Nutritional efficiency of cowpea varieties in the absorption of phosphorus

Eficiencia nutricional de variedades caupí en la absorción del fósforo

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ABSTRACT

The use of genotypes and/or varieties that are efficient in the absorption and use of phosphorus can be a complementary solution to increase productivity and reduce the cost of production in the crops. Thus, the present study aimed to evaluate the content, accumulation, and the efficiencies of uptake, transport and utilization of phosphorus by cowpea varieties cultivated in an Ultisol soil. The experiment used a completely randomized design in a 2 x 4 factorial scheme, with two levels of phosphorus (0 and 300 mg kg^{-1} soil), four varieties of cowpea (BRS Tumucumaque, BRS Guariba, BRS Cauamé and BRS Itaim) and five replications. The results led to the conclusion that the variety BRS Itaim presented differentiated behaviors in relation to plant height, stem diameter and dry mass production. The varieties BRS Tumucumaque and BRS Guariba were superior in total dry mass production, uptake, transport and utilization of phosphorus in low nutrient supply conditions. The aboveground production of dry mass and its phosphorus content were more sensitive to phosphorus deficiency in the three varieties, which shows that they were more appropriate for the use of phosphorus.

Key words: *Vigna unguiculata* (L.), mineral nutrition, nutrient uptake, fertility.

RESUMEN

El uso de genotipos o variedades eficientes en la absorción y la utilización del fósforo pueden ser una solución complementaria para aumentar la productividad y reducir los costos de producción de los cultivos. Así, el presente estudio tuvo como objetivo evaluar el contenido, la acumulación y la eficiencia de absorción, transporte y utilización del fósforo por variedades caupí cultivado en un suelo de orden Ultisol. El diseño experimental fue completamente al azar con distribuición factorial 2 x 4, con dos niveles de fósforo (0 y 300 mg kg^{-1} de suelo), cuatro variedades de caupí (BRS Tumucumaque, BRS Guariba, BRS Cauamé y BRS Itaim) y cinco repeticiones. Los resultados concluyen que la variedad BRS Itaim presentó un comportamiento diferencial en relación con la altura de planta, diámetro del tallo y producción de materia seca total. Las variedades BRS Tumucumaque y BRS Guariba fueron superiores en la producción de materia seca total, absorción, transporte y utilización de fósforo en las condiciones de bajo suministro de este nutriente. La producción de materia seca de la parte aérea y el contenido de fósforo fueron más sensibles a la deficiencia de fósforo, lo que permitió demostrar que son los más adecuadas para la evaluación de las variedades de fríjol caupí en el uso del fósforo.

Palabras clave: *Vigna unguiculata* (L.), nutrición mineral, absorción de nutrientes, fertilidad.

Introduction

The cowpea is distributed worldwide, especially in tropical regions, which present soil and climate conditions similar to those of its origin, Africa. According the FAO (2004), it is estimated that about 9.82 million ha of cowpea were grown worldwide in 2003. In Brazil, it is estimated that about 1.5 million ha of cowpea are grown, with an average yield of about 300 kg ha^{-1}. Among the various factors that contribute to the low average productivity of this species, soil fertility management stands out, particularly because of the insufficient phosphorus supply and the high fixing ability of this nutrient.

According to Macedo (1996), the rational use of the Brazilian Cerrado is one of the great achievements in the agricultural area of the tropics in the twentieth century and can be considered as an option to be followed elsewhere in developing regions around the world, especially in South America and Africa, where there are ecosystems similar to those of the Cerrado. However, Machado *et al.* (2001) reported that the Cerrado has certain limitations, such as its high acidity and low fertility. Acid soils and soils with high Al saturation, like those of the Cerrado, have problems with the solubility of its compounds, particularly nutrients, and, in the case of P, lower pH levels lead to a decrease in its availability for plants (Fernandes and Muraoka, 2002).

Therefore, the use of genotypes and/or varieties efficient in the uptake and utilization of phosphorus can be

Received for publication: 8 June, 2011. Accepted for publication: 30 October, 2012.

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a complementary solution to increase productivity and reduce production cost. Several studies have suggested alternatives to solve the fertility problems, which include, besides better techniques for fertilization and soil correction, to selection of varieties that are more tolerant to aluminum and more efficient in the absorption and utilization of phosphorus and other nutrients (Wang *et al.,* 2007).

From a physiological perspective, the nutritional efficiency refers to the ability of the genotype to absorb the nutrient from the soil, distribute it and use it internally (Mengel and Kirkby, 2006). The use efficiency of a nutrient is defined as the ratio between yield and concentration of the nutrient in the tissue (Malavolta, 2006). The efficiency of phosphorus utilization results from the absorption, transport and use efficiencies (Baligar *et al.,* 2001). Studies conducted by Alves *et al.* (2009) showed the high potential of the fertilization response by the cowpea crop in Cerrado soils, characterized by low phosphorus availability.

The nutrient availability, absorption and distribution in plants are the most determinant factors in dry matter production and distribution, which in turn affect plant survival and competitiveness, as well as crop yield (Epstein and Bloom, 2006). The nutritional status, especially of N and P, also affects dry matter production and distribution between the plant organs (Marschner, 1995).

In most of the regions where cowpea is grown, low yield levels can be observed, because of several factors, but particularly the inappropriate mineral nutrition used by farmers. Mineral nutrition is the fastest and cheapest way to increase crop yield. High yields, as well as optimal quality of products, are only reached with a balance in the supply of macro and micronutrients, which act in the plant metabolism.

Thus, this work aimed to evaluate levels, contents and the efficiency in absorption, transport and use of phosphorus by four varieties of cowpea (*Vigna unguiculata* [L.] grown in an Ultisol.

Material and methods

The experiment was carried out in a greenhouse of the Plant Production Department of the State University of Mato Grosso do Sul, in Aquidauana (Brasil), from August to November of 2010 (20º28'S; 55º48'W; 174 m a.s.l.). The climate is Aw, tropical wet and dry (rainy season in summer and dry season in winter), according to the Koppen classification.

An Ultisol was used in the experiment, and its chemical analysis showed a pH (H_2O) = 4.7; OM = 1.2%; P: 4.4 mg dm^{-3}; K: 24 mg dm^{-3}; Ca: 1.1 mg dm^{-3}; Mg: 1.2 mg dm^{-3}. Al: 0.4 mg dm^{-3}; H+Al: 2.7 mg dm^{-3}. SB: 2.54 mg dm^{-3}; CEC: 5.24 mg dm^{-3} and V (%) = 48.47. A completely randomized design was adopted, with a 2 x 4 factorial scheme, with five replications. The treatments were two P levels in the soil: low P level, corresponding to the natural P level in the soil and a high P level, with 300 mg kg^{-1} P of soil, applied as ammonium phosphate (48% P) in four cowpea varieties (Tumucumaque, BRS Guariba, BRS Cauamé e BRS Itaim). The experimental units were plastic 5-kg-capacity containers (polypropylene), which were filled with 5 kg of sieved soil (2-mm grid) from the 0-20 cm soil layer. Each container was placed in a thick plastic bag to prevent leaks. Five seeds were planted in each container and, after the establishment of the plants, thinning was done, leaving one plant per container. Irrigation was performed in order to maintain the soil at 70% of its field capacity. Nitrogen and potassium were applied as ammonium sulfate and potassium chloride in the same amount for all the containers, according to the soil chemical analysis.

Plant height and stem diameter determinations were performed at the end of the experiment. The former was obtained from the base to the top of the stem, using a ruler; the latter was obtained using a digital caliper near the base of the stem in each experimental unit.

Seventy after emergence, the plants were collected and divided into roots and shoots (stem, leaves and fruits). All the material was sequentially washed in a detergent solution (3 mL L^{-1}), running water, HCl solution (0.1 mol L^{-1}) and deionized water. The samples were packed in paper bags and dried in an oven with forced air circulation at 65º C for 72h. After drying, the dry weight was obtained and the material was ground in a Wiley mill (1-mm-grid sieve), placed in plastic bags, and subjected to nitric-perchloric digestion, using the methodology described by Malavolta *et al.,* (1997). The following efficiencies were calculated according to Baligar and Fageria (1999): a) phosphorus absorption efficiency (PAE) – total P content in the plant (mg) / dry root matter (g); b) phosphorus transport efficiency (PTE) – P content in the shoots (mg) / total P content in the plant (mg) x 100; c) use efficiency of absorbed phosphorus (UEAP) – total dry matter produced $(g)^2$ / total P content in the plant (mg).

The data were subjected to variance analysis using the statistical program SISVAR (Ferreira, 2000). The effects between the cowpea varieties, within each dose of P, were analyzed by Tukey test at 5% of probability.

Results and discussion

The production of root dry matter (RDM), shoot dry matter (SDM), total dry matter (TDM), shoot P level (SPL), shoot P content (SPC), root P content (RPC), P absorption efficiency (PAE) and P transport efficiency (PTE) were influenced significantly by at least one of the factors (P level and/or varieties), whereas plant height (PH), stem diameter (SD), root P level (RPL) and the use efficiency of absorbed P (UEAP) were influenced only by the varieties (Tab. 1).

There were significant differences between the varieties for plant height, stem diameter, root P level and use efficiency of absorbed P (Tab. 2). The varieties BRS Tumucumaque, BRS Guariba and BRS Cauamé were statistically equal in relation to plant height and stem diameter, whereas the variety BRS Itaim had the lowest height and stem diameter, being different from the others (Tab. 2). The BRS Cauamé variety had the highest root P level (Tab. 2).

The use efficiency of absorbed P, which is the capacity of a plant to redistribute and reuse the minerals from an older, senescent organ (Prado, 2008) varied significantly only between varieties (Tab. 2). Yan *et al.* (1995a, b) found great differences between bean genotypes in the absorption and use of P. Pacheco *et al.* (2005) reported in an experiment that this fact is due to the existence of different nutritional behavior related to genetic adaptability. The P use by the varieties of cowpea ranged from 19.18 to 26.84 mg of dry matter / g of absorbed P.

The varieties BRS Tumucumaque and BRS Guariba were statistically equal and superior in the conversion of the P available in the soil to dry matter, whereas BRS Itaim showed lower efficiency of P use (Tab. 2). Fageria *et al.* (1998) observed significant differences between genotypes of beans regarding of the use efficiency the absorbed P.

The productions of root, shoot and total dry matter were different between the studied varieties for both P levels in the soil (Tab. 3). In the low P level soil, because of the small amount of available P, the plants developed very little, showing lower production of root, shoot and total

TABLE 1. Analysis of variance summary for plant height (PH), stem diameter (SD), root dry matter (RDM), shoot dry matter (SDM), total dry matter (TDM), shoot P level (SPL), root P level (RPL), shoot P content (SPC), root P content (RPC), P absorption efficiency (PAE), P transport efficiency (PTE), use efficiency of absorbed P (UEAP), in relation to the cowpea varieties and phosphorus doses.

Source of variation	DF	Mean square					
		PH	SD	RDM	SDM	TDM	SPL
Variety (A)	3	11024.33*	3.13*	69.07*	217.04*	530.94*	0.13*
Dose (B)	1	921.6 NS	2.5 NS	126.02*	333.5*	869.55*	2.9*
A x B	3	92.9 NS	0.58 NS	12.26*	29.08*	16.13*	0.01 NS
Error	32	372.32	0.71	3.49	2.56	4.44	0.01
cv (%)		13.84	8.65	15.89	4.8	4.67	6.69
Source of variation	**DF**	**Mean square**					
		RPL	SPC	RPC	PAE	PTE	UEAP
Variety (A)	3	0.41*	1663.27*	141.84*	1.4 NS	73.91*	113.14*
Dose (B)	1	0.16 NS	8700.74*	565.03*	12.59*	22.38 NS	1.25 NS
A x B	3	0.06 NS	178*	45.21 NS	5.6*	76.14*	0.93 NS
Error	32	0.04	30.82	17.22	1.22	13.78	3.9
cv (%)		12.66	8.1	21.7	14.57	4.76	8.36

*Significant at 5% of probability; NS - Non-significant at 5% of probability.

TABLE 2. Plant height (PH), stem diameter (SD), root P level (RPL) and use efficiency of absorbed P (UEAP) by different varieties of cowpea.

Variety	PH (cm)	SD (cm)	RPL ($g\ kg^{-1}$)	UEAP ($mg\ g^{-1}$)
BRS Tumucumaque	162.30 a	10.33 a	1.39 a	26.84 a
BRS Guariba	154. 00 a	10.07 a	1.56 ab	25.49 a
BRS Cauamé	151.20 a	9.62 a	1.87 c	22.98 b
BRS Itaim	90.10 b	9.05 b	1.68 c	19.18 c

Means in the same column followed by the same letter are not significantly different according to Tukey test ($P \leq 0.05$).

dry matter than those grown in the high P level soil (300 mg dm^{-3}) (Tab. 3).

These results support those of Machado *et al.* (2001), who observed increases in shoot dry matter production with increased of P in the solution and between the studied corn varieties. Fageria *et al.* (2003) found that among the influences of P in the common bean cycle, the increase of shoot dry matter production stands out, because it is associated with productivity, therefore it is important to know the accumulation of dry matter during the crop cycle.

The varieties BRS Tumucumaque and BRS Guariba were superior in root, shoot and total dry matter production, probably because they are more efficient under low P supply conditions in the soil; whereas the varieties BRS Cauamé and BRS Itaim produced less when grown in the low P level soil. In the high P level soil there was great variation in the total dry matter production between varieties, ranging from 38.7 to 56.39 g, with BRS Tumucumaque and BRS Guariba as the most productive varieties, with 56.39 and 52.95 g, respectively. The BRS Itaim variety was the least productive of all, with 38.7 g, differing statistically from the others (Tab. 3).

This variation is related to the capacity of absorption and use of nutrients by the varieties. However, it does not mean they are more or less efficient in the absorption of P from the soil (Fernandes and Muraoka, 2002). This shoot production is the result of a combination of factors, such as a higher capacity of nutrients absorption, lower demand of available nutrients in the soil, etc.

The results obtained in this study are consistent with those found by Fernandes and Muraoka (2002), who observed significant differences between corn genotypes in dry matter production in low and high P level soils; and also with those found by Schjorrig *et al.* (1987), who observed significant differences in shoot dry matter production between barley cultivars as a function of phosphorus doses.

The shoot P level differed between cowpea varieties and in relation to the soil P levels and BRS Tumucumaque was the best variety in accumulating P in the shoots under the different soil P levels (Tab. 4). The P levels found in the leaves were higher than those recommended by Malavolta *et al.* (1997), which were 1.2-1.5 g kg^{-1}, however Linhares (2007), in studying three cowpea cultivars subjected to a lack of nutrients, obtained leaf P levels of 2.6-2.9 g kg^{-1}. Similar results were found by Fernandes *et al.* (2010), evaluating nutrient levels in leaves and the productive performance of cowpea cultivars cultivated in a single crop system and intercropped with corn.

The P contents in the shoots and roots responded significantly to the P levels in the soil, whereas there was no significant difference between varieties for the root P content in the low P level, differing statistically only in the high P level soil (300 mg dm^{-3}) (Tab. 4). The increase of available P concentration in the soil led to increases of P absorption by the plant, resulting in a higher dry matter production, justifying the accumulated P in the plant.

Machado *et al.* (2001) found that the shoot P content in corn plants differed in relation to varieties and phosphorus doses in the solution, while for root P contents there was no difference between groups of local and improved corn varieties.

There was no difference in the P absorption efficiency between the cowpea varieties and levels of P in the soil (Tab. 4). Plants grown in a low P level soil that have better or equal absorption efficiencies are classified as efficient, that is, they produce more or the same under stress conditions (Prado, 2008). This was found for the varieties BRS Tumucumaque and BRS Guariba, which did not respond to the variations of P levels in the soil, but showed higher absorption efficiencies in the soil with a low P level (Tab. 4).

According to studies performed by Machado *et al.* (2001), characteristics such as nutrient extraction capacity and strategies to minimize the need for nutrients caused by

TABLE 3. Root dry matter (RDM), shoot dry matter (SDM) and total dry matter (TDM) of cowpea plants grown in an Ultisol from the Cerrado with different levels of phosphorus.

	RDM (g/plant)		SDM (g/plant)		TDM (g/plant)	
Variety	**0 mg dm^{-3}**	**300 mg dm^{-3}**	**0 mg dm^{-3}**	**300 mg dm^{-3}**	**0 mg dm^{-3}**	**300 mg dm^{-3}**
BRS Tumucumaque	11.94 Aa	16.87 Ab	36.75 Aa	39.32 Ab	48.69 Aa	56.39 Ab
BRS Guariba	10.86 Aa	15.69 ABa	32.89 Ba	37.26 Ab	42.65 Ba	52.95 Ab
BRS Cauamé	9.75 ABa	12.66 Bb	27.89 Ca	38.33 Ab	38.75 Ca	51.19 Bb
BRS Itaim	7.41 Ba	8.95 Ca	24.43 Da	29.75 Bb	31.84 Da	38.7 Cb

Means in the same column followed by the same letters, upper-case in the rows and lower-case in the columns, are not significantly different according to Tukey test ($P \leq 0.05$).

TABLE 4. Shoot P level (SPL), root P content (RPC), shoot P content (SPC), P absorption efficiency (PAE) and P transport efficiency (PTE) by cowpea varieties grown in an Ultisol from the Cerrado with different phosphorus levels.

Variety	SPL ($g\ kg^{-1}$)		RPC (mg)		SPC (mg)		PAE ($mg\ g^{-1}$)		PTE (%)	
	0 mg dm^{-3}	300 mg dm^{-3}	0 mg dm^{-3}	300 mg dm^{-3}	0 mg dm^{-3}	300 mg dm^{-3}	0 mg dm^{-3}	300 mg dm^{-3}	0 mg dm^{-3}	300 mg dm^{-3}
BRS Tumucumaque	1.95 Aa	2.41 Ab	14.95 Aa	25.88 Ab	71.67 Aa	95.61 Ab	7.37 Aa	7.22 Aa	82.74 Aa	78.74 Aa
BRS Guariba	1.72 ABa	2.29 ABb	14.72 Aa	25.5 Ab	56.58 Ba	88.4 Abb	7.39 Aa	7.35 Aa	79.39 ABa	76.98 Aa
BRS Cauamé	1.66 Ba	2. 28 ABb	19.09 Aa	25.48 Ab	46.69 Ca	85.14 Bb	6.07 Aa	9.03 Ab	70.69 BCa	77.82 Ab
BRS Itaim	1.65 Ba	2.15 Bb	12.67 Aa	14.64 Bb	40.38 Ca	64.16 Cb	7.26 Aa	8.99 Ab	76.15 Ca	81.41 Ab

Means in the same column followed by the same letters, upper-case in the rows and lower-case in the columns, are not significantly different according to Tukey test ($P \leq 0.05$).

differences in metabolism are important for effective plant growth and better performance in low P level soils.

The transport efficiency is controlled by the capacity of the soil, or cropping system, to supply nutrients and by the plant capacity to absorb, use and remove nutrients. These factors vary with soil, genotypes/cultivars of the species, as well as climate conditions, involving a synchronism in the soil-plant-root system (Fageria, 1998). The P transport efficiency was statistically different between the varieties in the low P level soil, but did not differ in the high P level soil (Tab. 4). The BRS Tumucumaque and BRS Guariba varieties did not differ, showing P transport efficiencies of 82 and 79%, respectively, in the low P level soil whereas BRS Itaim was superior for this variable (88%) in the high P level soil (300 mg dm^{-3}).

The BRS Tumucumaque variety showed the best capacity to absorb and transport a significant amount of the nutrient to the leaves under low P level conditions, increasing dry matter production. Marschner (1995) explained that deficient plants increase their P redistribution from the shoot to the roots, causing an increase in the relation of root/shoot P contents. According to this author, under P deficiency, a higher P retention takes place in the roots and redistribution via the phloem brings additional P.

Conclusions

BRS Itaim showed different behavior in relation to plant height, stem diameter, total dry matter production and to level, content and efficiency of absorption, transport and use of phosphorus.

The varieties BRS Tumucumaque and BRS Guariba are superior in total dry matter production and in absorption, transport and use of phosphorus under conditions of low phosphorus supply.

Shoot dry matter production and shoot phosphorus level were the most sensitive to phosphorus deficiency, being therefore the most appropriate variables to evaluate cowpea varieties regarding the use of phosphorus.

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