). This occurs because most nutrients are not readily available in the soil solution but are 'stored' in the plant shoot and root biomass and also in the microbial biomass (Souza et al., 2008, 2010). Thus, when the recommendation for maximum economic efficiency is low (as occurred in Dom Pedrito, Mostardas, and Uruguaiana), the recommendation is to apply fertilizer at rates that are sufficient only to supply what is removed by the grains, maintaining the yield potential.

CONCLUSIONS

Grain yield of irrigated rice increases and the response to fertilization decreases with an increase in the period under integration between crop and livestock (beef cattle).

Higher economic return from fertilization in irrigated rice occurs when the amount of fertilizer applied is lower than that recommended according to soil analysis.

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