Semina: Ciências Agrárias
ISSN: 1676-546X
semina.agrarias@uel.br
Universidade Estadual de Londrina
Brasil

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Semina: Ciências Agrárias, vol. 38, núm. 2, marzo-abril, 2017, pp. 571-579
Universidade Estadual de Londrina
Londrina, Brasil

DOI: 10.5433/1679-0359.2017v38n2p571

Phosphorus bioavailability in soybean grown after pasture under different fertility regimes

Biodisponibilidade de fósforo em soja cultivada em sucessão à pastagem sob diferentes níveis de fertilidade

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Abstract

The aim of this study was to evaluate the residual effect of phosphorus (P) fertilizer applied to an *Urochloa decumbens* cv. Basilisk pasture on the P bioavailability to the following soybean crop. Low-productivity pasture, planted on an Oxisol in an experimental field at Embrapa Cerrados, was divided into three strips, each of 1.5 ha and fertilized by broadcasting annual applications of 0, 20 and 40 kg ha^{-1} of P_2O_5 for four years. After the pasture was desiccated with herbicide, soybeans were sown and fertilized with 0, 50 and 100 kg ha^{-1} of P_2O_5 applied within each strip, making a total of nine (3x3) P treatments. Residual available P content (Mehlich-1 and resin) from the pasture fertilization was lower than from soybean fertilization. However, the bioavailable residual P from the pasture, determined by P accumulated in plants, production of dry matter and grain yield, had similar availability to inorganic P applied to the soybean. Early P fertilization applied to pasture is technically feasible and can be used to maintain the pasture: it is recommended to replace corrective fertilization for following soybean crops.
Key words: *Urochloa*. Phosphorus availability. Phosphorus accumulation. Residual effect. No-tillage.

Resumo

O objetivo deste trabalho foi avaliar o efeito da adubação fosfatada antecipada aplicada na pastagem de *Urochloa decumbens* cv. Basilisk sobre a biodisponibilidade de fósforo para a cultura da soja em sucessão à pastagem. A pastagem de baixa produtividade, plantada sobre um Latossolo Vermelho em uma área experimental da Embrapa Cerrados, foi dividida em três piquetes (faixas) de 1,5 ha e adubada anualmente a lanço com 0, 20 e 40 kg ha^{-1} de P_2O_5, durante quatro anos. Após a dessecação da pastagem, foi realizada a semeadura da soja e a adubação nas diferentes doses de P_2O_5. As doses foram aplicadas em sulco correspondendo à 0, 50 e 100 kg de P_2O_5 ha^{-1}. O teor de P disponível no solo, avaliado durante o cultivo da soja, foi menor com a adubação na pastagem que com a adubação na soja. No entanto, o P residual biodisponível, determinado pelo acúmulo de P na planta, produção de matéria seca e rendimento de grãos, foi similar quando da aplicação de P na pastagem ou na soja. Assim sendo, a adubação fosfatada antecipada à pastagem é tecnicamente viável, apresentando-se como alternativa para manutenção da pastagem e recomendada para substituir a adubação corretiva na implantação da cultura de soja.
Palavras-chave: *Urochloa*. Fósforo disponível. Fósforo acumulado. Efeito residual. Plantio direto.

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Received: Nov 20, 2016 – Approved: Jan. 17, 2017

Introduction

The predominance of highly weathered soils with high sorption capacity and low phosphorus (P) availability, associated with a lack of regular P fertilization, decisively contributes to the decline of pasture productivity in the Cerrado Region over time, contributing to its degradation (BROSSARD; BARCELLOS, 2005; NOVAIS et al., 2007). Phosphorus is the nutrient that most limits the production of plants in acidic soils of the Cerrado (DIAS et al., 2015; VENDRAME et al., 2010). However, corrective fertilization of soils with large amounts of phosphate fertilizers is uneconomic and logistically impractical (KRUSE et al., 2015). Thus improved efficiency in its use by reducing amounts of fertilizer applied to the soil is important for the conservation of natural resources and sustainability of agro-ecosystems (BAVEYE, 2015).

The Cerrado Region contains 54 million hectares of grassland (SANO et al., 2010), where an estimated 50 to 80% have some degree of degradation (BROSSARD; BARCELOS, 2005). In Brazil, application of fertilizer to pasture represents only 1.6% of total consumption, which means a negligible amount of 4 kg ha^{-1} NPK (SOUSA et al., 2007). In this sense, annual crop and pasture rotation appears to be an alternative to chemical restoration and for maintaining the physical characteristics of soils (VILELA et al., 2011) and the sustainability of agriculture in the Cerrado (MACEDO, 2009).

One of the main benefits of annual crop rotation and pastures is the use, by pasture, of the residual effect of fertilizer applied to cereals (BALBINOT JÚNIOR et al., 2009). Since the crop rotation includes species that are very efficient at extracting P, such as *Urochloa*, the resulting increased P recovery adds up to 69% more to the soil than a system composed only of annual crops (SOUSA et al., 2007). This effect of *Urochloa* is due to root system morphology: the density of the roots and their association with mycorrhizal fungi increase the P uptake due to the exploitation of a larger volume of soil and solubilization of organic phosphates by phosphatases produced by the hyphae and the mobilization of inorganic P (CASTRO et al., 2013; JANEGITZ et al., 2013; YAO et al., 2001).

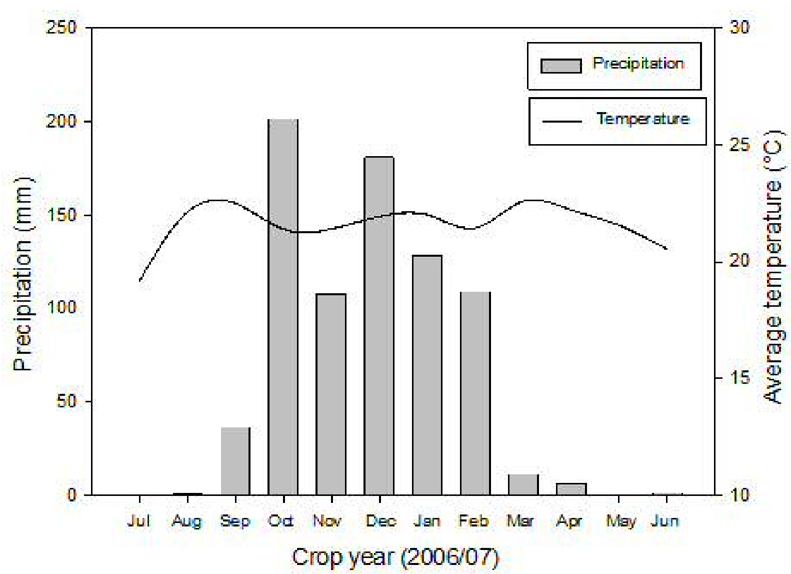
Another strategy is to apply all or part of the annual crop's fertilization to the preceding crop, which is usually a green manure in non-tilled pasture or crop-livestock systems (SOUSA et al., 2007). Francisco et al. (2007) and Rodrigues et al. (2009) reported that early P fertilization of wiregrass [*Eleusine coracana* (L.) Gaertn.], produced more plant biomass and an accumulation of P which did not affect soybean grain yield. Thus, early fertilization of the preceding crop can increase long-term biomass production, improving conservation of soil moisture through an increase in plant residues and improved nutrient cycling and biomass mineralization, releasing nutrients for the next crop (SEGATELLI et al., 2008).

With the increasing adoption of integrated crop-livestock farming in Brazil and the use of plants from the genus *Urochloa*, it is becoming necessary to assess the effect of the cultivation of these plants on the P cycling efficiency and consequent availability of this nutrient for subsequent crops. Hence the objective of this study was to assess the effect of early application of phosphate fertilizer to an *Urochloa decumbens* pasture on the availability of soil P and the bioavailability of P to the soybean following the pasture.

Materials and Methods

The study was conducted in 2006 in the Embrapa Cerrados experimental area, Planaltina-DF (15°38'46''S, 47°45'08''W, altitude 1120 m) on an Oxisol with the following features: 650, 120 and 230 g kg^{-1} clay, silt and sand, respectively, pH (water) of 5.21, 24.5 g kg^{-1} of total carbon, 2.78, 0.70, 0.09, 5.43 and 0.46 $cmol_c$ kg^{-1} of Ca, Mg, Al, H+Al and K, respectively; 2.37 mg kg^{-1} available P (Mehlich-1). The climate is tropical, seasonal (Aw), according to the Köppen classification, with an average annual rainfall of 1,500 mm and mean maximum and minimum temperatures of 26.4 and 15.9°C, respectively. Rainfall and mean monthly temperature during the growth of soybeans are shown in Figure 1.

Figure 1. Precipitation and average monthly temperature for the 2006/2007 crop.



Management of the experimental area began in 1998 when the plot received 1.1 Mg ha^{-1} of lime incorporated into the soil, 60 kg ha^{-1} of P_2O_5 in the form of simple superphosphate and 30 kg ha^{-1} of FTE® BR-10 (*Fritted Trace Elements*) for micronutrient correction. In 1999, *Urochloa decumbens* cv. Basilisk was sown and left fallow until 2002. In October of that year, when the pasture was already becoming degraded, the area was divided into three 1.5 hectare plots [175 m x 86 m], onto which 0 (P0), 20 (P20) and 40 (P40) kg ha^{-1} of P_2O_5 was broadcast annually, in the form of simple superphosphate, until 2006. During four years, the land was used for grazing. Over the four years, a total of 300 kg ha^{-1} of nitrogen was applied in the form of urea ($(NH_2)_2CO$) and 120 kg ha^{-1} of K_2O was applied as KCl, to maintain available soil K close to 1.3 mmol$_c$ kg^{-1} (VILELA et al., 2007).

In November 2006, the pasture was desiccated using 1.44 kg P ha^{-1} of glyphosate active ingredient to sow soybean cv. BRS Valiosa RR with no tillage. The treatments were stablished from the perpendicularly phosphorus fertilization (in relation to pasture fertilization) with triple superphosphate at doses of 0 (S0), 50 (S50) and 100 (S100) kg ha^{-1} of P_2O_5 in a split plot design strip block with four replications. The area of each plot was 58 m x 86 m (Table 1). The average soybean plant population in the area, 14 days after emergence (DAE), was 12 per meter of row, with rows spacing of 0.45 m.

Soybean plants (4 subsamples in each plot) were randomly collected, from 1 m lengths of two crop rows at the full bloom growth stage (R2) (100 DAE). The composite samples were dried at 65°C to constant weight and ground for chemical analysis. P content (P-Plant) was quantified by optical emission spectrometry with inductively coupled argon plasma (ICP-AES) after nitro-perchloric acid digestion (EMBRAPA, 1999). The amount of P accumulated by soybean (P-cumulative, kg P ha^{-1}) was calculated by multiplying the dry matter (DM) produced per hectare by P concentration. To measure soybean yield, an area of 10 m^2 was sampled with grain moisture corrected to 13%.

Soil samples were collected immediately after soybean sampling in the same places. The subsamples were collected within and between rows, from the 0-10 cm layer, totaling 12 subsamples per local. The samples were packed in plastic bags and stored in a refrigerator at 10°C until soil analysis to maintain the moisture and avoid possible changes in the nature of the P (BARTLETT; JAMES, 1980). Available P in the soil was determined using an anion exchange resin (resin-P) (QUAGGIO; RAIJ, 2001) and Mehlich-1 extractant (Mehlich-P) (EMBRAPA, 1999), and the results were expressed based on the dry weight of the samples. The soil P was analyzed within ten days after sampling. A non-parametric analysis using the Kruskal-Wallis test ($\alpha = 0.05$) was made after checking the absence of normality of data through Kolmogorov-Smirnov test ($\alpha = 0.05$). Multiple comparisons were made by the Student-Newman-Keuls test (SNK) with 5% probability level. The Bioestat 4.0 software (AYRES et al., 2005) was used for the statistical analysis.

Table 1. Amount of P fertilizer (kg P_2O_5 ha^{-1} yr^{-1}) applied to each plot of pasture land in 2003 to 2006 and soybeans in 2006.

Fertilized plot$^{(†)}$	P_2O_5 (kg ha^{-1}) applied on the pasture	P_2O_5 (kg ha^{-1}) applied on soya	Total P_2O_5 (kg ha^{-1}) applied
P0 + S0	0	0	0
P0 + S50	0	50	50
P0 + S100	0	100	100
P20 + S0	20	0	80
P20 + S50	20	50	130
P20 + S100	20	100	180
P40 + S0	40	0	160
P40 + S50	40	50	210
P40 + S100	40	100	260

$^{(†)}$ Phosphorus fertilization in pasture (P0, 0 kg ha^{-1} P_2O_5 $year^{-1}$, P20, 20 kg ha^{-1} P_2O_5 $year^{-1}$, P40, 40 kg ha^{-1} P_2O_5 $year^{-1}$) for 2003 to 2006, S, Phosphorus fertilization on soya (S0, 0 kg ha^{-1}, S50, 50 kg ha^{-1}, S100, 100 kg ha^{-1}).

Results and Discussion

Levels of available P in the 0-10 cm soil layer extracted by resin and Mehlich-1 in the unfertilized plot (0 kg P_2O_5 ha^{-1} in pasture and soybean) were 3.10 and 2.25 mg kg^{-1}, respectively (Table 2) and are considered low for growing rainfed annual crops (SOUZA; LOBATO, 2004) and medium for less demanding forage species (VILELA et al., 2004). If we consider the 0-20 cm layer, the P content would probably be even lower due to the accumulation of P at the surface and the absence of tillage, and soil P levels classified as very low and low, respectively, for growing annual crops and less demanding forage. Rossi et al. (1999), Corazza et al. (2003) and Vendrame et al. (2010) also reported low levels of available P in soils under unproductive pasture.

The maintenance fertilization of 20 and 40 kg of P_2O_5 ha^{-1} per year applied to pastures led to an increase in levels of P in soil (Table 2), now ranging from low to high according to the interpretation of Souza et al. (1987), although the amounts applied are considered relatively low and the soils have a high phosphate adsorption capacity (CHAPUIS-LARDY et al., 2001). Thus, from the residual effect of phosphorus applied annually in pasture maintenance for four years, the area became able to be used for growing annual crops without the need for corrective P fertilization.

Table 2. Levels of available P in soil extracted by anion exchange resin (resin-P) and Mehlich-1 (Mehlich-P) 100 days after soybean emergence as affected by earlier pasture fertilization and P applied to the soybean.

Pasture fertilization (kg ha^{-1} P_2O_5 yr^{-1})(†)	P-resin(‡)	P-Mehlich(‡)
	--------(mg kg^{-1})--------	
	0 kg ha^{-1} of P_2O_5	
0	3.10 c	2.25 b
20	6.79 b	3.35 b
40	13.09 a	6.77 a
	50 kg ha^{-1} of P_2O_5	
0	19.44 a	5.50 a
20	16.46 a	7.10 a
40	28.26 a	8.63 a
	100 kg ha^{-1} of P_2O_5	
0	24.96 a	8.28 b
20	45.66 a	40.00 a
40	38.91 a	13.87 b

(†)Applied from 2003 to 2006.
(‡) Means followed by the same letters in column, each of P fertilization in the soybean, do not differ by SNK test at 5% probability.

P-Mehlich levels were on average 48% lower than P-resin levels and were positively correlated with them ($r = 0.70$; $p<0.01$). The increased levels of P obtained with the resin extractant can be related to the fact that the labile reserve of P occurs mostly as aluminum phosphate (RAIJ, 1978), which restricts extraction by Mehlich-1, due to its acidity (SIMÕES NETO et al., 2009).

Levels of available P extracted by Mehlich-1 and resin showed a positive correlation ($p<0.01$) with the shoot dry mass of soybean ($r = 0.65$ and 0.72, respectively). However, the higher correlation coefficient was obtained with resin, indicating that it is the more sensitive method, agreeing with Alcântara et al. (2008) and Freitas et al. (2013). However, some authors have shown that the extractors Mehlich-1 and ion exchange resin were equally effective to assess available soil P (SCHLINDWEIN et al., 2008).

The available P extracted by resin and Mehlich-1 showed no difference between fertilization levels applied to the pasture on soybean, when the soybean was fertilized (doses of 50 and 100 kg ha^{-1} P_2O_5) (Table 2). However, considering the bioavailability as indicated by related variables (P-Plant, DM, GY and accumulated-P) it appears that there was a residual effect of fertilization on soybean in pasture (Table 3). It appears therefore that the extractants were not sensitive enough to detect residual P fertilizer in pasture and that the assessment based solely on the results of soil analysis would suggest that only the fertilization applied to the soybean was responsible for the availability of P. This is probably because the extractants used are inefficient to extract organic forms of phosphorus, since the resin and Mehlich-1 reacted mainly on the available inorganic P in the soil (SANTOS et al., 2008; SOUZA JÚNIOR et al., 2012).

Table 3. Phosphorus content in shoots, shoot dry mass, grain yield and phosphorus accumulated in shoots at 100 days after emergence of soybeans according to fertilization in pasture in the fertilization in soybean.

Fertilization in pasture (kg ha^{-1} P_2O_5 yr^{-1})(†)	Phosphorus content in shoots (‡) (g kg^{-1})	Shoot dry mass(‡) (kg ha^{-1})	Grain yield (‡) (kg ha^{-1})	Phosphorus accumulated in shoot (‡) (kg ha^{-1})
		0 kg ha^{-1} of P_2O_5		
0	1.45 c	1636 c	1525 c	2.37 c
20	1.88 b	2672 b	2857 b	5.05 b
40	3.06 a	3586 a	3647 a	10.96 a
		50 kg ha^{-1} of P_2O_5		
0	1.72 c	3222 b	2325 b	5.62 b
20	2.45 b	3575 b	3497 a	8.75 b
40	3.02 a	4781a	3905 a	14.50 a
		100 kg ha^{-1} of P_2O_5		
0	2.31 b	3906 b	3577 a	9.03 b
20	2.93 a	5444 a	4142 a	16.00 a
40	3.08 a	4586 ab	3902 a	14.16 a

(†)Applied from 2003 to 2006.

(‡) Means followed by the same letters in column, each of P fertilization in the soybean, do not differ by SNK test at 5% probability.

Soybean DM yields ranged from 1,636 to 5,444 kg ha^{-1} (Table 3). With the increase in pasture fertilization, there was an increase in DM yield for all three soybean fertilization levels. The DM yield of soybean also responded positively to the P applied in 0 and 20 kg ha^{-1} of P_2O_5 applied in pastures plots. However, on the plot where the pasture had received 40 kg ha^{-1} of P_2O_5 the P applied to soybean had no significant effect on its DM yield (Table 3), demonstrating that relatively low annual P applications to the preceding pasture over four years was as effective as applying P directly to the soybeans. Francisco et al. (2007), who assessed the dry shoot yield of soybean as affected wholly or partly by the residual effect of P applied to the preceding pasture, also did not observe differences between treatments.

The unfertilized soybean plot (P0 + S0) produced 1,636 kg ha^{-1}of DM, 58% less than the plot fertilized with 100 kg ha^{-1} of P_2O_5 applied only on the soybean, which produced 3,905 kg ha^{-1} of DM. The DM yield in the residually fertilized plot with 160 kg ha^{-1} P_2O_5 spread over four years in the pasture (P40 + S0) did not differ from the same treatment with 100 kg ha^{-1} of P_2O_5 applied to the soybean (P40 + S100) (Table 3). These results highlights the importance of aboveground biomass in no tillage rotation systems as seen by Mascarenhas et al. (1981) and Francisco et al. (2007).

Soybean grain yield (GY) ranged from 1,525 to 4,142 kg ha^{-1} (Table 3). In the residually fertilized strips from the 0 and 20 kg ha^{-1} of P_2O_5 on pasture, GY increased with the increase in soybean fertilization up to the maximum rate. On the other hand, in the 40 kg ha^{-1} of P_2O_5 residual fertilizer strip, GY was similar for all three directly applied P rates (S0, S50 and S100). Lana et al. (2003) and Francisco et al. (2007) found similar soybean yields when fertilizer was applied earlier in the same crop year, compared to application at sowing time.

With increasing levels of fertilization, there was also an increase in phosphorus concentration in shoots (P-plant) (Table 3). In all the plots, which received P, either directly or as a residue, P-plant reached levels at least twice as high as on the unfertilized plot. The P40 + S0, P20 + S100, P40 + S50 and P40 + S100 fertilized strips, with the highest levels of P_2O_5, had the largest amounts of accumulated P. However, for a three-fold increase in DM yield, 6.7 times accumulated P was needed

(Table 2). Ono et al. (2009) reported an increase in P concentration in soybean, which was greater than the corresponding yield increase. They attributed this to luxury consumption of P.

The accumulated P in soybean shoot from the residual P treatments from pasture fertilization (i.e. S0, Table 3) showed a relationship with the P-resin content in the soil (i.e. S0, Table 2), demonstrating that fertilization spread over four years in pasture has a residual effect on the P accumulation in the shoots and, consequently, on DM production and the grain yield of subsequent crops. On the other hand, after pasture fertilization with 40 kg of P_2O_5 ha^{-1} applied annually over the previous four years, neither P accumulation in shoots nor increases in grain yield were observed (Table 3).

The levels of phosphorus in soil (P-resin) and phosphorus in the soybean shoots (cumulative-P) for the S50 and S100 levels, showed that the accumulated P also increased with soil P availability, than when the soil P levels resulted purely from the fertilization of the pasture. Therefore, high levels of available P in soil did not result in a higher P accumulation in the plants when the crop had been directly fertilized with P. This shows that the P applied to the pasture preceding the soybean and available to the plant is used more efficiently than P fertilizer applied at soybean sowing. Rossi et al. (1999) evaluated the residual effect of four P levels and four phosphorus sources applied to two pastures (*Centrosema pubescens* and *Brachiaria decumbens*) preceding rice cultivation: they also noted the residual effect of P coming from triple superphosphate applied to pasture. Considering the role of the root system of grasses in the solubilization of P by the exudation of organic acids (CORRÊA et al., 2004), *Urochloa decumbens* may have played a key role in the absorption efficiency of residual P and its subsequent release by mineralization of P held in DM (organic P). Thus, when the phosphorus is applied – split into four years application to pasture or applied to the soybeans at sowing time – there will be an accumulation of similar amounts of P, suggesting that early fertilization on pasture may be an effective strategy to soybean fertilization. These results confirm the hypothesis that long-term grain production is more dependent on the accumulation of soil P with successive crops than with the management of P fertilization. This reinforces the need to consider management systems and tillage used when recommended levels of P in soil are interpreted.

Conclusions

The residual available P from the preceding pasture fertilization is more efficiently than P fertilizer applied at soybean sowing suggesting that early fertilization on pasture may be an effective strategy to soybean fertilization. Phosphate fertilization of soybean through P applications to the preceding pasture is technically feasible and may be an alternative to recover or maintain pasture productivity as a substitute for direct corrective fertilization in soybean planting.

Acknowledgements

To Honeywell-SN Centre, BUNGE Fertilizantes S/A and the Institut de Recherche pour le Développement (IRD-France) for funding and support for the project. To the soil chemistry laboratory at Embrapa Cerrados and Juaci Vitoria Malaquias from his help with statistical analysis.

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