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The dynamics of phosphorus, potassium and sulphur in the arable layer of the soil as a function of fertilisation[1]

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ABSTRACT - The method of applying fertiliser to the soil affects grain productivity. The aim of this study was to determine the dynamics of phosphorus, potassium and sulphur in the arable layer of the soil during the third year of agricultural production, as a function of the method of application. The study took place in the district of Diamantino, Mato Grosso, in an area of soybean-maize succession under minimum tillage. Five treatments were tested in a randomised block design: no phosphorus or potassium (P0-K0); broadcast phosphorus and in-furrow potassium (Pb-Kf); in-furrow phosphorus and potassium (Pf-Kf); in-furrow phosphorus and broadcast potassium (Pf-Kb); broadcast phosphorus and potassium (Pb-Kb). When the soybeans reached physiological maturity, soil samples were collected from the 0-0.05, 0.05-0.10, 0.10-0.15 and 0.15-0.20 m layers for analysis of the pH, and P, K, S and organic matter content. The soil attributes were submitted to analysis of variance and Tukey's test at 5%, and the nutrient dynamics in the soil profile were analysed by regression. The in-furrow application of phosphorus (Pf-Kb and Pf-Kf) improved P availability in the 0-0.05 m layer by 69.12% and 46.54% compared to the Pb-Kb treatment, by 73.93% and 50.71% compared to the Pb-Kf treatment, and by 136.77% and 105.16% compared to the P0-K0 treatment. The in-furrow application of phosphate fertiliser proved to be more effective in terms of phosphorus availability in the soil. The residual effect of broadcasting phosphate fertiliser on phosphorus availability in the soil can be seen from the third year of production onwards.

Key words: Broadcast fertilisation. In-furrow fertilisation. Cerrado region.

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INTRODUCTION

Among the factors that directly impact grain productivity is the availability of plant nutrients, which is influenced by the type of fertiliser and how it is applied to the soil. This is because nutrients differ in terms of their soil dynamics (MARTINS; CAZETTA; FUKUDA, 2014; SILVA *et al*., 2014), where fertilisation management interferes in the reactions that occur between the soil and the fertiliser and, consequently, in plant nutrition. The aim of this study, therefore, was to combine the operational, agronomic and economic aspects through the use of different methods of fertiliser application (FIORIN; VOGEL; BORTOLOTTO, 2016).

The challenge of combining the above aspects has lead researchers in agricultural sciences to develop studies to evaluate the effectiveness of applying fertilisers to large areas, with the aim of minimising problems regarding the nutritional imbalance of the soil. Prochnow *et al*. (2017) warned that the method of applying sources of P is a controversial issue, which polarises opinions between those who believe in the viability of broadcast fertilisation and those who affirm the need for it to be carried out in-furrow given the low mobility of P in the soil and the possible risks of surface runoff of the nutrient into water courses.

In addition to the method of application, another widely discussed topic is the influence of organic matter on phosphorus availability in the soil. Some authors claim that organic matter plays an essential role in reducing the binding energy of phosphate with the solid phase of the soil due to its potential to lower the maximum phosphate adsorption capacity of the soil, while other research shows that the capacity of organic matter to make available the phosphate adsorbed by the soil is low (BORTOLUZZI *et al*., 2015; FINK *et al*., 2016a, b; HINSINGER *et al*., 2011). From this perspective, there is much to be discussed regarding the soil dynamics of phosphate fertiliser, which indicates research gaps in this area of agronomy.

Another dilemma of the method of fertiliser application was pointed out by Fiorin, Vogel and Bortolotto (2016), i.e. the broadcast or in-furrow application of potassium chloride (KCl). Depending on the method chosen, the possibility exists of not meeting the needs of the crop or of causing damage to the root system of the plants. The same authors emphasised that the method of applying KCl deserves special attention due to its high degree of salinity.

Unlike the discussions concerning the application of phosphate and potassium fertilisers, with sulphur the challenge remains the need to monitor this nutrient in the soil, which is why Rheinheimer *et al.* (2005) cautioned about plant requirements for sulphur, as each species has a different ability for absorbing, translocating and using the nutrient and, as such, requires different levels of available SO_4^{-2} in the soil. Some Plants, such as legumes, only express their genetic potential in terms of productivity and quality when the availability of this nutrient in the soil is high.

Given the impact that the method of fertiliser application can have on soil nutrient availability to plants, and, consequently, on crop productivity, the aim of this study was to evaluate the dynamics of phosphorus, potassium and sulphur in the arable layer of the soil during the third year of agricultural production, as a function of the method of application.

MATERIAL AND METHODS

The study was carried out in an experimental area used for soybean-maize succession under minimum tillage located in the district of Diamantino, Mato Grosso. The area was in its third year of cultivation, with only broadcast fertilisation carried out during the first two crop years, 2011/2012 and 2012/2013. It should be noted that during the 2011/2012 crop year, following deforestation of the area, 2000 kg ha^{-1} of dolomitic limestone was broadcast, with a total relative neutralising power of 90%.

The soil in the experimental area was classified as a Dystrophic Red Oxisol with a very clayey texture (EMBRAPA, 2018). The area is located at an altitude of 410 m, the terrain is characterised as flat, and the original vegetation is Cerrado. According to the Köppen classification, the climate is type Cwa, with a mean annual precipitation of 2030 mm and mean annual temperature of 23.3°C. In an initial characterisation of the experimental area, the chemical and granulometric characteristics of the soil in the 0-0.20 m layer during the 2013/2014 crop year are shown in Table 1.

Table 1 - Chemical and granulometric attributes of the soil in the 0 to 0.20 m layer

$pH(H_2O)^{(1)}$	$P^{(2)}$	$K^{+(3)}$	$S^{(4)}$	$Al^{3+(5)}$	$Ca^{2+(6)}$	$Mg^{2+(7)}$	$H+Al^{(8)}$	$CTC^{(9)}$	$MO^{(10)}$	Areia	Silte	Argila
	----- mg dm^{-3} -----			-------------------- cmol$_c$ dm^{-3} --------------------					g kg^{-1}	------------- % -------------		
5.4	3.9	39.1	11.3	0.08	2.41	2.01	5.27	9.7	28.0	27.0	9.0	64.0

(1). Hydrogen potential; (2). Phosphorus; (3). Potassium; (4). Sulphur; (5). Aluminium; (6). Calcium; (7). Magnesium; (8). Potential acidity; (9). Cation exchange capacity; (10). Organic matter

Table 2 - Description of the different application methods, formulas and quantities of fertiliser used in the different treatments – crop year 2013/2014

Treatment		Dose (kg ha^{-1})	
Method of Application		MAP[1] + SS[2]	KCl[3]
P0-K0	No phosphorus or potassium	0	0
Pb-Kf	Broadcast phosphorus and in-furrow potassium	220	160
Pf-Kf	In-furrow phosphorus and potassium	220	160
Pf-Kb	In-furrow phosphorus and broadcast potassium	220	160
Pb-Kb	Broadcast phosphorus and potassium	220	160

1. Monoammonium phosphate; 2. Single superphosphate and 3. Potassium chloride

Five methods of fertiliser application were tested in an experimental design of randomised blocks. The experiment was divided into five sowing bands, each band equal to one experimental block where the different methods of fertiliser application were carried out (Table 2). Each experimental plot was 3 x 5 m in size, giving a total of 25 experimental units with a total study area of 375 m^2.

The fertiliser used in the experimental area during the 2011/2012, 2012/2013 and 2013/2014 crop years was the equivalent of 90 kg ha^{-1} K_2O and 70 kg ha^{-1} P_2O_5. The sources used were, respectively, potassium chloride and formulated 04-32-00 comprising monoammonium phosphate (MAP) and single superphosphate (SS). In addition to phosphorus (P) and potassium (K), the SS also supplied 8.8 kg ha^{-1} nitrogen (N) and sulphur (S). It should be noted that for the 2011/2012 and 2012/2013 crop years, only broadcast fertilisation was carried out.

For the 2013/2014 harvest, the fertiliser was distributed as per each treatment. When applying in-furrow, the fertiliser was placed parallel to the sowing row at a depth of 0.04 m, while the seeds were placed at a depth of 0.01 m. The furrows were then closed.

The seeds used in the experiment were from the TMG 132 RR soybean cultivar, maturation group 8.5. Sowing was carried out on 26/10/2013 at a density of 311,000 seeds per hectare; the cropping treatments, with the exception of fertilisation management, were common to each experimental treatment. At the physiological maturation of the soybean crop, a working area of 2 m^2 was marked out in each experimental plot, where three soil samples were collected from each of the 0-0.05, 0.05-0.10, 0.10-0.15 and 0.15-0.20 m layers.

The soil samples were submitted to the following analyses: pH in H_2O, P, K and S availability, and organic matter content, as proposed by Sousa and Lobato (2004). The phosphorus and potassium were extracted using the Mehlich-1 method, as per Teixeira *et al*. (2017).

The chemical variables were submitted to the Kolmogorov-Smirnov and Levene tests to verify the normality of the residuals and homogeneity of the variances, respectively; they then underwent analysis of variance, and when significant differences were found, were tested using Tukey's test at 5%. The nutrient dynamics in the soil profile (0-0.05, 0.05-0.10, 0.10-0.15 and 0.15-0.20 m layers) was analysed using analysis of variance and regression.

RESULTS AND DISCUSSION

There was a significant difference between the methods of fertiliser application for the following variables: pH (0-0.05 m layer), phosphorus (0-0.05 and 0.05-0.10 m layers) and sulphur (0-0.05, 0.05-0.10, 0.10-0.15 and 0.15-0.20 m layers). The changes in soil phosphorus (P) and sulphur (S) became more evident, showing the effect of the application method on the availability of these nutrients in the soil, which can have a direct impact on crop productivity (Table 3). According to Reetz Junior (2017), this is because optimising crop production also depends on the application method for each fertiliser.

The reduction in pH in the 0-0.05 m layer was due to the in-furrow application of potassium chloride (KCl) (Table 1), demonstrating how the large amount of chlorine released by the potassium chloride can occupy the exchange sites and group with cations in the soil solution, such as calcium, affording greater mobility and reducing the pH of the soil. According to Gebrim *et al*. (2008), ions such as Cl^- act as accompanying anions and are able to increase the mobility of bases, allowing them to reach greater depths in the soil profile.

Khan, Mulvaney and Ellsworth (2014) also found that the Cl^- ion suppresses the absorption and intensifies the leaching of such nutrients as calcium. Souza, Quaggio and Silva (2006) found that this process is more intense in fertigated systems, as the Cl^- ion released by KCl is responsible for approximately 35% of the cations leached from the soil, resulting in a reduction in pH.

Table 3 - pH, phosphorus, sulphur and potassium levels in the different layers of soil during post-harvest in the 2013/2014 soybean crop

Variable	Treatment	0-0.05 m	0.05-0.10 m	0.10-0.15 m	0.15-0.20 m
	Pb-Kf1	5.6 b	5.3	5.3	5.3
	Pb-Kb2	6.0 a	5.5	5.4	5.3
	Pf-Kf3	5.8 ab	5.5	5.4	5.3
pH (H_2O)	Pf-Kb4	6.0 a	5.5	5.4	5.4
	P0-K05	6.0 a	5.4	5.3	5.3
	F-Test	6.50**	2.39^{ns}	1.16^{ns}	0.54^{ns}
	CV6 (%)	3.88	2.35	1.87	2.38
	Pb-Kf	21.1 ab	11.1b	6.4	3.6
	Pb-Kb	21.7 ab	14.8 ab	9.3	5.7
	Pf-Kf	31.8 a	16.1 ab	9.8	4.5
P (mg dm^{-3})	Pf-Kb	36.7 a	24.1 a	12.2	6.1
	P0-K0	15.5 b	10.0b	6.3	3.7
	F-Teft	5.23**	5.22**	1.63^{ns}	1.25^{ns}
	CV (%)	43.50	46.78	51.79	48.67
	Pb-Kf	9.7 a	12.0 a	13.2 a	15.4 a
	Pb-Kb	7.5 b	8.6 b	9.6 b	10.8 b
	Pf-Kf	7.7 b	8.7 b	9.6 b	10.4 b
S (mg dm^{-3})	Pf-Kb	8.1 b	8.8 b	9.6 b	10.4 b
	P0-K0	8.0 b	8.8 b	9.5 b	10.4 b
	F-Test	11.34**	8.05**	8.20**	11.92**
	CV (%)	11.89	18.29	18.49	20.74
	Pb-Kf	60.0	39.4	32.8	27.4
	Pb-Kb	66.8	33.6	28.8	24.0
	Pf-Kf	73.2	52.2	47.0	41.8
K (mg dm^{-3})	Pf-Kb	80.8	56.0	47.4	40.2
	P0-K0	74.6	40.8	34.6	29.4
	F-Test	0.47^{ns}	2.77^{ns}	2.67^{ns}	2.71^{ns}
	CV (%)	34.79	32.19	34.70	37.64

1. Broadcast phosphorus and in-furrow potassium; 2. Broadcast phosphorus and potassium; 3. In-furrow phosphorus and potassium; 4. In-furrow phosphorus and broadcast potassium; 5. No phosphorus or potassium; 6. Coefficient of variation. Lowercase letters compare treatments using Tukey's test at 5%. **, * significant at 1% and 5% respectively by F-test. ns: not significant

In the stratified analysis of the soil, for the 0-0.05 m layer, treatments with the in-furrow application of P showed greater phosphorus availability compared to the control treatment (P0-K0), however, there was no statistical difference in P availability when the control was compared to the Pb-Kf and Pb-Kb treatments. In this study, when broadcasting the phosphate fertiliser, it was found that even though phosphorus was present and concentrated in the surface centimetres of the soil, it was not available to the plants, which demonstrated the low short-term efficiency of this application method. For this reason, the broadcast method did not differ from the control (P0-K0).

The low efficiency of phosphate fertilisers applied by broadcasting in areas that are in the early years of cultivation was verified in this study, since there is evidence that the P concentration on the soil surface makes it less soluble, which may be directly linked to soil colloids and the fact that the soil has little straw cover. This is because when P is in contact with colloids it becomes susceptible to precipitation reactions with aluminium and iron, and to adsorption on oxides, hydroxides and oxy-hydroxides of iron and aluminium. Guareschi *et al*. (2008) explain that in systems with little vegetation cover, broadcast fertilisation increases contact between the fertiliser and the soil.

Prado, Fernandes and Roque (2001) also found that the in-furrow application of phosphate fertiliser was more efficient than broadcast application. As such, although the adoption of the broadcast application of phosphorus has increased for annual crops, there is some concern due to the low mobility of this nutrient in the soil, and possible losses from precipitation with the Fe^{+3}, Al^{+3} and Mn^{+2} ions, which form insoluble phosphates (CASTRO *et al*., 2016). From this perspective, for the sustainable use of phosphorus, the methods of applying phosphate fertiliser should be improved, as it is a finite and extremely important resource for maintaining global food security (PANTANO *et al*., 2016).

In the 0.05-0.10 m layer of the soil, phosphorus availability under the Pf-Kb treatment differed from the Pb-Kf and P0-k0 treatments only; while Pf-Kf and Pb-Kb did not differ from the other treatments, including the control (P0-K0). This was explained by the fact that for in-furrow application, the fertiliser was placed at a depth of 0.04 m. This underlines how the availability and mobility of phosphorus in the soil is influenced by various factors, and represents one of the greatest challenges to crop fertilisation.

Rheinheimer, Gatiboni and Kaminski (2008) stated that phosphorus dynamics in the soil is affected by several factors, among which are geochemical and biological processes that transform natural phosphates into stable organic and inorganic forms. However, according to Valadão *et al*. (2015), due to the greater contact between fertiliser and soil in broadcast fertilisation, this method of application may require higher doses of fertiliser to obtain the same efficiency as in-furrow fertilisation.

It is worth noting that, for each treatment, the phosphorus content in the 0-0.05, 0.05-0.10 and 0.10-0.15 m layers of soil was classified as high (SOUSA; LOBATO; REIN, 2004). However, on average, the in-furrow application of phosphorus in the Pf-Kb and Pf-Kf treatments increased P availability in the 0-0.05 m layer by 69.12% and 46.54% compared to the Pb-Kb treatment, by 73.93% and 50.71% compared to the Pb-Kf treatment, and by 136.77% and 105.16% compared to the P0-K0 treatment (Table 3). In the 0.05-0.10 m layer, the Pf-Kb and Pf-Kf treatments increased P availability, respectively, by 62.83% and 8.78%, 117.11% and 45.00%, 141.00% and 61.00%compared to Pb-Kb, Pb-ks and P0K0.

Although not significant in any of the layers of soil under study, there was a trend towards an increase in P availability when the phosphate fertiliser was applied in-furrow, which can directly impact crop productivity, a fact defended by Barbosa *et al*. (2015), who showed that the in-furrow application of phosphate results in greater productive efficiency in the plants.

During the 2013/2014 crop year, mean values for P availability of 15.5, 10.0, 6.3 and 3.7 mg dm^{-3} were found in the 0-0.05, 0.05-0.10, 0.10-0.15 and 0.15-0.20 m layers of soil in the experimental plots of treatment P0-K0. However, a mean value of 3.9 mg dm^{-3} was found in the initial characterisation of the soil in the area (Table 1). Therefore, under the control treatment, there were improvements in P availability in the first three layers of soil of 297.43%, 156.41% and 61.54% compared to the P content found in the initial characterisation. Note that no phosphate fertiliser was applied during the 2013/2014 crop year in the P0-K0 treatment, the improvement in P availability being explained by the residual power of the P_2O_5 that was broadcast during the 2011/2012 and 2012/2013 crop years.

Bezerra *et al*. (2014) pointed out that during the first crop season only 5% to 20% of the applied phosphorus is recovered, with up to 70% available for use by successive crops; this depends on the dose, source, granulometry and application method of the phosphate fertiliser, as well as the type of production system. Silva, Aquino and Batista (2011), studying the residual effect of phosphate fertiliser, found that at a dose of 120 kg ha^{-1} P_2O_5, the presence of residual phosphorus in the soil promoted a significant difference in the productivity of sunflower in succession to cotton.

The S content was higher in the Pb-Kf treatment compared to the other treatments (Table 3). There was a greater accumulation of available sulphur from the single superphosphate in the soil when the P_2O_5 source was broadcast and that of K_2O applied in-furrow. The in-furrow application of K only may have significantly increased the availability of S in the soil solution; this can be explained by the fact that K, being fairly mobile in the soil, occupies the negative charges of the soil exchange sites and, as S occurs in the soil in the form of an anion (SO_4^{2-}), it remains free in the soil solution and is easily mobilised in the 0-0.20 m layer.

Considering the proposal of Sousa and Lobato (2004), and despite the difference in sulphur availability between the treatments in each of the layers of soil under study, the nutrient levels were considered high or medium for soybean development. The availability of sulphur in the soil was therefore guaranteed by the broadcast and in-furrow applications.

The different methods of potassium chloride application in the experimental plots promoted no significant changes in K stocks in the different layers of soil, probably as these are the results of only three years of fertiliser application, which may be insufficient to see any differences in the stocks, especially of macronutrients such as potassium, which is very mobile in the soil. However, it should be noted that, in many cases, the broadcast application of potassium fertiliser may not provide the amount of potassium necessary for initial plant development, while a high dose of in-furrow application may result in damage to the root system (FIORIN; VOGEL; BORTOLOTTO, 2016). The application of potassium to the soil should be carefully defined, depending on the soil texture.

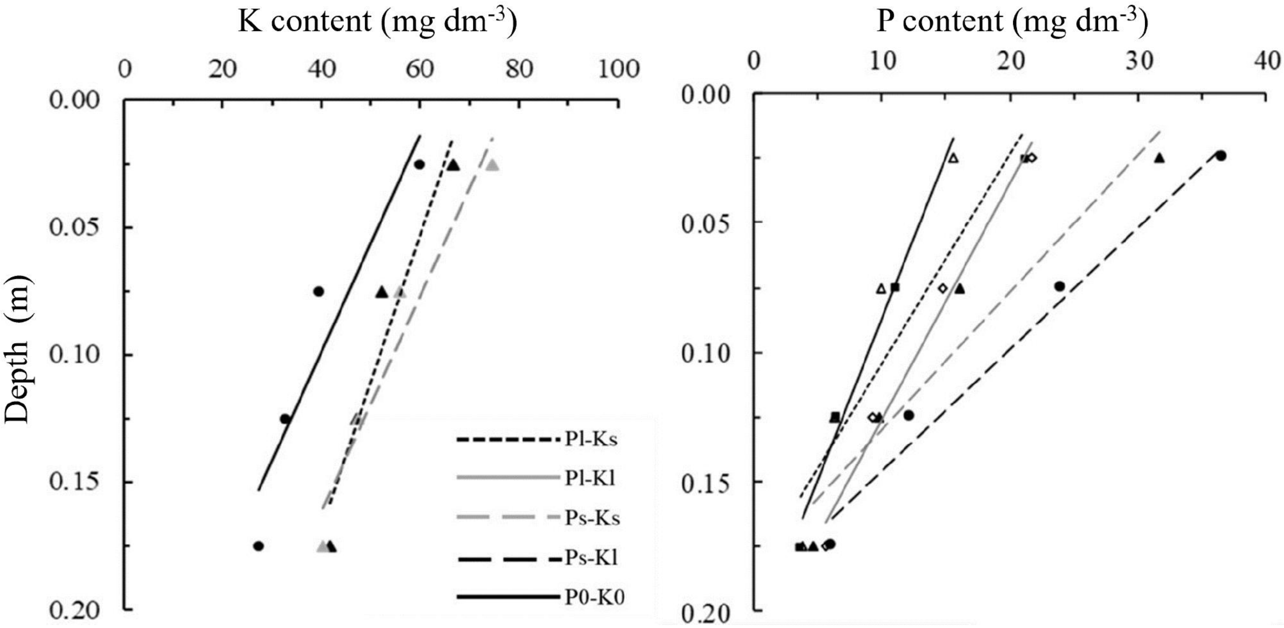
In all of the methods of fertiliser application under study, the coefficients of variation for P and K in the soil were greater than 43.50% and 32.19%, respectively. According to Dalchiavon *et al*. (2011), the variability of an attribute can be classified based on the magnitude of its coefficient of variation (CV), classifying it as very high when greater than 30%. As such, in this study, the coefficients of variation for P and K in the soil were classified as very high, mainly due to the different methods of fertiliser application.

In an area that was managed under a direct planting/minimum tillage system from the 2001/2002 crop year using the same method of fertiliser application and including a succession of soybean/maize and cotton crops, Zonta *et al*. (2014) found coefficients of variation for soil P and K of 39.49% and 12.01%, respectively, i.e. classified as very high and medium. Similarly, the coefficients of variation for P and K found in this study, were considered acceptable.

There was no difference in the mobility dynamics of soil K for the different methods of fertiliser application. As a result, it was not possible to propose mathematical models that described each of the treatments, only Pb-Kf, Pf-Kf and P0-K0 (Figure 1); this was also attributed to the short period of agricultural production in the study area.

With regard to P dynamics in the soil, each treatment showed a trend towards a marked reduction in the nutrient content with depth, regardless of the method of application. The stratified analysis of the soil showed that the in-furrow or broadcast fertilisation of P caused a high P gradient throughout the soil profile, which was more evident when the P was applied in-furrow. This result is associated with the localised application of phosphate fertilisers that predominantly accumulate at depth in the sowing furrow, and remain little changed over the period of cultivation, due to the lack of tillage and the low mobility of P (LEITE *et al*., 2010).

Figure 1 - Potassium and phosphorus dynamics in the 0-0.20 m layer of the soil



Potassium dynamics in the soil	Phosphorus dynamics in the soil
Pl-Ks[1]. Y = -0.0058x + 0.3992. R^2: 0.92.	Pl-Ks. Y = -0.0081x + 0.1854. R^2 0.92.
Pl-Kl[2]: not significant.	Pl-Kl. Y = -0.0092x + 0.2183. R^2: 0.98.
Ps-Ks[3]. Y = -0.0042x + 0.3306. R^2: 0.94.	Ps-Ks. Y = -0.0053x + 0.1819. R^2: 0.93.
Ps-Kl[4]: not significant.	Ps-Kl. Y = -0.0047x + 0.1934. R^2: 0.98.
P0-K0[5]. Y = -0.0043x + 0.2705. R^2: 0.89.	P0-K0. Y = -0.0124x + 0.2107. R^2 0.97.

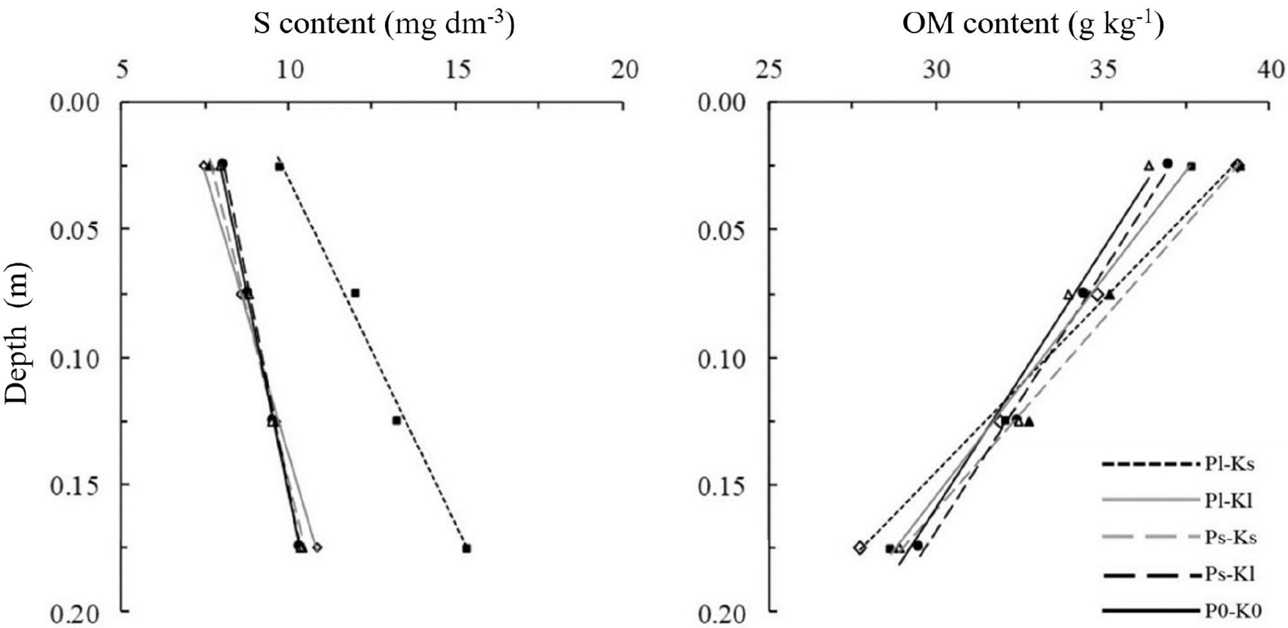
1. Broadcast phosphorus and in-furrow potassium; 2. Broadcast phosphorus and potassium; 3. In-furrow phosphorus and potassium; 4. In-furrow phosphorus and broadcast potassium; 5. No phosphorus or potassium

Phosphorus dynamics in the soil was described by mathematical models for each of the treatments, with R^2 values varying between 0.92 and 0.98, reinforcing the predictability of P availability and adsorption in the soil, even during the third crop year. According to Fink *et al*. (2016a), this is because tropical soils, due to their high levels of iron and aluminium oxides, have a high phosphorus adsorption capacity, which, according to Roy *et al*. (2016), requires the application of frequent, high doses from soluble sources, and results in an increase in P stocks in the soil. This accumulation of P was seen in the 0.20 m layer of soil in the study area, and contributed to the generation of mathematical models that described the dynamics of available P in the third-year soil, with satisfactory values for R^2.

It was possible to model the sulphur dynamics in each of the treatments, with values for R^2 of 0.99 (Figure 2). Unlike the other soil attributes under study, the sulphur content showed increasing dynamics throughout the soil profile, i.e. the deeper the layer, the higher the sulphur content. This is because the application of soluble phosphates reduces the adsorption of SO_4^{2-} and increases its availability in the soil solution, which is the main inorganic form of S, and can be absorbed by plants (ERCOLI *et al*., 2012). However, in this form, it can also easily be lost through leaching (PIAS *et al*., 2019). This explains why greater levels of sulphur were found in the 0.15 to 0.20 m layer compared to the 0-0.05 m layer, and also explains why it is common to find greater levels of this ion in the deeper layers of the soil.

Similar to the phosphorus and potassium, the organic matter dynamics was seen to reduce throughout the soil profile; this is because soil organic matter decreases with increasing depth, which is due to the natural accumulation of plant residue on the soil surface, especially in agricultural areas cultivated under more-conservationist systems, such as minimum tillage. It should be noted that in this study, there was no effect from the organic matter on P dynamics in the soil.

Figure 2 - Sulphur and organic matter dynamics in the 0-0.20 m layer of the soil



Sulphur dynamics in the soil	Organic matter dynamics in the soil
Pl-Ks[1]. Y = 0.027x – 0.2405. R^2: 0.99.	Pl-Ks. Y = -0.0135x + 0.5506. R^2 0.99.
Ps-Kl[2]. Y = 0.0659x – 0.507. R^2: 0.99.	Ps-Kl. Y = -0.0204x + 0.7818. R^2: 0.99.
Ps-Ks[3]. Y = 0.0538x – 0.3902. R^2: 0.99.	Ps-Ks. Y = -0.015x + 0.6101. R^2: 0.99.
Pl-Kl[4]. Y = 0.0448x – 0.3089. R^2: 0.99.	Pl-Kl. Y = -0.017x + 0.6643. R^2: 0.99.
P0-K0[5]. Y = 0.0635x – 0.4826. R^2: 0.99.	P0-K0.Y = -0.0204x + 0.771. R^2 0.97.

1. Broadcast phosphorus and in-furrow potassium; 2. Broadcast phosphorus and potassium; 3. In-furrow phosphorus and potassium; 4. In-furrow phosphorus and broadcast potassium; 5. No phosphorus or potassium

CONCLUSIONS

1. In-furrow phosphate fertilisation proved to be more effective in terms of phosphorus availability in the soil;
2. Broadcast phosphate fertiliser has a residual effect, increasing phosphorus availability in the soil from the third year of cultivation onwards;
3. During the third year of production in soil of a very clayey texture, the method of applying the fertiliser had no effect on the availability of potassium or sulphur.

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