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Phosphorus release from poultry litter to the soil due to the management

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The study aimed to evaluate phosphorus release (P) from poultry litter (composted and uncomposted poultry litter) to the soil under different pH and depth conditions of application in typical Red Distroferric Oxisolin the city of Toledo, western Paraná state. The experiment was conducted under field conditions, in a randomized block design with treatments arranged in a 2x2x3 factorial scheme, consisting of two soil pH adjustments (5.5 and 6.0), two types of poultry litter (composted and uncomposted), and three different application depths (0, 0.05 and 0.10 m), with four replications. Regarding the assessment, P levels were determined from soil samples collected at the time of experiment implementation, followed by three other collections with 15days intervals. The largest P release into the soil at all depths of application and types of poultry litter was observed at pH 6.0 respect of pH 5.5. The application of uncomposted poultry litter onto the surface under pH 6.0 and during 45 days of evaluation released more P 45 days after application, followed by those at depths of 0.05 and 0.10 m. Uncomposted poultry litter was more efficient that composted in providing P, as evaluated by Mehlich-1 extractor.

Key words: Decomposition, organic fertilizer, nutrient availability.

INTRODUCTION

Brazilian agriculture can be considered the major world supplier of food, whether of plant or animal origin and at the same time it has become an important focus of studies and potential supplier of renewable energy. Among the energy recycling forms there is the use of residue from agricultural activities such as poultry litter, which can be used by farmers as a source of nutrients infertilization (Zhang et al., 2002), thus providing an increase of total carbon and organic matter content to the soil (Adeli et al., 2008; Singh et al., 2009), improving the physical, chemical and biological quality of the soil (McGrath et al., 2009) and increasing crop productivity (Sistani etal., 2004).

The use of poultry litter as fertilizer is the most common method and generally the most desirable form of organic fertilizer use as it provides essential nutrients to the plants (Costa et al., 2009). Manure from the intensive farming of chickens and hens fed with food rich in nutrients, especially phosphorus (P), but low in cellulose. That is why, its decomposition is faster, rapidly releasing the nutrients contained therein (Souza and Resende, 2003). Fertilization with poultry litter correctly performed, provides a greater potential yield and it can be used in different cultures and in the recovery of degraded areas due to their chemical, physical and microbiological benefits to the soil (Correa and Miele, 2011).

Poultry litter is considered as an excellent P source for plant, with 24% more P when compared to swine manure, and it has the ability to provide increases extractable phosphorus content with increasing doses (Fioreze and Ceretta, 2006).

P has a fundamental role inplant metabolism, as part of the rich energy compounds (Novais and Smyth, 1999), making it one of the most essential elements for plants survival, being present in the structural components of cells such as nucleic acids and phospholipids of the biomembranes, the second most limiting element to the crops productivity in tropical soils (Taiz and Zeiger, 2013).

However, the availability of most nutrients in the soil is affected by several factors, including soil pH, becoming one of the limiting factors the cultures development (Nachtigall et al., 2009). Brazilian soils are generally acid with low availability of nutrients needed for higher crop yields. Therefore, a practice that is needed is the correction of this acidity creating favorable conditions for the growth and development of plants (Silva, 2010).

With regard to poultry litter management, once removed from the shed it can be applied directly to the soil or temporarily stored in outdoor windrows for composting. Its storage, prior to application to the soil, allows flexibility at the time of application and a consequent synchronization between the liberation of nutrients starting from the needs of the plant, which reduces the risk of environment contamination (Gil et al., 2008). During the storage period, it is possible to perform poultry litter composting, with a combination of organic material, water, and oxygen. Composting reduces the volume and weight of the original organic substrate and in the end, results in a material which is biologically stable, odorless, and useful to fertilization of the soil (Moore Jr. et al., 1995a). On the other hand, a strategy that could improve the availability of P would be its incorporation into the soil, thus favoring the decomposition and minimizing P losses by fixing to colloids (iron and aluminum oxides) from highly weathered tropical soils.

Accordingly, because of the high growth of poultry activity in western Paraná, generating large amounts of organic fertilizer (poultry litter), it could become a way to obtain good-quality organic fertilizer at a reduced cost. However, experimental studies that demonstrate such efficacy of using poultry litter as fertilizer are scarce in the region.

The objective of this study was to evaluate P release from the poultry litter of the soil at different pH conditions and application depths of poultry litter (compost and composted) in typical Red Distroferric Oxisol in the city of Toledo, western Paraná state.

MATERIALS AND METHODS

The experiment was conducted in the Agronomy course's experimental farm, at the Agricultural Sciences and Veterinary Medicine School of the Pontifical Catholic University of Paraná (Pontifícia Universidade Católica do Paraná - PUCPR), Toledo campus-Paraná, situated in the geographical coordinates 24º 43'40 40" S and 53º 46'01 68" W, with an average altitude of 581 m. According to the Köppen climate classification, the climate of the region is humid subtropical mesothermal (Cfa), characterized by hot summers with average temperatures above 22°C, and winters with average temperatures of 18°C or below and an average annual rain fall of from 1600 to 1800 mm (Iapar, 2003). Climatic data on temperature and precipitation for the period of November 27, 2012 to January 28, 2013 were collected daily by the weather station installed in the campus of PUCPR and are presented in Figure 1.

The soil of the experimental unit was classified as typical Red Distroferric Oxisol, a loamy soil, slightly hilly relief (Embrapa, 2006). The experimental area used has become degraded due to the superficial horizon removal, which was used in an embankment and further construction of the administrative block of the university campus, leaving horizon B exposed. Prior to the implementation of the experiment, soil sample collection was carried out at 0– 0.20 m depth for the determination of chemical characteristics, with the following results: pH at $CaCl_2$of5.6, 15.63gdm^{-3}M.O., 8.23mgPdm^{-3}, 3.23; 2.78; 0.30; 0.0;4.54cmol^c dm^{-3}, respectively, Ca^{2+}, Mg^{2+}, K^+, Al^{3+} e H^+ + Al^{3+}; and determination of the granulometric proportion of this soil, presenting 720, 160, and 120g kg^{-1} of clay, silt, and sand, respectively, as the method proposed by Embrapa (1997).

The experimental design adopted was a randomized block in a 2x2x3 factorial scheme, with two pH adjustments (5.5 and 6.0), two types of poultry litter (with and with out composting) and application of the bed in three deep in the soil (0, 0.05, and 0.10 m), with four replications, each portion measuring 3.15 x 5.75 m. The poultry litter used in the experiment was acquired from farm of the region, coming from 14 production batches of broilers. Chemical analyses

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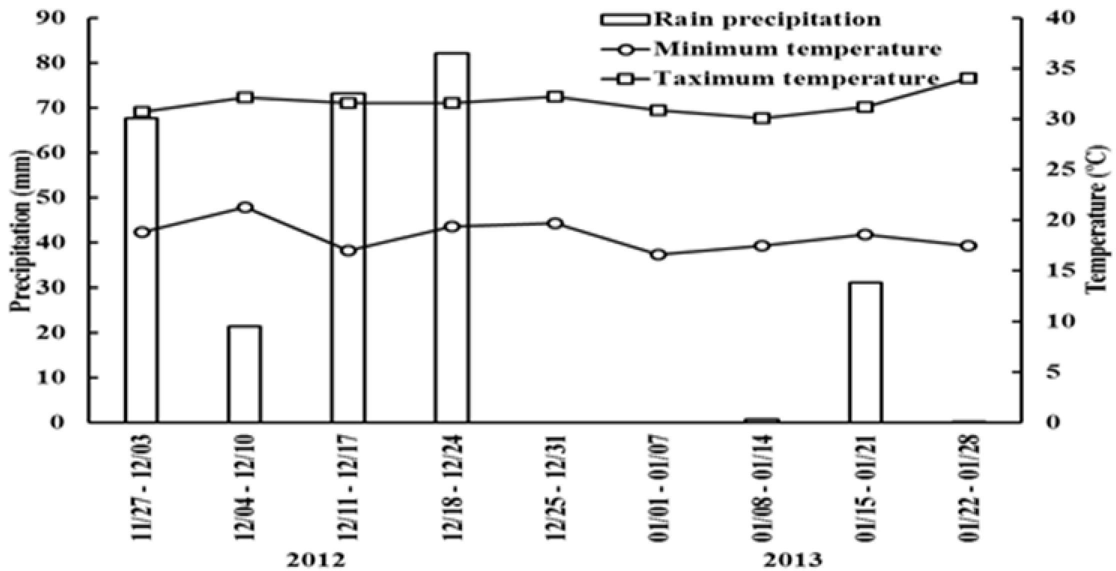

Figure 1. Weekly average rainfall and maximum and minimum temperatures during the period of November 27, 2012 to January 28, 2013.The accumulated rainfall was 276.4 mm. Source: Information collected by the weather station of the Pontifical Catholic University of Paraná, Toledo Campus -PR.

were performed to determine their composition, as shown in Table 1.

With this, it was found that the P content in the compost bed with avian was 14.70 g kg^{-1} at least as compared to avian without composting bed. As for the copper content, zinc, iron, manganese and boron, they were much higher than in poultry manure with compost. This was possibly due to the composting process because addition of the nutrient levels vary depending on the type of material used in the bed, the particle size, batch number, production system (Kiehl, 2010), feed composition, amount of material used in the shed floor covering, season, bird stocking density, the shed ventilation and characteristics of excreta of birds (Aires, 2009; Eghball, 2002) reports that the storage form also influence the levels of nutrients which make up the poultry litter.

The material collected was separated into two parts, the first being intended for the composting process, for a period of 90 days, according to the methodology described by Kiehl (2004), for use in the treatment of composted poultry litter. The other part was stored in a dry place, aiming at preserving their natural characteristics for subsequent use in the treatment of uncomposted poultry litter. As for poultry litter dose, it was applied 10 Mg ha^{-1} based on dry matter. This dose was established in an experiment in a green house, which was efficient for providing nutrients to corn crop.

A calibration curve was performed for pH adjustment, which consists of obtaining neutralization curves of soil acidity by incubation with $CaCO_3$. For this, we used the methodology described by Lana et al. (2010), in which soil samples were incubated with increasing doses of $CaCO_3$ p.a., keeping its humidity near field capacity for a period of approximately 30 days in order to determine the required amount of $CaCO_3$ for increasing the soil pH to the pre-established values.

Every two weeks, samples were collected from the incubated soil for measuring $CaCl_2$pH and SMPpH. After the occurrence of the overall reaction, the relevant data to pH values were subjected to analysis of variance and subsequent polynomial regression analysis using Sisvar software (Ferreira, 2011). By applying the equation: $5.239286+0,001345x-0,0000002x^2$ and $R^2=0.98$, we determined the limestone dosage ($kgha^{-1}$) required to raise soil pH values to 5.5 and 6.0.

Subsequently, in September 2011, application of limestone in each plot was carried out and incorporated into the soil with subsoiler. After a year of application of the calcitic limestone, anew soil sampling at 0–0.20 m depth was made in all plots to check soil pH. The soil samples were sent to the Laboratory of Soil Fertility at PUCPR, dried and sieved for further determination of pH in $CaCl_2$0.01 mol L^{-1} according to the methodology described by Lana et al. (2010). In the results obtained, it was found that both soil pHs were according to the levels desired for developing the present study (soil pH 5.5 and 6.0), thus enabling the conduct of the experiment.

Prior to the application of poultry litter, soil samples were collected for the determination of P content. We collected approximately 0.5kg of soil in each experimental unit, which were packed in plastic bags and sent to cold chamber, where they remained refrigerated (between 4 and 5°C) for several days until the determination of the content of this nutrient.

To perform the application of poultry litter into the soil, we opened grooves aided by a tractor anda seeder, equipped with a furrow opener in seven lines, thus performing the marking of the lines. Further, with a two-rod rake made of wood (spaced 0.45 m between the rods, which were adjusted to depths of 0.05 and 0.10 m),the opening of the grooves in the respective depths was performed manually. After the grooves were opened,the litter was applied as the established treatments, and the groove closure was then made by using a hoe.

Three soil samples collection were performed at intervals of 15 days for evaluation. The first collection was performed before the application Poultry litter into the soil and the others occurred at 15, 30 and 45 days after addition of the bed. In each plot, six sub-samples were collected through a dutch auger, putting them together to form a composite sample and storing the min plastic bags, then stocking in a cold chamber at the PUCPR Veterinary

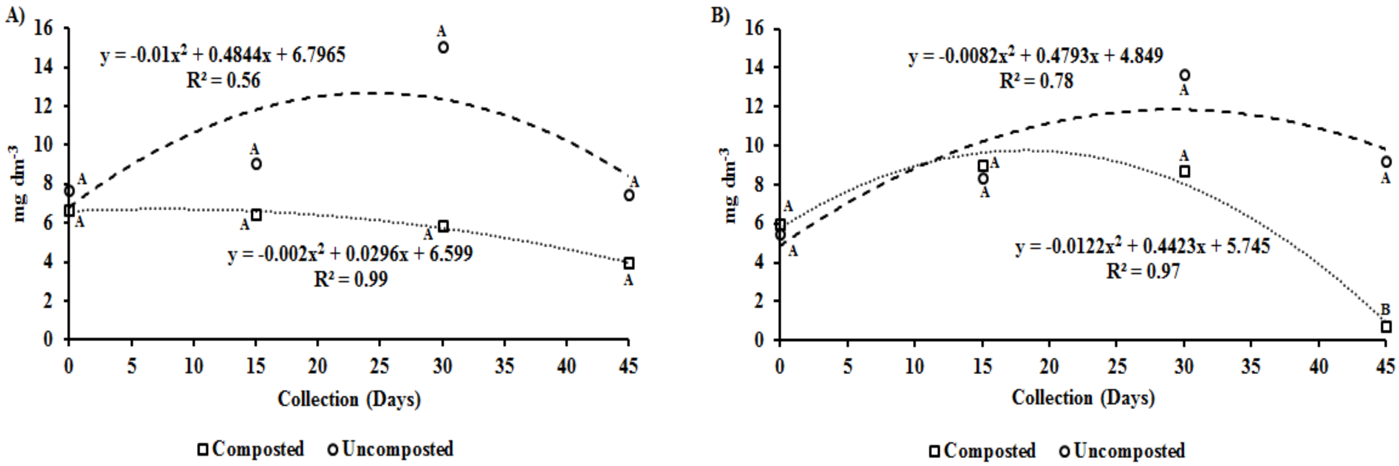

Figure 2. Average results for P availability due to the type of poultry litter (composted and uncomposted) and the number of days in each pH range 5.5 (A) and 6.0 (B) of a typical Red Distroferric Oxisol in the city of Toledo-PR. Averages followed by the same uppercase letter, in the column, do not differ between them by Tukey test at 5% probability.

Hospital. To determine P content, these samples were sent to the Laboratory of Soil Fertility, where drying was carried out, followed by their homogenization through a strainer with a 2 mm mesh. P extraction was conducted by using Mehlich-1 extraction solution, and subsequent determination of P in spectrophotometry was done, according to the methodology described by Lana et al. (2010).

Data obtained were subjected to analysis of variance,and when significant, the averages were compared with a Tukey test at 5 and 10% probability by using the Sisvarstatistical software (Ferreira, 2011).

RESULTS AND DISCUSSION

Analysis of variance revealed significant differences ($p<0.05$) for pH x poultry litter interaction among the soil sample collected, as shown in Figure 2. P levels for pH 5.5 ranged from 3.93 to 15.10 mg dm^{-3}, where as P levels for pH 6.0 were from 0.73 to 13.68 mg dm^{-3}. We can observe that the highest values were obtained for uncomposted poultry litter at pH6.0. Regarding the types of poultry litter (composted and uncomposted) in pH 5.5, there were no significant differences for P release ($p>0.05$) among the samples taken; however, significant responses were found ($p<0.05$) for soil pH 6.0, significant differences were observed in the collection at 45 days.

This is probably due to the fact that immobilization of inorganic P occurred with composted poultry litter, which started at 30 day sand extended, increasing the immobilization until 45 days after application. Alleoni and Melo (2009) found that when the C/P ratio is below 200:1, mineralization predominates, and over 300:1, immobilization predominates. Possibly with composted poultry litter, this balance has not occurred due to the composting process, which has probably reduced the concentration of P in the poultry litter. According Hartz et al. (2000), the decrease in mineralization process of organic compounds over time is related to its C/N ratio. It is initially faster in the compounds of lowest C/N ratio.

Due to this characteristic, a smaller amount of P was released to the soil by composted poultry litter, while the uncomposted poultry litter reached this C/P ratio due to its intense P release to soil at the beginning of the study. It started an inorganic P immobilization process which can be observed in the collection after 45 days from the application of poultry litter. Results similar to these were found in Araujo (2011), which reported finding higher P content available in the soil with the natural organic material, than with the addition of composted organic material, corroborating this study.

With regard to the application of poultry litter at different depths the soil (0, 0.05, and 0.10 m) in pH 5.5 and 6.0, we can see that the collection occurred 45 days after this application showed significant differences ($p<0.10$). The application at 0 m under pH 6.0 resulted in the highest P release to soil, followed by the application at 0.05 m, which was higher than the application at 0.10 m, corresponding to the values of 8.57, 5.72, and 0.60 mg dm^{-3} (Figure 3). However, the application of poultry litter at 0 and at 0.05 m were not statistically different ($p>0.10$) as well as the application of poultry litter at 0.05 and at 0.10 m.

These results indicate that mineral P release in to the soil collected at 45 days was only higher at 0 m compared to the application depth at 0.05 m, possibly due to the mineral P immobilization process in this collection. Such immobilization is also observed in pH 5.5 of the soil, due to the intense release of the mineral P in the previous samples (15 and 30 days) after the application of poultry litter in to the soil. That possibly

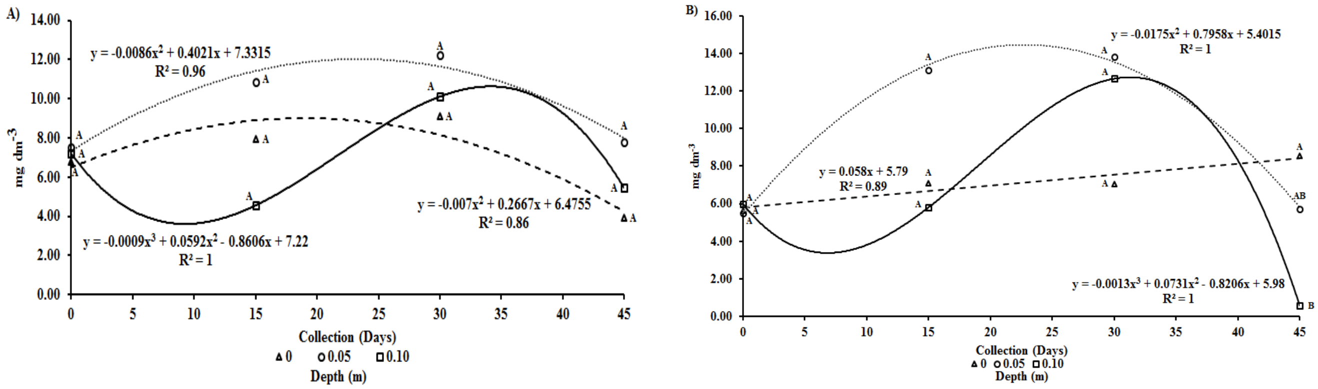

Figure 3. The average results of mineral P available according to the depth of the application of poultry litter (0, 0.05 and 0.10 m) and according to the days of collection at pH 5.5 (A) and 6.0 (B) soil. Averages followed by the same uppercase letter, in the column, do not differ between them by Tukey test at 10% probability.

happened because the condition that each of the depths provided for a higher or lower litter decomposition rate and also for mineralization of organic P released in the decomposition process.

With the application process of the poultry litter at the 0.05 m depth, it is possible that the soil conditions were more favorable for the litter decomposition process and mineralization of organic P, such as those conditions involving temperature, humidity, and oxygenation, since humidity and oxygen are the most limiting factors for organic material decomposition and there for the mineralization of organic P. Table 1 showed that precipitation was very favorable in relation to soil moisture, with heavy rains during the beginning of the study, except during the period 12/25/2012 to 07/01/2013 when there was no rain fall, with its return only after this period. It was also noted that the temperatures were always high, which were favorable to the process of poultry litter decomposition and mineralization of organic P duringall periods of implementation of this work.

However, with the high temperature, moisture reduction occurs on the ground surface, which explains the lower amount of inorganic P at 0 m in relation to litter application at 0.05 m depth. With the deep litter application we also have the location factor because when it is incorporated, its particles are in closer contact to the ground and the microorganisms, which accelerate the decomposition and mineralization processes. The efficiency of the incorporation process was studied by Freitas et al (2006), who found that the incorporation of organic waste decreases the amount of P in the organic residue, thus increasing the amount of P released and mineralized into the soil.

As for the application of poultry litter at the 0.10 m depth, we can see that P release to the ground was higher in the collection performed 30 days after the application for both soil pH levels (5.5 and 6.0). This was possibly due to the lower poultry litter decomposition and organic P mineralization rate in addition to a possible immobilization of inorganic P caused by the elevation of the C/P.

Decomposition and mineralization processes are possibly not very suitable for such depth because they present a very limited amount of oxygen, and this limitation may have been enhanced by the large amount of rainfall that occurred during the study period. This explains the higher P concentration at 0 m than at 0.10 m depth. These results disagree with the study presented by Souto et al. (2005) who found higher decomposition and mineralization rates at depths of 0.10 m. However, Rocha et al. (2005) observed that P availability is in greater quantity on the ground surface (the first 0.05 m) because the climatic conditions favor the decomposition and mineralization processes, besides P being a virtually immobile nutrient in the soil, results that corroborate the results found in the present work.

As noted above in Figure 2, for both soil pH levels(5.5 and 6.0), we can see that the collection 30 days after the application was the one that presented the higher P released into the ground for composted poultry litter, possibly due to P immobilization. Similar availability occurred in Figure 3, where both soil pH levels (5.5 and 6.0) showed the highest P availability level in the soil 30 days after the litter application, where as the only depth which did not have a higher release after 30 days was applying at 0 m in the soil at pH 6.0, possibly because of the P immobilization process caused by its intense initial release. These increases in P level the soil over time were observed and reported by Silva et al. (2011).

Similar results to those of the present study were found by Singh et al. (2009) who found that P release occurred mainly during the first 20 days after hatching, accounting for 15 to 17% of the total P. Similar results were also found by Adami (2012), who studied P release through

Table 1. Results from chemical analyses of the poultry litter (composted and uncomposted) used in the experiment.

Determination	Poultry litter	
	Composted	Uncomposted
Nitrogen (g kg^{-1})	27.90	42.60
Phosphorus (g kg^{-1})	37.70	98.60
Potassium (g kg^{-1})	18.20	42.80
Calcium (g kg^{-1})	76.70	32.40
Magnesium (g kg^{-1})	16.70	10.00
Sulfur (g kg^{-1})	8.60	7.50
Carbon (g kg^{-1})	264.60	410.70
Organic Matter (g kg^{-1})	454.90	706.40
Copper (mg kg^{-1})	240.70	76.28
Zinc (mg kg^{-1})	1,452.00	671.10
Iron (mg kg^{-1})	21,770.00	1,654.00
Manganese (mg kg^{-1})	1,805.00	637.40
Boron (mg kg^{-1})	209.70	73.06
pH ($CaCl_2$ 0,01mol L^{-1})	7.58	8.05
C/N Ratio	9.47	9.65
C/P Ratio	7.02	4.16
Humidity (%)	2.51	6.19

Source: Analyses performed at Laborsolo Analysis Lab.

poultry litter incubation in the field and found that, after 30 days, 23% of P had been released, which corroborates the present work. This is because the release of nutrients in poultry litter is slower, particularly P due to its low mobility, and due to be in organic form, which needs to go through an incorporation and mineralization process by the microorganisms, beyond being P incomplex forming the organic material.

Regarding the type of manure (with and without compost) at each level of soil application (0, 0.05, 0.10 m) in the pH range of 5.5 solo, you can see that there has been no significant difference ($p>0.05$), as well as each type of bed within each level of depth, as shown in Table 2. However, if we look at the range of pH 6.0 soil in Table 3, it can be seen with regarding the type of manure (with and without composting) in each application of the ground level (0, 0.05, 0.10 m) had significant difference ($p<0.05$), in which the collection at 45 days after application of the bed to 0 m, the composting bed showed no release of P exceeding bed composted.

As for the evaluation of each poultry litter type (composted and uncomposted) within each level of depth (0, 0.05 and 0.10 m) at a soil pH of 6.0, we can see that it also showed a significant difference ($p<0.05$), in which the uncomposted poultry litter in the collection performed 45 days after application released more P when applied to soil at 0 m, followed by the application at 0.05 m and lastly by the application at 0.10 m. However, the application of the uncomposted litter at 0 and at 0.05 m, as well as the application at 0.05 and 0.10 m, did not differ statistically. These results can be verified in Table 3. They possibly occurred because of the soil pH.

Regarding the higher mineral P content released by applying at 0 m, this was possibly due to the mineral P immobilization process at the 0.05 m depth of application. Possibly this immobilization was due to the large amount of P released in to the soil, and this release can be seen in the Table 3 on collections related to15 and 30 days after application of the poultry litter into the soil. This large amount released is due to the processing that this depth provides, and also due to the higher soil pH.

With the intense P release to soil, the C/P ratio of the poultry litter rose, which induced the immobilization process of the mineral P, there by reducing the amount of P released in to the soil in the collection at 45 days after the application.The same situation occurred at the 0.10 m depth of litter application, and results were similar to those found by Caires et al. (2003) and Tirloni et al. (2009).

With respect to the soil pH, we can see in Tables 2 and 3 that P release values were higher at pH 6.0 compared to at pH 5.5, which serve as references that the soil pH was possibly the factor that influenced the increased release of P in to the ground collected at 45 days, since both soils under went the same climatic, environmental influences, and the same processes (surface application

Table 2. Average results of mineral P availability due to the type of poultry litter (composted and uncomposted) and depth application(0; 0.05 and 0.10 m) at a soil pH level of 5.5.

Depth (m)	Poultry litter	
	Composted	Uncomposted
	mg dm^{-3}	
	Collection at the application	
0	6.20 Aa	7.40 Aa
0.05	6.55 Aa	8.48 Aa
0.10	7.19 Aa	7.24 Aa
	Collection at 15 DAA	
0	5.00 Aa	10.84 Aa
0.05	8.15 Aa	13.58 Aa
0.10	6.28 Aa	2.84 Aa
	Collection at 30 DAA	
0	6.37 Aa	11.86 Aa
0.05	6.80 Aa	17.62 Aa
0.10	4.40 Aa	15.82 Aa
	Collection at 45 DAA	
0	2.98 Aa	4.84 Aa
0.05	4.60 Aa	11.00 Aa
0.10	4.22 Aa	6.66 Aa

Averages followed by the same uppercase letter, in the column, and lower case letter, in the line, do not differ between them by Tukey test at 5% probability.

Table 3. Average results of mineral P availability due to the poultry litter type (composted and uncomposted) and application depth (0; 0.05 and 0.10 m) at a soil pH level of 6.0.

Depth (m)	Poultry litter	
	Composted	Uncomposted
	mg dm^{-3}	
	Collection at the application	
0	5.60 Aa	5.70 Aa
0.05	5.58 Aa	5.42 Aa
0.10	6.70 Aa	5.26 Aa
	Collection at 15 DAA	
0	5.97 Aa	8.24 Aa
0.05	15.31 Aa	10.91 Aa
0.10	5.68 Aa	5.93 Aa
	Collection at 30 DAA	
0	4.13 Aa	9.97 Aa
0.05	7.40 Aa	20.28 Aa
0.10	14.51 Aa	10.80 Aa
	Collection at 45 DAA	
0	0.77 Ab	16.37 Aa
0.05	1.13 Aa	10.31 ABa
0.10	0.30 Aa	0.91 Ba

Averages followed by the same uppercase letter, in the column, and lower case letter, in the line, do not differ between them by Tukey test at 5% probability.

of uncomposted poultry litter), differing only in their pH levels.

By comparing there sults in Figures (2 and 3) and Tables (2 and 3), we can see that the P released into the soil was higher at pH 6.0 in the composted poultry litter as well as in the uncomposted poultry litter. That is due to the P availability and o their nutrients occurring in the soil pH range of 6.0 to 7.0, which is recommended for most cultures because of the higher release of nutrientes (Lopes and Guilherme, 2000).

In a study, Ernani et al. (2001) reported that soil pH close to neutral (pH 7.0) influenced the application of methods (embedded and superficial), providing for a higher P content availability for plants. These results were similar to those of this study.

The largest increase in the amount of P which was released by the poultry litter was provided at pH 6.0 levels. The rise in pH increases negative charges to the ground and decreases iron and aluminum solubility, thus increasing the amount of available inorganic P for plants. A reduction of this reaction occurs according to the acidification of the soil; that is, as soil pH is reduced. However, pH 5.5 is more acidic, and most P present in the soil is strongly retained in the positive charges of the solid phase and in the form of iron and aluminum phosphate precipitates. Similar results were found by Souza et al. (2006), who observed that when soil pH is close to 4.1, P availability for the plant was very low, but when it got close to 6.5, the release of P for plants was enough to meet their needs, corroborating this study.

Conclusion

The largest P release into the soil at all depths of application and types of poultry litter was observed at pH 6.0 respect of pH 5.5. The application of uncomposted poultry litter onto the surface under pH 6.0 and during 45 days of evaluation released more P 45 days after application, followed by those at depths of 0.05 and 0.10 m. Uncomposted poultry litter was more efficient that Composted in providing P, as evaluated by Mehlich-1 extractor.

Conflict of Interest

The authors have not declared any conflict of interest.

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