Phosphorus use efficiency of upland rice cultivars on Cerrado soil

Eficiência no uso de fósforo de cultivares de arroz em solos de Cerrado

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Abstract

Rice (*Oryza sativa* L.) is one of the most economically important cereal in developing countries and the phosphorus is the most deficient nutrient in the majority of Brazilian soils because their low natural level and high adsorption capacity, therefore it is a crop limiting factor. Rice cultivars have differentiated nutritional requests and tolerances about stress of essential nutrients. This work aimed to evaluate the efficiency about use and response to phosphorus application in upland rice cultivars (BRS-Primavera, BRS-Caiapó, BRSMG-Curinga, BRSMG-Conai, BRS-Sertaneja, BRS-Bonança and Epagri-109) in Cerrado soil. To simulate environments with low and high phosphorus levels were utilized levels of 20 and 120 kg ha^{-1} of P_2O_5 respectively. The experimental data were submitted to individual and joint analysis of variance applying the F test. Phosphorus influenced each cultivar differently and were not identified efficient cultivars about use and responsive to its application. The cultivars Epagri-109, BRS-Sertaneja and BRSMG-Conai are indicated to farming systems with high level of phosphorus.

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The cultivars BRS-Bonança, BRSMG-Curinga, BRS-Primavera and BRS-Caiapó are indicated to farming systems with low level of phosphorus.

Key words: *Oryza sativa* L.; abiotic stress; mineral stress.

Resumo

O arroz é considerado um dos cereais de maior importância econômica em países em desenvolvimento e o fósforo é o nutriente mais deficiente na maioria dos solos brasileiros, devido ao baixo teor natural e a alta capacidade de fixação, portanto é fator limitante da cultura. Os genótipos de arroz mostram exigências nutricionais e tolerâncias diferenciadas para estresses de nutrientes essenciais. Assim, objetivou-se com este trabalho avaliar a eficiência quanto ao uso e resposta a aplicação de fósforo em cultivares de arroz de terras altas em solos de Cerrado. Foram utilizados os cultivares BRS-Primavera, BRS-Caiapó, BRSMG-Curinga, BRSMG-Conai, BRS-Sertaneja, BRS-Bonança, Epagri-109. Para simular ambientes com baixo e alto nível de fósforo, foram utilizadas as doses 20 e 120 kg ha^{-1} de P_2O_5 respectivamente. Os dados experimentais foram submetidos às análises individual e conjunta de variância, com aplicação do teste F. O fósforo influencia cada cultivar de forma diferenciada e não foram identificadas cultivares eficientes quanto ao uso e responsivas à sua aplicação. As cultivares Epagri-109, BRS-Sertaneja e BRSMG-Conai são indicadas para cultivos de alta tecnologia. As cultivares BRS-Bonança, BRSMG-Curinga, BRS-Primavera e BRS-Caiapó são indicadas para cultivos de baixa tecnologia.

Palavras- chave: *Oryza sativa* L.; estresse abiótico; estresse mineral.

Introduction

The rice (*Oryza sativa* L.) is considered one of most important cereal in developing countries, being the basic food for nearly 2.4 billion people. Due to its increasingly demand, more efficient techniques must be studied in order to increase the production, yield and the quality of grains (FAGERIA et al., 1997). Cultivated and consumed in all continents, the rice crop stands out for its production of over 590 million tons of grain, representing actually nearly 30% of the total grain production in the world and it is cultivated in an area of 150 million hectares, playing a strategic role in the social and economic level (FALQUETO et al., 2007).

In Brazil, rice is grown in lowland and upland ecosystems under diverse cropping systems. The upland rice crop system, in spite of hold 60% of the cultivated area, it corresponds with only 31% of the national production, because of its low average yield (EMBRAPA, 2008). In Tocantins, this crop is present in lowland and upland spread all over the Estate. In the harvest 2007, the upland rice production was 168,812 ton, on 100,361 ha, standing for an average yield of 1682 kg ha^{-1} (SEAGRO, 2010).

Among the primary macronutrients, phosphorus is the one with the smallest exigency by rice crop, however it has biggest percentage of exportation in the grain (FORNASIERI FILHO; FORNASIERI, 1993).It is an integral component of important compounds of vegetal cells, including sugar phosphates, nucleic acids, nucleotides, coenzymes, as well as phospholipids that composes vegetal membranes and also has a key role in reactions that involve ATP (TAIZ; ZEIGER, 2009). The severe limitations of P availability, results in restrictions in development, limiting the plant growth, including its radicular system from that it can't further overcome, even if the supply of this nutrient is increased to adequate levels (WISSUWA, 2003). Its deficiency decreases the number of tillers and the leaf area, so consequently reduces the plant photosynthetic process. Among other physiological and biochemical function, this nutrient increases the number of panicles in the rice plant (EMBRAPA, 2008). The P is the most deficient nutrient in most Brazilian soils, due to its low natural content and the high adsorption capacity (FAGERIA, 1999). The adequate supply of P is essential since the early growth stages of the plant (TANGUILIG et al., 1987).

The selection of high efficient genotypes in phosphorus utilization is taken as one of the most appropriate manner to decrease the rice crop production cost (FAGERIA; BARBOSA FILHO, 1982). That is because genotypes within the same species have differentiated nutritional needs and stress tolerance for essential nutrients (FAGERIA; BARBOSA FILHO, 1981; FURLANI et al. 1983). Rotiliet al. (2010) and Cancellier et al. (2011) evaluating efficiency and response of rice cultivars, found differences among the studied cultivars, as well as Fidelis et al. (2009) did selecting maize populations for phosphorus stress, finding differentiated behavior among cultivars.

Therefore, this paper aimed to evaluate the use efficiency and response to phosphorus fertilization in upland rice cultivars on Cerrado soil.

Material and Methods

The cultivars evaluation was carried out on two trials, containing the contrasting levels of 20 and 120 kg of P_2O_5phosphorus (low and high level), on upland soil at municipality of Gurupi (TO), at Farm Chaparral (11° 40' S and 49° 01' W and altitude of 280m), in a sandy soil, harvest 2008-2009.

In both trials, the experimental design was randomized blocks with four replications. The experimental plot was composed by four lines of 5.0 m long, spaced 45 cm with 60 seeds per linear meter. As useful area, were used 4.0 meters long from two central lines. The cultivars BRS-Primavera, BRS-Caiapó, BRSMG-Curinga, BRSMG-Conai, BRS-Sertaneja, BRS-Bonança and Epagri-109 were tested.

The soil tillage was carried out with disking followed by harrow disking. The soil acidity correction was carried out according to the soil analysis sampled in each trial (Table 1). The seeding was manually done, on December 10^{th} of 2008. The fertilizer was applied in the seeding line at sowing time, following the regional recommendations and the soil analysis result. To simulate environments with low and high phosphorus, were utilized levels of 20 and 120 kg ha^{-1} of P_2O_5 respectively, utilizing simple superphosphate as source of P. These two contrasting levels were identified in previous trials, to differentiate the rice cultivars about P usage (FAGERIA, 1991). The nitrogen topdressing was divided into two applications of 45 kg ha^{-1} of N_2O with urea as source, being applied at tillering and panicle differentiation, as indicated on figure 1.

Table 1. Result of soil chemical analysis to high and low phosphorus trials of experimental field. Gurupi, TO, Harvest 2008-2009

Sample (cm)	Ca	Mg	H+Al	K	P*	M.O	pH**
			($cmol_c dm^{-3}$)		(mg/dm^3)	(%)	
High P 0-20	3.2	1.7	3.3	0.4	53	1.4	4.7
Low P 0-20	2.7	1.3	3.4	0.3	11.1	0.8	4.8

*Note: *Mehlich extraction **pH in $CaCl_2$.*

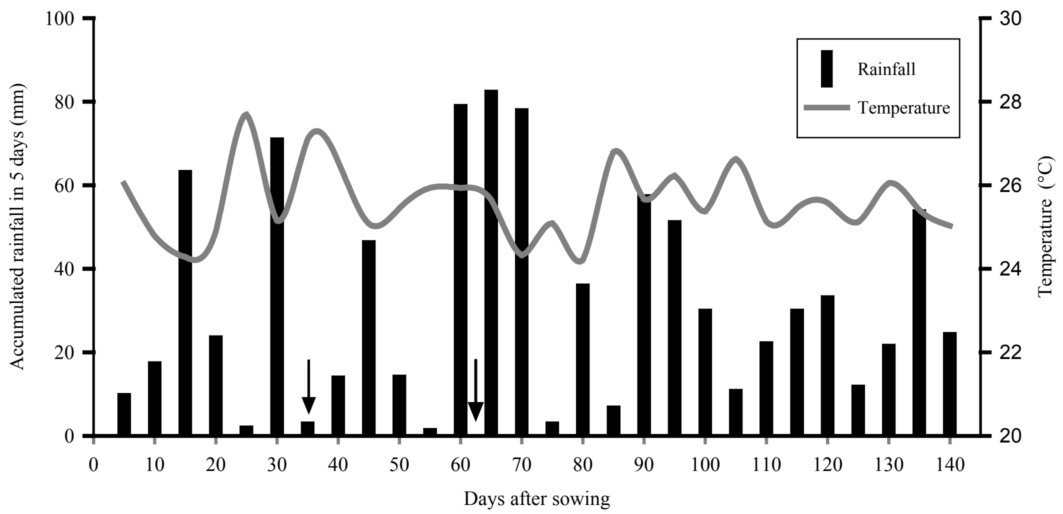

Figure 1. Accumulated rainfall, average temperature and date of topdressing (↓), from sowing day until harvest, Gurupi, TO, Harvest 2008-2009

The cultural traits were carried out utilizing manual weeding when necessary. There was no need of pesticides and fungicides sprayings during the trial conduction.

The evaluated characteristics were, number of days to heading date (HD): number of days to 50 percent of the panicles have excerpted from the boot from seeding. Plant height (PH): measured from ground surface until the top panicle of the central culm, excluding awn when present; Grain yield (GY): yield of clean grains with 13% of moisture, in kg ha^{-1} and one hundred grains mass (HGM): mass of a sample of one hundred grains.

The experimental data were submitted to individual and joint analysis of variance, with application of F test. The joint analysis was carried out under homogeneity conditions of residual variances. To comparison between treatments averages the Turkey test ($P< 0.05$) was used, being carried out on the software SISVAR (FERREIRA, 2000).

To cultivars differentiation was utilized the method proposed by Fageria and Kluthcouski (1980) and Fageria and Baligar (1993), that suggests the cultivars classification about phosphorus use efficiency and response to its application (efficiency and response – ER). Where the nutrient use efficiency is defined the grain yields average under low phosphorus fertilization. The response to its utilization is obtained by the difference between the grain yields in the two environments divided by the difference between the two levels of fertilization, according to the following equation:

RI = (HP-LP)/DBL.

Where:
RI = Response Index;
HP = Yield with high phosphorus level;
LP = Yield with low phosphorus level;
DBL = Difference between P levels (kg ha^{-1}).

In order to classify the cultivars, a representation in the Cartesian plane was made. In the abscissas axis (x), is found the phosphorus use efficiency and in the ordinate axis (y), the response index to its use. The origin point of the axis is the cultivars average efficiency and the average response index. In the first quadrant are represented the efficient and responsive cultivars (ER); in the second, the non-efficient and responsive (NER); in the third, the non-efficient and non-responsive (NENR) and in the fourth, the efficient and non-responsive (ENR) cultivars.

Results and Discussion

According to the analysis of variance (Table 2), there was a significant effect (P<0.01) in the interaction cultivars x phosphorus levels to days to heading date and grain yield. In this sense, is verified the influence of environments in a differentiate way towards the cultivars response, therefore these characteristics must be studied in conjunct, thus the factors were unfolded. Without significance in the interaction cultivars x phosphorus levels to plant height and one hundred grain mass, the factors were singly studied in these characteristics. In the factor of cultivars, there was significance (P<0.01) to all evaluated characteristics, indicating that the cultivars differ in their behavior. Through the analysis of variance was verified that phosphorus levels influenced also the number of days to heading date(P< 0.01) and plant height, fact that was not observed to one hundred grain mass and grain yield.

To the variable plant height, we observed that the cultivars BRS-Caiapó and BRS-Primavera had the biggest plant height, without differing from BRS-Sertaneja (Table 3). The cultivars BRS-Bonança and Epagri-109 had the smallest plant height, despite I have not differed from BRSMG-Curinga and BRSMG-Conai.Silva et al. (2009) at Cassilândia - MS, also evaluated the

Table 2. ANOVA summary for characteristics number of days to heading date (HD), plants height (PH) and one hundred grains mass (HGM), grain yield (GY), of seven rice upland rice cultivars grown at south of Estate of Tocantins, harvest 2008-2009

SV	Mean Square				
	DF	PH (cm)	HD (days)	HGM (g)	GY (kg ha^{-1})
Blocs/Environments	6	27.178 ^{ns}	3.279 ^{ns}	0.116 ^{ns}	6314.313 ^{ns}
Cultivars (C)	6	666.767**	916.827**	0.273**	238054.908**
Phosphorus level (PL)	1	504.000**	70.875**	0.031 ^{ns}	179.931ns
C x PL	6	75.875 ^{ns}	13.458**	0.072 ^{ns}	394164.932**
Error	36	39.845	2.626	0.041	8136.417
General average		78.392	83.803	2.465	893.195
C V (%)		8.05	1.93	8.23	10.10

*Note: ^{ns} non-significant; ** significant at P < 0.01; *significant at P < 0.05 by F test.*

cultivars BRSMG-Curinga, BRS-Bonança and BRSMG-Conai finding superior plant height averages to those observed in the same cultivars in this study, probably due to the edapho climatic conditions of southern of Tocantins state. According to Embrapa (2008), plants height is a characteristic determined mainly by breeding, but also the environmental conditions may influence it, as the air temperature, that over 35 °C increases respiration and consequently decreases the plant height and grain yield.

Concerning the environments, the low phosphorus level led to bigger plants height (Table 3) when compared to high phosphorus environment. Pinto et al. (2008) in a trial carried out in the same region of this current work did not find significant effect of phosphorus fertilization over plant height. Staut and Athayde (1999) evaluating phosphorus effect over cotton plant height, found a slight decrease in the plant height according to the increase of phosphorus level, however, without significant effect. Nevertheless, these results disagree with those obtained by Fageria and Baligar (1997) and Fageria et al. (1988), that report the effect of phosphorus level over the upland rice growth. This effect probably occurred due to the excess of phosphorus provided by fertilization associated with the available phosphorus in soil, taking to a physiological imbalance, aside with the competition with other anions in soil (MARSCHNER, 1995).

For number of days to heading date, the cultivars BRS-Primavera and BRSMG-Curinga had significant interaction with phosphorus levels, so that, the low phosphorus environment decreased the number of days to heading date, with reduction of 4.65 days to BRS-Primavera and 6.25 days to BRSMG-Curinga. For the other cultivars there were no significant differences between environments. The earliest cultivars in stressing environments were BRSMG-Conai and BRS-Primavera, however in high P environment, the only cultivar to compose the earliest cultivars group was BRSMG-Conai. In both environments, low and high P, the cultivar Epagri 109 was the most

Table 3. Average of characteristics plants height (PH), number of days to heading date (HD) and one hundred grains mass (HGM) with low and high phosphorus level to seven upland rice cultivars grown at south of Estate of Tocantins, harvest 2008-2009

Cultivars	PH (cm)			HD (days)		HGM (g)		
	Low P	High P	Average	Low P	High P	Low P	High P	Average
BRS-Primavera	93.4	84.6	88.9 a	71.0 dB	75.7 cA	2.28	2.26	2.27 b
BRS-Caiapó	95.1	87.2	91.2 a	86.5 bA	86.5 bA	2.72	2.71	2.71 a
BRSMG-Curinga	80.5	67.5	73.9 bc	79.2 cB	85.5 bA	2.39	2.34	2.36 b
BRSMG-Conai	78.9	69.2	74.0 bc	70.5 dA	70.2 dA	2.79	2.69	2.73 a
BRS-Sertaneja	83.8	80.8	82.2 ab	87.2 bA	87.0 bA	2.21	2.52	2.36 b
BRS-Bonança	73.5	67.4	70.5 c	82.5 cA	84.7 bA	2.42	2.29	2.35 b
Epagri-109	65.1	71.1	68.0 c	101.7 aA	104.7 aA	2.30	2.62	2.45ab
General Average	81.4 A	75.4 B	78.4	82.67	84.92	2.44 A	2.49 A	2.44

Note: Averages followed by the same letter uppercase within rows and lowercase within columns, do not differ statistically between themselves by Tukey test (P< 0.05).

delayed. According to the environments average (Table 3), in the high phosphorus levels, the cultivars heading date occurs 2.25 days later than those grown on low phosphorus environment. Pinto et al. (2008) also observed anticipation in the heading date under low phosphorus availability. For Taiz and Zeiger (2009) the deep deficiency of nutrients leads to an accumulation of endogenous gibberellins that in turn leads the plant to reproductive maturity, thus, anticipating the heading date.

The cultivars that presented the biggest one hundred grains mass were BRSMG-Conai and BRS-Caiapó, despite not having differed statistically from cultivar Epagri-109 (Table 3). These results corroborate with Cancellier et al. (2009) and Cancellier et al. (2011) that evaluating nitrogen nutritional stress in rice at State of Tocantins, also did not find difference between levels of nutrients to one hundred grains mass. Yoshida (1981) claims this characteristic to be affected mostly by genetic issues than the environmental ones.

For grain yield, in the environment with low phosphorus level, the cultivars BRS-Primavera, BRS-Caiapó and BRSMG-Curinga composed the highest yield group, while Epagri-109 obtained the lowest yield (Table 4). In high phosphorus environment the cultivar BRS-Bonança was inferior to the others, that did not differed among them. There was no significant difference between the averages of phosphorus levels, pointing out that upland rice in Cerrado region has been showing a high adaptability to low fertility soils. Corroborating results obtained by Kluthcouski et al. (2000) that found in their work, that levels of fertilization do not affect the average yield, with only a slight tendency to bigger yields in the highest levels of potassium and phosphate fertilization. However these studies disagree with Fageria (1991), whom reported increases in upland rice yield with bigger levels of phosphorus.

The cultivars Epagri-109, BRS-Sertaneja and BRSMG-Conai were the only ones that increased their yields significantly with the high phosphorus level, when

Table 4. Grain yield average of seven upland rice cultivars grown at south of Estate of Tocantins, harvest 2008-2009

Cultivars	GrainYield (kg ha^{-1})			Response Index
	Low P	High P	Diference	
BRS-Primavera	1,239.5 aA	906.1 aB	-333.4	-3.3
BRS-Caiapó	1,235.0 aA	897.0 aB	-338.1	-3.4
BRSMG-Curinga	1,080.8 abA	1,006.2 aA	-74.6	-0.8
BRSMG-Conai	802.6 cB	943.0 aA	140.4	1.4
BRS-Sertaneja	755.6 cB	903.1 aA	147.5	1.5
BRS-Bonança	925.0 bcA	502.6 bB	-422.0	-4.2
Epagri-109	226.4 dB	1,081.8 aA	855.4	8.6
Averageyield	895.0 a	891.4 a	-3.6	-0.04

Note:Averages followed by the same letter uppercase within rows and lowercase within columns, do not differ statistically between themselves by Tukey test (P< 0.05).

compared to the low level, while BRSMG-Curinga had no significant difference between the levels of P. Yet for cultivars BRS-Bonança, BRS-Primavera and BRS-Caiapó there was a yield decrease in the high phosphorus environment.

By the obtained results, the cultivars BRS-Bonança, BRSMG-Curinga, BRS-Primavera and BRS-Caiapó can be sorted into efficient in phosphorus usage because they presented the highest grain yields when grown in low P environment, thus, they are located in the first and forth quadrant of figure 2. The uptake and use efficiency of P for grain production by these cultivars compared to the others, allow us to infer that process associated to uptake, translocation, assimilation and redistribution of P are more efficient in these cultivars than in the others. According to Clark and Brown (1974) efficient plants in P uptake are those which accumulate bigger amounts of this nutrient when grown in low P level.

Concerning the response to P application, the biggest indexes were obtained by cultivars Epagri-109, BRS-Sertaneja and BRSMG-Conai that are located in the first and second quadrant of figure 2. Cultivars that present high response indexes are desirable because of their high capability to increase yield in response to phosphorus application. The cultivar Epagri-109 presented a response index of 8.55, that is, increase its yield in 8.55 kg ha^{-1} of grains for every kilogram of P supplied per hectare (Table 4).

Based on the method proposed by Fageria and Kluthcouski (1980) was not sort of any of the evaluated cultivars as efficient in use and responsive to phosphorus

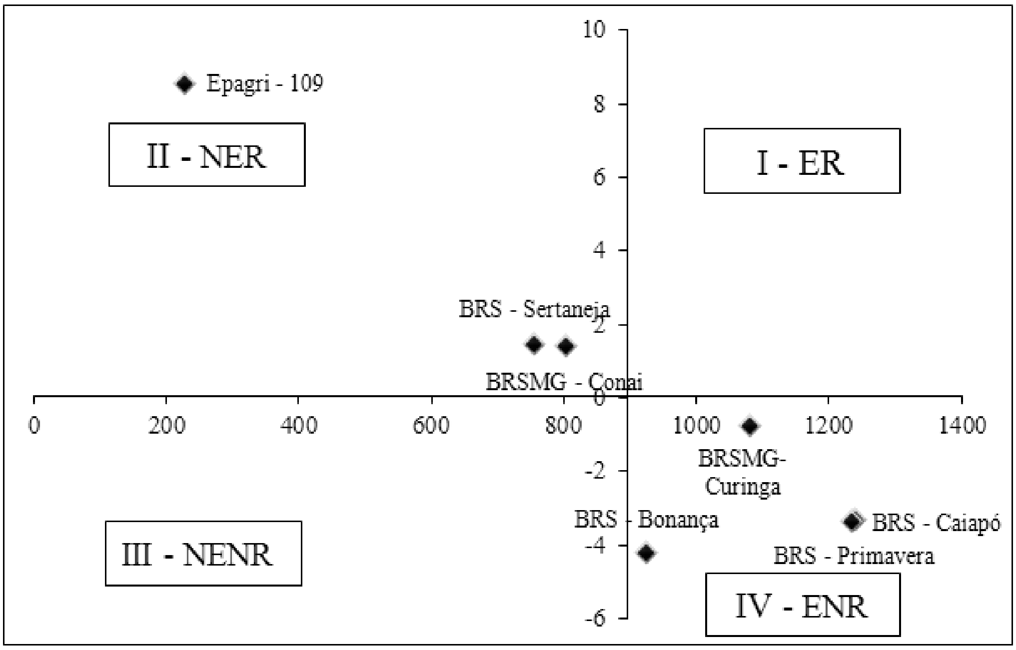

Figure 2. Efficiency in use and response to phosphorus application in upland rice cultivars, by Fageria and Kluthcouski (1980) methodology

application (first quadrant of Figure 2). Cultivars considered efficient and responsive are recommended to be grown in farming systems that adopt since low to medium and high technologic level, regarding fertilizers input, because as well as having a middle yield on low P level, they respond to increases on the level of P in the soil, increasing yield.

The cultivars Epagri-109, BRS-Sertaneja and BRSMG-Conai were sorted as non-efficient and responsive (second quadrant of Figure 2), because these cultivars yielded under cultivars average in low phosphorus environment (Table 4). However, when grown in high P environment, obtained values of response index bigger than the general average (Table 4). Cultivars from the non-efficient and responsive group are indicated to be grown by farmers who work with a high technology farming system. These results corroborate with Matias (2006) whom also sorted the cultivars BRS-Bonança and BRS-Primavera as non-efficient and responsive to phosphorus application.

The utilized methodology did not sort any of the cultivars into non-efficient in use and non-responsive to phosphorus application (third quadrant of Figure 2). Cultivars sorted as non-efficient and non-responsive wouldn't be recommended to be cultivated even in low technology farming systems.

In the quadrant of efficient and non-responsive are located cultivars BRSMG-Curinga, BRS-Primavera, BRS-Caiapó and BRS-Bonança (Figura 2), that yielded over the low P environment average. However, these cultivars obtained smaller response indexes than the general average (Table 4), highlighting the lack of response towards increases on nutrient supplies. Cultivars sorted as efficient and non-responsive are recommended to farmers who carry out low technology farming system. These results disagree with those reported by Matias (2006), who sorted in his study the cultivar BRMG-Curinga as efficient and responsive to phosphorus application; however similar result was found in the sort of cultivar BRS-Caiapó, that was also classified as efficient and non-responsive.

The cultivars grain yield average in low and high P environments were inferior to the Estate's average in harvest 2006-2007, that was 1,682 kg ha^{-1} (SEAGRO, 2010). Yet Guimarães et al. (2007) evaluating 51 inbreed lines on field under low and high P, obtained average yield of 478 kg ha^{-1} and 1619 kg ha^{-1}, respectively. Crusciol et al. (1999) reported in their study that the observed differences in literature about uptake and nutrients utilization are related to differences among the utilized cultivars.

Conclusions

Cultivars efficient in phosphorus usage and responsive to its application were not identified. The cultivars Epagri-109, BRS-Sertaneja and BRSMG-Conai are indicated to farming systems with high level of phosphorus. The cultivars BRS-Bonança, BRSMG-Curinga, BRS-Primavera and BRS-Caiapó are indicated to farming systems with low level of phosphorus.

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