Phosphorus movement in the topsoil layer after long-term surface broadcast amendment: field and controlled conditions studies

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Abstract. Phosphorus movement into soil profile might be increased when coupling no-till crop production with surface broadcast phosphorus (P) application. The objective of this study was to evaluate soil P movement in the topsoil layer affected by P application via surface broadcast and its availability evaluated by two soil test methods. Field research in a long-term experiment (Ultisol) was used to evaluate corn and wheat yields affected by P application. After 429 days we evaluated soil P distribution in topsoil layer. Laboratory research was carried out in soil columns to compare soil P movement in two different soils (Ultisol and Oxisol) affected by P application. In the laboratory research we evaluated soil P availability by Mehlich-1 and resin strips (previously buried) in different soil depths to access P movement into the soil profile 180 days after P application. Soil P movement in topsoil layer of field research increased according to P rates applied until 6 cm (Mehlich-1) and 10 cm (resin), while in laboratory research soil P movement evaluated by Mehlich-1 and resin was greater until 6 cm in the Ultisol and was greater until 2 cm in the Oxisol. Surface broadcast application of soluble P in rates above that those recommended to adequate crop yield increases soil P availability in concentrations higher than the critical level, mainly in soil surface increasing soil P movement in soil profile and more this effects is more evident in sandy soils.

Key words: phosphorus movement; soil tests; phosphorus in the environment.

Movimento de fósforo na camada superficial do solo após a aplicação em superfície: estudos em campo e condições coltroladas.

Resumo. O solo cultivado no sistema plantio direto e a adubação com fósforo (P) aplicado em superfície pode causar o seu movimento no perfil do solo. Este trabalho teve por objetivo avaliar o movimento de P nas camadas superficiais do solo devido a doses de fertilizantes fosfatados aplicados em superfície, comparando os teores extraídos por dois métodos de análise de solo. Experimentos de campo e de laboratório foram conduzidos: Um experimento de campo (em Argissolo) foi utilizado para avaliar o rendimento de milho e trigo submetido a doses de P e após 429 dias foi avaliado a distribuição de P no perfil do solo; no experimento de laboratório foi usado colunas de solo onde foi comparado o movimento de P em dois solos (Argissolo e Latossolo) que receberam aplicações de doses de P. Neste estudo foi utilizado lâminas de resinas previamente enterradas em diferentes profundidades e o movimento de P foi avaliado em 180 dias após a aplicação de P. O movimento de P nas camadas superficiais do solo, na maior dose de P em relação a testemunha a campo, foi até 6 cm, determinado por Mehlich-1 e até 10 cm determinado por resina; já no experimento de laboratório o movimento de P determinado pelas metodologias foi maior até 6 cm no Argissolo e até 2 cm no Latossolo. A aplicação de P solúvel acima das doses recomendadas para as culturas aumenta a disponibilidade no solo, com concentrações acima do nível crítico na superfície do solo, causando movimento de P nas camadas superficiais do solo, principalmente em solos arenosos.

Palavras-chave: movimento de fósforo; análises de solo; fósforo no ambiente.

1. INTRODUCTION

The in-furrow fertilizer application coupled with below and side-seed bed is an operation recommended in order to provide fertilizers efficiency use to promote root growth trajectory (positive geotropism). However, some studies have shown that fertilizer application method based on surface broadcasting has a similar result on crop yield compared to in-furrow application even for phosphate fertilizer applied in no-till crop production[1,2]. Many farmers choose to apply fertilizers via surface broadcast in no-till crop production to increase planting operation with some advantages such as increase operating income, reducing recharge time (seeds), maneuvers and, consequently, fuel consumption is reduced.

When applied in high doses Phosphorus may saturate soil adsorption sites increasing its availability to plants and to the environment as well[3]. In clayey soils the amount of soil P adsorption capacity sites is higher than sandy soils[4,5]. In sandy soils is weakly adsorbed in the soil matrix and it increase soil P mobility in soil profile. Saturation of P sorption sites in soil increase the risk of P transfer from soil to surface water due soil P losses associate with water in surface runoff and sediment mainly in croplands with high surface P concentration[6,7,8,9].

Diffusion is the major mechanism of P supply to plants, being generated by nutrient concentration gradient, from a more concentrated zone to a less concentrated one, in other words, from the interface soil-solution to the soil solution and then to interface solution of soil-root[10]. In soils where P has been applied in-furrow it moves through lower levels[11,3]. In no-till crop production, due to nutrient concentration in soil surface and topsoil layers enhanced by surface broadcast fertilizer application and nutrient recycling [12,2]; soil P can be leached in the soil profile and its depth vary according to soil properties such as soil clay content, sorption P capacity and others.

In regions with rainfall regime is higher than evapotranspiration, soil water percolates into soil profile creating flow mass increasing the possibility of soil P in the soil solution (usually less than 0.1 mg kg^{-1}) be moved through soil profile[10]. Soil P movement into soil profile is more evident in sandy soils under no-till crop production with high P application (mineral or organic), increasing soil surface P concentration and consequently saturation of adsorption sites[3]. To access soil P movement in soil profile a simple soil test can be performed such as Mehlih-1 and resin strips, which are soil test P used in Rio Grande do Sul State to evaluate soil P availability to plants[12];

The aim of this study was to evaluate soil P movement in the soil profile after P application by surface broadcast in two distinct situations: i) long-term field research in a sandy soil under no-tillage corn and wheat cropping system rotation; ii) laboratory research carried out in soil columns with the long-term sandy soil and a clayey soil under no-till crop production.

2. MATERIAL AND METHODS

Field research was conducted on the Agronomic Research Farm at Federal University of Rio Grande do Sul (Southern Brazil) in an Ultisol which soil attributes are presented in Table 1 under long-term (10 years) no-till crop production that have been used to studies regarding soil P calibration to crops, cultivated with corn and wheat, respectively[12]. Crops were planted using a no-till planter and added nitrogen and potassium with the same rates for all treatments (60 and 50 kg ha^{-1} K_2O, 60 and 50 kg N ha^{-1} to corn and wheat, respectively) at time of planting. For the first crop corn was planted in September 29 (2000/2001) and P was applied immediately after planting via surface broadcast at rates of: 0, 60, 120, 240 and 480 kg ha^{-1} P_2O_5 using triple superphosphate as P source. After the corn harvested was planted wheat in March 2 (2001) and were applied the following P amounts: 0, 50, 100, 200 and 400 kg ha^{-1} P_2O_5 using triple superphosphate as P source by broadcast surface application. Corn and wheat were grown until the grain stage to crop yield evaluation. The experimental design was randomized blocks with three replicates. The total P applied into soil surface considering corn and wheat was: 0, 110, 220, 440 and 880 kg ha^{-1} P_2O_5. During the crops growing season, which were from September 2000 through July 2001 the precipitation under either natural rainfall or irrigation was 1986 mm (an average of 32.4 mm per week).

After the wheat harvested (July 2001), soil samples were taken at different soil depths. The samples were taken 429 days after the first P application. Three treatments were selected: 0, 220 and 880 kg ha^{-1} P_2O_5. Soil samples from each plot were composed of three sub-samples at depths of 0-1, 1-2, 2-4, 4-6 and 6-10 cm different soil depths. The samples were dried in an oven with air forced flow (60°C) and passed through a hammer-mill and sieved in two millimeters sieve. Soil P was extracted with Mehlich-1 solution and ion-exchange resin membrane and the determination of P in the extract was determined colorimetrically ascorbic acid method [17].

Table 1: Soil attributes of soils used to evaluate the phosphorus movement in the soil profile[1].

Soil	Clay	Carbon	pH in H_2O	P	K	Ca	Mg
	------- g kg^{-1} ---------			----------------- mg kg^{-1} -----------------			
Ultisol	260	16	5.0	4.0	225	660	225
Oxisol	720	18	5.3	5.1	96	640	200

[1] Methods used: Clay: hydrometer method; Carbon: Walkley-Black; P and K: Mehlich-1; Ca and Mg: KCl 1M.

The second study was a laboratory research under controlled conditions. In this study, we used two soils (Table 1), an Ultisol (260 g kg^{-1} clay) sampled from the control treatment of the first study, and an Oxisol (700 g kg^{-1} clay) cultivated by 12 years under no-tillage in a soybean-wheat-corn-oat rotation. Soil samples were taken from a 0-10 cm soil depth. The samples were air dried and ground to pass through a 4 mm sieve. The soil acidity correction was carried out through the surface application of a 2 t/ha equivalent of $CaCO_3$/$MgCO_3$ with a molar ratio of 3:1 to set the pH up to around 6.0. The soils were kept with moisture closest to the field capacity continued for 30 days in an opened plastic bag to allow the lime reaction. After this period, the samples were re-dried and then, assembled into the columns to receive the different treatments.

Columns were previously prepared with the following dimensions: diameter of 6.8 cm and height of 14 cm. The lower base of the columns was partially closed keeping small holes to allow the water percolation throughout the soil. Resin strips saturated with 0.5 M of sodium bicarbonate were placed in different soil depth at: 1, 2, 4 or 6 cm from the soil surface in each soil column. Each soil depth was kept separated from each other by a non-charged membrane with a 0.5 mm sieve to facilitate the remove process of the resin strip at the end of the study, and to avoid soil mixing from different soil depths. In each soil depth the soil P was evaluate with both resin and Mehlich-1 methods which are methods used to estimate soil P availability in soils from Rio Grande do Sul state[15].

Each soil column received via surface application an amount of a mixture of plant residue (70% oat and 30% vetch, equivalent to about 6 t ha^{-1} which is common in agricultural soils under no-till in Southern Brazil). The objective of residue addition was to protect the soil surface of the direct impact of water and minimize excessive moisture losses after irrigation. Soil moisture was kept close to field capacity, with weekly watered equivalent to 32.4 mm (similar with the first study), by 30 days. After this period, were applied in the soil surface the following P doses: 0, 110, 220 and 880 kg ha^{-1} P_2O_5. The statistical design was a factorial completely randomized with three replicates (96 columns), with four soil layers, four levels of P and two soils.

The experiment was carried out by 180 days. During this period, the soil moisture was kept close to field capacity by weighting. After 180 days of the P application, the soils were taken from the columns in each soil depth to assess the availability of soil P by resins strips buried. Furthermore, we evaluated the availability of P in the layer immediately above the resin strips with Mehlich-1 solution[17].

Statistical analysis was performed with regression analysis to test P crop response. The differences between soil P depths were evaluated by Tukey test (0.05).

3. RESULTS AND DISCUSSION

3.1 Soil Phosphorus, and wheat and corn yields affected by broadcast surface phosphorus application in soil under no-tillage

Soil P distribution in the soil profile affected by surface broadcast P application and extracted with different soil test is shown in Figure 1. Soil P amounts extracted with Mehlich-1 solution and resin were different with depth to the rates of 220 and 880 kg ha^{-1} P_2O_5. The soil P in the control treatment (without P application) did not differ significantly with the depth, but the numerical values were higher in the surface layers (0-1 and 1-2 cm) to the amounts extracted with Mehlich-1 and resin, respectively. The highest values obtained in the surface layer may be due to recycling of soil P[13,1,14,2].

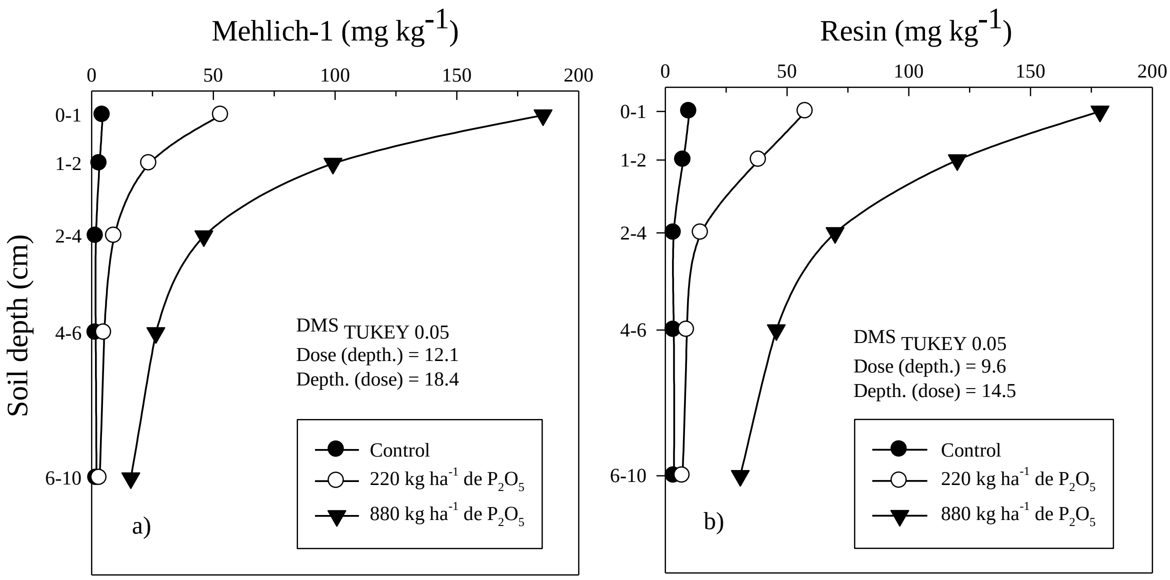

Figure 1: Soil phosphorus extracted with Mehlich-1 solution (a) and resin method (b) in a Ultisol under a cropping and no-tillage systems amended with phosphorus applied via surface broadcast.

The soil P amounts extracted with Mehlich-1 solution were significantly higher in the depth of 1-2 cm, while to treatments of 220 and 880 kg ha^{-1} P_2O_5, the higher P extracted where found at depth of 4-6 cm (Figure 1a). However, soil P amounts extracted with resin method were significantly higher in control at depth of 2-4 cm, while in the treatments of 220 and 880 kg ha^{-1} P_2O_5, higher P were found at depth of 6-10 cm (Figure 1b). The soil P higher values according to depth are possibly due to vertical movement of soil P. Although it was applied via surface broadcast and no-till, at planting a little soil mobilization occur to place seed at correct soil depth which may facilitate soil P movement. High levels of P applied can saturate the surface sites of P adsorption, due the P adsorption capacity is lower in sandy soils[3,4,5], increasing the mobility of this nutrient.

The vertical mobility of P was observed by[11] ,that after 121 days from the P application observed P movement up to 3.0 cm away from the granular fertilizer in a similar Ultisol used in this work. The vertical P movement was also observed in soils sampled from different layers of field research with P applied by surface broadcast and crops grown under conservation tillage, although the results have been interpreted as both of soil P vertical variation and/or P recycling [13,14,2].

The high P amounts in the topsoil layer (Figure 1), represents the risk of P transfer to surface waters by runoff due the high intensity of rainfall in Southern Brazil, and the landscape of the croplands are generally with more than 10% of slope. In addition, most of the areas from Southern Brazil, with soils with considerable erodibility in high slopes are cultivated without conservationists' practices although the no-tillage is the major practice. However, supporting practices such as terraces, contour planting, crop rotation, that increases the soil surface cover and reduces the impact of the rainfall and surface runoff are unused in large amounts of areas. Studies have shown that cultivated soils under no-tillage with broadcast surface fertilizer application under either natural or simulated rainfall, showed losses of water and sediments[6,9]. The authors found positive and significant linear correlation between the levels of total P in water and sediments with the P amounts in the topsoil layer (0-2.5 cm). In addition, the losses of dissolved P in surface runoff decreased exponentially after the first rainfall event, tending to stabilize similar to control with the incorporation of P in the topsoil from the third rain. The risks of environmental contamination can be reduced when the soils are under surface covered, adequate soil physical attributes such as porosity and others high amounts of organic matter and supporting practices to reduce surface runoff. The effects of P losses by runoff and its effects on the environment are well documented in the literature worldwide[7,8] however, for Southern Brazil conditions there is a gap of information that must filled out regarding to its effects, dealing with environmental soil test P, method and source of P application and others with focus on best management practices of P.

Corn yield increased with the P application, while wheat which is a crop that is less P demanding[15,16] showed no effect of P application on its yield (Figure 2). Wheat low yield was probably due to the final growing season decease caused by excessive rainfall, reducing the effect of fungicides. Estimated yield of corn in the control treatment was 6,264 kg ha^{-1} and P in soil is classified as "very low"[15]. The estimated corn yield increased around of 25 kg of grain for each kg ha^{-1} P_2O_5 applied until near the maximum productivity of 10,040 kg ha^{-1} (307 kg ha^{-1} P_2O_5). [16] studied 16 evaluations of experiments with corn grown in no-tillage systems in several locations from Southern Brazil and the authors found a corn yield increase of 47 kg of grain for each kg ha^{-1} P_2O_5 applied. In these evaluations the P_2O_5 doses estimated for both maximum technical and economic efficiency were 141 and 109 kg ha^{-1}, respectively. In the most nutrient calibration programs the doses of maximum economic efficiency are calculated for 90% of the maximum technical efficiency. Thereby, for this study, the dose of maximum economic efficiency would be 276 kg ha^{-1} P_2O_5, which is greater than the dose recommended by the Southern Brazil nutrient guidelines[15] and that found by[16].

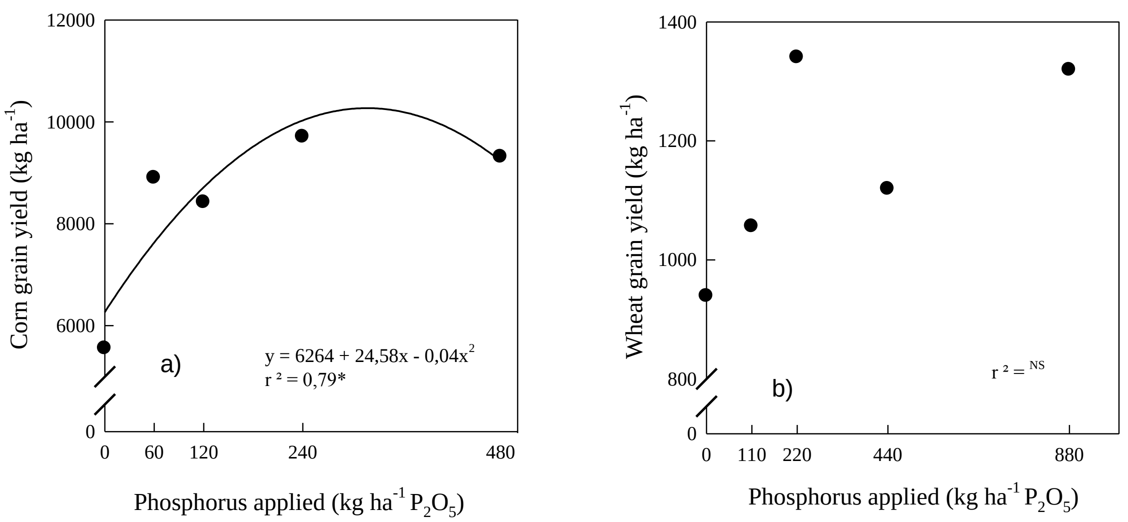

Figure 2: Corn (a) and wheat (b) grain yields in an Ultisol under no-tillage affected by the broadcast phosphorus fertilizer application.

Plants uptake nutrients from a various soil profile depths; however, nutrient uptake is larger in soil depth with more nutrient concentration[10] and, it is expected that more deep is the soil layer with high nutrient concentration; consequently plants yield might be high. The results showed P displacement in the soil profile and maize yield increased with P doses.

3.2 Phosphorus movement in soil columns study

Soil P extracted with resin buried and Mehlich-1 solution is shown in Figure 3. The soil P extracted in sandy soil with resin buried strip was significantly higher in soils with P application compared to control treatment to all of the most soil depths (Figure 3a) In the clayey soil, the P extracted with resin was higher in control plots at depths of 0-1, 1 and 2 cm than those in the treatments with doses of 110, 220 and 880 kg ha^{-1} P_2O_5, respectively (Figure 3b). The soil P amounts extracted with Mehlich-1 solution in the control sandy soil were lower than the P amounts extracted in the layers of 0-1, 0-1 and 4-6 cm depth, at rates of 110, 220 and 880 kg ha^{-1} P_2O_5, respectively (Figure 3c). For the clayey soil the differences were observed only in the surface layers (Figure 3d).

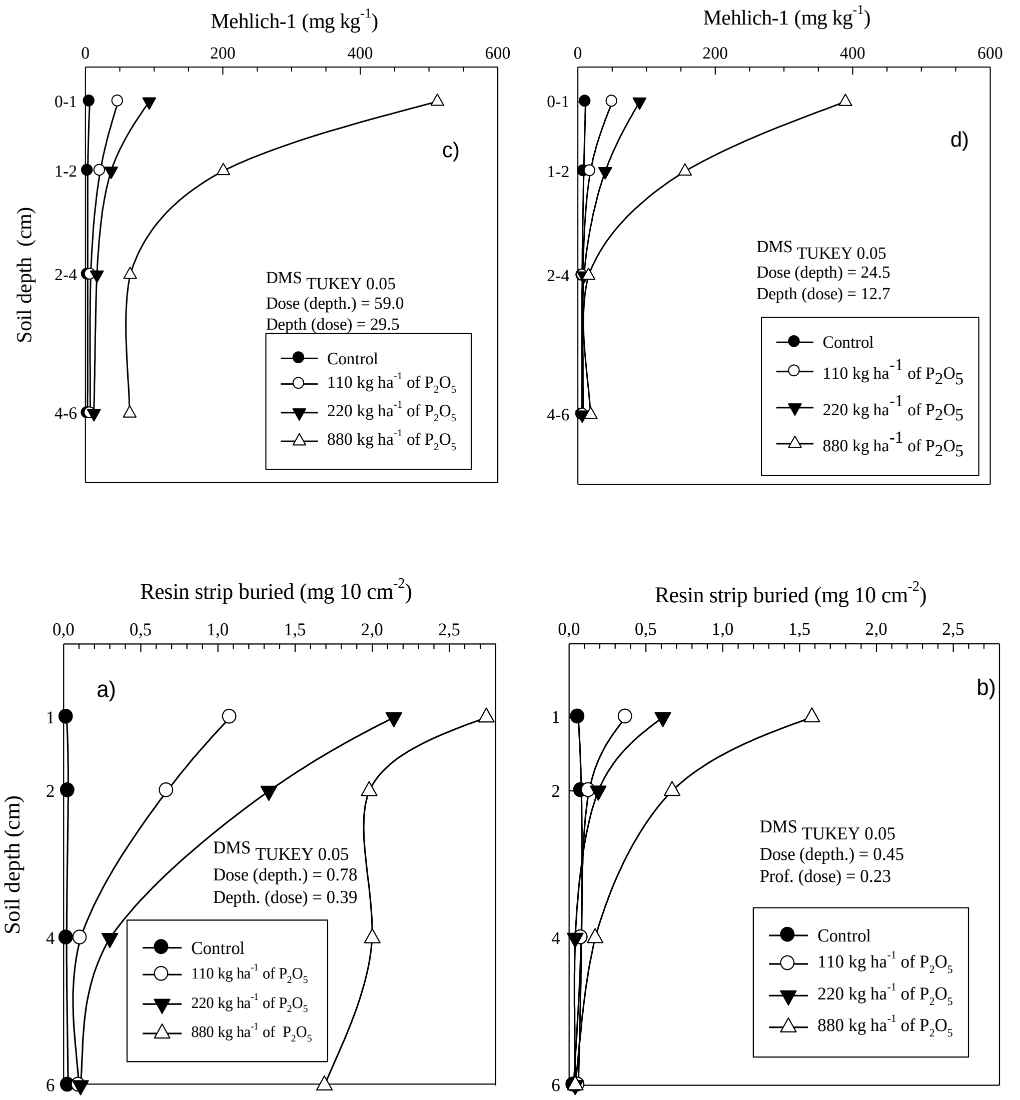

Figure 3: Soil phosphorus extracted with resin strip buried in an Ultisol (a) and Oxisol (b) and extracted with Mehlich-1 in an Ultisol (c) and Oxisol (d) affected by the broadcast phosphorus fertilizer application.

The P movement in the soil profile estimated with Mehlich-1 and resin in the sandy soil compared to clayey soil was possibly due to the fewer sites for adsorption of P in the sandy soil allowing P moving throughout the soil profile[3,4,5]. The soil P movement that is well known and widely studied is the diffusion, that occurs in the case of P supply to crop nutrition and it should be higher in clayey soils[10]. Thus, it was expected to be higher amounts of P with depth with resin in the clayey soil than in sandy soil. Theoretically, the resin buried in the soil should remove P from the soil solution as well as plant roots, creating a P concentration gradient as related to the concentration in the soil solution interface with colloids promoting the diffusion process[10]. Apparently, the P movement by mass flow could have been more important to explain the movement of P in the soil profile, mainly due the watering was made weekly and with an amount of 32 mm, allowing a vertical movement of soil water.

Phosphorus movement in the topsoil layer observed in soil columns experiment showed similar tendencies to the results observed in the field evaluated with Mehlich-1 and resin, increasing the possibility to carry out this kind of study in controlled conditions using a wide range of soil types with a remarkable environmental control.

4. CONCLUSION

The broadcast application of soluble phosphorus in rates above that those recommended to crops increases the phosphorus availability in soil, with concentrations higher than the critical level in the soil surface, allowing the phosphorus movement in the soil profile, mainly in sandy soils. This situation might increase the potential risk of phosphorus losses by surface runoff in both soils and by leaching in sandy soils.

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