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Full Length Research Paper

Soil nitrate, phosphorus and potassium concentration after four years of liquid swine manure application on Tifton 85

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One major problem of swine production is the huge volume of manure generated; this involve difficulties in proper handling of the residue when applied to the soil, given that such elements can be toxic to the environment. This study examined the vertical movement of the P, K and mineral N in the soil profile cultivated with *Cynodon dactylon* cv. Tifton 85 which was submitted consecutively to rates of Liquid Swine Manure (LSM) application (four years). The experiment was done using a randomized block design with four replications in a split-plot arrangement, where the whole plots were semiannual applications (November, 2002 to September, 2006) of increasing levels of LSM (0, 30, 60, 90, 120 and 180 m^3 ha^{-1}); while the sub-plots were the soil samples at different depths (0-10, 10-20, 20-40, and 40-60 cm). The N-NO_3^- leaching was observed when application of LSM exceeded 90 m^3 ha^{-1} twice annually or during the year, suggesting a limit level for fertilizer on Tifton 85 pastures. Phosphorous and potassium accumulation was observed at higher LSM rate, mainly at the 0-10 cm soil layer since the soil P levels increased up to the highest evaluated depth at the 180 m^3 ha^{-1} LSM level. LSM meets the Tifton 85 nutritional requirement regarding N, P and K when applied semi-annually at the rate of 90 m^3 ha^{-1} without causing pollution effects; although the grass production responds up to 180 m^3 ha^{-1} levels.

Key words: *Cynodon dactylon*, environmental contamination, mineral nitrogen, organic fertilizers.

INTRODUCTION

Swine production is an important part of the Brazilian agribusiness that consuming large quantities of grains and water, with daily water consumption of 9.05 to 22.05 L^{-1} pig^{-1} (Nardi, 2009). Consequently, this activity produces large quantities of residue, since each liter of ingested water generates 0.6 L^{-1} of liquid swine manure (Oliveira, 1993); often times, distributed in small areas. Majority of swine growers in the country are smallholders (Mohedano et al., 2014). It is important to determine the Liquid Swine Manure (LSM) effect as a soil pollutant under different crops in order to illustrate the rates its use would be acceptable long term (Scherer et al., 2010; Maccari et al., 2016).

LSM is a nutrient and organic matter source for

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cultivated soils, and lots of plant production systems can benefit from the agriculture cycling of swine manure (Couto et al., 2013). Its usage in pastureland, if conducted properly, can contribute to the system's sustainability, given that it is capable of increasing production and quality of pastures (Vielmo et al., 2011). In addition, lack of fertilization is one of the major factors contributing to the degradation of pasture land in Brazil and the LMS applications can remediate this kind of degradation.

A significant amount of the macro and micronutrients ingested by the swine are excreted in dung and urine (Berenguer et al., 2008). If the organic fertilization is cautious, it can replace chemical fertilization of crops in part or whole (Ourives et al., 2010). However, when used irrationally, disregarding soil-support capability with no application rate limits, the LSM can become a great source of pollution for water springs (Domene et al., 2007).

Approximately 70% of the N present in the LSM stocked in dunghills is in ammoniacal form (Scherer et al., 1996). When applied to the soil, it is oxidized to nitrate by nitrifying bacteria (Whitehead, 1995) in a relatively fast pace (Aita et al., 2006). Therefore, highly productive pastures like Tifton 85 can exhibit higher utilization rates of the mineral N present in the soil arising from the LSM application. Aita et al. (2006) observed higher mineral N in soils under fallow compared to soils cultivated with black oats under the 80 m^3 ha^{-1} of LSM rate. This behavior can be maximized by the use of perennial pastures like the *Cynodon* ones.

Nevertheless, the swine manure application can be a possible source of soils and water contamination through nitrate (NO_3^-) (Puig et al., 2017). This can result from excessive fertilizer application in the soil, independent of the fertilizer type, which can be dangerous to both human and animal health (Robertson, 2005; Bryan et al., 2012). Various studies show N mobility to have higher depths when cultivated with annual crops (Ceretta et al., 2010). Such mobility can vary for soils under perennial forage species given their root system structure, greater cultivation period, and pasture utilization.

Besides N, elements that are deeply required by the cultures like phosphorus and potassium are added to the soil when the LSM is applied and are absorbed by the plants when available (Ceretta et al., 2010) or can be lost by leaching, primarily P, which is the main element associated with eutrophication problems (Sharpley et al., 2001; Gatiboni et al., 2015).

Therefore, knowledge on N, P and K behavior in the soil profile under different rates and constant application of LSM is important to support the use of this organic fertilizer in pastures to ensure there is no environmental contamination. The research aim to evaluate the vertical movement of nitrate and ammonium as well as the P and K behavior in a soil cultivated with perennial summer grass (*Cynodon dactylon* cv. Tifton 85) under a semiannual application. This was done within four years of increasing rates of LSM and the forage production response of the pasture.

MATERIALS AND METHODS

Study area

The research was conducted from November 2002 to September 2006, in an area located at 26° 07' S and 52° 41' W , at 700 m a.s.l, under a climatic condition that transits from Cfb (temperate climate) to Cfa (subtropical climate), according to the Köppen climate classification (Maak, 1968). The precipitation regime in the past 10 years was on an average of 2000 mm. The soil is classified as a Dystrophic Red Oxisol (Ferritic Ferralsols, according to classification World Reference Base for Soil Resources, WRB, 2014). The soil is on a hilly topography with a clay texture and under a 10 year no-tillage planting system.

Sampling and experiment designs

Sprigs of *Cynodon* sp cv. Tifton 85 were planted in November 2002. The first LSM application was in March 2003, when the pasture was established and subsequent applications happened semi-annually; totaling six LSM applications with rates of 0, 30, 60, 90, 120 and 180 m^3 $ha^{-1.}$

The experimental design was in a randomized block with four repetitions in a split-plot. The treatments consisted of increasing LSM rates (0, 30, 60, 90, 120 and 180 m^3 ha^{-1}) for the whole plots and the sampling depths as the sub-plots. In September 2006, soil samples were collected at different depths of (0-10, 10-20, 20-40, and 40-60 cm) to evaluate the N-NO_3^-, N-NH_4^+, P and K concentrations. In 2004, P and K concentrations were evaluated under the same depths. Soil samples were collected at eight different sites per plot, which were later dried at 55°C for 72 h, and the N-NO_3^- and N-NH_4^+ concentrations were determined through the method described by Pavan and Miyazawa (1996). The K and P contents were extracted by the double acid method Melich-1, and later flame photometer, and the P determined the K by atomic absorption spectrophotometry.

The dry matter production of Tifton 85 evaluation started in November 2003 when the plant canopy in each plot was 30 cm high on average. Samples were cut to a 10 cm stubble, from a 0.25 m^2. Four subsamples were taken in each plot, and mixed to represent one plot sample, which were dried at 55°C in a forced-air oven to constant weight. Forage production was calculated (kg ha^{-1} de MS) annually (from January to December of each year). Winter cuts were not performed due to minimal plant growth.

Statistical analysis

An analysis of variance multifactorial was conducted. The variables considered homogeneous had their treatments evaluated with the F-test. When the results were significant at 5%, polynomial regressions were fitted for LSM rates, versus N-NO_3^-, N-NH_4^+, phosphorus and potassium concentration, for different depths, seeking the model with higher significance level.

RESULTS AND DISCUSSION

The interaction between LSM rates and sample depth

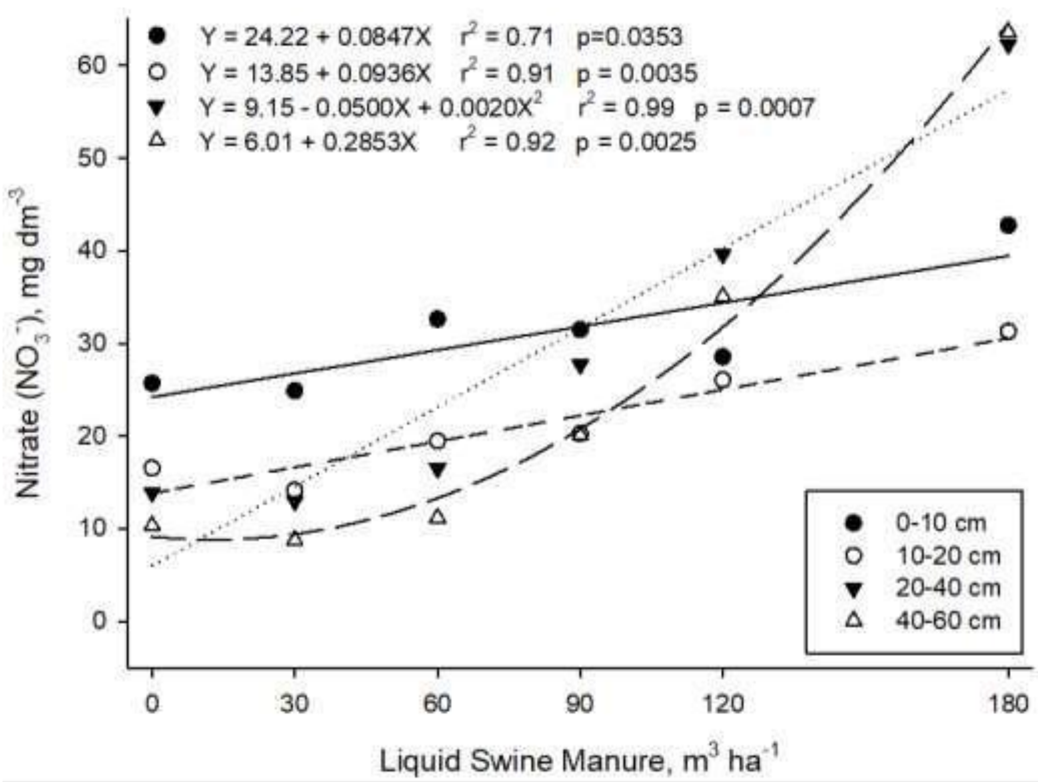

Figure 1. Soil nitrate concentration at different depths as a function of Liquid Swine Manure application rates.

(Figure 1) was observed for N-NO_3^- soil concentration. After 46 months of the experiment establishment and six semiannual LSM applications according to stated rates, the highest N-NO_3^- concentrations were observed in the topsoil layer (0-10 cm) using LSM application of 90 m³ ha^{-1}. For higher rates, N-NO_3^- accumulation was observed for layers from 20 to 60 cm depth, which indicates N-NO_3^- leaching potential for LSM applications from 90 to 180 m³ ha^{-1} (Figure 1). Therefore, these rates of LSM are not recommended for areas under *C. dactylon* cv. Tifton 85 cultivation.

The higher nitrate concentration in the 10 to 60 cm depth, as a consequence of the higher LSM rates, may result in contamination of the water table which depends on the leaching rate of N-NO_3^- in the soil profile. The leaching rate of N-NO_3^- is a consequence of the volume of infiltrated water and Tifton 85 root system's ability to absorb N-NO_3^- in the deep layers.

Basso et al. (2005) observed higher N-NO_3^- losses through percolated water when the LSM rate applied increased from 0 to 80 m^3 ha^{-1}, exposing that 40 m^3 ha^{-1} rates do not present N-NO_3^- leaching concern. Aita et al. (2006) have observed evidence of N-NO_3^- leaching for layers beyond 60 cm depth using LSM at 80 m^3 ha^{-1} with annual species (corn, weeds and black oat). Sacomori et al. (2016) verified that high doses of DLS applied to the soil surface (200 m^3 ha^{-1}) contributed to the leaching of nitric N at the depths of 40 and 80 cm.

Nikiéma et al. (2013), when assessing the application of DLS in wheat cultivation up to the dose of 68 m^3 ha^{-1} in a sandy soil, verified that nitrate leaching is mainly related to annual rainfall. In years where rains were above average, DLS N losses extended to 29.3%. In addition to the climatic conditions, the soil characteristics determine the intensity of the leaching process occurrence, since it is inversely proportional to the number of adsorption sites (Mota et al., 2015). For the research presented here, this fact can also be stated for rates over 90 m^3 ha^{-1} applied semiannually, indicating that Tifton 85 may present higher potential for N-NO_3^- utilization when LSM is used. Other studies evidenced the high potential of nitrogen utilization of organic fertilizers using grasses. Franzluebbers and Stuedemann (2005), after 5 years of application of different nitrogen sources (organic and inorganic), observed that there was little nitrate loss through leaching, despite the application of 200 kg N ha^{-1} $year^{-1}$; this indicates that the uptake of N by bermudagrass (*C. dactylon* (L.) Pers) was efficient to reduce the losses, mainly by the habit of vigorous growth of the roots in a way that potentiates the use of this element by the plants.

The N-NH_4^+ concentration were fitted to a positive linear model to the LSM rates applied to the soil (Figure 2), with an increase of 2.3 mg dm^{-3}, from the lower to the

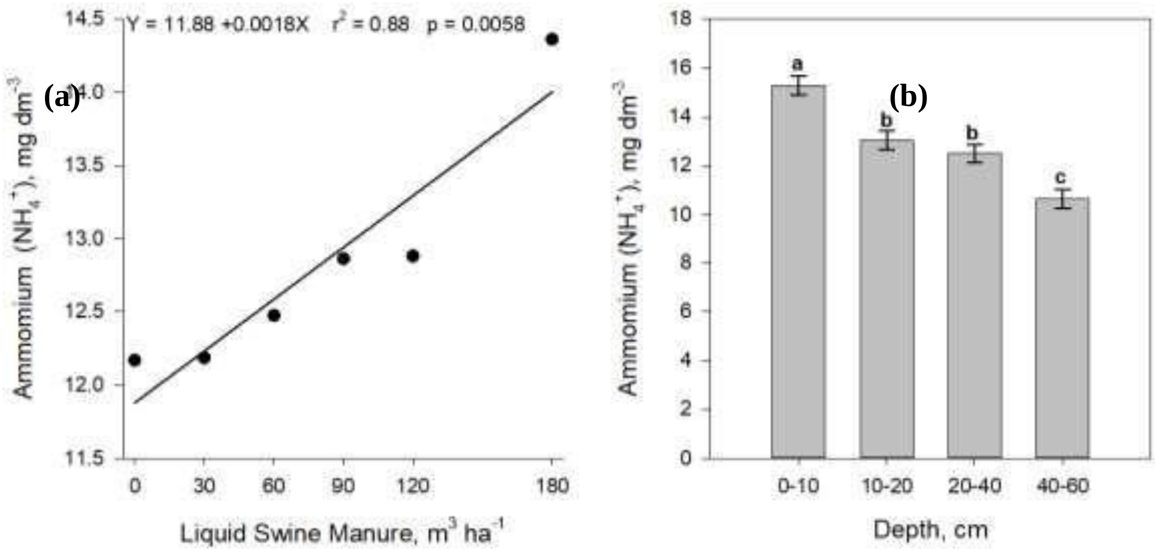

Figure 2. Soil ammonium concentration as a function of LSM application rates (Figure 2A) and for different soil depths (Figure 2B).

higher LSM rate without considering the high fertilizer amount. This is justified by the fast nitrification of the ammoniacal N applied via LSM (Aita et al., 2006).

Higher $N\text{-}NH_4^+$ concentrations were observed at the topsoil layer (0 to 10 cm), significantly higher from the deeper layers of the soil profile; with lower $N\text{-}NH_4^+$ concentration at the 40 to 60 cm layer (Figure 2). This $N\text{-}NH_4^+$ increment with higher LSM rates and the higher concentration at the topsoil layer were expected, since the ammonium, being a cation, is stable in the soil, and is adsorbed by the soil negative charges; consequently, presenting low mobility (Oliveira et al. 2011). Therefore, ammonium does not contribute extensively to contamination problems of subsurface water.

The effect of the interaction between LSM application rate and sample depth was not observed (Figure 3) for potassium concentration in year 2004 and 2006. The highest K concentration of the experiment was observed under the 180 m^3 ha^{-1} rate, in the topsoil layer, with significant variations in the 0 to 10 cm layer and 10 to 20 cm due to LSM applied rates. During the two evaluation years, K concentration was higher in the topsoil layer and higher accumulations were observed with higher LSM rates.

These results are not the same with those found by Ceretta et al. (2003), who conducted an experiment in a Chromic Orthic Alfisol with low clay percentage under natural grassland, and observed decrease of available K quantity in the topsoil layer with LSM application, when compared with the control treatment. Results from this study suggest that the behavior of K present in the LSM in Dystrophic Red Oxisol with high clay percentage differs from its behavior in sandy soils. Queiroz et al. (2004), in a Red-Yellow Sposol in Rio Grande do Sul also observed exchangeable K accumulation in the topsoil layer when swine manure was applied.

Therefore, it is possible to state that there is a tendency of higher K accumulation in the topsoil layers in soils with high clay percentage, when increasing LSM rates are applied; leaving the nutrient available to the pasture or to leaching. When the LSM is applied at 90 m^3 ha^{-1}, the K concentration at the 0-20 cm depth (Figure 3), depth at which analysis and correction of the soil under pastures are recommended, is within that recommended for high productivity forage species, such as Tifton 85.

K accumulation in the soil was not observed from 2004 to 2006 in the respective LSM rates (Figure 3). The only difference observed was between LSM rates and sample depths. Scherer et al. (2007) did not observe LSM rate effects on the K concentration in the soil with LSM application from 0 to 115 m^3 ha^{-1} for three years, leading to decrease of K concentration with depth; which is similar to this research. Lourenzi et al. (2016) observed increases in the available K content, mainly in the superficial layers of the soil after 6 years of applying organic pig waste (DLS + shavings); reaching 159% K increase with application of 16 Mg ha^{-1} of the compound in the 0-4 cm depth layer.

P concentration at the beginning of the experiment was below that recommended for the forage species Tifton 85, at approximately 5 mg dm^{-3}; whereas the recommended is above 12 mg dm^{-3} (CQFSRS/SC, 2016), which is good for a soil located at the southwest of Paraná and west of Santa Catarina. However, with the semiannual LSM application, an increase in P concentration was observed in the soil to levels that are considered high. The CQFSRS/SC (2016) considers that P concentration extracted by the Mehlich^{-1} method, as

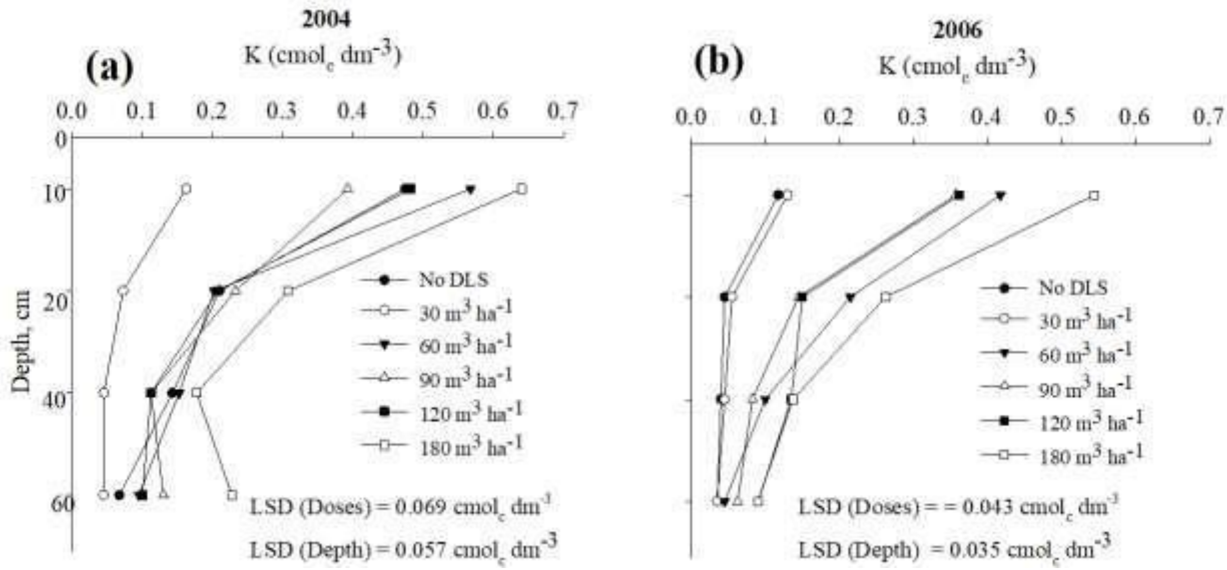

Figure 3. Soil potassium concentration at the depths of 0-10, 10-20, 20-40 and 40-60 cm, as a function of the 0, 30, 60, 90, 120, and 180 m^3 ha^{-1} of LSM application rates. Year 2004 (Figure 3A) and year 2006 (Figure 3B). LSD: Least significant difference.

performed in this study, should not exceed 24 mg dm^{-3} since there is the possibility of fertilizer loss and waste, as well as surface water contamination by phosphates (Berwanger et al., 2008).

Interaction between LSM rates and sample depth was observed for phosphorus concentration in the soil cultivated with Tifton 85 in 2004 and 2006 (Figure 4). The utilization of increasing LSM rates altered P concentration in the soil. Higher concentrations of this element were found when 180 m^3 ha^{-1} LSM was applied. This increment in the concentration, as well as its tendency of higher concentration in the topsoil layer is consistent with results obtained by Ceretta et al. (2003).

There was P accumulation from 2004 to 2006 only in the 0-10 cm layer, for up to 120 m^3 ha^{-1} of LSM use (Figure 4). Under the application of 180 m^3 ha^{-1}, the P concentration also increased at deeper soil layers (0-60 cm). This high LSM rate suggests the possibility of P loss from runoff (Ceretta et al., 2005) since the concentration remained the same between 2004 and 2006. Although higher P concentration was observed at deeper layers, there is evidence of nutrient loss from runoff, which characterizes a rate with potential polluting effect (Menezes et al., 2018).

The accumulation at the topsoil layer was expected, since it presents low mobility in the soil. According to Scherer et al. (1996), approximately two thirds of soil phosphorus is not soluble in water; potentially being part of organic structures and this contributes to the residual effect of manure. Thus, it can be stated that this nutrient stays practically unavailable to plants right after its application, requiring microorganism participation to become available in larger quantities. Phosphorus residual effect in the soil is therefore a consequence of that exposed.

Results published by Berwanger et al. (2008) also point to P increments in deeper soil layers (0-15 cm), attesting nutrient mobility within the soil profile and a contamination risk to subsurface water (Ceretta et al., 2003).

Some studies indicate that 90% of the P applied via LSM might be organic, that is insoluble (Takalson and Leytem, 2009), which contributes to the low leaching of the element in soil profile (Figure 4), under applications that is up to 120 m^3 ha^{-1} and accumulation at the 0-10 cm soil layer. This is not the case for soluble mineral fertilizers which present higher leaching potential of soluble reactive P when compared with organic fertilizers (Bertol et al., 2010). Consequently, LSM stands as an option for fertilization of forage production fields.

The increase in soil fertility, provided by successive LSM applications, led to higher levels of forage production of Tifton 85 in 2003, 2004, 2005 and 2006 (Figure 5), which was observed under higher LSM application rates. In 2003, measured forage production was lower when compared with subsequent years, possibly due to winter and first-year (establishment) carryover effect, even though fertilization responses were already noticeable. Quantification of forage production started in November, 2003.

For 2004, 2005 and 2006, the responses to the organic fertilizer were fitted to positive quadratic models (Figure 5a). There was response to the forage production at 180 m^3 ha^{-1} LSM rate, although $N\text{-}NO_3^-$ concentrations were observed at deeper layers of the soil.

Drumond et al. (2006) observed forage production

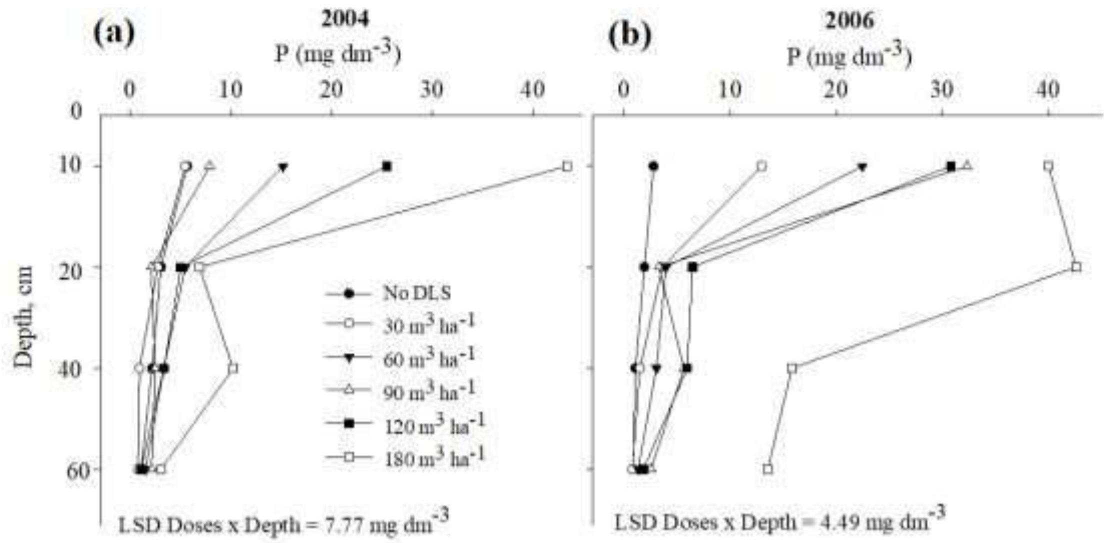

Figure 4. Soil phosphorus concentration at the depths of 0-10, 10-20, 20-40 and 40-60 cm, as a function of 0, 30, 60, 90, 120, and 180 m^3 ha^{-1} of LSM application rates. Year 2004 (Figure 4A) and year 2006 (Figure 4B). LSD: Least significant difference.

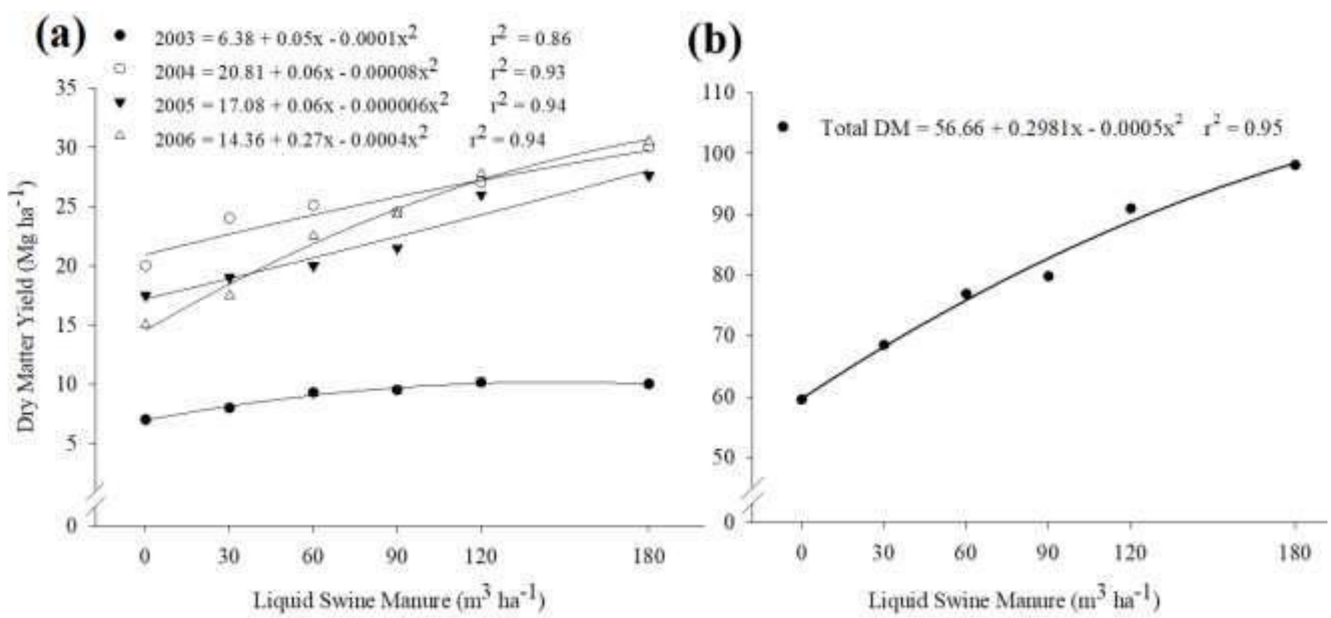

Figure 5. *Cynodon dactylon* cv. Tifton 85 dry matter production as a function of Liquid Swine Manure application rates (0, 30, 60, 90, 120, 180 m^3 ha^{-1}) for the years of 2003, 2004, 2005 and 2006 (Figure 5a) and total accumulated during four years (Figure 5b). IAPAR: Research Station of Pato Branco, 2006.

(Tifton 85) of 5828 DM kg ha^{-1} when 200 m³ of LSM were applied. Their result is not in agreement with the findings of this study, since the LSM application of 180 m^3 ha^{-1} resulted in an annual production of 25000 to 30000 kg ha^{-1} of dry matter between 2004 and 2006 (Figure 5).

Accumulated forage increase with LSM application rates in the four years of study (Figure 5b), portraying the potential of LSM as a fertilizer for perennial forage species, enabling its use as nutrient source to these plants and an option for discard of the manure, which is a concern since it is an environmental contaminant. Given the forage production levels obtained with the application LSM rates of 90 and 120 m^3 ha^{-1}, it is suggested that high quantities should not be used, given the $N\text{-}NO_3$ and P potential for contamination, as shown in this study.

Conclusions

$N\text{-}NO_3$ leaching occurs in Tifton 85 pastures when LSM is applied semiannually, at the rate of 90 m^3 ha^{-1}. This rate is suggested as the limit to the use of this fertilizer in respective pasture.

The LSM supplies the nutritional need of Tifton 85 in respect to the availability of N, P and K at a 90 m³ ha^{-1} rate, applied semiannually without causing polluter effect.

Tifton 85 dry matter production responds up to 180 m³ ha^{-1} of LSM application rates. However, the fertilizer utilization efficiency decreases at higher LSM rates, when mineral N, P and K are accumulated in the soil with applications of 120 m³ ha^{-1} of the organic fertilizer presenting an environmental contamination risk.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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