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PHOSPHORUS CONTENTS IN THE SOIL IN FUNCTION OF THE MODES OF APPLICATION OF PHOSPHATE FERTILIZER IN TWO CROPS IN SUCCESSION

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ABSTRACT - Tropical soils are naturally poor in phosphorus and, due to the strong interaction with mineral constituents, the ways of applying phosphate fertilizers can increase the efficiency of absorption by crops. The objective of this analysis was to evaluate the distribution of P at different depths depending on the application of phosphate fertilizer in wheat and common bean crops grown in a Dystrophic Red Latosol from Toledo, western Paraná. The work was carried out under field conditions at the experimental unit of the Agronomy course at the Pontifical Catholic University of Paraná (PUCPR), Campus from Toledo. The block design was used in the case, in a scheme of sub-subdivided plots in the space, the first factor being the application mode, the second local factor (lines and between lines), and the third-factor sampling depth (0 – 5, 5 – 10, 10 – 15, 15 – 20 cm), and collections were carried out at seven points in each plot, in two consecutive years. The first soil collection was carried out after the wheat harvest, with soil samplings being performed to quantify the amount of P added to the soil. The soil samples were collected at seven points per plot, four between the lines and three in the sowing lines, in a straight line in each plot, the same procedure was performed after harvesting the bean crop and the second collection was carried out after the bean crop harvest, repeating the analyses, using the Mehlich-1 method. Phosphate fertilizer application modes did not influence P contents in the soil. The highest P contents were obtained at 0-5 cm depth, decreasing along the sampled depths.
Keywords: Soil analysis, diffusion, depth. Phosphorus content.

TEORES DE FÓSFORO NO SOLO EM FUNÇÃO DOS MODOS DE APLICAÇÃO DE FERTILIZANTE FOSFATADO EM DUAS CULTURAS EM SUCESSÃO

RESUMO - Solos tropicais são naturalmente pobres em fósforo e em função da forte interação com os constituintes minerais os modos de aplicação dos fertilizantes fosfatados podem aumentar a eficiência de absorção pelas culturas. O presente trabalho foi desenvolvido com o objetivo de avaliar a distribuição de P em diferentes profundidades, em função do modo de aplicação do fertilizante fosfatado, nas culturas do trigo e feijoeiro cultivados em Latossolo Vermelho Distroférrico. O experimento foi conduzido em condições de campo, na unidade experimental da Pontifícia Universidade Católica do Paraná (PUCPR), *Campus* Toledo. O delineamento experimental utilizado foi blocos ao acaso, em esquema de parcelas sub-subdivididas no espaço, sendo a parcela o modo de aplicação, a subparcela o local (linhas e entre linhas) e a sub-subparcela, as profundidades de amostragem (0-5 cm, 5-10 cm, 10-15 cm e 15-20 cm), sendo as coletas realizadas em sete pontos de cada parcela (quatro nas entrelinhas e três nas linhas de semeadura, em linha reta em cada parcela), por dois anos consecutivos. A primeira coleta de solo foi realizada após a colheita do trigo, realizando as amostragens de solo para quantificar o P acrescentado ao solo e a segunda coleta realizada após a colheita da cultura do feijão repetindo as análises, utilizando o método de Mehlich-1. Os modos de aplicação do fertilizante fosfatado não influenciaram os teores de P no solo. Os maiores teores de P foram obtidos na profundidade 0-5 cm, reduzindo ao longo das profundidades amostradas.
Palavras-chave: Análise de solo, difusão, profundidade, teor de fósforo.

INTRODUCTION

From the 1970s, grain production in Brazil, which was carried out under the conventional tillage system (CTS), started to be conducted in the no-tillage system (NTS), due to the various advantages provided by the NTS, such as, accumulation of organic matter, lower temperature and higher soil moisture, reduced erosion, providing new soil fertility dynamics (NUNES, 2011).

The search for productivity increases in several crops has provided a great deal of research related to the efficiency of phosphorus (P) fertilization, such as its different modes of application in the soil, sources and doses used, in addition to the improvement of analytical methodologies for quantification of P in the solution of the soil (BARBOSA et al., 2015). The intensity of the reactions of phosphate fertilizers in the soil differs in the different soil management systems and fertilizers used, over the years,

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with the use of NTS, caused a greater accumulation of P in the soil surface layer (TEIXEIRA et al., 2013). The transport of P in the soil is directly linked to the absorption of the nutrient, whose main mechanism of transport is diffusion, being mainly influenced by the soil colloids and their interaction with the nutrient, due to the concentration of the nutrient in the soil and the distance from the roots, generating barriers for phosphate fertilization (COSTA et al., 2006).

The most commonly used fertilizer application modes for grain production are sowing furrows; broadcast on the surface incorporated or not in pits and strips, among these the application method by broadcast without incorporation is frequently used in several producing regions in Brazil (SOUZA et al., 2004). The way in which P is applied can influence the increase in plant rooting and assist in the redistribution of the nutrient in the soil, due to root decomposition, increasing the levels in deeper layers (OLIVEIRA JUNIOR et al., 2008).

Several authors have studied the method of application of phosphate fertilizers in relation to their vertical and horizontal distribution, in different types of soil and P contents in the soil, types of crops, and years of cultivation, in order to obtain detailed recommendations for each situation of cultivation (RESENDE et al., 2006; NUNES et al., 2011; TEIXEIRA et al., 2013; BROGGI et al., 2015; BARBOSA et al., 2015; ROSSI et al., 2018). In this context, the objective of this work was to evaluate the distribution of P at a depth of 0-20 cm, in three modes of application of phosphate fertilizer and in two consecutive crops, in Dystroferric Red Latosol in the region of Toledo.

MATERIAL AND METHODS

The work was carried out under field conditions, at the experimental unit of the Pontifical Catholic University of Paraná (PUC/PR), Campus Toledo, located at the geographic coordinates 24°42’49” S and 53°44’35” W, with an average altitude of 574 m. According to the Köppen climate classification, the climate of the region of Toledo is characterized as being humid subtropical mesothermal, with hot summers, no dry seasons, and few episodes of frost (NITSCHE et al., 2019). During the conduct of the experiments, the meteorological data of minimum, average, and maximum temperature, and rainfall are presented in Figure 1.

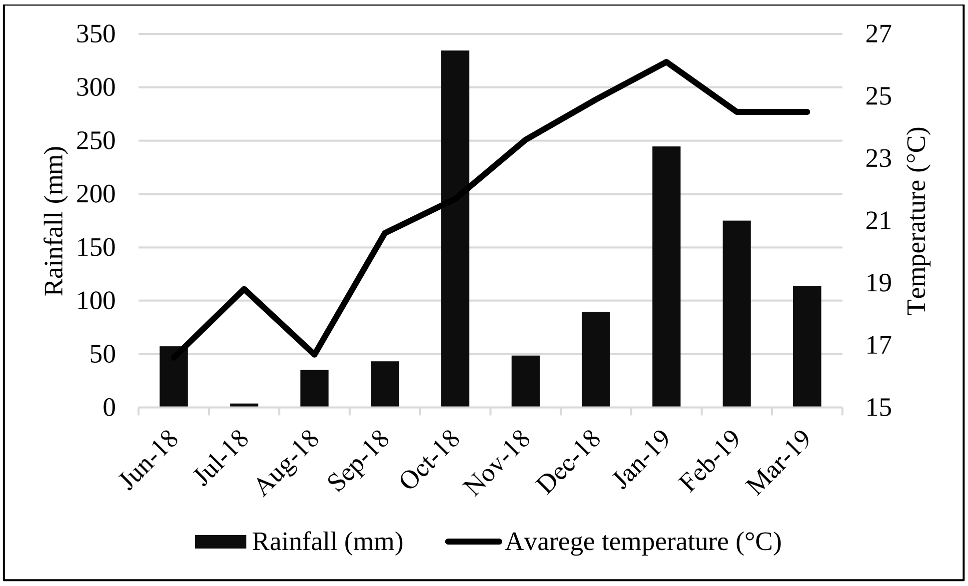

FIGURE 1 - Meteorological data on average temperature and rainfall covering the period from June 2018 to March 2019, data provided by the meteorological station at PUC, Campus Toledo, Paraná.

The soil of the experimental farm is classified as a typical Dystroferric Red Latosol, moderate A horizon, smooth undulating relief, and very clayey texture (SANTOS et al., 2014). Prior to the installation of the experiment, the soil was collected at a depth of 0-20 cm, subsequently sent for fertility assessment (LANA et al., 2016), with the following results: pH in $CaCl_2$ 0.01 mol L^{-1}: 5.04; P: 11.70 mg dm^{-3}; S: 7.78 mg dm^{-3}; Ca, Mg, K and H + Al, 4.57; 2.10; 0.26 and 5.26 $cmol_c$ dm^{-3}, respectively, SB: 6.92, CTC: 12.18 and V% 56.82, B: 0.08 mg dm^{-3}; Cu: 5.34 mg dm^{-3}; Fe: 98.95 mg dm^{-3}; Mn: 71.53 mg dm^{-3} and Zn: 1.09 mg dm^{-3}. The particle size analysis showed 175, 162.5, and 662.5 g kg^{-1}, respectively, sand, silt, and clay (EMBRAPA, 1997).

The experimental design used was randomized blocks, in a scheme of sub-divided parcels in space, with the parcel being the 3 modes of application (100% furrow, 100% broadcast, and 50% broadcast/50% furrow), the local sub-parcel (rows and between lines) and as a sub-sub-parcel the sampling depths (0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm), with collections being carried out at seven points of each parcel, in two consecutive years after the wheat crop and after the bean crop.

To carry out this study, wheat crops were used and after the crop was harvested, the bean crop was implemented in succession. As for the wheat crop, the variety BRS Gralha Azul was used, spacing 0.17 m and population of 300 plants m^{-2}, with sowing carried out on

June 11, 2018, using a seeder-fertilizer. For the bean crop, the variety used was BRS-Estilo, spacing of 0.45 m between rows and population of 12 plants m^{-2}, with sowing on November 12, 2018.

Maintenance fertilization for both wheat and common bean crops was calculated using the P export tables, according to Paulletti (1998), as well as the nutrient consumption factor (CF) of wheat and common bean crops was used (CUNHA et al., 2014). The fertilizer used was triple superphosphate (TSP) (00-41-00), applying 115 kg ha^{-1} for the wheat crop, aiming for an expected yield of 3000 kg ha^{-1} and 250 kg ha^{-1} for the crop of beans, expected to produce 4000 kg ha^{-1}. The applications in the sowing furrow were carried out with the aid of a seeder-fertilizer at the time of sowing the crops and for treatments with the broadcast application, it was carried out manually right after sowing the cultures for greater precision.

The topdressing in the wheat crop was carried out in the tillering period at stage E1 according to the Feekes Scale (1942), applied 60 kg ha^{-1} of N in the form of urea (45-00-00) and 40 kg ha^{-1} of K_2O in the form of potassium chloride (00-00-60). For bean crop, topdressing occurred in the vegetative phase (V4), applying 90 kg ha^{-1} of N in the form of urea (45-00-00) and 75 kg ha^{-1} of K_2O in the form of potassium chloride (00-00-60), on December 26, 2018. The cultural treatments (control of weeds, pests, and diseases) were carried out in the wheat crop with two applications of Trifloxystrobin and Tebucanazole for disease control and two applications of Imidacloprid and Beta-Cyfluthrin for insect control, weed control was performed manually through weeding. In the bean crop, the same applications of fungicides and insecticides were carried out according to the dosage on the package insert of each product for the crop.

The first soil collection was carried out after the wheat harvest, and soil sampling was carried out to determine the amount of P added to the soil. Soil samples were collected at seven points per plot, being four between the rows and three in the sowing lines, in a transverse position in each plot. Stratification was performed at each point, collecting samples of 0-5 cm; 5-10 cm; 10-15 cm, and 15-20 cm, as proposed by Barbosa et al. (2015). The collection was carried out using a cutting shovel with a graduated tape measure to assist in this stratification. After collecting the soil samples, they were properly packed in plastic bags and then sent to the Soil Fertility Laboratory at PUC/PR, Campus Toledo. Afterward, the samples were placed to dry in an oven at 40°C for 24 h, then they were ground using a mill with a 2 mm mesh sieve (ADFS – air-dried fine soil). After grinding, in the soil samples, the P content was determined using Mehlich^{-1} as an extractor, according to the methodology described by Lana et al. (2016). The same procedure was performed after the bean crop harvest, totaling two collection times in two crop cycles, wheat, and common bean.

The data obtained were subjected to analysis of variance and, when significant, the means were compared with each other by the Tukey test, at 5% probability of error, using the SISVAR software (FERREIRA, 2011).

RESULTS AND DISCUSSION

For the modes of application of phosphate fertilizer (furrow and broadcast) and sample collection site (row and inter-row), no significant differences were obtained ($p>0.05$), however, there were significant variations ($p<0.05$) in the P contents among the depths of collection of soil samples (after the wheat crop) and for the interaction site of collection x depth, after the bean crop (Table 1).

TABLE 1 - Summary of the analysis of variance for P contents and soil averages, as a function of application modes, sampling location, and sampling depth of a Dystroferric Red Latosol in Toledo.

Sources of variation	DOF	MS	
		After corn harvest	After bean harvest
Block	4	503.69*	517.92*
Mode (M)	2	88.98^{NS}	159.51^{NS}
Residue A	8	154.57	477.62
Location (L)	1	48.51^{NS}	1.86 ^{NS}
M x L	2	237.12^{NS}	57.49^{NS}
Residue B	4	356.80	355.18
Depth (D)	3	12933.50*	7677.75*
L x D	3	264.07^{NS}	771.76*
M x D	6	107.82^{NS}	280.29^{NS}
M x L x D	6	238.06^{NS}	143.29^{NS}
Residue C	80	214.48	204.70
Coefficient of variation 1 (%)		34.35	70.87
Coefficient of variation 2 (%)		52.18	61.12
Coefficient of variation 3 (%)		40.46	46.40

^{NS}, * and **, respectively, are non-significant and significant at 5% and 1% of error probability, by the F test. DOF is the Degree of freedom and MS is the mean square.

For the modes of application of phosphate fertilizer, numerically the highest content was obtained when 100% of the fertilizer broadcast was applied, followed by 50% in the furrow and 50% in broadcast, and 100% in the sowing furrow in both collections (Table 1). The initial P content in the 0-20 cm layer was 11.70 mg dm^{-3}, it is observed that there was a significant increase in the P content, which is directly linked to the application of phosphate fertilizer, not being influenced by application modes. According to Paulletti et al. (2017), this initial P content in the soil is interpreted as high (9-12 mg dm^{-3}) for very clayey soils, as is the case with the soil in this study.

Barbosa et al. (2015) observed higher values of the 0-2.5 cm surface layer using spray application of P 100% and 75%. Results obtained by Santos et al. (2008) report that the broadcast application of P helps to improve the P content of the soil, as a result of the saturation of adsorption sites, reducing P deficiency, but no differences were observed between the modes of application in the present work. Therefore, regardless of the phosphate fertilizer application mode, there was an increase in the P content from the studied fertilization management. Resende et al. (2006), verified that a higher P content occurred when the application of phosphate fertilizer was applied to the seed furrow, favoring the diffusion of P and its absorption by the crop. Deith et al. (2005) state that the application of phosphate fertilizer in furrows tends to be more efficient because the concentration of fixed P is higher when applied to the soil.

As for the sample collection sites, row and inter-row, no significant difference was obtained ($p>0.05$) in both collections (Table 1). However, it was observed numerically greater concentration of P in the inter-rows of both collections, this may be linked to greater extraction of P in the sowing row and by both wheat and bean crops. Another factor that may have influenced is the low mobility of P, which applied on the surface limited the development of roots and the search for the nutrient by the crop (BARBOSA et al., 2015), as well as the transport of P in the soil, which occurs preferably by diffusion, influenced mainly by soil colloids and their interaction with P, by the nutrient content in the soil and distance from which it generates barriers to phosphate fertilization (COSTA et al., 2006).

For the depths of collection of soil samples, there was a significant difference ($p<0.05$) (Table 2), after wheat cultivation there was an accumulation of P on the soil surface, in the 0-5 cm layer, higher than all the others too. In the 5-10 cm and 10-15 cm layers, there was no significant difference between them, but they were superior to the 15-20 cm layer. Barbosa et al. (2015), working with phosphorus application modes, observed a greater accumulation of P in the topsoil. This is linked to the low mobility of P in the soil. Silva and Delatorre (2009), in their work, found that P has low mobility in the soil, consequently reducing nutrient uptake by crops, thus decreasing the amount of soil explored by the roots. Momiya et al. (2004) and Pauletti et al. (2009) also obtained as results higher P contents in the topsoil. Costa et al. (2009) used 3 application modes (broadcast, furrow, and in rows on the surface) and also observed a greater accumulation of P on the surface, with the highest concentrations at 0-5 cm.

These results can be attributed to the modes of application of the phosphate fertilizer, since as P is immobile in the soil when applied on the surface or in the seed furrow, this nutrient accumulates at the place of its deposition. Ernani et al. (2001) obtained similar results with a higher concentration of P in the first centimeters of the soil, attributing this to the low mobility of P, being favored by the application of soluble phosphate fertilizers and deposition of phosphate fertilizer on the surface. Nunes et al. (2011) observed that in the 0-5 cm and 5-10 cm layers the P contents come from root residues, broadcast fertilizer application, and the furrowing procedure by fertilizer sowing.

TABLE 2 - Soil P contents as a function of application methods in the depths of a Dystroferric Red Latosol in Toledo.

Depth	After wheat harvest
-------- cm --------	----------- mg dm^{-3} -----------
0-5 cm	65.11 a*
5-10 cm	34.52 b
10-15 cm	29.04 b
15-20 cm	16.11 c

*Means followed by the same lowercase letter do not differ from each other, by Tukey's test, at 5% probability of error.

Corrêa et al. (2004) in a study in Dystrophic Red Latosol, with low P content, obtained an increase in P contents up to 3 cm in depth using a broadcast application, being influenced by the reduction of adsorption in view of the presence of straw and organic acids, the same was observed in the present work, which presented a high straw rate. For the first collection carried out after the cultivation of the wheat crop, the non-differentiation between the values of the collections in rows and inter-rows (Table 3) can be explained due to the reduced spacing used in the seeding of the crop being 17 cm, causing in very close proximity between two rows of cultivation. Kurihara et al. (2016) report that some factors influence the availability of P in the soil, through the addition of phosphate fertilizers, including the spacing used by the crop, due to the greater distribution the smaller the spacing, and the sampling depth.

After bean cultivation, the location x depth interaction was significant ($p<0.05$) (Table 3), with a higher P content inter-rows on the 0-5 cm surface layer, possibly linked to nutrient extraction at the seeding row. Costa et al. (2009) report greater availability of P due to less soil contact with fertilizer when deposited in a furrow, with P uptake by the plant in depth and surface deposition through nutrient cycling, when there is a higher content in the 0-5 cm layer.

Costa et al. (2009) found in their experiment that the increase in P contents inter-rows is linked to the rooting of cultures in P absorption, mainly in the 0-5 cm layer. The application of phosphate fertilizer in furrows can be more efficient because the fixed P content is higher when applied to the soil (DEITH et al., 2005). Regarding the depth of 5-10 cm, there was no difference between row and inter-rows in the collection after the bean plant, one of the factors influencing the availability of P in the soil is the spacing used by the crop, due to the greater distribution the smaller the spacing and depth sampled (KURIHARA et al., 2016).

TABLE 3 - Soil P contents as a function of sampling locations (row and inter-row) and sampling depths of a Dystroferric Red Latosol in Toledo.

Depth	After corn harvest – Location: Rows	After corn harvest – Location: Inter-rows
--------- cm ----------	-------------- mg dm^{-3} --------------	
0-5	67.20 a	63.01 a
5-10	34.65 a	34.39 a
10-15	24.19 a	33.90 a
15-20	16.20 a	16.01a

Depth	After bean harvest – Location: Rows	After bean harvest – Location: Inter-rows
--------- cm ----------	-------------- mg dm^{-3} --------------	
0-5	45.98 aB*	57.49 aA
5-10	28.35 bA	30.59 bA
10-15	35.94 abA	22.85 bcB
15-20	12.57 cA	12.92 cA

*Means followed by the same lowercase letter in the column and uppercase in the row, do not differ by Tukey test, at 5% probability of error.

In the second collection, a greater accumulation of P was observed in the line at a depth of 10-15 cm, this is directly linked to the mode of application used because when the fertilization is carried out in the seed furrow using seeder-fertilizer, it is possible to carry out the deposition of P in greater depth in the seeding line. Motomiya et al. (2004) and Pauletti et al. (2009) observed higher concentrations of P in the depth of 0-20 cm performing the application of P in the seed furrow.

Regarding the depth of 15-20 cm in the collection after the bean plant, the data did not differ, possibly because when fertilization was carried out there was no fertilizer deposition in this layer, also observing lower P values (12.57 and 12.92), in rows and inter-rows, respectively. The higher concentrations of P in the soil surface layer can represent some disadvantages, such as the loss of the nutrient due to erosion (ANDRASKI et al., 2003), they can cause a higher surface concentration of the roots, making the plant more susceptible in periods with water deficit and causing lower nutrient availability in draught (NOVAIS; SMYTH, 1999).

The present work showed that in soils with medium to high P contents, the recommendation for phosphate fertilization can be carried out both in the form of furrows in the planting and broadcast. However, further studies are needed for an assertive recommendation regarding the maximum potential of crop productivity as well as the replacement and non-degradation of P contents, in addition to work carried out in soils where the contents are classified as low or critical, in order to achieve a previous correction to be able to apply P broadcast.

CONCLUSIONS

The phosphate fertilizer application modes did not influence the P contents in the soil.

The highest P contents were obtained at 0-5 cm depth, decreasing along the sampled depths.

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