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# Phosphate fertilization strategies for soybean production after conversion of a degraded pastureland to a no-till cropping system

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## ABSTRACT

A considerable area of previously degraded pastureland in Brazil is appropriate for agricultural use, mostly for soybean cultivation. These degraded soils can be restored by establishing no-till systems which should protect the soil, enhance nutrient cycling, and be economically feasible. One of the main challenges when performing agricultural operations in these soils is soil phosphorus (P) status, due to the low levels and difficult management of this nutrient in highly weathered soils. This is mainly related to a lack of information regarding the best management strategy with respect to fertilizer sources and their placement and time of application. We hypothesized that applying P to the cover crop, rather than to the soybean furrow, is a better strategy for the production system, because it would improve P recycling and soil cover and guarantee better timing and operational efficiency in soybean sowing. A 4-year field trial examined the effect of P application (44 kg P $ha^{-1}$ $year^{-1}$) using various P sources (RPR – Reactive Phosphate Rock, TP – Thermophosphate and TSP – Triple Superphosphate) at different times (black oat furrow or soybean furrow), on a sandy loam Oxisol of a degraded pastureland in Southern Brazil. A black oat (*Avena strigosa* Schreb) – soybean (*Glycine* max L. Merrill) cropping sequence was used for 4 years after no-till establishment. Soil P content, plant nutrient uptake, black oat dry biomass yield, and soybean grain yield were assessed. Soil P content increased from 2.5 to 13.3 mg $dm^{-3}$ (0–0.20 m depth) on average across all times and sources of P application after 4 years. Different application times resulted in a residual P for black oat (when P was applied to soybean furrow) and soybean (when P was applied to black oat furrow). Soybean exhibited better use of residual P (based on nutrient uptake and grain yield) than black oat (based on effects on nutrient uptake and biomass yield). Black oat P uptake was positively correlated with soybean P uptake ($r = 0.71, p < 0.01$) and soybean yield ($0.69, p < 0.01$). The use of the TSP source led to a greater P-use efficiency, which was about 67 kg of black oat dry biomass for each kg of P applied to the black oat sowing furrow, and about 40 kg of soybean grain for each kg of P applied to the sowing furrow of black oat or soybean. Compared to TSP, less soluble phosphate sources (RPR and TP) led to a two to three times lower P-use efficiency. Results suggest that, on a previously degraded sandy loam Oxisol, P application to cover crop boosts P recycling and improves soybean yield by improving soil cover, and increases operational efficiency at sowing, even at low soil P levels. The use of water-soluble P sources should be preferred over less-soluble sources for the application on cover crop furrow.

## 1. Introduction

In Brazil, low yield pasturelands cover approximately 200 million hectares (Mha), and about 20% of these areas are degraded (Barretto et al., 2013; Dias-Filho, 2014). Increased yields in these areas, without associated environmental risks, are possible if good management practices are applied, especially with regard to soil fertility (Bruun et al., 2015; Cerdà et al., 2009). Conservative agriculture practices that avoid improper management are essential to the establishment of agricultural crops on previously degraded soils, which is particularly

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*Abbreviations:* PUE, Agronomic P-use efficiency; RPR, BG4-reactive phosphate rock; TP, Thermophosphate; TSP, Triple superphosphate

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important because these soils are highly vulnerable to erosion (Cerdà, 2000; Trabaquini et al., 2015). The no-till system is a recommended conservation system for annual crops in Brazil, and it is currently used in just over 32 Mha (Derpsch et al., 2010). The establishment of no-till cropping systems is beneficial to improve yield and to cultivate annual crops in previously degraded pasturelands. However, several limitations need to be addressed, especially those associated with soil fertility.

The low availability of phosphorus (P) in the soil is a concern in degraded pastureland restoration. This plant nutrient is likely to be in short supply and, therefore, techniques that recycle P and minimize its loss should be developed (Lal, 2001). The consumption of fertilizers including P has recently increased, especially in tropical regions (Cordell and White, 2011; Rodrigues et al., 2016), due to high P fixation in highly weathered soils (which require high P concentrations) and to increased P demand resulting from the inclusion of new croplands (typically degraded areas) that require high P addition (Rodrigues et al., 2016; Santos et al., 2008; Tiecher et al., 2015). The efficiency of P use is associated with the ability of a cultivated crop to acquire this nutrient. Some studies in Brazil showed the remarkable importance of soil organic P in the enhancement of P-use efficiency (Carvalho et al., 2014; Rosolem and Calonego, 2013; Tiecher et al., 2012).

The cultivation of cover crops during the winter is a common practice in Southern Brazil, and this practice can help ensure high levels of organic P. In highly weathered soils, P fixation is a concern. To increase P availability in these soils, it is important to ensure proper P sources and application times (Novais and Smyth, 1999). Plants with enhanced capacity to absorb P from the soil can help recycle P, especially if they are cultivated as cover crops. Black oat (*Avena strigosa* Schreb.) is a cover crop with this capacity (Dalla Costa and Lovato, 2004), as well as other cover crops cultivated in tropical regions (Almeida and Rosolem, 2016; Merlin et al., 2013; Teles et al., 2017). Increased P recycling results in a reduced time of mineral P exposure to soil particles, and this might help minimize P fixation. However, several uncertainties remain about the feasibility of applying P-fertilizers to cover crops and these uncertainties must be addressed to boost P recycling and to potentially provide P to the grain crops cultivated after cover crops.

The success of P management also depends on the P source. Several studies have demonstrated the feasibility of less soluble P sources (Chien et al., 2009; Galvani et al., 2008; Olibone and Rosolem, 2010; Prochnow et al., 2006). When using P sources with higher solubility (e.g., superphosphates), it is necessary to ensure P supply during times of higher P uptake (Raij, 2011). However, if part of the P supply is not properly used by the crop, the risk of loss increases. In this sense, less soluble P sources might be an interesting alternative, particularly when applied in advance and in narrow rows to simulate total incorporation into the soil. On the other hand, P sources with high water-soluble P contents can provide enough P for cover crop development, thus increasing soil protection and P recycling.

Improvements in soil-P status during the conversion from degraded pasturelands to no-till cropping systems are highly important. However, there are concerns about better strategies that improve soil-P efficiently without using high P inputs. In highly weathered soils, it is essential to ensure good soil cover for the establishment of a no-till system. In this regard, phosphate fertilization on the cover crop is promising, since it improves both P recycling and crop development. Moreover, the application of P to the winter crop row instead of the soybean row results in advantages regarding the rapidity of soybean sowing operations, which could help avoid late sowing and the subsequent crop yield restrictions (Pavinato and Ceretta, 2004), and improves horizontal P distribution. Therefore, this study aimed to evaluate the effects of P fertilization strategies, using a 4-year black oat-soybean succession, by varying P sources and P application times to ensure improved no-till establishments in a previously degraded pastureland.

**Table 1**
Results of soil chemical and particle-size distribution analyses for different depths in April 2009, before the establishment of the experiment.

| Attributes | Depth (m) | | | |
|---|---|---|---|---|
| | 0–0.05 | 0.05–0.10 | 0.10–0.20 | 0–0.20 |
| pH (1:2.5 soil:0.01 M $CaCl_2$ suspension) | 4.5 | 4.2 | 4.1 | 4.3 |
| Total acidity pH 7.0 (H + Al) ($mmol_c\ L^{-1}$) | 62.1 | 62.1 | 58.6 | 61.0 |
| Organic carbon ($g\ L^{-1}$) | 11.6 | 11.1 | 10.0 | 10.9 |
| P (Resin) ($mg\ L^{-1}$) | 4.9 | 2.7 | 1.2 | 2.5 |
| Exchangeable cations ($mmol_c\ L^{-1}$) | | | | |
| $Ca^{2+}$ | 8.0 | 3.5 | 1.3 | 4.0 |
| $Mg^{2+}$ | 3.7 | 1.5 | 1.6 | 2.0 |
| $K^{+}$ | 1.0 | 0.8 | 0.6 | 0.8 |
| $Al^{3+}$ | 4.0 | 7.0 | 8.0 | 6.0 |
| Effective cation exchange capacity (ECEC) ($mmol_c\ L^{-1}$) | 16.7 | 12.8 | 11.5 | 12.8 |
| Cation exchange capacity pH 7.0 (CEC) ($mmol_c\ L^{-1}$) | 74.8 | 67.9 | 62.1 | 67.8 |
| Base saturation (%)[a] | 17.0 | 8.5 | 5.6 | 10.0 |
| $Al^{3+}$ saturation (%)[b] | 24.0 | 54.7 | 69.6 | 46.9 |
| Particle-size distribution ($g\ kg^{-1}$) | | | | |
| Clay | | | | 190 |
| Silt | | | | 103 |
| Sand | | | | 707 |

[a] Base saturation = 100 ($Ca^{2+} + Mg^{2+} + K^{+}$ / CEC pH 7.0).
[b] $Al^{3+}$ saturation = 100 (Al/ECEC).

## 2. Materials and methods

### 2.1. Field and soil characterization and agricultural management

The experiment was performed in Ponta Grossa, PR, Brazil (25°10′S; 50°05′W) on an Oxisol (sandy loam, kaolinitic, and thermic Typic Hapludox). According to the Köppen-Geiger System (Peel et al., 2007), the climate at the site is categorized as a Cfb type (mesothermal, humid, and subtropical) with mild summers and frequent frosts during the winter. The average altitude is 970 m, and average maximum and minimum temperatures are 22 and 13 °C, respectively; annual rainfall is approximately 1550 mm. The experimental area was used as an extensive pasture with grassland vegetation. Before the establishment of the experiment, in April 2009, 20 soil cores were taken at different depths in the trial area using a hand soil probe, which were mixed to obtain a composite sample. Soils were air-dried and ground to pass a 2-mm sieve, and chemical and particle-size distribution analyses were performed, according to standard methods described by Raij et al. (2001) and Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA, 1997), respectively. Table 1 shows the results of soil chemical (0–0.05, 0.05–0.10, 0.10–0.20, and 0–0.20 m) and particle-size distribution (0–0.20 m) analyses. The soil was highly acidic with low base, P, and organic carbon contents. X-ray diffractograms performed on the clay fraction (EMBRAPA, 1997) indicated dominance of kaolinite and gibbsite and presence, to a lesser degree, of iron oxides, mainly hematite.

Dolomitic lime was applied to the soil surface at a rate of 4.8 Mg $ha^{-1}$, and it was incorporated at 0.20 m depth in May 2009. For this incorporation, half of the lime was ploughed down to 0.20 m depth using a disk plough, whereas the other half was harrowed to 0.10 m depth with a disk harrow. The lime rate was calculated to raise the base saturation in the topsoil (0–20 cm) to 70%. The utilized dolomitic lime contained 200 g $kg^{-1}$ calcium (Ca), 109 g $kg^{-1}$ magnesium (Mg), and 84% effective calcium carbonate equivalent (ECCE). Afterwards, a no-till experiment was established, and there was no soil disturbance apart from sowing operations.

The field trial was conducted from June 2009 to April 2013 through