PHOSPHATE FERTILIZATION EFFICIENCY IN SOYBEAN CULTIVARS INDICATED FOR *CERRADO* TROPICAL SOIL REGIONS

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ABSTRACT: Phosphorus deficiency (P_2O_5) is among the main abiotic stresses that limit soybean production in *cerrado* soils. Its low availability in soils, especially in the more weathered and acidic ones, the increased demand and its scarcity estimations leadto the need for the development of cultivars more efficient in the use of this mineral. This experiment was conducted under field conditions in the municipality of Imperatriz, state of Maranhão, Brazil, under planosol conditions, in a randomized complete block design, with treatments arranged in a 2x4 factorial scheme with four replicates, four P levels (0, 60, 120 and 180 kg ha^{-1}), and two soy bean cultivars (BRS 333 RR and BRS 9180 IPRO) indicated for tropical regions or Brazilian *cerrado*. In this study, P_2O_5 efficiency use was evaluated based on plant height, shoot dry mass (SDM), pod dry mass (PDM) and number of pods (NP). BRS 333 RR cultivar obtained the highest efficiency with doses of 84.35 kg ha^{-1} and 94.46 kg.ha^{-1}, producing 696,76.76g e 86,72.06g for SDM and PDM respectively, average height of94.15 cm with 123.98 kh.ha^{-1} and phosphate fertilizer use efficiency (FUE) of 13%.

KEYWORDS: ecotone,P fixation, *Glycine max*, weathering.

EFICIÊNCIA DA ADUBAÇÃO FOSFATADA EM CULTIVARES DE SOJA INDICADAS PARA REGIÕES DE SOLOS TROPICAIS DE CERRADO

RESUMO: A deficiência de fósforo (P_2O_5) está entre os principais estresse sabióticos que limita a produtividade da soja em solos de cerrado. Sua baixa disponibilidade nos solos, principalmente nos mais intemperizados e ácidos, o aumento da demanda e das estimativas de sua escassez, inferem na necessidade de desenvolvimento de cultivares mais eficientes na utilização desse mineral. O experimento foi conduzido em condições de campo, na cidade de Imperatriz – MA, Brasil, sob condições de Planos solo, em delineamento blocos casualizados, fatorial 2x4, com quatro repetições, quatro níveis de P 0, 60, 120, 180 kg.ha^{-1}, e duas cultivares de soja BRS 333 RR e BRS 9180 IPRO indicadas para regiões de zona tropical ou cerrado brasileiro. Neste estudo, avaliou-se a eficiência do uso de P_2O_5 com base na altura de plantas, produção de massa seca da parte aérea (MSPA), massa seca de vagens (MSV) e número de vagens. A cultivar BRS 333 RR obteve a maior eficiência com doses de 84,35 kg.ha^{-1}e 94,46 kg.ha^{-1} produzindo 696,76.76g e 86,72.06g de MSPA e MSV respectivamente, uma altura média ideal de 94.15cm com 123,98 kg.ha^{-1} e eficiência no uso de P (EU) de 13%.

PALAVRAS CHAVE: Ecótono. fixation de *P. Glycine*Max. Intemperização.

INTRODUCTION

Among the three primary macronutrients (N, P and K), phosphorus (P_2O_5) is the least extracted by plants and is usually the nutrient used in greater amounts as fertilizer. The risk of scarcity will increase in the coming decades due to limited world reserves and population growth estimates of nine billion, leading to an inevitable increase in demand for food, fiber and energy and therefore use of phosphate (CORDELL et al, 2009; ROY et al., 2016)

Most Brazilian soils present high retention/ fixation capacity of this macronutrient, as they are highly weathered and acidic, which favors the strong tendency of phosphorus (P) applied to the soil to react through adsorption and precipitation reactions with Al (aluminum) Fe (iron) and Ca (calcium), forming low-solubility compounds. Therefore, doses of phosphorus higher than those required by plants are often applied via fertilizers, especially in new cultivation areas (MARTIN and MARSCHNER, 2006; NOVAIS et al., 2007; WITHERS et al., 2018).

P is an element that plays a fundamental role in all metabolites related to the acquisition and use of energy, being an important nutrient for legume nutrition, as well as for nodulation and fixation of atmospheric nitrogen. Thus, its deficiency is one of the main abiotic stresses that affect plants growth, especially in tropical soils (MALAVOLTA et al., 1989; OLDAY, 2006; NOVAIS et al., 2007). Stress caused by low P availability in the soil leadsthe efficiency of nutrient utilization by plants to be different among species and among cultivars of the same species (MAHANTA et al., 2014; LYNCH, 2015; FAGERIA, 2016).

Estimates of scarcity combined with low P soil availability, successive increases in phosphate fertilizer and food prices, and potential geopolitical stress indicate the need to improve phosphorus (P) efficiency of the agricultural sector by developing strategies, together with good management practices, allowing plants to be more efficient in the absorption and utilization of nutrients. The objective was to evaluate the efficiency of phosphate fertilization in commercial soybean cultivarsof Brazilian cerrado soils, identifying the most efficient P use cultivar (FUE) and if this cultivar is the most productive in terms of shoot dry matter (SDM), pod dry mass (PDM), number of pods (NP) and responsive regarding height parameter.

MATERIAL AND METHODS

The experiment was conducted under field conditions in an experimental area provided by *EmpresaBrasileira de InfraestruturaAeroportuária* (INFRAERO) located in the municipality of Imperatriz, Brazil (5º 31’ 32’S and 47º 26’ 35’W), with average altitude of 92 meters above sea level. The region climate is defined as Tropical *Aw*, according to the Köppen classification (PEEL et al., 2007), with annual average rainfall of 1476 mm.

The experimental field soil was classified as Planosol(SANTOS, 2013). The soil chemical characteristics and granulometric fractions are shown in Table 1.

Table 1. Soil chemical analysis of the experimental area.

pH	MO	P	K	Ca	Mg	Al	H+Al	CTC	SB	V	m	S
$CaCl_2$	$g.dm^{-3}$	$mg.dm^{-3}$		$mmol_c.dm^{-3}$						%		$mg.dm^{-3}$
4.8	18.4	13.5	0.2	1.6	0.69	0.00	1.70	4,19	2,49	59,43	0	4.23
Sand: $780g.kg^{-1}$. silt: $110g.kg^{-1}$. clay: $110g\ kg^{-1}$.												

The experimental design was randomized complete block design, with treatments arranged in a 2x4 factorial scheme, two soybean cultivars and four phosphorus levels, 0, 60, 120 and 180 kg ha^{-1}, with four replicates, totaling 32 experimental units. Each unit had an area of 4 m^2 and single superphosphate was used as P_2O_5 source.

Soybean cultivars used were BRS 333 RR and BRS 9180 IPRO, made available by the *Empresa Brasileira de Pesquisa Agropecuária* (Embrapa), unit of Imperatriz, MA, Brazil. BRS 333 cultivar of RR technology (Roundup Ready) has a determined growth rate and maturation cycle from 118 to 128 days, high resistance to lodging, excellent productive potential combined with wide adaptation, good plant branching and resistance to diseases like stem canker, frogeye leaf spot, bacterial pustule and soybean mosaic virus (smv). BRS 9180 cultivar, *INTACTA* RR2 PRO technology, with growth rate and flower coloring similar to the previous one, has purple coloring flower, average height of 78 cm, maturation from 104 to 131 days, moderate resistance to lodging, rusticity, high capacity to withstand summer and excellent branching, and resistance to diseases such as stem canker *(Diaporthephaseolorum f. sp. meridionalis)*, frogeye leaf spot *(Cercosporasojina)* and bacterial pustule (*Xanthomonas axonopodis* pv. *glycines*).

Soybean seeds were inoculated with peat-based inoculant containing *Bradyrhizobium japonicum* bacteria, nitrogen fixers to assist in the availability of this nutrient to plants, with dose of 200 g of inoculant and 300 ml of additive for 50 kg of soybean seeds, according to manufacturer's recommendations.

Seeding was carried out in September 2016, in 4 rows per plot, with spacing of 0.4 m between rows and 8 cm between plants. The 2 central rows were used for sampling, while the 2 lateral rows were considered border.

At 20 days after emergence (DAE), some plants were sampled to verify the inoculation efficiency with nitrogen fixing bacteria, and it was observed that the incidence of nodules in the root system was very low. It was decided to provide 40 kg ha^{-1} of nitrogen at 30 DAE through urea, incorporating it to the strip next to the planting row (Sediyama, 2015).

Weed management was carried out through application of 0.5 L ha^{-1} of FUSILADE 250 EW, which is a class III systemic herbicide and active ingredient Butyl (R) - 2-(4-(5−trifluoromethyl−2-pyridyloxy)-phenoxy)-propionate (FLUAZIFOP-P-BUTYL) Butyl (R) - 2-(4-(5-trifluoromethyl-2-pyridyloxy)-phenoxy)-propionate (FLUAZIFOP-P-BUTYL).

High incidence of silverleaf whitefly (*Bemisiaargentifolii*) was observed, being controlled at 30 DAE with the use of *CONNECT* systemic insecticide of active ingredient BETA-CYFLUTHRIN and IMIDACLOPRID at concentration of 750 ml L in 100 L syrup ha^{-1}, according to recommendations in the product registration for the crop. Twenty days after application, the same insecticide was used to control brown stink bug (*Euschistosheros)*, at dose of 20 ml to 10 L.

At 40 and 55 DAE, 9180 I PRO and 333 RRcultivars, respectively, were present at R1 stage, at the beginning of flowering, at which time height was measured with the help of a measuring tape, sampling 10 plants located in the central rows of each plot.

BRS 9180 IPRO cultivar was harvested at 79 DAE and BRS 333 RR cultivar at 86 DAE for determination ofshoot dry mass (SDM) and pod dry mass (PDM). With the aid of pruning shears, five plants were removed from each experimental unit with cut of 5 cm above the soil surface and pods were separated from shoots. The plant material was packed in paper bags, duly identified and submittedto forced air circulation oven with temperature of 60 ºC until reaching constant weight.

Phosphate fertilizer use efficiency was evaluated by the following equation:

$$\mathbf{FUE} = \frac{\mathbf{SDMf - SDM0}}{\mathbf{Pf}}$$

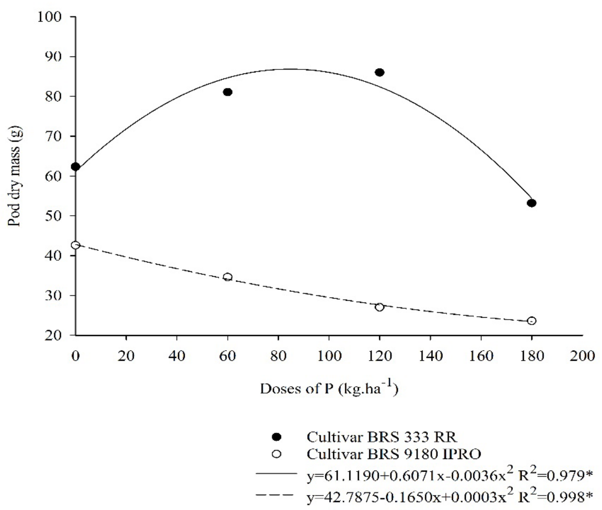
Where: FUE is the fertilizer use efficiency; SDM*f* is the shoot dry mass of plants that received phosphate fertilizer; SDM*0* is the shoot dry mass of plants that did not receive phosphate fertilizer; Pf is the dose of phosphate fertilizer applied (FAGERIA, 1998).

Data were analyzed for normality by the Shapiro-Wilk test (SHAPIRO et al., 1968) and homoscedasticity by the Levene test (Levene, 1960) with no need for data transformation. Data obtained were submitted to regression analysis, adjusting equations based on phosphorus doses using the Sigmaplot statistical software version 13. The interaction by the 5% F significant test and the magnitude of determination coefficientswas adopted as criterion in the choice of the model. Subsequently, data were submitted to analysis of variance at 5% error probability.

RESULTS AND DISCUSSION

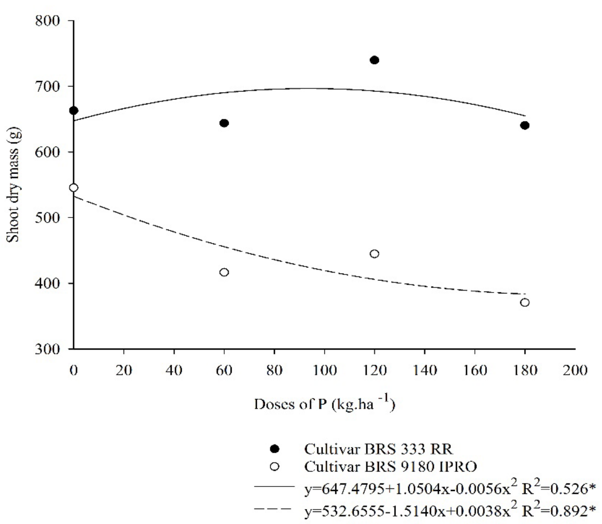
Cultivars presented different behaviors in relation to P2O5doses for the evaluated variables. BRS 333 RR cultivar showed significant quadratic behavior that, in treatment with 93.78kg.ha^{-1} P2O5,obtained higher physical yield in biomass production with696.73g MSPA (Figure 1). Treatment with no phosphate fertilization obtained average SDM higher than treatment with 180 kg ha^{-1}. This behavior evidences the lack of need of phosphate fertilization for this soybean cultivar under similar fertility conditions.When evaluating SDM of BRS 9180 IPRO cultivar (Figure 1), significant linear decrease was observed as phosphate fertilizer doses increased. In control treatment, adjusted SDM was 532.65g, while under high P_2O_5 (180 kg.ha^{-1}), minimum SDM result of 383.31g was obtained.

Figure 1. Average shoot dry mass values of BRS 333 RR and BRS 9180 IPRO cultivars (p≤0.05).



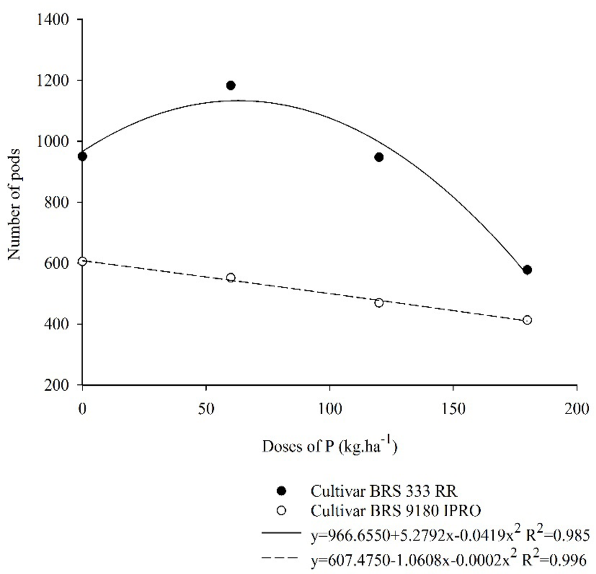
In figure 2, dose of 84.347 kg.ha^{-1} had maximum efficiency with 86.72g of PDM in BRS 333 RR cultivar, while BRS 9180 IPRO cultivar once again behaves linearly and negatively with doses of P_2O_5, reaching 22.91g under conditions of 180kg.ha^{-1}.This adjustment, although not significant for the effect of P_2O_5 dose factor, was negative to the linear model, indicating that probably this cultivar has relative efficiency for biomass production under conditions of average P_2O_5 levels in soils with adequate N and K supply and water availability.

Figure 2. Average pod dry mass values of BRS 333 RR and BRS 9180 IPRO cultivars (p≤0.05).



BRS 333 RR cultivar again behaves according to a quadratic curve, where the highest average height for the cultivar was under conditions of 120 kg ha^{-1} P2O5, with 94.15 cm (Figure 3). These results corroborate those of Rosa et al. (2015) who, in an INTACTA technology soybean test using P2O5doses 50, 100, 150 and 200 kg ha^{-1} in the clayey dystrophic yellow red Latosol of Brazilian *Cerrado*, in Mato Grosso - MT, Brazil, verified that the different phosphorus doses influenced the height of plants, where the highest values were obtained with the highest applied dose.

Figure 3. Average plant height values of BRS 333 RR and BRS 9180 IPRO cultivars (p≤0.05).



Cavalcante et al. (2010) evaluated BR 5033 cultivar under controlled conditions using Yellow Latosol soil and P_2O_5 doses of 0, 50, 100 and 150 kg.ha^{-1} and recorded quadratic adjustment with the application of doses, obtaining maximum plant height of 108 cm with P_2O_5 dose of 137.5 kg ha^{-1} and higher shoot dry mass with the application of 120 kg.ha^{-1}. The authors pointed out that at doses higher than those mentioned above, no increase in height and SDM values was observed.

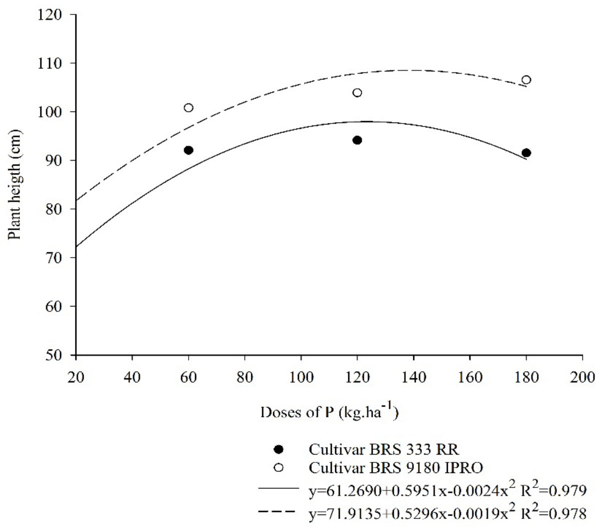
For height variable, BRS 9180 IPRO showed non-significant increasing effect as a function of P doses (Figure 3). Control treatment presented the lowest adjusted height, which was 71.91cm, close to the average value described for the cultivar, which is 78 cm (NORTE et al. 2016), confirming the cultivar genotype characteristics under medium soil fertility and adequate water availability conditions. The highest mean height was obtained in treatment with 180 kg.ha^{-1} P_2O_5, reaching 106.55 cm.Mundstock andThomas (2005) reported that excess water in years of intense rainfall is reflected in excessive vegetative growth. This factor, together with adequate P, N and K availability may have contributed to the excessive vegetative development of this cultivar, which average height is 78 cm (Vilela et al., 2016).

Dry mass productivity is associated with nutrient accumulation by plants. Mauad et al. (2010) reported that soybean plants with excessive growth and large leaves reduce radiation distribution inside the crop due to shading, reducing the photosynthetic activity and consequently formation of pods. This fact may explain the decreased average valuesof BRS 9180 IPRO cultivar as a function of P_2O_5 doses. The provision of adequate, and mainly balanced, amounts of essential elements is more important to achieve high yields than the provision of larger amounts of these nutrients alone (Primavesi, 1985). This fact may explain the lower SDM and PDM production at dose of 180 kg ha^{-1}.

Single superphosphate has high solubility in water and is readily available to plants. Considering that soil presents low buffer capacity for P and sandy texture (Table 1), high P_2O_5 doses (120 and 180 kg ha^{-1}) did not reflect economic returns for BRS 9180 IPRO cultivar in this experiment, since high doses of this fertilizer may have promoted an antagonistic interaction with Zn, since there are reports in literature that point to the antagonistic effect between P and Zn. Parker et al. (1992) reported that under high doses of phosphate fertilizers, reduction in dry matter yield was observed in two tomato cultivars for a certain Zn level in soil.

Variables production and productivity were not evaluated in this project, considering that there was no grain harvest; however, data on the number of pods were obtained, where BRS 333 RR cultivar obtained the highest average with 1182.75 pods, under conditions of 60 kg h^{-1}, and even results were not statistically significant, cultivar under dose of 120 kg ha^{-1} produced average number of pods of 947.50 (Figure 4), which reinforces the results of other works such as the Zucareli et al. (2011) and Silva et al. (2015), who reported the same economic efficiency with dose 120 kg h^{-1}, in quadratic response for the yield of 'Carioca' beans and soybean respectively, and in soils with low phosphorus availability. Colombo et al., (2016) presented average of 69 pods per soybean plant in high P_2O_5 environment with 120 kg ha^{-1}, which represented an increase of 56.8% in relation to plants under conditions of low P_2O_5 (40 kg ha^{-1}) with 44 pods per plant.

Figure 4. Average number of pods of BRS 333 RR and BRS 9180 IPRO cultivars (p≤0.05).



Fertilizer doses considered economical correspond to more than 80% of the dose responsible for maximum production, which may represent the economic viability of the use of phosphate fertilizer in soybean cultivation. According to de Sousa & Lobato (2003), the economic efficiency for phosphate fertilizer is between 80% and 95% of maximum grain yield.

FUEof BRS 333 RR cultivar was similar between P2O5doses of 60 and 120 kg ha^{-1}, which reached 12% and 13% of phosphate fertilizer use efficiency for each dose, respectively (Table 2). Dose of 180 kg ha^{-1}, in addition to presenting the lowest average PDM, also presented the lowest FUE of P fertilizer applied, 3%.

Table 2. Phosphate fertilizer use efficiency (FUE) by the evaluated soybean cultivar.

Doses of P (kg.ha^{-1})	BRS 333 RR
	FUE
	%
60	12
120	13
180	3

FUE calculations were performed using average SDM values of each dose.

The supply of suitable doses of readily soluble phosphate fertilizers such as single superphosphate or triple superphosphate from the beginning of soybean crop development is essential for the formation of the essential reproductive parts and for the good formation of pods and grains, increasing crop production (Taiz and Zeiger, 2017).

Therefore, during the growth and development of soybean plants in experimental field, single superphosphatedose of 123.98 kg.ha^{-1}, together with nutrients added to the soil (K and N), met the nutritional balance of this cultivar, considering that there was efficiency variation in the different parameters tested, with doses ranging from 62.99 kg.ha^{-1} for number of pods to 123.98 kg.ha^{-1} for plant height.

In this context, the probability of occurrence of response of BRS 333 RR soybean cultivar in relation to phosphate fertilization in soils with medium P availability and sandy texture will be lower when P supply is higher than 123.98 kg.ha^{-1}, reducing plant height, SDM, DPM and number of pods,respectively. BRS 333 RR cultivar can showed reduction about 65.51% per hectare under the consumption of phosphate fertilizer in the Brazilian cerrado.Thus, after further field trials to confirm the hypotheses tested, the cultivar could be presented as responsive and P_2O_5 use efficient.BRS 333 RR cultivar exhibits satisfactory behavior in terms of soil fertility by decreasing the consumption of inputs, whileBRS 9180 IPRO cultivar obtained negative response to high P_2O_5 doses, differing from reports in literature regarding culture and mineral.

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