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Phosphorus and zinc fertilization for cowpea in Amazonia

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Abstract – Phosphorus (P) fertilization can increase zinc (Zn) requirement of cowpea for grain production. The objective of this study was to evaluate the effects of P and Zn rates on two cowpea cultivars grown under field conditions in Amazonia. The cultivars were BRS Imponente and BRS Tumucumaque. Each cultivar was studied in a field experiment separately. The experiments were 4 x 4 factorials conducted in randomized complete block designs with three replicates. Treatments in each experiment were combinations of P (0 kg P_2O_5 ha^{-1}, 40 kg P_2O_5 ha^{-1}, 80 kg P_2O_5 ha^{-1} and 120 kg P_2O_5 ha^{-1}) and Zn (0 kg Zn ha^{-1}, 2 kg Zn ha^{-1}, 4 kg Zn ha^{-1} and 6 kg Zn ha^{-1}) rates. P application increased grain yield of both cultivars. Response to Zn application was found only for the cultivar BRS Imponente. The highest yield for the cultivar BRS Imponente (2,195 kg ha^{-1}) was achieved with combined application of 120 kg P_2O_5 ha^{-1} and 2 kg Zn ha^{-1}. P rate of 77 kg P_2O_5 ha^{-1} was sufficient for maximum yield (1,984 kg ha^{-1}) of the cultivar BRS Tumucumaque. The need for combined P and Zn fertilization for cowpea in Amazonia depends on the cultivar.

Index Terms: fertilizer, Humid Tropics, micronutrient, *Vigna unguiculata*.

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Fertilização com fósforo e zinco para feijão--caupi na Amazônia

Resumo – Fertilização com fósforo (P) pode aumentar a exigência de zinco (Zn) do feijão-caupi para produção de grãos. O objetivo deste estudo foi avaliar os efeitos de doses de P e Zn em cultivares de feijão-caupi em condições de campo na Amazônia. As cultivares foram BRS Imponente e BRS Tumucumaque. Cada cultivar foi estudada separadamente em um experimento de campo. Os experimentos foram fatoriais 4 x 4 em delineamento em blocos ao acaso com três repetições. Os tratamentos em cada experimento foram combinações de doses de P (0 kg ha^{-1}, 40 kg ha^{-1}, 80 kg ha^{-1} e 120 kg ha^{-1} de P_2O_5) e Zn (0 kg ha^{-1}, 2 kg ha^{-1}, 4 kg ha^{-1} e 6 kg ha^{-1} de Zn). Aplicação de P aumentou a produtividade de grãos de ambas as cultivares. Resposta à aplicação de Zn foi constatada somente para a cultivar BRS Imponente. A mais alta produtividade da cultivar BRS Imponente (2.195 kg ha^{-1}) foi conseguida com aplicação combinada de 120 kg ha^{-1} de P_2O_5 e 2 kg ha^{-1} de Zn. Dose de P de 77 kg ha^{-1} de P_2O_5 foi suficiente para produtividade máxima (1.984 kg ha^{-1}) da cultivar BRS Tumucumaque. A necessidade de fertilização combinada com P e Zn para feijão-caupi na Amazônia depende da cultivar.

Termos para indexação: fertilizante, micronutriente, Trópicos Úmidos, *Vigna unguiculata.*

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is one of the most important and strategic staple foods in tropical and subtropical world. In Brazil, including Amazonia region, this crop is an important social and economic alternative to supply food for smallholders (Salvador, 2017).

However, cowpea grain yields in Brazilian lands are low, varying from 300 kg ha^{-1} to 900 kg ha^{-1}, particularly due to the non-use or inadequate use of fertilizers (Freire Filho et al., 2005). In highly weathered tropical soils (as *Latossolos* in the Brazilian classification system or Oxisols in Soil Taxonomy), phosphorus (P) fertilization is essential to increase the yield of most crops of economic interest (Sanchez; Salinas, 1981), since such soils are characterized by low P availability and high phosphate adsorption capacity (Melo, 2002; Melo et al., 2003; Falcão; Silva, 2004).

Results of field experiments have revealed high response potential of cowpea to P fertilization in soils of the brazilian Amazonia region. In Roraima State, Silva et al (2010) have observed higher grain yield (944 kg ha^{-1}) with the application rate of 90 kg P_2O_5 ha^{-1} in a *Latossolo* (Oxisol). In another *Latossolo* (Oxisol) of Roraima, Oliveira (2010) have found maximum economic yield (1,343 kg ha^{-1}) of the cultivar BRS Novaera with 120 kg P_2O_5 ha^{-1}. In a field study performed in Pará State, maximum grain yield (1,322 kg ha^{-1}) of the cultivar BR-3 Tracuateua has been reached with 103 kg P_2O_5 ha^{-1} applied to a *Latossolo Amarelo distrófico* (Oxisol) (Rodrigues et al., 2014). These studies show optimum P rates for cowpea varying from 90 kg P_2O_5 ha^{-1} to 120 kg P_2O_5 ha^{-1}, which could be considered relatively high.

Abundant P supplying has been showed inducing zinc (Zn) deficiency in crop plants (Loneragan; Weeb, 1993). Although the factors responsible for this P-Zn interaction are incompletely understood, Zn application seems to avoid negative effect on yield of cowpea under high P rate. Rosal (2013) has shown maximum grain yield of the cultivar BRS Guariba (1,648 kg ha^{-1}) by applying 125 kg P_2O_5 ha^{-1} combined with 2.6 kg Zn ha^{-1} to a stony soil of Piauí State, northeast Brazil. No study on P and Zn application for cowpea in the Amazonia region was found.

The objective of this study was to evaluate the effects of P and Zn rates on two cowpea cultivars grown under field conditions in Amazonia.

Material and Methods

Two experiments were carried out at the Experimental Station of Embrapa Amazônia Oriental (Embrapa Eastern Amazon) (01°27’21’’S, 48°30’16”W and elevation 10 m), in the Belém municipality, Pará State, Brazil. The climate of Belém is Af, according to the Köppen classification, with annual average temperature of 26 ºC, average annual rainfall of 3,000 mm and relative air humidity around 80% (Instituto..., 2017). The soil of the experimental site was classified as a *Latossolo Amarelo distrófico* (Oxisol) (Falesi; Veiga, 1986) and it was physically and chemically characterized following methods described in Silva et al (2009) and Teixeira et al (2017). Characteristics of this soil at the surface layer (0–20 cm) are shown in Table 1.

Table 1. Characteristics of the soil at the 0-20-cm depth in the experimental site before the installation of the experiments.

pH H_2O	OM(1)	M1-P(2)	K	Ca	Mg	Al	H+Al	$CEC_{pH\ 7}$(3)	BS(4)
	g kg^{-1}	mg dm^{-3}	$cmol_c\ dm^{-3}$						%
5.8	16.8	1	0.03	1.2	0.2	0.2	3.5	4.9	29
M1-Cu(2)	**M1-Fe(2)**	**M1-Mn(2)**	**M1-Zn(2)**		**Coarse sand**	**Fine sand**	**Total sand**	**Silt**	**Clay**
mg dm^{-3}					**g kg^{-1}**				
0.5	167	1.2	1.5		634	213	847	33	120

(1) Organic matter.

(2) Nutrient extracted with Mehlich 1.

(3) Cation exchange capacity at pH 7.

(4) Base saturation.

The experiments were 4 x 4 factorials conducted in randomized complete block designs with three replicates. Treatments in the two experiments were combinations of P (0 kg P_2O_5 ha^{-1}, 40 kg P_2O_5 ha^{-1}, 80 kg P_2O_5 ha^{-1} and 120 kg P_2O_5 ha^{-1}) and Zn (0 kg Zn ha^{-1}, 2 kg Zn ha^{-1}, 4 kg Zn ha^{-1} and 6 kg Zn ha^{-1}) rates. Cowpea cultivar BRS Imponente was used in an experiment while in another one the cultivar was BRS Tumucumaque. Both cultivars were included in this study due to high commercial acceptance of their grains. Triple superphosphate and zinc sulfate were the sources of P and Zn, respectively.

The experimental plots of 15.0 m^2 were composed of six 5.0 m row, spaced 0.50 m between rows, with 0.20 m between plants within the row, being evaluated as useful area the two central rows of the plot, corresponding to an area of 5.0 m^2.

Limestone (32% CaO and 17% MgO) was incorporated at the 0-20-cm soil depth 30 days before cowpea sowing to increase base saturation at 60%. P and Zn fertilizers were applied into sowing furrow immediately before planting. Potassium (K) was also applied in this occasion at the rate 60 kg K_2O ha^{-1}, according to Cravo and Souza (2007), using KCl as a source.

Seeds were inoculated using inoculant prepared with a specific rhizobium (SEMIA 6462) and applied at the rate 100 g of product per 25 kg of seeds. Inoculated seeds were then sown in small holes located in the sowing row (four seeds per hole). Seedlings were thinned to two plants per hole.

Leaf sampling was performed by collecting in each plot 30 fully expanded trifoliate leaves from the main branch of plants at the beginning of flowering. Leaf samples were prepared and digested according to Miyazawa et al. (2009). P was measured colorimetrically by the molybdenum blue method and Zn was determined by microwave plasma atomic emission spectrometry.

Plants were harvested 70 days after sowing, when 100% of pods were dry. Grains were weighted for determination of grain yield.

Analysis of variance (ANOVA) was carried out for each experiment separately. When ANOVA was significant, polynomial regression analysis was conducted. All analyses were performed in R (R Core…, 2018) at the 5% significance level.

Results and Discussion

There were significant effects of P rate, Zn rate and P x Zn interaction on grain yield for the cowpea cultivar BRS Imponente (Table 2). The interaction effect was evaluated by the response of yield to P rates within each Zn rate. Figure 1 shows the result of this evaluation. Grain yield increased linearly with increasing P rate in all Zn levels. The highest yield (2,195 kg ha^{-1}) was achieved with the combined application of 120 kg P_2O_5 ha^{-1} and 2 kg Zn ha^{-1}. These P and Zn rates are similar to those (125 kg P_2O_5 ha^{-1} and 2.6 kg Zn ha^{-1}) which have resulted in the highest grain yield (1,648 kg ha^{-1}) of the cultivar BRS Guariba in the work of Rosal (2013).

Table 2. Effect of P (expressed as P_2O_5) and Zn rates on grain yield and P and Zn concentration in leaf for two cowpea cultivars.

Fertilization	Cowpea cultivar BRS Imponente			Cowpea cultivar BRS Tumucumaque		
	Grain yield ($kg\ ha^{-1}$)	Leaf P ($g\ kg^{-1}$)	Leaf Zn ($mg\ kg^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Leaf P ($g\ kg^{-1}$)	Leaf Zn ($mg\ kg^{-1}$)
P_2O_5 rate ($kg\ ha^{-1}$)						
0	961	1.41	79.6	1,280	1.29	68.7
40	1,285	1.92	81.7	1,702	2.02	72.3
80	1,686	2.61	68.6	2,092	2.92	72.0
120	1,722	3.28	57.3	1,723	3.10	63.9
Zn rate ($kg\ ha^{-1}$)						
0	1,179	2.25	68.8	1,517	2.53	59.8
2	1,517	2.25	68.2	1,689	2.38	68.4
4	1,455	2.41	72.3	1,657	2.23	74.7
6	1,504	2.33	78.0	1,934	2.18	74.1
ANOVA						
P_2O_5 rate	***	***	***	***	***	ns
Zn rate	**	ns	ns	ns	ns	*
P_2O_5 x Zn	*	ns	ns	ns	ns	ns
CV (%)	17.4	24.0	16.8	23.8	31.3	18.7

ns: not significant; * significant at the 5%probability level; ** significant at the 1% probability level;

*** significant at the 0.1% probability level.

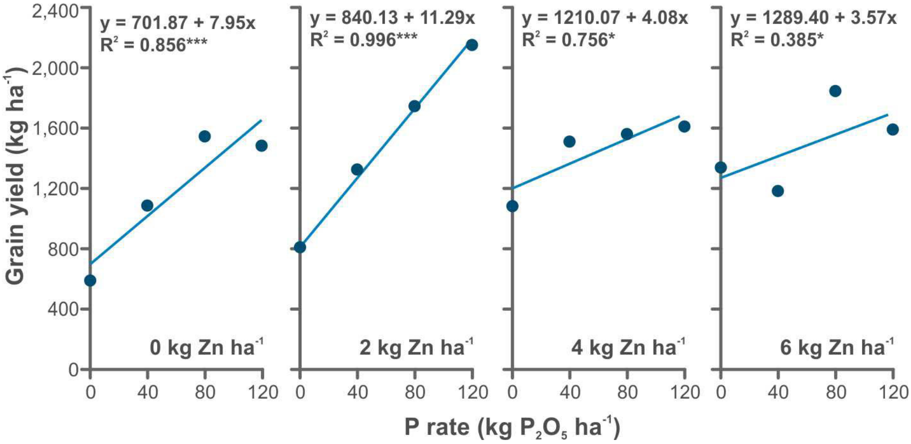

Figure 1. Effect of P (expressed as P_2O_5) rates within each Zn rate on grain yield of the cowpea cultivar BRS Imponente.
* significant at the 5% probability level; *** significant at the 0.1% probability level.

There was a significant effect of P rate on P concentration in leaf of the cowpea cultivar BRS Imponente (Table 2). However, there were no significant effects of both Zn rate and P x Zn interaction (Table 2). Leaf P concentration increased linearly with increasing P rate (Figure 2A), varying from 1.36 g kg^{-1} without P application to 3.26 g kg^{-1} with 120 kg P_2O_5 ha^{-1}, according to estimates derived from the regression equation. This leaf P concentration in the control treatment (0 kg P_2O_5 ha^{-1}) was below the critical levels calculated by Smith and Cravo (1990) (1.8 g kg^{-1}) and Rosal (2013) (2.01 g kg^{-1}), this last exclusively for the cultivar BRS Guariba. This indicates P-deficient cowpea and explains why the plant responded to P application in the present work. Such P insufficiency and consequent response to P fertilization are supported by the low soil available P content before the experiment installation (M1-P = 1 mg dm^{-3}; Table 1). The P rate also significantly affected the leaf Zn concentration (Figure 2B). Foliar Zn decreased linearly with increasing P rate (Figure 2B), varying from 83.8 mg kg^{-1} without P application to 59.8 mg kg^{-1} with 120 kg P_2O_5 ha^{-1} as estimated by regression. This occurred probably due to dilution of Zn in plant tissues. Such phenomenon has also been suggested as one of the mechanisms for the decline of Zn concentration in common bean (*Phaseolus vulgaris* L.) fertilized with P (Singh et al., 1988).

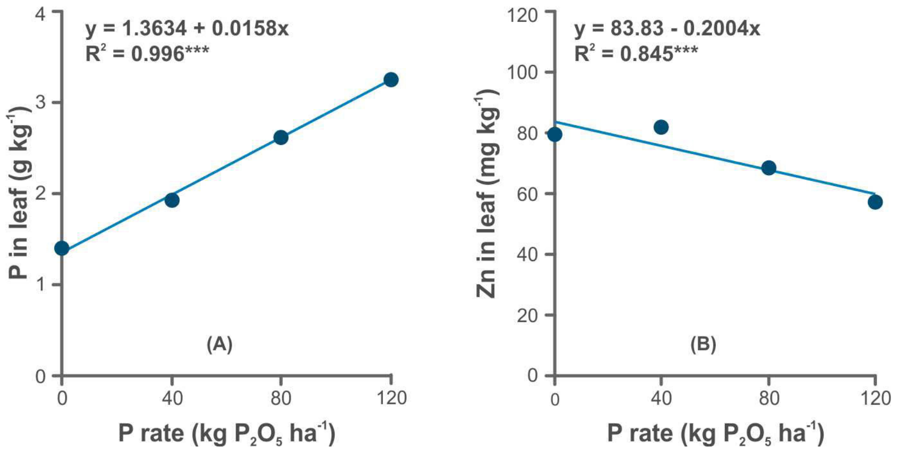

Figure 2. Effect of P (expressed as P_2O_5) rates on P (A) and Zn (B) concentration in leaf of the cowpea cultivar BRS Imponente.
*** Significant at the 0.1% probability level.

Although there was a significant effect of Zn rate on grain yield, applied Zn had no significant effect on Zn concentration in leaf of the cultivar BRS Imponente (Table 2). Type of sampled leaf, chosen sampling time, or both factors may not have been appropriate to express the effect of Zn fertilization on foliar Zn level. In addition, P fertilization may have contributed to this lack of Zn application effect. Zn concentrations for this cultivar (Table 2) were higher than those for the cultivar BRS Guariba in the work of Rosal (2013).

For the cowpea cultivar BRS Tumucumaque there was a significant effect of P rate on grain yield (Table 2). Grain yield increased quadratically with increasing P rate (Figure 3). Maximum estimated yield (1,984 kg ha^{-1}) was achieved with the P rate of 77 kg P_2O_5 ha^{-1}. This rate is quite lower than that for the cultivar BRS Imponente (Figure 1), suggesting large difference in P requirement between these two cultivars. Differential response of cowpea genotypes to P supply has been reported in literature (Ankomah et al., 1995; Sanginga et al., 2000; Krasilnikoff et al., 2003). Unlike the effects for the cultivar BRS Imponente, there were no significant effects of Zn rate and P x Zn interaction on grain yield of the cultivar BRS Tumucumaque (Table 2). This lack of response suggests lower Zn requirement in relation to the cultivar BRS Imponente. Furthermore, soil available Zn content (M1-Zn: 1.5 mg dm^{-3}; Table 1) before experiment installation could be considered sufficient to meet the need of the cultivar BRS Tumucumaque.

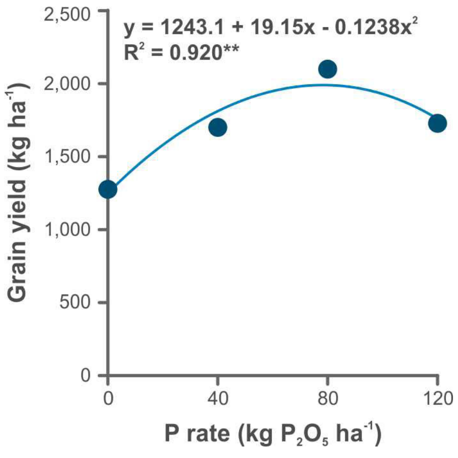

Figure 3. Effect of P (expressed as P_2O_5) rates on grain yield of the cowpea cultivar BRS Tumucumaque.
** Significant at the 1% probability level.

P concentration in leaf of the cowpea cultivar BRS Tumucumaque was significantly affected by P rate (Table 2). Increasing P rate increased P concentration linearly (Figure 4A). Estimates from regression (Figure 4A) show P concentrations varying from 1.38 g kg^{-1} to 3.29 g kg^{-1} in the range of the P rates tested in the experiment. This variation is very close to that of the cultivar BRS Imponente. P concentration associated to the maximum estimated yield was calculated to be 2.60 g kg^{-1}. This concentration is above the critical levels defined by Smith and Cravo (1990) and Rosal (2013), corroborating high grain yields in P-sufficient plants. Similarly to the cultivar BRS Imponente, no significant effects of Zn rate and P x Zn interaction were observed on P concentration in leaf of the cultivar BRS Tumucumaque (Table 2).

Zn concentration in leaf of the cowpea cultivar BRS Tumucumaque was significantly affected only by Zn rate (Table 2). Linear increase in Zn concentration as a function of Zn rate was observed (Figure 4B). According to estimates derived from regression (Figure 4B), foliar Zn varied from 61.9 mg kg^{-1} without Zn application to 76.6 mg kg^{-1} with application of 6 kg Zn ha^{-1}. This variation is slightly greater than that for the cultivar BRS Imponente, which could explain at least partially the significance for the effect of Zn rate on leaf Zn concentration of the cultivar BRS Tumucumaque and the lack of effect on the cultivar BRS Imponente.

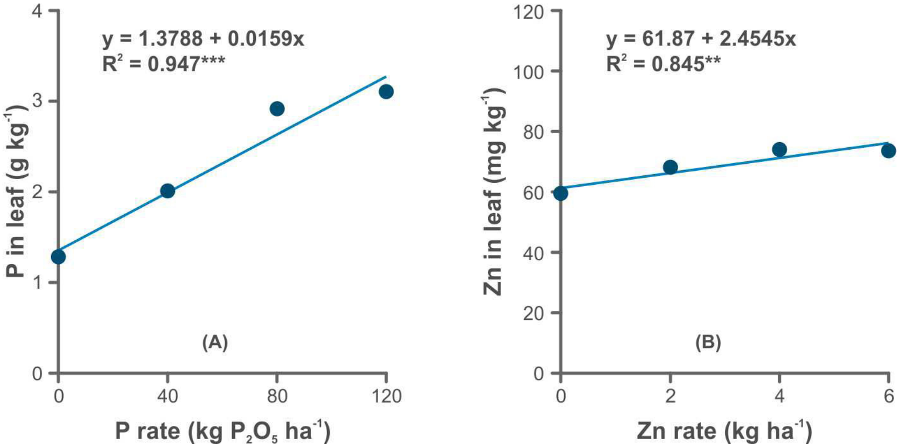

Figure 4. Effect of P (expressed as P_2O_5) and Zn rates respectively on P (A) and Zn (B) concentration in leaf of the cowpea cultivar BRS Tumucumaque.
** Significant at the 1% probability level; *** Significant at the 0.1% probability level.

Conclusions

P application increased the grain yield of the cowpea cultivars BRS Imponente and BRS Tumucumaque. Response to Zn application was found only for the cultivar BRS Imponente. The highest yield for cultivar BRS Imponente was achieved with combined application of 120 kg P_2O_5 ha^{-1} and 2 kg Zn ha^{-1}. P rate of 77 kg P_2O_5 ha^{-1} was sufficient for maximum yield of the cultivar BRS Tumucumaque. The need for combined P and Zn fertilization for cowpea in Amazonia depends on the cultivar.

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