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SOILS

Methods and rates of poultry litter fertilization for corn silage in organic system

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ABSTRACT. The creation of proper soil fertility is fundamental to the agroecological transition phase and guarantees the sustainability of organic agribusiness. In a randomized complete block design with a 3 x 2 factorial scheme with 1 additional treatment (control, without organic fertilizer), we tested three poultry litter rates (7, 14, and 21 Mg ha^{-1}) at sowing or splitting between sowing (30%) and side-dressing (70%) for two summer corn whole-plant silage crops and for the soil chemical attributes. The splitting of the poultry litter rate during the rainy season preserves the soil K content, prevents the accumulation of soil P and increases the efficiency of the increasing yields of the organic whole-plant corn silage crop. The reapplication of pre-sowing poultry litter can lead to an accumulation of P and Ca in the soil but favors fresh matter and cob dry matter yields in the dry season. The splitting of the poultry litter rate for whole-plant corn silage can guarantee technical and environmental sustainability in rainy years, but on the other hand, the reapplication of this organic fertilizer only at pre-sowing can increase the fresh matter yield and protein quality of organic whole-plant corn silage cultivated in an Inceptisol in the dry season.

Keywords: organic fertilization; splitting fertilization; *Zea mays*.

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Introduction

The concept of agroecology defined as a political stratagem to meet the conventional technical standards of modern agriculture, is covered with a 'scientific aura' of techniques without scientific support (Navarro, 2013). This concept does not consider that there is an inverse relationship between the capitalization degree of family farmers and the adoption of agroecological practices, that reduce the economic risk of agricultural activity (Assis & Romeiro, 2005). Actually, resource scarcity drives a very deficient agroecological implementation or transition phase and consequently harms the technical, economic, environmental and social sustainability of this agribusiness. Thus, the lack of specific research results, the academic-scientific alienation of many cases and mainly the realistic practices of family farmers, demands technical subsidies for the agroecological construction of soil fertility.

In a transition phase, when the conversion of mineral N from fertilizer to organic sources occurs, a highly demanding crop such as corn requires two or more years to reach maximum yield via the accumulation of mineralized N (Pang & Letey, 2000). In an agroecological system, poultry litter (PL) increased ($p < 0.05$) corn grain yields after two years of repeated applications, and PL stood out in comparison to other commonly used practices, such as the use of biofertilizers, solutions of diluted cow urine, and intercrops of corn with legumes, did not increase corn yields during four consecutive years (Hanisch, Fonseca, & Vogt, 2012). In the organic production of corn in a crop-livestock integration system, Novakowiski, Sandini, Falbo, & Moraes (2013) observed that PL rates with a maximum technical efficiency of 9.0 and 12.0 Mg ha^{-1} corresponded to maximum grain yields of 7,654 and 10,931 Mg ha^{-1}, respectively.

Correlated scientific literature also supports the application of PL for conventional corn cultivation and indirectly for research in the agroecological conversion phase. The results obtained by Sistani et al. (2010) indicated that no-till corn cultivated with 13.5 Mg ha^{-1} year^{-1} of PL for four consecutive years resulted in corn grain yields similar ($p > 0.05$) to corn cultivated with mineral fertilization without causing residual levels of P, Cu, and Zn that could be harmful to surface waters or subsequent crops. Tewolde, Sistani, & Adeli (2013) observed that only 31% of N from an application of 18.0 Mg ha^{-1} of PL in the spring was released in the first year, and when compared with the fall application resulted in average increases ($p < 0.05$) of 14% for ear leaf N concentrations and of 24% for corn grain yields during three years.

Poultry litter is a residue produced in large amounts in small areas in the south of Brazil, and more than 90% of the N from PL is in the organic form that must be mineralized to become available to plants (Rogeri, Ernani, Mantovani, & Lourenço, 2016). However, excessive PL applications may cause soil P accumulation and decrease the P sorption capacity, which promote leaching of the nutrients to subsurface waters (Abdala, Ghosh, Silva, Novais, & Alvarez-Venegas, 2012) and base leaching in the soil profile, probably due to the presence of malic and oxalic acid in organic manure (Gebrim et al., 2008). Furthermore, ammonia (NH_3-N), and greenhouse gases can be released with PL application and can contribute to environmental contamination (Eugene et al., 2015). To prevent P accumulation from organic nutrient sources, it is necessary to use complementary N sources such as N-fixing or N-rich fertilizers to balance P budgets (Maltais-Landry, Scow, Brennan, Torbert, & Vitousek, 2016). Thus, we hypothesize that splitting the application of rates of PL for organic corn silage can improve the agronomic efficiency of organic fertilization, which would prevent the soil P accumulation.

With the aim to technically assist the agroecological implementation and transition phases, our objective was to evaluate the rates and timing of repeated applications of PL on the yield of the organic corn silage and on the chemical attributes of a loamy clay textured Inceptisol.

Material and methods

The experiment was conducted in medium texture Inceptisol at the Agronomic Institute of Paraná (IAPAR) in the Lapa municipality (25° 46' 11" S; 49° 42' 57" W; 908 m above sen level), Paraná State, Brazil. Soil samples were physically characterized (Empresa Brasileira de Pesquisa Agropecuária [Embrapa], 1997) at depths of 0 to 0.2 m presenting, 347 g kg^{-1} clay, 346 g kg^{-1} silt and 307 g kg^{-1} sand. Soil chemical analyses were also performed (Pavan, Bloch, Zempulski, Miyazawa, & Zocoler, 1992) by extracting P and K using the Mehlich1 method, the organic C using the Walkley-Black method, the pH (1:2.5; soil: 0.01 mol L^{-1} $CaCl_2$), Ca and Mg using KCl (1 mol L^{-1}) and H+Al using the SMP buffer solution. In soil layer of 0 to 0.2 m the results were, respectively, 3.6 mg dm^{-3} P, 20.7 g dm^{-3} C, 4.5 pH, 0.12 $cmol_c$ dm^{-3} K, 3.2 $cmol_c$ dm^{-3} Ca, 2.2 $cmol_c$ dm^{-3} Mg, 6.7 $cmol_c$ dm^{-3} of H + Al and 45.2% of base saturation index (V%).

The site has a Cfb climate according to Köppen's Climate Classification, with a humid subtropical climate with a mild summer, rainfall evenly distributed, no dry season and the mean temperature of the warmest month not reaching 22°C. The annual precipitation varies from 1,100 to 2,000 mm. The cumulative rainfall data and average maximum and minimum temperatures during the experimental period between September 2015 and February 2017 are presented monthly in Figure 1.

The experiment was carried out in randomized complete block design with the factorial scheme (3 x 2) + 1. The treatments consisted of three PL rates (7, 14, and 21 Mg ha^{-1}, corresponding to 6.1, 12.2, and 18.3 Mg ha^{-1} on a dry weight basis) and two methods of applying PL [at pre-sowing (PS) and half at pre-sowing and half at side-dressing (PS + SD)] with an additional treatment without organic fertilizing (control). The splitting of the PL rates was characterized by the application of 30 at pre-sowing and 70% at side-dressing (V6 stage). At side-dressing, the organic manure was incorporated into the soil with the aid of a cultivator. The experimental plots were composed of the equivalent dimensions of five rows of corn spaced at 0.8 m between rows, 4 m in length. The chemical analysis (Tedesco, Gianello, Bissani, Bohnen, & Volkweiss, 1995) of the PL (12.9% humidity) revealed (g kg^{-1}): 17.6 of N; 22.1 of P; 31.9 of K; 72.7 of Ca, and 10.0 of mg; and (mg kg^{-1}): 530 of Cu; 817 of Zn; 42 of B and 626 of Mn.

The area was lightly harrowed and received the PL rates at corn pre-sowing according to the treatments, approximately 15 days before corn sowing in September of 2015 and 2016. After corn cultivation in 2016, the soil was prepared with light harrowing and sowing of forage pea (*Pisum sativum* L.) cv. IPR 83 with a sowing density of 50 kg of seeds per hectare. At the end of the cycle, the grains were harvested, and the plants were lightly incorporated into the soil with light harrowing for corn sowing in the 2016/2017 summer season. The respective treatments were reapplied to the same plots in both years after preparing the soil and before sowing corn, variety IPR 164, at an estimated plant population of 87,500 plants ha^{-1}. The phytosanitary treatments consisted of applications of *Bacillus thuringiensis* for the control of *Spodoptera frugiperda* and neem oil at 4% for the control of *Euschistus heros*; both were applied two times each in the two corn crops. The harvests were performed according to the visual criteria cited by Lugão, Bett, Moro, & Lançanova (2011) when the consistency of the grains varied from farinaceous to farinaceous-hard. For the corn silage yield component estimation, seven plants from the two central lines were harvested per plot. The plants were segmented into leaves, stems and cobs, and after, the total fresh corn yield was calculated. The plants samples were weighed, crushed and subsampled for dry matter yield determination after drying in an oven at 65°C with forced air circulation until constant weight. Soil samples were collected in each plot (0 – 20 cm) at the end of the first cultivation of corn silage via the collection of six simple samples per plot, which were sent for chemical analyzes according to the methods described in Pavan, Bloch, Zempulski, Miyazawa, & Zocoler (1992).

The results were submitted to an analysis of variance F test at $p < 0.05$, considering the (3 x 2) + 1 factorial scheme with three replicates. The quantitative factors were deployed in each method of application of the organic fertilizer, at pre-sowing and fractioned at pre-sowing and at side-dressing, through a polynomial regression analysis at 5 and 1% probability. The significant differences ($p < 0.05$) between the methods of PL application at each rate studied were characterized by Tukey's test. Comparisons between the two summer crops with corn silage were performed by means of a joint analysis of experiments, considering seven treatments, three replications and a difference of less than 7:1 between the residual squares of both experiments as a prerequisite (Banzatto & Kronka, 1995).

Results and discussion

The PL rates applied only at pre-sowing (PS) or half at pre-sowing and half at side-dressing (PS + SD) linearly increased the fresh matter yields (FMY) of the aerial part of the corn silage crop in both years (Figure 2). The alterations in the chemical and physical fertility of the soil by PL applications to a low fertility Inceptisol can justify the obtained results. The total concentrations of N, P_2O_5 and K_2O with the maximum PL rate were equivalent to approximately 425, 1,223, and 926 kg ha^{-1} year^{-1}, respectively, far above the inorganic fertilizer recommendations for corn silage in low fertility soil (*Núcleo Estadual Paraná-Sociedade Brasileira de Ciência do Solo* [Nepar-SBCS], 2017). Moreover, ammonium (NH_4^+-N) accumulation occurred on the soil surface due to lower aeration when increasing PL rates were lightly incorporated (Pengthamkeerati, Motavalli, Kremer, & Anderson, 2006), and higher NH_4^+-N nitrification was observed with PL incorporation into the soil in relation to its application to the surface due to the closer contact of the organic fertilizer with soil nitrifying microorganisms (Rogeri, Ernani, Lourenço, Cassol, & Gatiboni, 2015).

The splitting of PL rates resulted in FMY increases ($p < 0.05$) of 88.5% compared to 66.9% obtained with solely pre-sowing rates in the first year (Figure 2a). When the application of 4 Mg ha^{-1} of PL at sowing and the application of this rate divided equally at sowing and at side-dressing were compared, Boateng, Kornahrens, & Zickermann (2007) observed higher ear leaf N with the full rate at sowing but did not observe differences ($p < 0.05$) in biomass or grain yields. In organic production systems, the anticipated application of PL in oat (*Avena strigosa* L.) without sheep grazing preceding the corn crop in the summer resulted in increases of approximately 4,000 kg ha^{-1} (63.5%) in corn grain yields for the highest studied rate, 8 Mg ha^{-1} (Novakowiski et al., 2013).

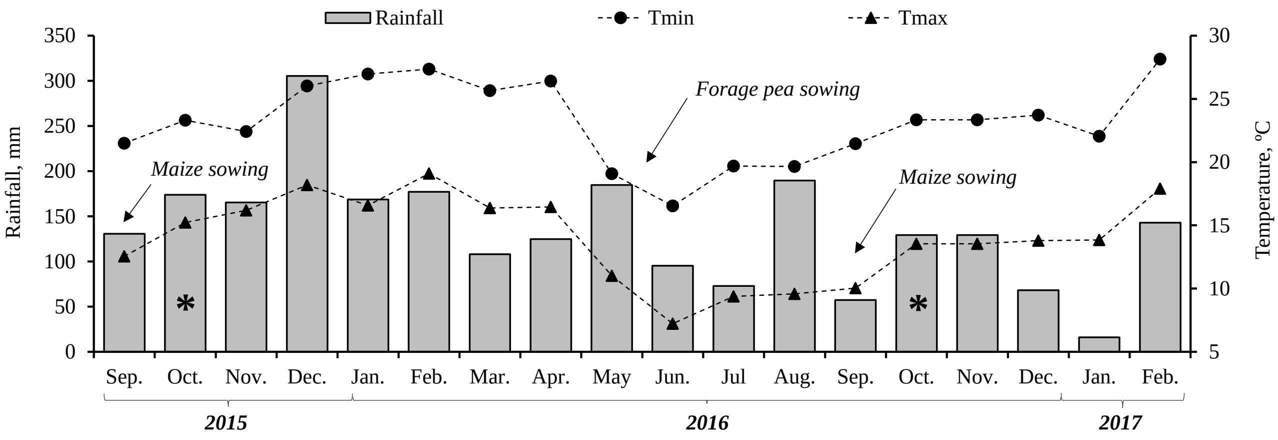

Figure 1. Rainfall and maximum (Tmax) and minimum (Tmin) temperatures during the experimental period. Lapa, Paraná State, Brazil. *PL side-dressing.

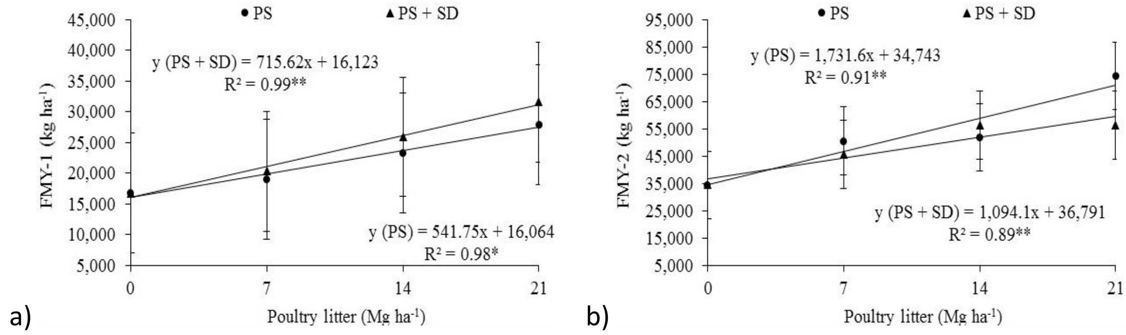

Figure 2. Fresh matter yields (FMY) as a function PL rates at pre-sowing (PS) and half at pre-sowing and half at side-dressing (PS + SD) in 2015-2016 (a) and after reapplication in 2016-2017 to a whole-plant corn silage crop (b). ** and *: Significant at 1 and 5% probability, respectively. Vertical bars indicate the range of minimum significant difference ($p < 0.05$) between application methods for the same PL rate.

When the maximum PL rate was split into 30% at pre-sowing (127 kg ha^{-1}) and 70% at side-dressing (297 kg ha^{-1}), it may have minimized nitrate (NO_3^--N) leaching and provided better N nutrition to the plants, as opposed to the potential damage that may have been caused by the equivalent 425 kg ha^{-1} $year^{-1}$ only at pre-sowing. With one corn crop per year for three consecutive years, an early application of PL in fall resulted in N losses of up to 37% of the total mineralized N mainly due to NO_3^--N leaching; whereas a PL application in spring resulted in N loss up to 72% of the total mineralized N mineralized via denitrification (Feng et al., 2015). The splitting of PL fertilization may have mainly prevented or minimized nutrient losses via leaching and/or laminar erosion because it rained 97.3% (318 mm) more during the first three months after corn sowing in the first period than in the last period of corn silage crop growth (Figure 1). Excessive PL applications can result in N (Feng et al., 2015), P (Abdala et al., 2012) and cation (Gebrim et al., 2008) leaching and environmental problems such as those that can also be caused by inorganic fertilizers.

In the subsequent corn silage crop after reapplication of the treatments, with 97.3% less rainfall than in the previous year especially in the first three months of sowing (Figure 1), the reverse occurred: a 115.7% FMY increase with PL rates solely at pre-sowing *versus* a 63.6% increase with the splitting of PL fertilization (Figure 2b). In the last season, repeated pre-sowing applications of 21 Mg ha^{-1} $year^{-1}$ PL increased FMY to 39,951 kg ha^{-1} compared to FMY with split fertilization (21,958 kg ha^{-1}). Poultry litter amendments until a rate of 21 Mg ha^{-1} $year^{-1}$ may have also resulted in better soil physical conditions in a period with less water availability, as observed in the second crop of whole-plant corn silage (Figure 1). The cumulative effects of PL application at pre-sowing were also observed only in the second year by Feng et al. (2015), in which the N content of the diagnostic leaf and the grain yields were similar ($p < 0.05$) for the mineral fertilization treatments. Light harrowing with PL rates of 18.7 Mg ha^{-1} and with PL incorporation up to a maximum of 0.15 m of soil depth did not affect soil total porosity, macroporosity, mesoporosity, microporosity or bulk density (Pengthamkeerati et al., 2006). On the other hand, the results obtained in an analogous Inceptisol indicated that intensive incorporation of PL with a rototiller resulted in superficial crusting and sealing in the dry season, caused, in turn, by clay dispersion with the PL application in the rainy season (Thierfelder, Amezquita, & Stahr, 2005).

This result is also probably related to the forage pea cultivation in the winter between the two corn silage crops, which may have potentially affected the organic fertilization with poultry litter. Unfortunately, it was not possible to measure the possible residual effects of the rates of PL applied in both methods on the winter legume yields, which were only 135 kg ha^{-1} of grains. Nevertheless, the effect of forage pea could also explain the yields of the control treatment. The FMY of the control treatment without PL fertilization was 17,779 (106.1%) Mg ha^{-1} higher ($p < 0.05$) in the last year of the corn silage crop than that of the first year. The approximately 34,500 kg ha^{-1} FMY for the control treatment in the second year was above the highest FMY observed with the highest PL rate in the first year regardless of the application method (29,769 kg ha^{-1} on average). In conditions of high soil fertility and with forage pea adaptation to the climatic conditions of the winter in the State of Parana, Brazil, this legume can accumulate up to 209 kg ha^{-1} of N and contribute up to 84 kg ha^{-1} of N to the soil in the first two weeks (Viola et al., 2013). Thus, the substantial increases up to approximately 40,000 (115.7%) and 22,000 kg ha^{-1} (63.6%) FMY with 21 Mg ha^{-1} of PL at corn pre-sowing and with half at pre-sowing and half at side-dressing, respectively, suggest a synergistic effect between the green manure and the reapplication of the organic fertilizer incorporated into the soil.

Therefore, the use of combined techniques, organic and green fertilizers, promotes the agroecological construction of a fertile Inceptisol. The incorporation of pelleted PL into the soil with hairy vetch (*Vicia villosa* Roth) or hairy vetch with cereal rye (*Secale cereale* L.) residues provided higher rates of decomposed organic fertilizer and higher delivery of N to the subsequent plants in relation to those from the incorporation of organic fertilizer with grass residues only (Poffenbarger et al., 2015). In contrast, the DMY and the N inputs of the forage pea may have been consistent with the residual effect of the rates and methods of PL despite the withdrawal of large amounts of nutrients by the whole-plant corn silage crop. The synergistic effect between the use of PL and forage pea was confirmed by means of an eventual improvement in protein quality of the whole-plant corn silage. For the corn silage plant segments, the DMY of the cob was 1,590 kg ha^{-1} (31.2%) higher ($p < 0.05$) with 21 mg ha^{-1} of PL at pre-sowing than that at the split rate (Figure 3f).

The dry matter yield (DMY) of the leaves, stems and cobs linearly increased with the PL rate in both fertilization methods and in both seasons (Figure 3). There were no differences ($p < 0.05$) between the methods of application in each rate of PL for the DMY of the leaves, stems and cobs in the first season of the corn silage crop. These parameters increased on average to 650 (70.5%), 2,211 (108.7%), and 1,159 (60.5%), respectively, with 21 Mg ha^{-1} PL in relation to those of the control (Figures 3a, c and e). The leaf DMY in the second season also did not show a difference for the method of application of the PL rates, but it did have an average linear increase of 1.576 kg ha^{-1} (79.8%) with the highest rate, which was 78.3% higher than the leaf DMY in the first season. This result emphasize the synergistic effect observed between animal and green manures. In the second season, with the reapplication of the treatments, the 86.5% (3,097 kg ha^{-1}) increase in cob DMY with 21 Mg ha^{-1} at pre-sowing was higher ($p < 0.05$) than the 42.1% (1,507 kg ha^{-1}) increase in cob DMY with the same PL but split at pre-sowing and side-dressing (Figure 3f). A possible increase in the protein quality of whole-plant corn silage was observed with the reapplication of 21 Mg ha^{-1} at corn pre-sowing, but it was counterbalanced by the higher ($p < 0.05$) stem DMY (1,127 Mg ha^{-1}; 32.5%) from the splitting of the organic fertilization (Figure 3d).

The soil samples collected before the second corn silage crop showed few variations in chemical attributes (Figure 4), probably due to the short time between treatment application and soil sampling. The PL rates did not influence the levels of organic P (Figure 4a), organic C (Figure 4b) and Mg (Figure 4e) for either method of organic fertilization. After 14 years of annual PL application to corn and soybean crops in a Typic Hapludult, there were effects ($p < 0.05$) of organic fertilization on P, K, Ca, Mg, organic C, CEC, and mineralizable C and N (Watts, Torbert, Prior, & Huluka, 2010).

In the present study, however, there was a quadratic effect ($R^2 = 0.95^*$) of the splitting of the PL rate for pH ($CaCl_2$) values (Figure 4c) and a linear increase in the Ca ($R^2 = 0.57^*$; Figure 4d) and K ($R^2 = 0.83^*$; Figure 4f)) content with the PL rate solely at pre-sowing and at both pre-sowing and side-dressing, respectively. The pH ($CaCl_2$) values increased (only 0.4 units) up to the rate of 10.2 Mg ha^{-1}, reaching 5.5; whereas in the highest split PL rate, the value decreased to 5.1, lower ($p < 0.05$) than that of the same PL rate solely at pre-sowing (Figure 4c). The increase in the pH with PL application can occur through the release of hydroxyls (OH^-), with ligand exchange reactions by the organic anions in Fe and Al oxides and with the reduction of Fe and Mn oxides via the electron rich environment provided by the PL application (Hue, 1992). On other hand, both with larger rates of PL and with any rate of PL solely at pre-sowing, the NH_4^+-N nitrification process may have generated protons that mitigate the acidity of the soil.

The linear increase in K levels only in the treatment with the split application of PL rates may be another indication that there were fewer nutrients lost with this fertilization method in the rainy year (Figure 4f). While the K contents increased by 47.0% with the PL application at side-dressing, the K contents from the treatment with pre-sowing PL did not increase with the incorporation of up to 926 kg ha^{-1} of K_2O, which suggests that, in addition to N, there were substantial losses of K. N losses due to NO_3^--N leaching can occur because of the high rates of NH_4^+-N accumulation (Pengthamkeerati et al., 2006) and nitrification (Rogeri et al., 2015) with slight PL incorporation. PL can favor the release of Ca, Mg, K, and Na to deeper soil layers, particularly via the contribution of basic cations by the organic fertilizer itself and the effect of the combination of organic and inorganic anions, especially NO_3^--N (Gebrim et al., 2008). With the supposed losses of K via leaching for the treatment with PL incorporation, there may have been conditions that increased the Ca content for this treatment (Figure 4d). This did not occur with the split application of PL due to absorption by the corn plants that responded better to organic fertilization in the rainy year (Figure 2a).

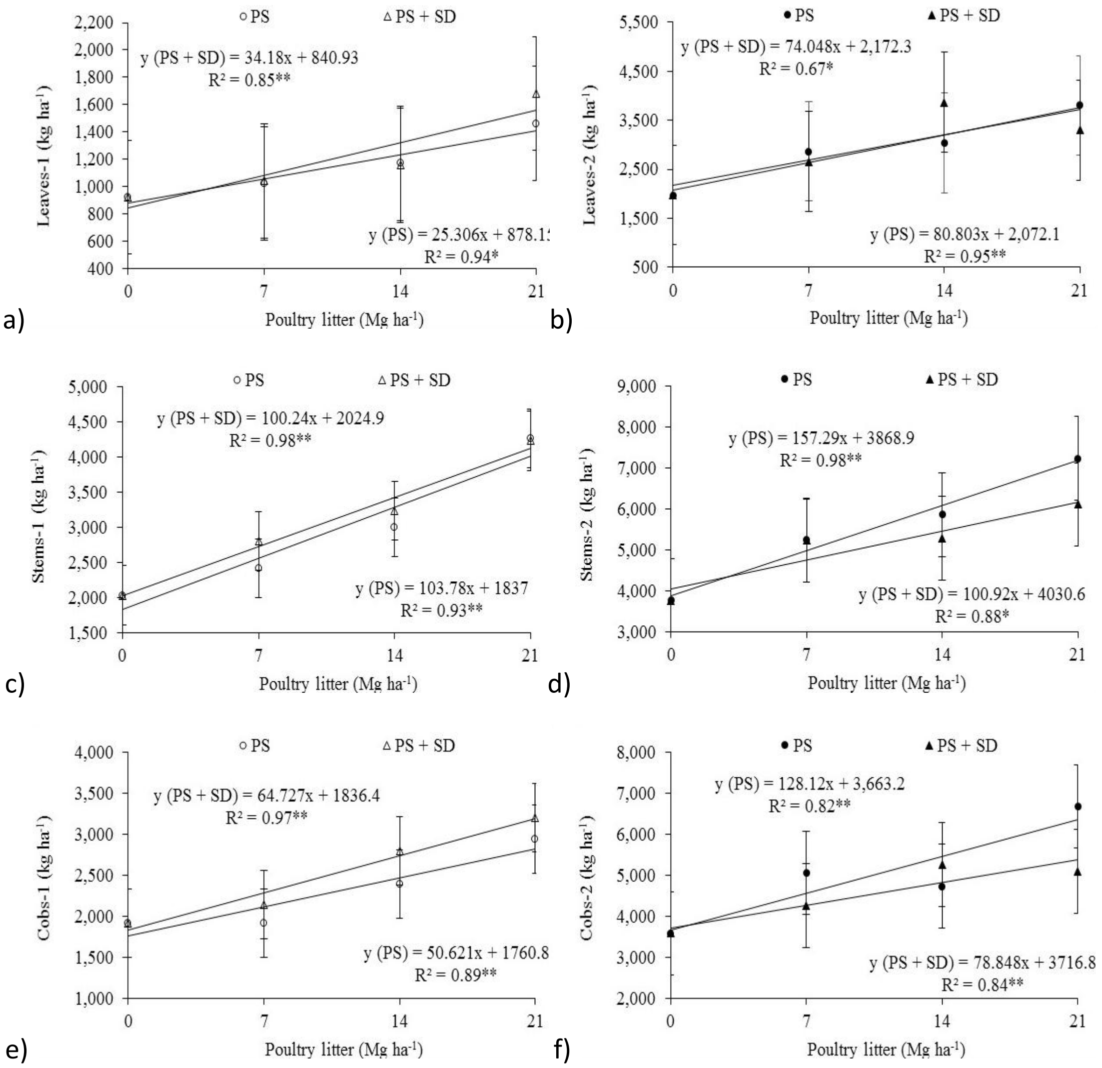

Figure 3. Dry matter yields of the leaves (LDM), stems (SDM) and cobs (CDM) as a function of PL rates at pre-sowing (PS) and half at pre-sowing and half at side-dressing (PS + SD) in 2015-2016 (a, c, e) and after reapplication in 2016-2017 to a summer corn silage crop (b, d, f). **, * and NS: Significant at 1 and 5% probability and nonsignificant, respectively. Vertical bars indicate the range of the minimum significant difference ($P < 0.05$) between application methods of the same PL rate.

There was no interaction ($p > 0.05$) between rates and method of PL application for the soil P contents, and there was not any effect of PL rate independent of the application method (Figure 4a). However, there was an isolated effect of the application method independent of the PL rate where the splitting of the PL rate resulted in 34.5% ($p < 0.05$) less P than the PL rates applied only at pre-sowing (Figure 5). The accumulation of P with the pre-sowing PL application (Figure 5) is in agreement with the increase in the Ca content for the same treatment (Figure 2d), since stable complexes between Ca and P can be formed in the soil exchange complex. In soils fertilized with PL, the formation of Ca-P complexes increases the P sorption maxima and binding energies, making the bioavailability of P runoff lower than when applying inorganic P fertilizers (Robinson & Sharpley, 1996).

The higher level of P with the pre-sowing PL application are consistent with the larger increases in FMY with the splitting of the PL rate at pre-sowing and side-dressing than that with only the pre-sowing rate (Figure 2b), which probably demanded a higher uptake of P by the plants. In contrast, the results obtained in the second corn silage crop, in which there were higher yields ($p < 0.05$) of FMY with the pre-sowing rate in relation to the treatment with the splitting of the PL rate (Figure 2b), suggest that the lower level of P in this treatment (Figure 5) are due to the higher yields that also demanded more nutrients. The organic nutrient sources are unbalanced, and small N:P ratios result in the accumulation of P in the soil, suggesting the need for complementary sources of N, such as green manures and N-rich fertilizers, to balance soil P budgets (Maltais-Landry et al., 2016). Considering the results obtained, it can also be added that, with a possible increase in the efficiency of the split PL fertilization, there was an increase in the N:P ratio that reduced the accumulation of P for this treatment in comparison to the fertilization with PL only at corn pre-sowing (Figure 5).

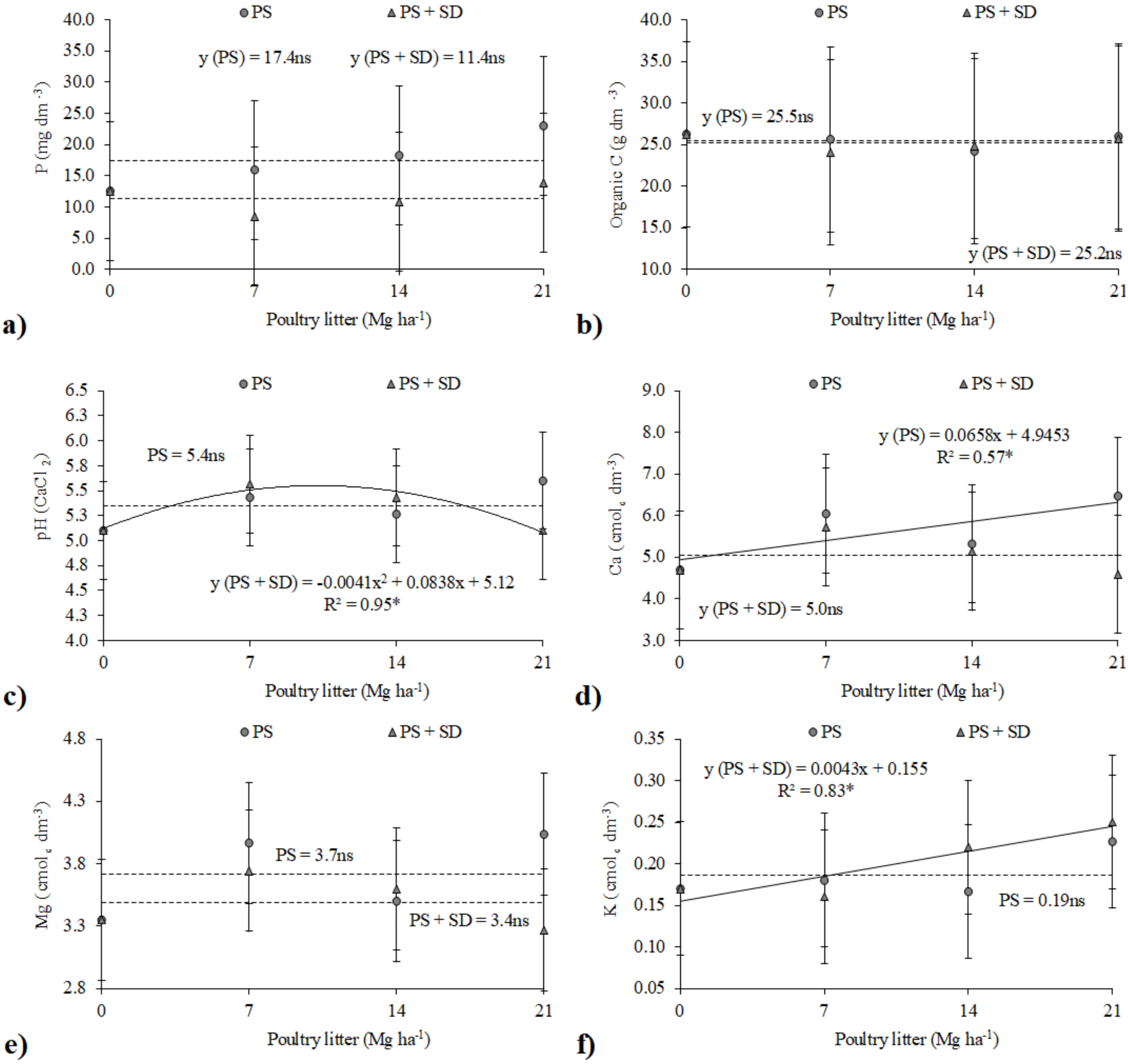

Figure 4. Phosphorus-P (a), organic C (b), pH ($CaCl_2$) (c), calcium-Ca (d), magnesium-Mg (e) and potassium-K (f) as a function PL rate at pre-sowing (PS) and half at pre-sowing and half at side-dressing (PS + SD). **, * and NS: Significant at 1 and 5% probability and nonsignificant, respectively. Vertical bars indicate the range of the minimum significant difference ($P < 0.05$) between application methods of the same PL rate and in interactions ($P < 0.05$).

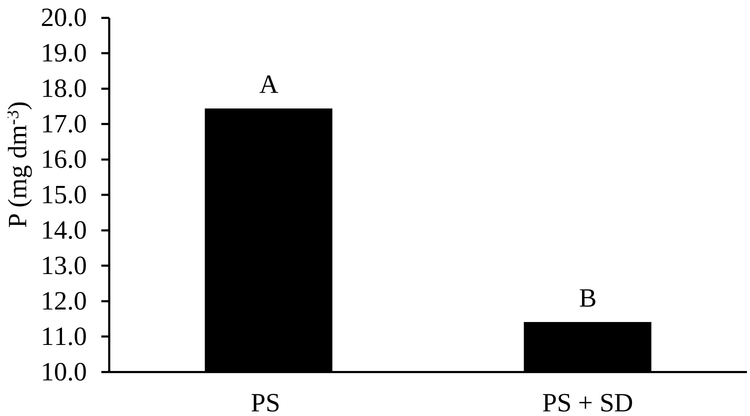

Figure 5. Average levels of soil P as a function PL rate at pre-sowing (PS) and half at pre-sowing and half at side-dressing (PS + SD). Different letters indicate significant differences ($P < 0.05$) between application methods.

Conclusion

The splitting of the poultry litter rate during the rainy season preserves the soil K content, prevents the accumulation of soil P and increases the efficiency of the increasing yields of the organic whole-plant corn silage crop. Reapplication of pre-sowing poultry litter can lead to accumulations of P and Ca in the soil but favors fresh matter and cob dry matter yields in the dry season. The splitting of the poultry litter rate for the whole-plant corn silage crop can guarantee technical and environmental sustainability in rainy years, but on the other hand, reapplication of this organic fertilizer only at pre-sowing can increase fresh matter yields and protein quality of organic whole-plant corn silage cultivated in an Inceptisol in the dry season.

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