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Gypsum and phosphorus in the development of upland rice under a no-tillage system

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The use of gypsum in a no-tillage system may be a feasible alternative for cultivating upland rice because of its ability to move some nutrients to greater depth in the soil and thereby stimulate root growth. Additionally, phosphorus is one of the nutrients that most limits crop production in the Brazilian Cerrado. Thus, the objective of this work was to study the effect of combining gypsum (applied to the soil surface without tillage) and phosphorus at sowing on soil attributes, plant height, number of panicle m^{-1}, seed mass, and grain yield in a no-tillage cultivation system. The experiment was conducted using a randomized complete block experimental design with four replicates in a factorial scheme of gypsum doses (0, 1000, 2000 and 3000 kg ha^{-1}), phosphorus doses in the furrow (0, 50, 100 and 150 kg ha^{-1}) and growing seasons (2011/2012 and 2012/2013). Gypsum applications provided incremental increases in soil calcium and increased potassium levels in the deeper soil layers, but it did not affect plant height, number of panicle m^{-1}, or grain yield of upland rice cultivated under a no-tillage system. Increasing doses of phosphorus applied at sowing resulted in a significant increase in the plant height, number of panicles m^{-1} and grain yield.

Key words: *Oryza sativa* L., fertilization, Cerrado, leaching.

INTRODUCTION

Rice is a food that is part of the diet of half the world's population (Kumar and Ladha, 2011), and most of this grain is grown in Asia using a controlled-flooding irrigation system (Farooq et al., 2009; Prasad, 2011). However, the reduced availability of water resources for irrigation of crops due to increasing industrial and human consumption has generated a demand for alternatives in the form of water-saving rice cultivation systems (Feng et al., 2007). As alternatives, rice could be cultivated in upland ecosystems, which can be sprinkler irrigated or not irrigated depending on rainfall (Bouman et al., 2007; Crusciol et al., 2013; Nascente et al., 2013). As a component of these alternative cultivation methods, the no-tillage system (NTS), due to its characteristic of

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maintaining a covering of straw over the soil, could bring advancements to rice production as a result of greater retention of water in the soil.

In a NTS, adequately managing soil fertility at depth layers is important to ensuring the system's sustainability (Silva and Lemos, 2008). To this, gypsum ($CaSO_4.2H_2O$) could be used for improving the root environment in deep soil layers (Santos et al., 2006). This product is a soil conditioner and his moderately soluble (2.5 g L^{-1}). It can provide Ca^{2+} and SO_4^{2-} ions in solution, which can be leached, thereby enriching subsoil layers with both nutrients and reducing the saturation of Al^{3+} at depth layers (Alcordo and Rechcigl, 1993). Thus, gypsum use could allow the development of roots in deep layers of the soil, thereby increasing the volume of explored soil and, consequently, the tolerance of plants to drought (Sousa et al., 2005). The successful use of gypsum to enhance the root environment has been implemented extensively in the Brazilian Cerrado region, where approximately 80% of the area has some type of subsoil acidity and a high incidence of dry periods, especially in the months of January and February, which are critical for the development of summer crops (Ramos et al., 2006; Caires et al., 2008). Moreover, gypsum can be found in many parts of the world and often has a low commercial cost for farmers (Melo et al., 2008).

Among the primary macronutrients, phosphorus (P) is the nutrient least required by rice crops; however, it is highly exported in harvested grains crops (Soratto et al., 2010; Fageria et al., 2011) and is less abundant in most tropical Brazilian soils. Its deficiency in Cerrado soils is due to a low natural content and a high fixation capacity (Fageria et al., 2011). This nutrient also has a significant effect on root growth and grain yield of rice (Crusciol et al., 2005).

For upland rice, data on the combined application of gypsum and P are still scarce with regard to soil management carried out in an NTS. Thus, the objective of this work was to determine the effect of the combination of gypsum applied to the soil surface without tillage and P applied in the sowing furrow on soil attributes, plant height, number of panicles m^{-1}, seed mass, and grain yield of upland rice.

MATERIALS AND METHODS

The experiments were conducted at Fazenda Capivara at Embrapa Rice and Beans, which is located in Santo Antônio de Goiás, GO, Brazil, at 16º28'00" S and 49º17'00" W and an altitude of 823 m. The climate is tropical savanna and is considered Aw according to the Köppen classification. There are two well-defined seasons, one normally dry season from May to September (autumn/winter) and one rainy season from October to April (spring/summer). The average annual rainfall is between 1500 to 1700 mm, and the average annual temperature is 22.7°C, ranging annually from 14.2 to 34.8°C. During the two growing seasons in the present study, there was no problem with dry periods.

The soil is classified as a clay loam (kaolinitic, thermic Typic Haplorthox) acidic soil (Embrapa, 2006). Prior to the experiment, in 2010, chemical analysis was performed in the depth ranges 0 to 10, 10 to 20 and 20 to 40 cm for the characterization of the experimental area (Table 1). The chemical analyses were performed according to the methodology proposed by Claessen (1997). The soil pH was determined in water. Exchangeable Ca, Mg, and Al were extracted with neutral 1 mol L^{-1} KCl in a 1:10 soil:solution ratio and determined by titration with a 0.025 mol L^{-1} NaOH solution. Phosphorus and exchangeable K were extracted with a Mehlich 1 extracting solution (0.05 M HCl in 0.0125 M H_2SO_4). The extracts were colorimetrically analyzed for P, and flame photometry was used to analyze K. The base saturation values were calculated using the results from exchangeable bases and total acidity at pH 7.0 (H + Al). Organic matter was determined by wet combustion with external heat.

The experimental area had been cultivated in crop-livestock rotation using a no-tillage system (NTS) for seven consecutive years. The rotation program included soybean (*Glycine max*) (summer), followed by rice (*Oryza sativa*) (summer) and common bean (*Phaseolus vulgaris*) (winter), followed by corn (*Zea mays*) + *Urochloa brizantha* (summer) and two years of grazing pasture. Installation of the current experiments in both years was conducted in plots where upland rice was the crop to be grown as part of the established program of crop rotation.

The experimental design was a randomized complete block in a 4 × 4 × 2 factorial scheme with four replications. The treatments consisted of combinations of gypsum (0, 1000, 2000 and 3000 kg ha^{-1} applied in both years), P in the sowing furrow (0, 50, 100 and 150 kg of P_2O_5 ha^{-1} applied in both years) and growing seasons (2011/2012 and 2012/2013). The plots consisted of 10 five-meter-long rows, spaced 0.35 m apart. The useful area of each plot was formed by the nine central m of the six central rows.

Approximately 15 days before sowing, the experimental area was cleared of weeds with glyphosate + 2,4D. The gypsum application (17% S and 22% Ca) was broadcast on the surface of one day before rice sowing. Based on soil analysis, the recommended P dose for the rice crop was estimated to be 100 kg ha^{-1} (Sousa and Lobato, 2004). The base fertilization applied in the sowing furrows was calculated according to the soil chemical characteristics and the recommendations of Sousa and Lobato (2004). The fertilizer consisted of 40 kg ha^{-1} of N as urea and 50 kg ha^{-1} of K_2O as KCl and was applied together with P_2O_5 as triple superphosphate at sowing. Additionally, topdressing fertilization was performed 21 days after crop emergence using 40 kg ha^{-1} of N as urea.

The sowing was performed mechanically using 80 kg ha^{-1} of rice seeds from a mutant line 07SEQCL441 CL that was derived from a Primavera variety and was resistant to Imazapyr + Imazapic herbicide. The seed was sown on December 15th, 2011 and November 1st, 2012 in the first and second growing seasons, respectively. Before sowing, seeds were treated with Carboxin + Tiram (250 mL 100 kg of $seeds^{-1}$) + Fipronil (100 mL 100 kg of $seeds^{-1}$). Weed control was accomplished using Imazapyr + Imazapic herbicide applied at 16 (100 g ha^{-1}) and 26 (50 g ha^{-1}) days after crop emergence. Other cultural practices were performed according to standard recommendations for a rice crop to keep the area free of diseases and insects.

The soil strata were sampled four months after gypsum application in the first season (14/03/2012), in 0-0.10, 0.10-0.20 and 0.20-0.40 m soil layers. Fifteen simple disturbed samples were collected using a screw auger, randomized in each plot and for each depth (five in the sowing row and 10 in the inter-rows), to constitute the work samples. The work samples were air dried, sieved (2 mm mesh), and subsequently analyzed for pH (water) and for exchangeable Al, Ca, Mg and K as described previously.

In addition, the plots were evaluated with regard to: plant height (m), which was determined by measuring 10 plants per plot at the time when the crop was at the phonological stage of pasty grains and recording the distance between the soil surface and the top end of the highest panicle; number of panicles m^{-1} which was

Table 1. Chemical characteristics of the soil in the total experimental area prior to the experiment, in the growing season 2010/2011.

Depth	pH	SOM[1]	P	Al	H+Al	K	Ca	Mg	CEC[2]	V[3]
cm	Water	g dm^{-3}	mg dm^{-3}	----------------------mmol$_c$ dm^{-3}--------------------						%
0-10	5.7	27	15	0.0	40	2.0	17	12	71.0	44
10-20	5.8	26	16	0.0	37	0.6	18	13	68.9	46
20-40	5.9	23	8	0.0	34	0.6	12	9	55.6	39

[1]SOM, soil organic matter; [2]CEC, Cation exchange capacity; [3]V = (K+Mg+Ca/ H+Al+K+Mg+Ca) * 100.

determined by counting the number of panicles within 1.0 linear m of one of the rows in the useful area of each plot; mass of 1000 grains which was evaluated randomly by collecting and weighing two samples of 100 grains from each plot, corrected to 13% of water content; and grain yield which was determined by weighing the harvested grain of each plot, corrected to 13% of water content and converted to kg ha^{-1}.

For statistical analysis, SAS Statistical Software, SAS Institute, Cary, NC, USA (SAS, 1999) was used. Data were subjected to an analysis of variance and, when necessary, compared by a Tukey test at $p<0.05$. When rates of gypsum and P were significant, the results were submitted to regression analysis at $p<0.05$.

RESULTS AND DISCUSSION

Gypsum applications did not result in statistical significant changes in pH, Mg, Al or P attributes (Table 2). However, it caused significant changes in the Ca content of the 0 to 0.10 and 0.10 to 0.20 m layers, and in the K content of the 0 to 0.10, 0.10 to 0.20 and 0.20 to 0.40 m layers. Based on these results, the Ca data were fitted with quadratic equations (Figure 1). According to Caires et al. (2004), the application of gypsum can provide an increase in the exchangeable Ca content of the soil. Rocha et al. (2008) reported that a 30-day interval after gypsum application was enough to increase the exchangeable Ca content of the deepest soil layer (0.80 m), even when gypsum was broadcast without incorporation in an Oxisol. Soratto and Crusciol (2008) also reported increases in Ca at depth 12 m after gypsum application in an Oxisol.

Through the results obtained in this work, it was observed that there was a reduction in K levels in all layers evaluated. Based on this observation, it was possible to infer that the leaching of K to deeper layers of the soil (> 0.40 m) was caused by the application of higher doses of gypsum (Figure 2). Similar results have been reported by other authors (Caires et al., 1998). According to Caires et al. (2004) and Santos et al. (2013), gypsum application may result in movement of nutrients to deeper soil layers and may also be responsible for nutrient losses, especially a loss of Mg and K, because of the interaction with SO_4^-.

Plant height measurements showed no effects of gypsum application (Table 3). Similar results were obtained by Oliveira et al. (2009) when studying the effect of gypsum on the development of *Brachiaria humidicola*. The authors explained the results as being due to the low Ca requirement of that forage which is similar to that of a rice crops (Fageria et al., 2011). In contrast, P application positively affected plant height (Table 2), and thus, the data were fitted to a quadratic equation (Figure 3). Likewise, Tonello et al. (2012) observed a significant increase in plant height due to the application of increasing P. Garcia et al. (2009) reported significant and positive effects of increasing P on seedling growth in upland rice. According to Fageria et al. (2011), P is the nutrient that most limits crop development, especially in soils of low fertility, such as those of the Brazilian Cerrado, and supplying P, results in improvements in plant growth.

For yield components and grain yield, it was observed that gypsum application did not affect any of the evaluated parameters (Table 3). Santos et al. (2013) also did not observe responses in grain yield when analyzing the effects of gypsum application on two *Pennisetum purpureum* varieties. Similarly, Gomes et al. (2000) found no effect of gypsum applications of up to 20 Mg ha^{-1} on rice. Additionally, Soratto et al. (2010) did not observe increases in upland rice grain yield as a function of gypsum dose. The results of the present study is supported by the findings of previous studies indicating that rice is undemanding with regard to Ca as reported by Fageria et al. (2011).

The results of the present study which were repeated for two consecutive years could reflect this soil does not need Ca or SO_4^-. According to Sousa et al. (2005), using soil analysis results from 0.20 to 0.40 m layer, if Al saturation exceeds 20% or if Ca amount is less than 5 mmol$_c$ dm^{-3}, it is possible to see a response to gypsum application. The experimental area used in this work, in both years, had low Al saturation, and Ca values were higher than 5 mmol$_c$ dm^{-3} at 0.20 to 0.40 m (Table 1). Under these conditions, the absence or low response to gypsum application in the development of agricultural crops could be expected, especially for rice crop which shows low demand for Ca. In addition, according to Sousa et al. (2005), in places with dry periods during the growing season, it is possible to identify effects of gypsum application on growing plants. We did not have a problem with dry periods which could be another reason and we did not observe any effects from gypsum.

Based on the results, one could question whether the

Table 2. Chemical characteristics of the soil cultivated with upland rice in a no-tillage system with regard to phosphorus dose, gypsum doses and sampling depth in the growing season 2011/2012.

0-0.10 m depth*						
Treatments	**pH**	**Ca**	**Mg**	**Al**	**P**	**K**
Gypsum doses (kg ha^{-1})		---------------**mmol$_c$ dm^{-3}**-----------------			---------**mg dm^{-3}**--------	
0	6.37	34.94	17.10	0.14	15.79	78.10
1000	6.26	38.53	17.04	0.00	12.57	68.53
2000	6.41	39.00	14.98	0.79	15.68	67.00
3000	6.15	41.09	14.31	0.07	11.20	65.93
Phosphorus doses (kg ha^{-1})						
0	6.35	37.40	16.50	0.05	14.74	76.23
50	6.36	37.71	15.38	0.86	15.02	65.71
100	6.25	39.31	15.87	0.00	13.33	73.85
150	6.25	35.79	15.87	0.13	12.56	68.53
Factors			**ANOVA – Probability of F test**			
Gypsum (G)	0.1291	0.0403	0.3817	0.8378	0.5741	0.0490
Phosphorus (P)	0.4835	0.6672	0.4392	0.4274	0.8356	0.3756
G × P	0.9503	0.9438	0.8174	0.1519	0.87989	0.4367
0.10-0.20 m depth						
Gypsum doses (kg ha^{-1})						
0	6.22	24.43	11.58	0.10	9.76	84.33
1000	6.12	26.97	10.84	0.00	8.79	76.47
2000	6.33	27.39	12.32	0.00	8.32	71.93
3000	6.11	28.51	10.95	0.07	6.06	66.14
Phosphorus doses (kg ha^{-1})						
0	6.19	27.30	11.41	0.09	11.39	82.18
50	6.21	25.91	11.22	0.07	5.76	76.21
100	6.18	27.89	11.20	0.00	7.10	77.85
150	6.19	25.40	11.55	0.00	7.30	73.60
Factors			**ANOVA – Probability of F test**			
Gypsum (G)	0.1912	0.0434	0.3381	0.6384	0.4177	0.0441
Phosphorus (P)	0.6080	0.8629	0.9325	0.5240	0.9386	0.4567
G × P	0.9160	0.9849	0.3617	0.6151	0.7999	0.3166
0.20-0.40 m depth						
Gypsum doses (kg ha^{-1})						
0	6.18	18.93	7.75	0.05	3.95	89.57
1000	6.08	15.97	7.08	0.00	2.23	89.13
2000	6.27	20.30	8.59	0.00	12.84	76.57
3000	6.02	17.98	7.30	0.23	1.83	68.54
Phosphorus doses (kg ha^{-1})						
0	6.15	18.41	7.76	0.14	10.40	87.95
50	6.09	17.46	7.51	0.00	2.15	82.07
100	6.17	20.39	7.81	0.00	2.42	82.77
150	6.16	17.47	7.85	0.07	2.13	81.93
Factors			**ANOVA – Probability of F test**			
Gypsum (G)	0.1110	0.3564	0.2407	0.1497	0.1791	0.0325
Phosphorus (P)	0.7937	0.6629	0.6747	0.2128	0.1698	0.9965
G × P	0.8432	0.7252	0.6812	0.7297	0.2241	0.1589

*Samples were collected 120 days after phosphorus and gypsum application.

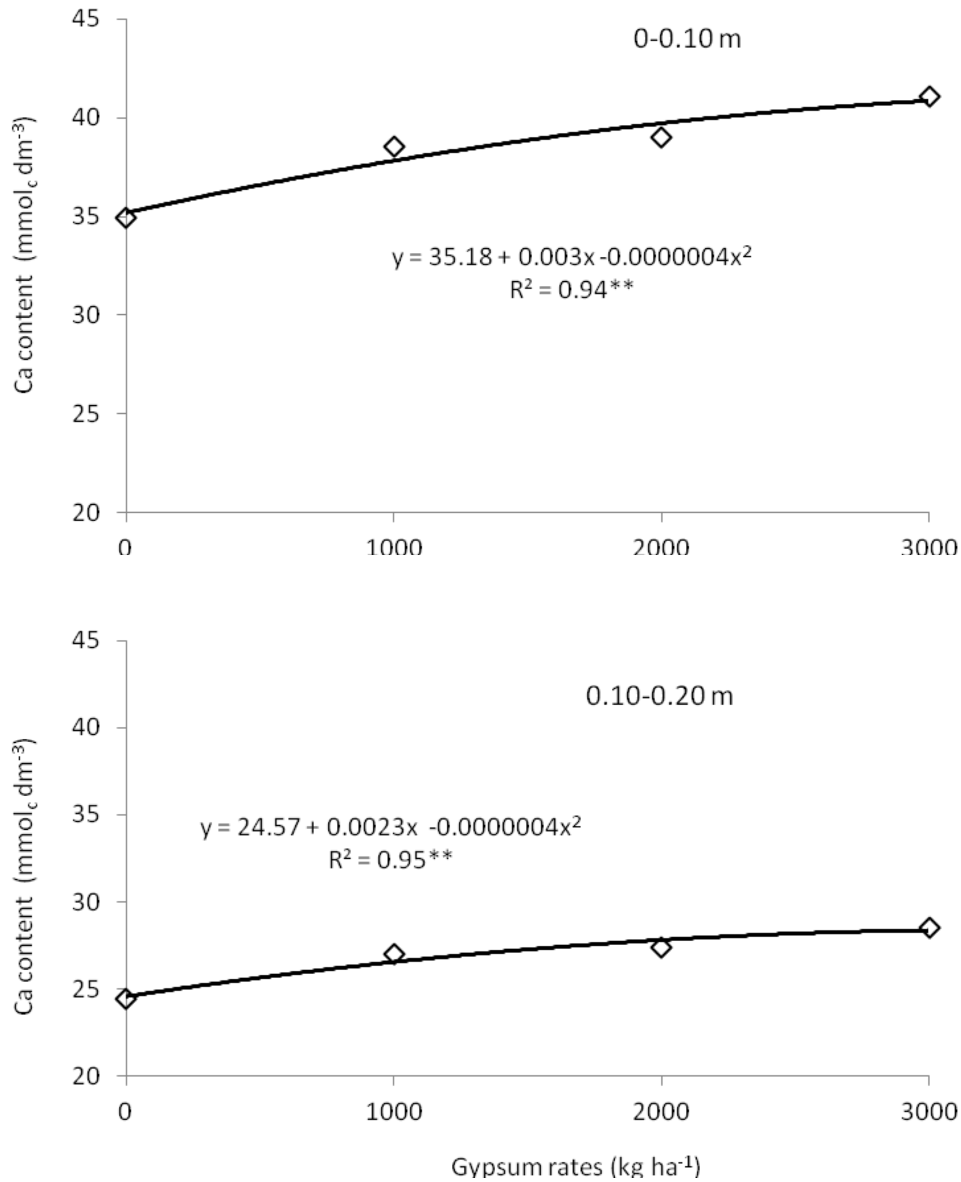

Figure 1. Calcium levels in the soil at depths of 0-0.10 and 0.10-0.20 m in relation to gypsum dose. 2011/2012 growing season.

experimental area was the right choice. However, it appears that this area is representative of those used for growing maize and soybeans in the Cerrado soil, which are naturally acid with low levels of bases (K, Ca and Mg) but after many years using liming and fertilizers by farmers provided high base saturation and fertility to the soil (Oliveira-Júnior et al., 2011; Montezano et al., 2006). Thus, these results are an important guide for farmers; in corrected soils with low subsurface Al and adequate Ca levels (>5 mmol dm^{-3}) gypsum application is not necessary.

Considering the result obtained, what could be expected in relation to gypsum application and that upland rice is considered a high-risk crop because it is a high-water-demand crop (Crusciol et al., 2013), there are some concerns about the cultivation of upland rice. The use of gypsum could help to reduce the subsurface Al concentration and increase Ca levels to stimulate root development at depth (Ritchey et al., 1982). In a NTS, due to the concentration of nutrients, organic matter and moisture in the first few centimeters of the soil, the rice root system tends to concentrate superficially (Nascente et al., 2013). Thus, the rice plant which has a higher demand for water than other crops, such as soybeans and maize, and has a less developed root system, becomes more subject to water stress and absorbs less

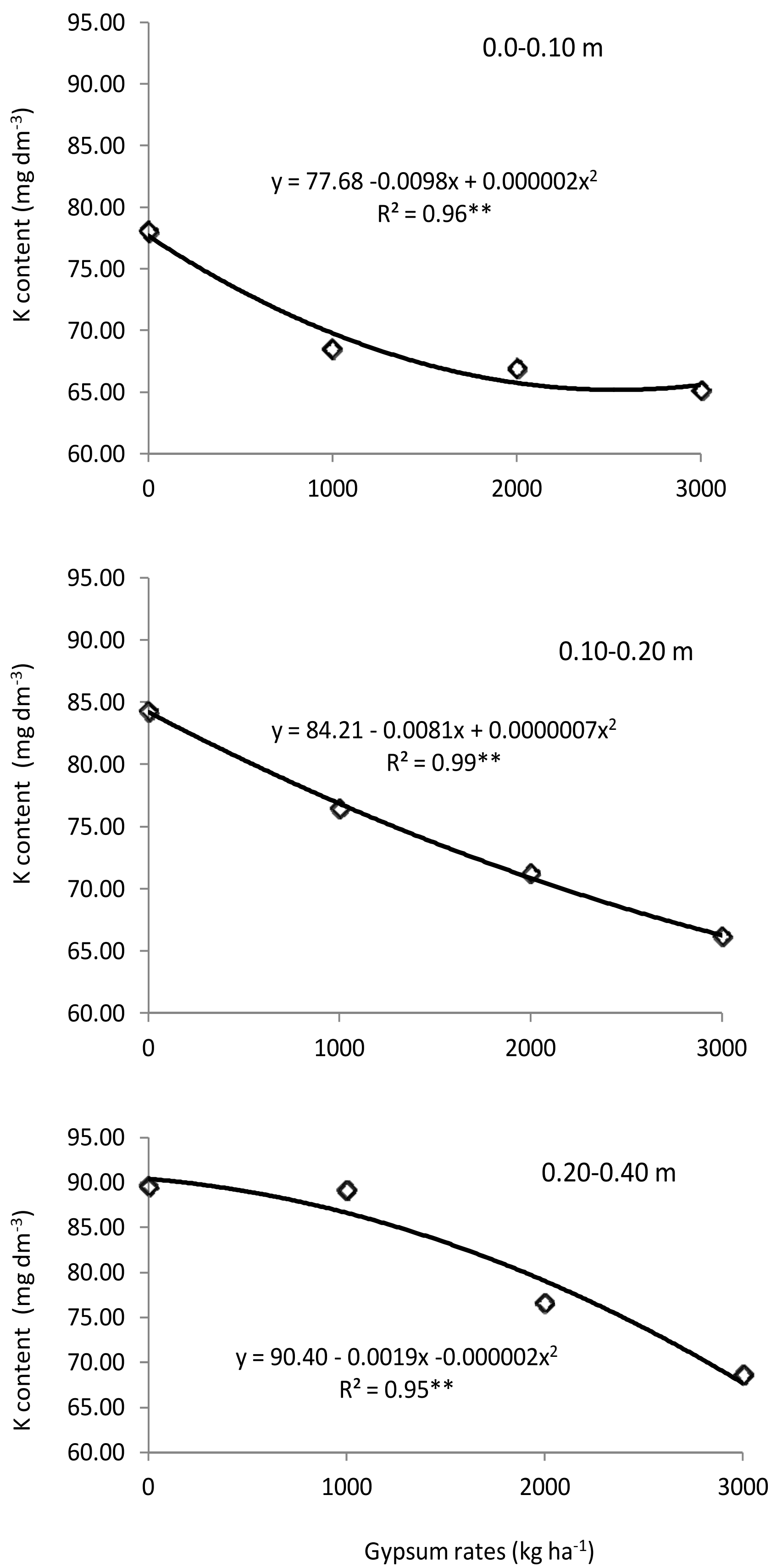

Figure 2. Potassium levels in the soil at depths of 0-0.10, 0.10-0.20 and 0.20-0.40 m as a function of gypsum rates 2011/2012 growing season.

Table 3. Plant height, number of panicles m-[1], mass of 1000 grains and grain yield for upland rice cultivated in a no-tillage system in relation to phosphorus dose, gypsum dose and growing season (2011/2012 and 2012/2013).

Factors of Gypsum doses (kg ha^{-1})	Plant height (cm)	Number of panicles (m^{-1}) Number	Mass of 1000 grains (Grams)	Grain yield (kg ha^{-1})
0	104.5	101.91	25.25	5092
1000	105.0	101.00	25.21	4993
2000	102.8	103.30	24.90	4860
3000	108.0	102.31	25.19	5133
Phosphorus doses (kg ha^{-1})				
0	103.8	101.64	25.26	4735
50	104.4	103.13	24.98	4970
100	105.0	103.36	25.09	5103
150	107.4	103.81	24.93	5207
Growing seasons				
2011/2012	105.4a[1]	90.1b	25.17a	4157.7b
2012/2013	104.8a	115.9a	24.97a	5849.7a
Factors		**ANOVA – Probability of F test**		
Growing seasons (GS)	0.4828	<0.001	0.1772	<0.001
Phosphorus (P)	0.0388	0.0155	0.3594	0.0386
Gypsum (G)	0.1003	0.7551	0.1943	0.7606
GS x P	0.9030	0.6866	0.4303	0.7613
GS x G	0.9873	0.4000	0.9219	0.6564
P x G	0.0521	0.6440	0.5551	0.8766
G x P x GS	0.9980	0.5359	0.5231	0.9049

[1]Means followed by the same letter do not differ by the Tukey test for p<0.05.

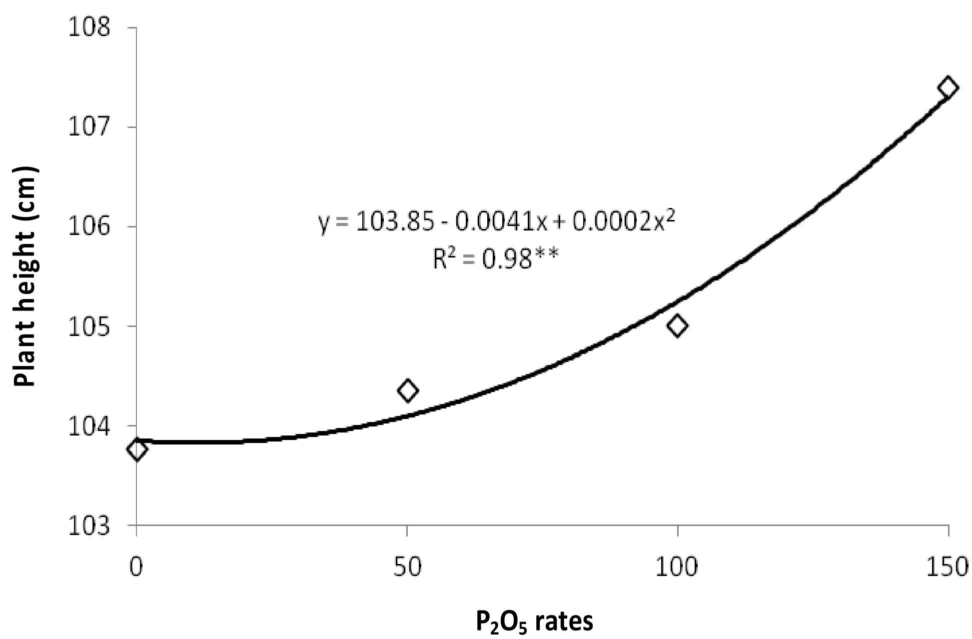

Figure 3. Rice plant height as a function of phosphorus rates applied in the sowing furrow. Average of two growing seasons.

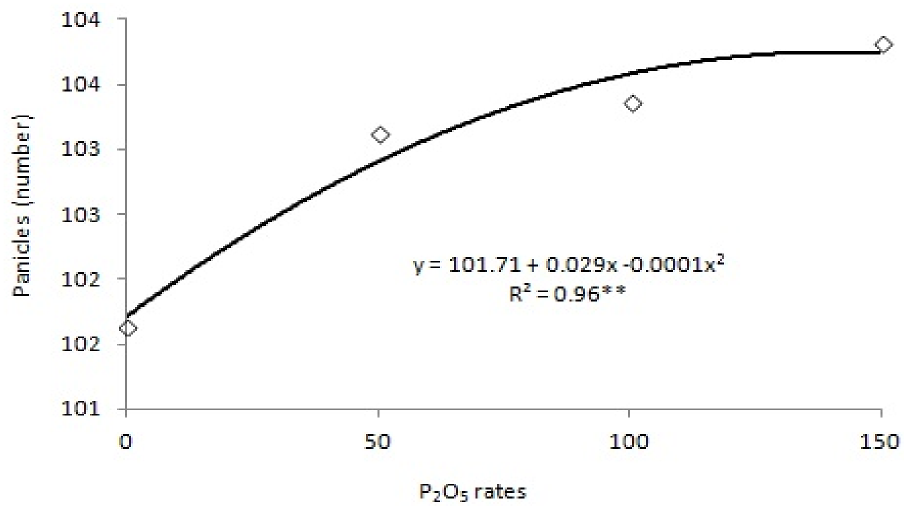

Figure 4. Rice number of panicles m^{-1} as a function of phosphorus rates applied in the sowing furrow. Average of two growing seasons.

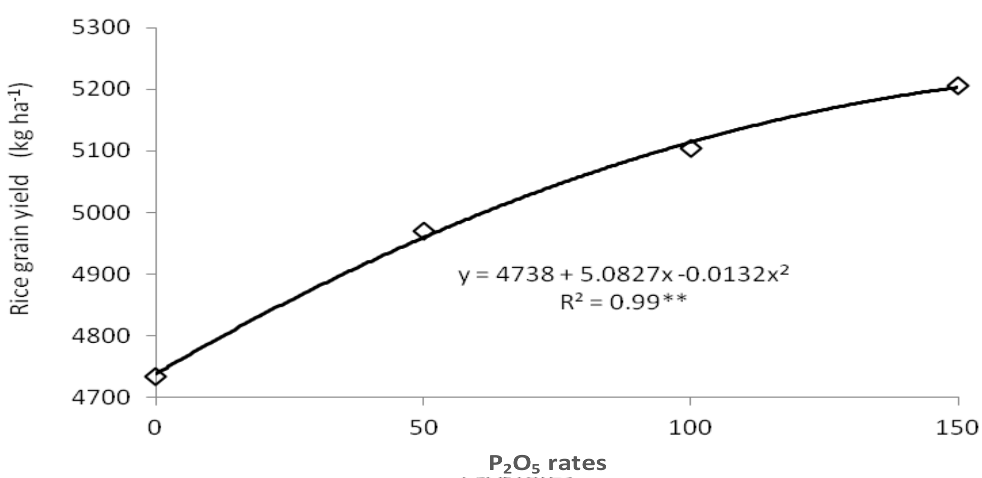

Figure 5. Rice grain yield as a function of phosphorus rates applied in the sowing furrow. Average of two growing seasons.

nutrients, which could cause grain yield reductions (Kluthcouski et al., 2000; Guimarães et al., 2006). As no effect of gypsum was observed in this study, it is possible that the rice root system had not developed in depth, thus, other strategies must be studied with regard to deepening rice root systems and, consequently, increasing the plant's drought resistance.

With respect to P levels, there were significant effects on the number of panicles m^{-1} and grain yield (Table 3). Thus, the data were fitted to quadratic equations for these two parameters (Figures 4 and 5). Crusciol et al. (2005) evaluated four upland rice varieties and also observed significant increases in crop production due to increased P availability. It is important to highlight that grain yield results were close to 5000 kg ha^{-1} in all treatments, even in the treatment with no P, and this is considered a high yield for upland rice. This result is probably due to the high level of P in the soil (Table 1), which had a significant effect on the rice grain yield. According to Fageria et al. (2011), P in the soil directly affects tillering, root development, number of panicles m^{-1} and the grain yield of rice crops.

Regarding growing seasons when evaluating grain yield and its component results in the second year, a higher number of panicles m^{-1} was observed than in the previous growing season (Table 3). Similarly, as rice grain yield is determined by the yield components, including the number of panicles m^{-1} (Yoshida, 1981), higher grain yields were also observed in 2012/2013 growing season.

The results of this experiment allowed us to infer that for the evaluated conditions (absence of Al toxicity in depth), P was more important for the development of the crop than gypsum. In Cerrado soils, which exhibit low natural fertility, it is common to find nutrient deficiencies, although with the development of agriculture in the region, corrected and high fertility soils can be found. Therefore, it is important to evaluate the initial fertility of each area with the objective of determining the real need for crop fertilization. Phosphorus, however, due to its high fixation in Cerrado soils, still has a high probability of response, and its doses should be adjusted to yield expectations to make its use profitable.

Conclusion

The application of gypsum provided incremental increases in Ca levels in addition to increased levels of K in deeper soil layers and did not affect plant height, yield components or grain yield of upland rice cultivated in a no-tillage system. By contrast, the application of increasing doses of P at sowing gave a significant increase in plant height, number of panicles m^{-1} and grain yield of upland rice cultivated in a no-tillage system.

Conflict of Interest

The authors have not declared any conflict of interest.

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