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Phosphorus availability and dynamics in soil affected by long-term ruzigrass cover crop

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ABSTRACT

The use of grasses as cover crops in the off-season of cash crops under no-till has been largely adopted. However, soil phosphorus (P) uptake was previously shown to be reduced when ruzigrass is introduced in the rotation, affecting the viability and sustainability of this cropping system. The objective of this study was to assess the effect of ruzigrass on soil P availability and desorption kinetics under different P fertilizer application rates. A long-term field experiment where soybean (*Glycine* max) has been grown in rotation with ruzigrass (*Urochloa ruziziensis*) or fallow for 10 years, with the application of 0, 13, and 26 kg ha^{-1} of P, was evaluated for two consecutive years. Soil P desorption kinetics was assessed using diffusive equilibrium (DET) and gradient in thin films (DGT) techniques, as well as the DGT-induced fluxes in soils model (DIFS). Microbial biomass P (MBP) was assessed to verify if soil solution P (P_{DET}) was reduced due to immobilization by microorganisms. Ruzigrass reduced MBP and P_{DET} especially when P fertilizer was applied. The concentration of labile P (P_{DGT}) was also lower after ruzigrass than in fallow. The soil ability to resupply P to soil solution was lower after ruzigrass regardless of P rates due to a slower desorption in response to the perturbation imposed by DGT. Growing ruzigrass as cover crop in the soybean off-season decreases soil P availability regardless of P fertilizer application rates by fundamentally reducing P mobility and P resupply from soil solid phase into soil solution.

1. Introduction

Ruzigrass [*Urochloa ruziziensis* (R. Germ. and C.M. Evrard) Morrone and Zuloaga] has been preferentially used as cover crop in the off-season of cash crops and as forage in integrated crop-livestock systems than other Urochloa grasses, due to its ease of management in desiccation, high yield, palatability, nutritional quality for animal feed, high adaptability to poor phosphorus (P) soils, long residue persistence protecting the soil, and adaptability to climatic conditions during off-season (Boddey et al., 1996; Nascente et al., 2013). These characteristics are very interesting in conservational soil management such as no-till, to increase soil organic matter (SOM), aggregation and biological activity, as well as to protect the soil against erosion, keep soil moisture, and provide an opportunity to increase crop productivity (Castro et al., 2015; Franzluebbers et al., 2014; Lienhard et al., 2012). Additionally, the high P uptake capacity of ruzigrass is important in improving soil P cycling and P use efficiency (Almeida and Rosolem, 2016; Merlin et al., 2015). However, lower yields of cash crops have been observed after growing ruzigrass compared with those in fallowed soil (Almeida et al., 2018c). Almeida et al. (2018c) observed a lower soybean [*Glycine* max (L.) Merrill] grain yield and leaf P concentration after ruzigrass than fallow in four consecutive years. A lower P uptake by maize (*Zea mays* L.) was also observed after ruzigrass than in fallowed soil (Almeida et al., 2018b).

The lower bioavailability of P after growing ruzigrass has been attributed to a possible lower soil P desorption and increased soil P

Abbreviations: DET, diffusive equilibrium in thin films; DGT, diffusive gradient in thin films; DIFS, DGT induced fluxes in soils and sediments model; k_{-1}, desorption rate constant; K_d, equilibrium distribution coefficient between solid phase and soil solution; MBP, microbial biomass phosphorus; P_{DET}, soil solution P concentration measured by DET; P_{DGT}, DGT measured time average P concentration at the interface of soil and DGT device; P_E, effective P concentration; P_{resin}, soil phosphorus extractable with anion exchange pearl resin; R, ratio of P_{DGT} and P_{DET}; R_{diff}, ratio of P_{DGT} to P_E in the case where there is no P resupply from the solid phase; R-R_{diff}, relative resupply from solid phase; SOM, soil organic matter; T_c, response time of (de)sorption process

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Table 1
Selected chemical characteristics of soil, at four soil depths, for each treatment, with ruzigrass or fallow, and with 0, 13, or 26 kg ha^{-1} of P, in 2014 and 2015.

Depth	pH[a]	P_{resin}[b]	H + Al[c]	CEC[d]	Depth	pH[a]	P_{resin}[b]	H + Al[c]	CEC[d]
cm		mg dm^{-3}	$mmol_c$ dm^{-3}		cm		mg dm^{-3}	$mmol_c$ dm^{-3}	
Ruzigrass					Fallow				
2014									
0 kg ha^{-1} of P									
0–5	6.3	13	13	56	0–5	6.2	15	13	56
5–10	5.1	5	19	41	5–10	5.7	5	17	43
10–20	4.8	6	27	36	10–20	4.8	5	28	39
20–40	4.4	3	35	42	20–40	4.2	3	44	50
13 kg ha^{-1} of P									
0–5	6.4	19	12	61	0–5	6.3	18	13	53
5–10	5.7	7	18	45	5–10	5.6	9	18	43
10–20	4.6	5	30	41	10–20	4.7	6	27	39
20–40	4.2	3	39	44	20–40	4.2	3	39	45
26 kg ha^{-1} of P									
0–5	6.3	26	13	52	0–5	6.4	26	12	60
5–10	5.5	18	22	47	5–10	5.9	13	16	44
10–20	4.5	7	34	45	10–20	4.8	7	27	39
20–40	4.2	4	39	44	20–40	4.3	3	39	44
2015									
0 kg ha^{-1} of P									
0–5	6.5	13	13	60	0–5	6.7	15	13	57
5–10	6.0	8	18	48	5–10	7.5	7	15	44
10–20	5.4	7	24	39	10–20	5.8	8	25	40
20–40	5.0	3	34	44	20–40	5.2	3	40	49
13 kg ha^{-1} of P									
0–5	7.1	22	12	64	0–5	6.7	20	13	61
5–10	6.6	8	18	49	5–10	6.2	10	19	47
10–20	6.1	6	28	43	10–20	5.2	4	28	42
20–40	5.6	3	41	48	20–40	4.9	3	35	44
26 kg ha^{-1} of P									
0–5	6.6	32	14	68	0–5	6.7	24	14	57
5–10	6.1	27	22	51	5–10	6.5	20	18	48
10–20	5.5	14	31	47	10–20	6.1	8	26	42
20–40	5.2	2	38	45	20–40	5.7	3	35	42

[a] Soil pH measured in calcium chloride solution.
[b] Phosphorus extracted with pearl resin.
[c] Potential acidity.
[d] Cation exchange capacity.

adsorption sites due to interactions of iron (Fe) and aluminum (Al) oxides with SOM (Almeida et al., 2018b). The low soil P bioavailability in soil cultivated with ruzigrass was also showed by a lower depletion of P in the rhizosphere soil of maize, despite the observed increase in P concentration in the bulk soil (Almeida et al., 2018b). Almeida et al. (2018c) found no correlation of plant available P and the estimated P availability by resin method (Raij et al., 1986). Additionally, using Hedley P fractionation (Hedley et al., 1982), Almeida and Rosolem (2016) observed a higher concentration of Resin-, $NaHCO_3$-, and NaOH-extractable P, considered labile and moderately labile P fractions, after growing ruzigrass than in fallow. The lack of correlation between standard soil P tests and P uptake by soybean indicates that ruzigrass effect is not well represented by these extraction methods, and other more realistic methods are needed to reflect the plant experience of soil P availability and understand the ruzigrass effect on P mobility and desorption.

Plant P uptake results in P depletion in the rhizosphere, inducing P diffusion towards roots and release of P from soil solid phase (Barber et al., 1963). The diffusive gradient in thin films (DGT) method mimics the plant uptake action, creating a P sink, and inducing P resupply from the soil solid phase to the soil solution (Lehto, 2016). The method of DGT has been successfully used on a wide range of soils to estimate P availability to crops, such as maize (Heidari et al., 2017; Six et al., 2013), barley (*Hordeum vulgare* L.) (Tandy et al., 2011), and wheat (*Triticum aestivum* L.) (Mason et al., 2010). According to Six et al. (2012), the better prediction of soil P availability than conventional P extractions is explained by the diffusional process accounted for by DGT method, the lower anionic interferences with DGT, the non-labile P extracted by shaking and small solid:solution ratios in conventional extractions, and because P determination is unreliable if the extract P concentrations are near the detection limit. The use of an adequate soil analysis to estimate soil P availability not only renders a more precise determination of P bioavailability, but also an accurate diagnosis of the mechanisms behind the data variability, contributing in the search for more sustainable food production systems.

The objective of this study was to test the long term effect of ruzigrass on soil P availability and desorption kinetics at different P fertilizer application rates at field conditions. Specifically, we aimed to test the hypothesis that growing ruzigrass (cover-crop) in the off-season reduces P availability to the soybean (cash-crop) due to reduced soil P desorption rates.

2. Material and methods

2.1. Experimental site and treatments

A long-term field experiment located in Botucatu, State of São Paulo, Brazil (22°50′00″ S; 48°25′31″ W; and altitude of 806 m), was carried out for two years (2014 and 2015). The soil is a Rhodic Hapludox (Soil Survey Staff, 2014) with 670 g kg^{-1} of sand and 210 g kg^{-1} of clay. The area selected for the experiment has been under no-till since 1998. From 1998 to 2005, all plots received a total of