Revista Brasileira de Ciências Agrárias
ISSN: 1981-1160
agrarias.prppg@ufrpe.br
Universidade Federal Rural de Pernambuco
Brasil

Faria Scherrer Menezes, June; Pina da Silva, Mariana; de Melo Benites, Vinicius; de Lima Ribeiro, Rênystton; Ferreira Leite, Anny Kacia
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Revista Brasileira de Ciências Agrárias, vol. 11, núm. 4, 2016, pp. 359-366
Universidade Federal Rural de Pernambuco
Pernambuco, Brasil

Agrária - Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.11, n.4, p.359-366, 2016
Recife, PE, UFRPE. www.agraria.ufrpe.br
DOI:10.5039/agraria.v11i4a5403
Protocolo 5403 - 31/08/2016 • Aprovado em 18/11/2016

Nitrate and ammonium content in percolated water after successive application of swine manure in soil cultivated with soybean

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ABSTRACT

The objective of this study was to determine the amount of percolated water per day and the levels of ammonium and nitrate leachate during soybean cultivation, based on precipitation and fertilization (mineral fertilization, 25 and 100 m^3 ha^{-1} of liquid swine manure) in order to provide results that improve the handling of liquid swine manure, reducing costs and avoiding possible environmental impacts. After 14 years of successive applications of pig slurry, nitrate concentrations determined in water were lower than the maximum values established by the environmental guidelines (Conama 396), indicating that the risk of soil and water contamination is low.

Key words: organic fertilization, lysimeter, environmental monitoring

Teor de nitrato e amônio na água percolada após aplicação sucessiva de dejeto suíno em solo cultivado com soja

RESUMO

O trabalho teve como objetivo determinar as quantidades de água percolada diariamente e os teores de amônio e nitrato lixiviados, durante o cultivo da soja, com base nas precipitações e adubações (adubação mineral, 25 e 100 m^3 ha^{-1} de dejetos líquidos de suínos), de modo a fornecer resultados que aperfeiçoem o manejo de dejetos líquidos de suínos, reduzindo custos e evitando possíveis impactos ambientais. Após 14 anos de aplicações sucessivas de dejetos líquidos de suínos, as concentrações de nitrato determinadas na água foram menores do que os valores máximos estabelecidos pelas diretrizes ambientais (Conama 396), indicando que o risco de contaminação do solo e da água é baixo.

Palavras-chave: adubação orgânica, lisímetro, monitoramento ambiental

Introduction

Animal waste is used in agriculture as a source of nutrients for the development of plants. The application of pig slurry in soil has been a method used to make nutrients available to plants, besides representing an adequate form of disposal of this material (Ceretta et al., 2005). Its application to crops has increased in recent years, especially in the central-west region of the country, due to the presence of an intensive system of pig farming to meat industries.

Because they are successively applied in the soil, these waste increase the levels of nitrate (N-NO_3^-), ammonium (NH_4^+), phosphorus (P), zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe) in the soil. Sometimes these contents may be beyond the need of the crop and, in some cases, beyond the capacity of adsorption of soils, leading to nutritional imbalance (Gatiboni et al., 2008; Girotto et al., 2010) and contributing to nutrient losses due to percolation or surface runoff, with consequent contamination of surface and subsurface waters (Ceretta et al., 2010).

Pig slurries have been often applied on soil surfaces, with consequent accumulation of chemical elements (N, P, K, Ca, Na, Mg, Mn, Fe, Zn, Cu and other elements included in animal diets) in the first layers of the soil, and contamination of water resources, when water sources are reached as a result of transportation by rainstorms in plantations (Bertol et al., 2005; 2010; 2011).

High concentrations of N and P in surface and groundwater have caused not only environmental problems, but also problems to human health (Owens, 1994; Sharpley & Halvorson, 1994). In addition to eutrophication, N may cause problems to human health such as blue baby syndrome or meta-hemoglobinemia, which is induced by N in the form of NO_3^- in waters (Dinnes et al., 2002). Due to these reasons, N concentrations in the forms of NO_3^- and NH_4^+ are controlled by Brazilian legislation, to ensure water quality (Timofiecsyk et al., 2012).

Conama Resolution 396, published on April 8, 2008 (Brazil, 2008), establishes the classification of waters throughout the national territory according to their prevailing uses and regulates the Maximum levels of potentially hazardous chemicals, including various metals and pesticides (maximum levels = Non-ionizable ammonia 0.02 mg $L^{-1}NH_3$; Nitrate 10 mg L^{-1} N and Nitrite 1.0 mg L^{-1} N) in addition to physico-chemical and biological parameters (fecal coliforms).

According to USEPA (1992), and the World Health Organization (WHO) the maximum tolerable amount of nitrogen in the form of nitrate (NO_3^-) in drinking water is 10 mg L^{-1}. In Brazil, the maximum value allowed for ammonium (N-$NH4^+$) is 1.5 mg L^{-1} for drinking water (Gonçalves et al., 2005), but the natural amount of nitrate and ammonia in surface water is low (<1 mg L^{-1}). Concentrations above 5 mg L^{-1} of nitrate (NO_3^-) usually indicate pollution by fertilizers used in agriculture, or by human and animal waste (Oliveira et al., 2001).

In subtropical conditions, after 20 days of application of 130 kg ha^{-1} of ammonia N with liquid swine manure, practically all the ammoniacal N is oxidized to nitrate. With the rapid nitrification of the ammoniacal N from the waste, the formation of nitrate in the soil can occur at a speed higher than the absorptive capacity of plants and microorganisms. Thus, nitrate can be lost by leaching, contaminating the surface water and the water table, and by denitrification, increasing the emission of N_2O into the atmosphere, which is one of the gases that cause greenhouse effect (Chantigny et al., 2004). Thus, it is important to monitor areas where liquid swine waste is applied, observing the contamination of water tables, rivers and soils, due to high levels of nitrate (N-NO_3^-) and ammonium (N-NH_4^+) percolated, aiming to avoid contamination.

The objective of this work was to determine the amount of percolated water per day and the levels of ammonium and nitrate leachate during soybean cultivation based on precipitation and fertilization (mineral fertilization, 25 and 100 m^3 ha^{-1} of liquid pig slurry), in order to provide results that may improve the management of liquid swine manure in a satisfactory manner, reducing costs and avoiding possible environmental impacts.

Material and Methods

The work was conducted in an experimental area belonging to the University of Rio Verde, Rio Verde municipal area - GO, under the coordinates 17°14'53"S and 50°55'14" W, and 715 meters a.s.l. The soil of the site is dystrophic Red Latosol of clay texture, with 540 g kg^{-1} of clay (Embrapa, 2006). The experimental area is dedicated to the project "Monitoring the environmental impact caused by the use of liquid swine slurry in agriculture", carried out in partnership with the University of Rio Verde, Embrapa and BRF, since the 1999/2000 harvest.

The project has been conducted for 15 years, with successive applications of waste. Each year, soybean and corn crops are implanted in the area, successively, and the soybean crop was cultivated in the 2014/2015 harvest.

A monitoring system integrated to the water and solute soil dynamics (SISDINA) was set up in 1999. This consists of nine lysimeters made up of a metal structure that simulates a controlled soil and allows the simultaneous quantification of the infiltrated water and, within the soil, the percolation, monitoring, therefore, the water quality. SISDINA is composed of an area for collection of rain or irrigation water, which is delimited by galvanized iron sheets.

Lysimeters have 1.8 m in depth, 3.6 m in length and 2.0 m in width, covered by a 800-microns-thick PVC blanket, with a bottom moeller shape in the bottom to facilitate water drainage and percolation. The re-composition of the soil inside the lysimeter obeys the same sequence in function of the horizons of the soil, trying to maintain the original density. At

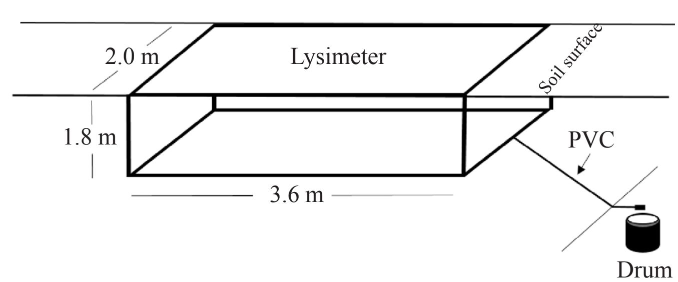


Figure 1. Schematic representation of infiltration and water collection in lysimeters

the bottom of the lysimeter, a 25 mm diameter PVC pipe was installed, connecting it to the collecting pit of water samples where collector drums with a maximum capacity of 60 liters were installed, which store percolated water until collection.

A randomized block design (DBC) consisting of three treatments with three replicates was applied, and each experimental plot consisted of one lysimeter. The treatments applied were: T1 - 25 m^3 ha^{-1} of liquid swine manure; T2 - 100 m^3 ha^{-1} of liquid swine manure; and T3 - fertilization with mineral fertilizer in the dose of 188 kg/ha P_2O_5 in MAP form plus 80 kg ha^{-1} of K_2O as KCl, as based on the interpretation of soil fertility in the 0-20 cm layer collected before application of treatments (based on Sousa & Lobato 2004).

Treatments with LSM were applied to the surface of dry soil, by spraying it only once (10/28/2014) before sowing the soybean. The LSM were obtained from a farm with Vertical Terminator System (VTS) and 30 days passed in anaerobic stabilization pond with capacity of 120 m^3. The mineral fertilizer was applied to the furrow at the moment of planting.

At the time of application to the soil, one LSM sample was collected to determine the amount of nutrients supplied to the soil. Analyses were performed following the methodology of Silva et al. (1999) (Table 1).

Planting was carried out after the application of liquid swine manure on 06/11/2014 using a variety of high productive capacity (7300 Intacta IPRO2), with spacing of 0.5m and 19 seeds per meter, in a no-till system (14 years). Phytosanitary management and treatments were carried out according to the recommendations and needs of the crop.

Evaluations were carried out during the rainy season (October 2014 to May 2015). Measurements of percolated water were performed by the following procedures: 1) daily measurement of the amount of percolated water, when necessary or according to rainfall; the higher the precipitation, the more frequent the sampling; 2) homogenization of the percolate, for daily collection of one 60 mL-sample; 3) discarding the excess; 4) repositioning the drum in its proper place to store the percolate to the next step.

After the 60 mL-sample was collected, chemical analysis was carried out at the Laboratory of Soil Analysis of the University of Rio Verde, analytically determining nitrogen contents ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) following the methodologies of Embrapa (Silva et al., 1999), pH and electrical conductivity. Subsequently, the amount of water percolated in the soil profile and the nitrate and ammonium contents, and the accumulated N loss during the period from October/2014 to May/2015, were determined as a function of precipitation and fertilization.

Data were submitted to analysis of variance at 5%. Meteorological data were collected at the INMET normal meteorological station, located at the University of Rio Verde.

Leached nitrate and ammonium contents were compared to the standard levels for drinkable water of the Health Surveillance Secretariat of the Ministry of Health (Brasil, 2006).

In relation to the total volume of water and total losses of nitrogen in the percolated water, data were submitted to analysis of variance and, when significant, the Tukey test was applied at 5% of probability, using the SISVAR statistical program (Ferreira, 2011).

Table 1. Chemical composition of liquid swine manure applied to soil in 2014

N[1]	P[2]	K[3]	Ca	Mg
		kg m^{-3}		
1.3	0.83	0.60	1.51	0.74
pH	**Density**	**MO**	**MS**	**$S\text{-}SO_4$**
	g cm^{-3}	%		kg m^{-3}
7.53	1,009	1.96	2.94	0.29

Percentage of conversion of nutrients applied: N = 50%[1], P = 60%[2] and K = 100%[3] (CFSEMG, 1999).

Results and Discussion

Total precipitation in the experimental area in the 2014/2015 harvest was 1,586.6 mm (Figure 2), which may influence the percolation of nutrients in the soil, especially the most mobile ones.

Pluviometric indexes above 40 mm were observed in the months of December, March and April (Figure 2). The highest pluviometric volumes after application of LSM occurred on 14/11/2015, 12/12/2014, 14/12/2014, 07/03/2015 and 14/04/2015, with a precipitation of approximately 67.9; 79.5; 86.5; 51.6 and 90.6 mm, respectively.

Percolation of water in the soil profile (Figure 3) was similar in the three treatments regardless fertilization (organic or mineral), as it followed precipitation indexes (Figure 2). The stronger and the more frequent were precipitation events, the more leaked water was in captured in lysimeter collection drums.

During the first 19 days after application of liquid swine manure (DAAD), precipitation occurred in the experimental

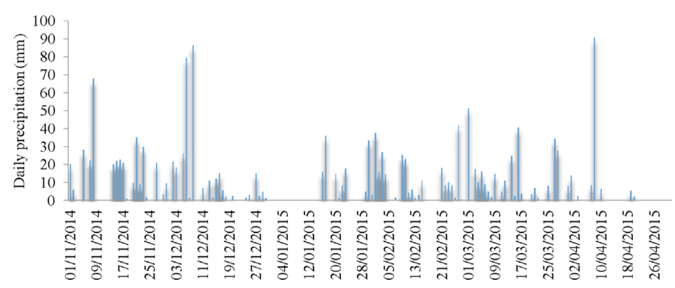


Figure 2. Daily rainfall in the experimental area after application of liquid swine manure in the period from November 2014 to April 2015 in soybean culture

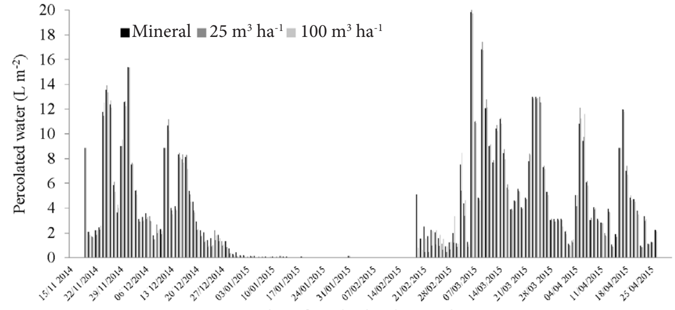


Figure 3. Daily percolated water volume with applications of 25 m^3 ha^{-1} and 100 m^3 ha^{-1} of swine slurry and mineral fertilization during soybean cultivation in the 2014/2015 harvest

area, corresponding to 210.1 mm (Figure 2). However, in these first days, no water percolation occurred in any of the treatments (Figure 3). This condition can be explained by low soil moisture, initially, due to absence of rainfall. Precipitation is absent during winter (May-September) in this region, a fact confirmed in the experiment. In the first rains, the soil was dry, with a high water-holding capacity, as well as macro and micropores taking some time to saturate with water and also to gravitational force (Basso et al., 2005).

After frequent precipitation events, the amount of percolated water in the soil profile was similar, regardless of the treatments. The maximum percolations occurred on 04/03/2015 and 07/03/2015, between 127 and 130 DAAD, respectively (Figure 3).

From the 67 DAAD (01/03/2015) to the 112 DAAD (02/17/2015), there was no loss of percolated water, due to dry spells that occurred in the area (Figure 2). However, after the 123 DAAD, water losses resumed because precipitation occurred (20 mm).

The total volume of water percolated as a function of fertilization did not differ between treatments ($P < 0.01$). Percolated water was 547.05 L m^{-2} and 552.39 L m^{-2} with doses of 25 m^3 ha^{-1} and 100 m^3 ha^{-1} of LSM, respectively and 573.03 L m^{-2} for mineral fertilization (Figure 4). Results were similar to those of Santos (2007), in which the total volume of percolated water was influenced by rainfall. This was in fact due to the percolation time of water and not to doses of applied waste (Owens et al., 2000). This has no connection with the volume of manure applied, which was of 25,000 liters and 100,000 liters per hectare with doses of 25 and 100 m^3 ha^{-1}, three times more water with the highest dose of waste.

Pig waste can be used to fertilize crops as organic fertilizer, bringing greater economic gains to the rural producer and without compromising the quality of the soil and the environment only if nutrient balance criteria are adopted and water losses are monitored, specially water quality (Seganfredo & Perin Júnior, 2005).

NH_4^+ contents in the percolated water were similar regardless treatments (Figure 5). Higher losses of N- NH_4^+ initially up to 25 DAAD were observed due to higher water percolation (Figure 3) and also due to the fact that soybeans were in the early stages of development of the crop (V6-V8 stages).

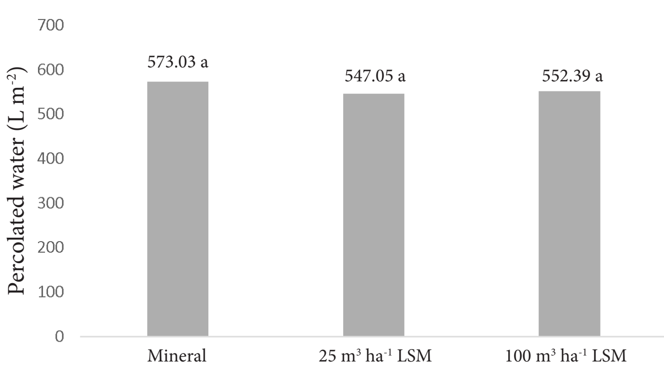


Figure 4. Total volume of percolated water as a function of fertilization: mineral, 50 m^3 ha^{-1} and 100 m^3 ha^{-1} of liquid swine manure during soybean cultivation in the 2014/2015 harvest

The mean NH_4^+ contents were 0.85, 0.94 and 0.98 mg L^{-1}, with mineral fertilizer doses, 25 and 100 m^3 ha^{-1} of LSM, respectively. These levels were similar to those determined in the percolate of the same lysimeters in the crop 2013/2014 with corn, corresponding to 1.11, 1.08 and 1.36 mg L^{-1} of ammonium (Matos & Menezes, 2015). However, in maize crop, doses of 50 and 200 m^3 ha^{-1} of LSM were applied, which are higher doses than those applied in soybean crop.

Although doses of manure in soybean crop were smaller, the ammonium contents were probably similar due to the low N mineral utilization by the soybean crop caused by biological fixation of atmospheric nitrogen (BNF). Consequently, excessive N in the system increased leaching. According to Hungary et al. (2005), BNF contributes 72 to 94% of the N absorbed by soybean. The concentration of N in the wastes was 1.3 kg m^{-3}, applying 32.5 kg ha^{-1} and 130 kg ha^{-1}, at 25 and 100 m^3 ha^{-1} doses of LSM, respectively (Table 1).

According to Scherer et al. (1996), even if the soluble ammoniacal N (40-60%) prevails in the LSM, this can be transported and retained by the soil in deeper layers, decreasing the N availability for transport and, consequently, its amount in the leachate (Bertol et al., 2005). Levels of N-NO_3^- in the percolated water have different behaviors as a function of treatments along the crop cycle (Figure 6). The pH of 7.5 (Table 1) may contribute to shift this equilibrium towards N-NH_3 and later to N-NO_3^-, which would mean an increase in N-NO_3^- concentrations in percolated water. This possibility is justified by the observation of Sørensen (1998) that the increase in soil pH resulting from oxidation of volatile fatty acids present in the waste influences the NH_4^+/NH_3 equilibrium, favoring N-NH_3. According to Owens et al. (2000), high doses of N applied successively in crops result in excessive levels of N-NO_3^- leached in concentrations that may exceed the maximum threshold allowed by law for drinkable water, which corresponds to the possible contamination of water with N-NO_3^- with the dosage applied.

In the case of fertilization with 100 m^3 ha^{-1} of LSM, 38% of nitrate levels in percolated water were higher than 10 mg L^{-1} [According to the WHO, levels above 10 mg L^{-1} are considerably pollutants, with risk of environmental contamination (USEPA, 2002)], while in the other treatments, only 1 and 3% were observed in mineral fertilizations and 25 m^3 ha^{-1} of LSM, respectively (Figure 6) (Silva et al., 2011; Timofiecsyk et al., 2012), a fact that is also observed by Santos et al. (2015) conducted in the same site of the present work.

According to Dynia et al. (2006), in the case of annual crops, few applications of high doses of organic waste present a risk of contamination of groundwater with nitrate in a relatively short time.

Nitrate levels in percolated water were 1.73 mg L^{-1} and 5.00 mg L^{-1}, corresponding to the doses of 25 and 100 m^3 ha^{-1} of LSM and 1.62 mg L^{-1} with application of mineral fertilization (Figure 6). It was noted that the average levels of nitrate in the percolate with the highest dose of LSM were three times higher than the levels of nitrate in mineral fertilization. This is similar to data found by Matos & Menezes (2015). The average nitrate content in the percolated water throughout the analyzed period

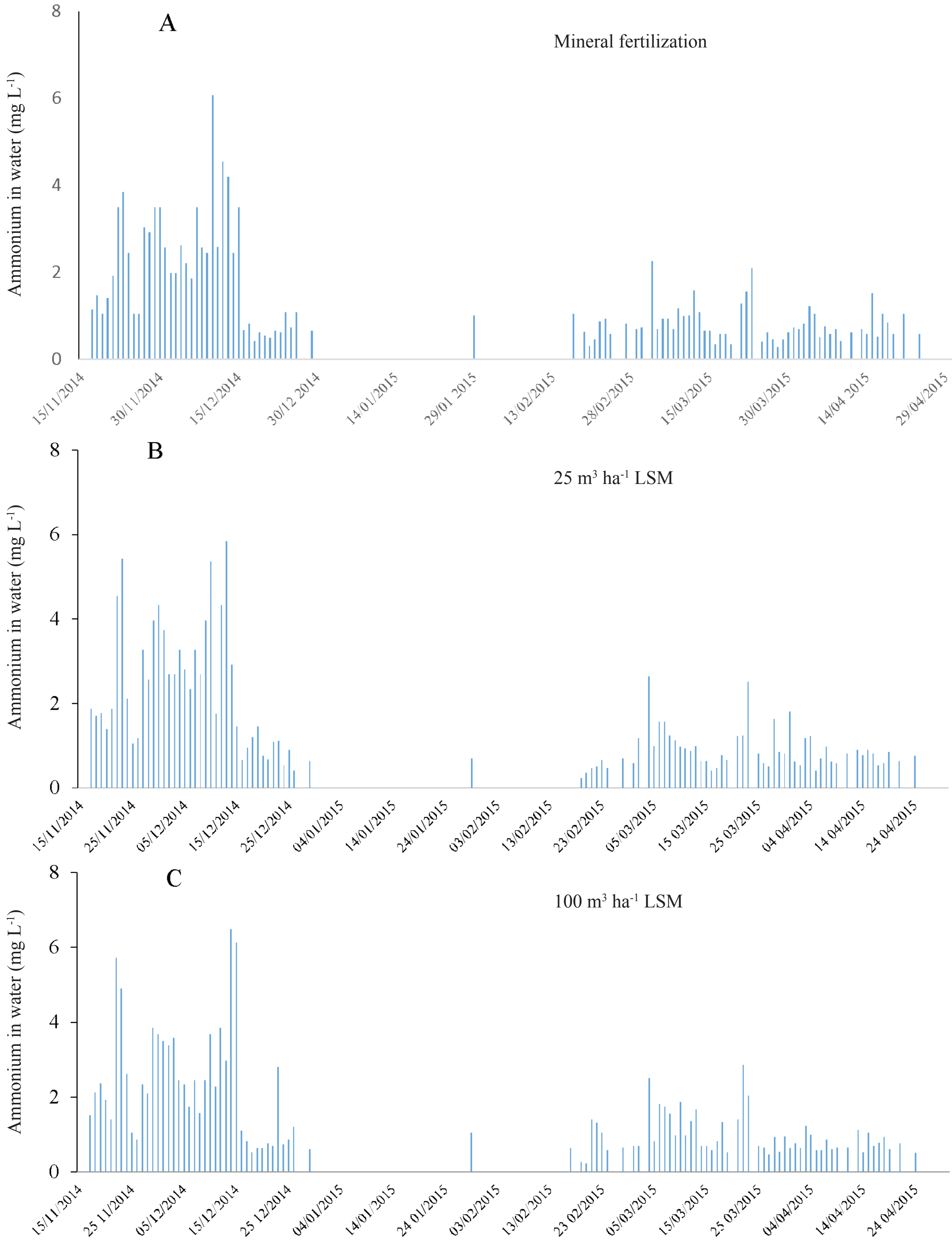
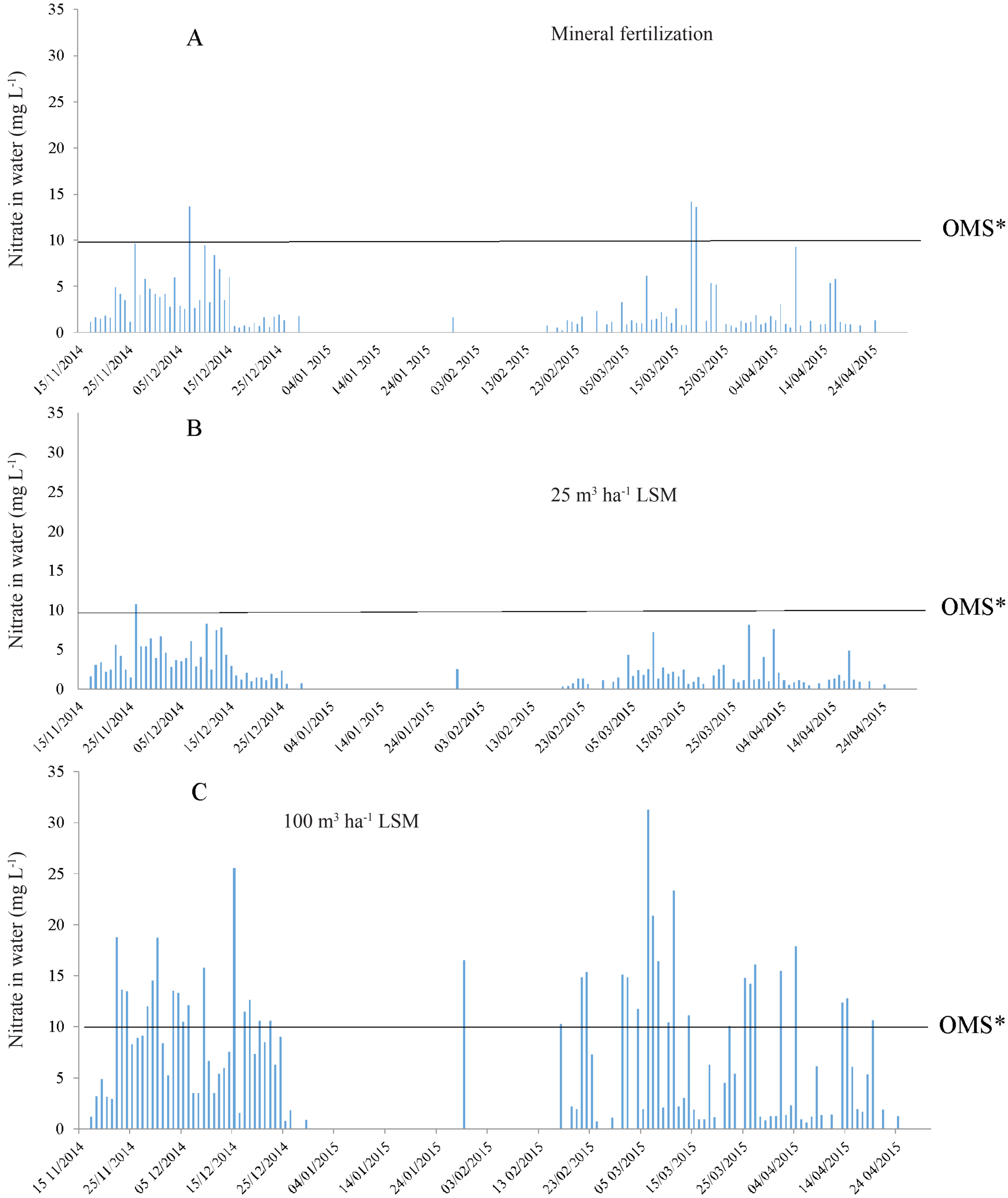


Figure 5. Daily levels of ammonium in percolated water as a function of the application of 25 m^3 ha^{-1} and 100 m^3 ha^{-1} of LSM and mineral fertilization in soybean cultivation during the 2014/2015 harvest

was 2.78 mg L^{-1}, remaining below the levels of non-drinkable water (USEPA, 2002).

The total amount of N lost in percolated water was 26.36 kg ha^{-1}, 60.79 kg ha^{-1} and 26.24 kg ha^{-1} with fertilizations of 25 and 100 m^3 ha^{-1} and mineral fertilizer, respectively (Figure 7). These values indicate that much N was lost in the percolated water compared to the N applied, mainly in the higher dose of LSM, in which 53% of the N applied to the soil was lost in the water. Most of the N applied in the soybean crop was not exported, but remained in the soil and leached in the soil profile. The amount of LSM applied as well as the volume of precipitation are factors that affect the concentration of



WHO * - Acceptable levels of nitrate (mg L^{-1}) for drinkable water according to the World Health Organization

Figure 6. Daily nitrate levels in percolated water as a function of application of 25 m^3 ha^{-1} and 100 m^3 ha^{-1} of LSM and mineral fertilization in soybean crop during the 2014/2015 harvest

$N\text{-}NO_3^-$ in percolated water, and the long-term application of the maximum recommended levels represents a risk of soil and water contamination.

Matos & Menezes (2015) used doses of 50 and 200 m^3 ha^{-1} of LSM and verified that the total losses of N were 5.58 kg ha^{-1} and 15.72 kg ha^{-1}, which are values four-fold below those determined in the present work. Basso et al. (2005), in a study aimed at evaluating the percolation of N in the area with liquid swine dewatering, observed that the increase of dosages in wastewater applications would result in an increase in nitrate concentrations in percolated water. Under aerobic conditions, N applied to soil in organic and/or ammoniacal forms is rapidly oxidized to nitrate. Therefore, the monitoring of $N\text{-}NH_4^+$ concentration in the soil profile is not an indicator to evaluate leaching of this element.

Because the presence of positive charges in the colloids makes nitrate to be weakly retained by the soil, this tend to remain in solution. Organic matter has an electronegative character in the solid phase, and phosphates contain free positive charges, thus offering higher chance of leaching

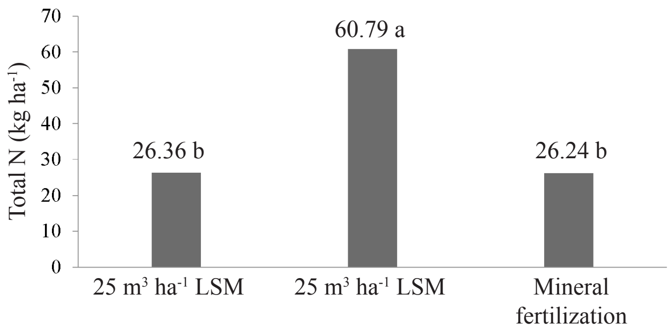


Figure 7. Total nitrogen losses in percolated water as a function of mineral fertilization, application of 25 m^3 ha^{-1} and 100 m^3 ha^{-1} of LSM in the soybean crop during the 2014/2015 harvest

nitrate, causing surface runoff and eutrophication of surface and groundwater sources (Resende, 2002).

According to Reichard et al. (2009), a crop rarely harvests more than 60% of N applied as fertilizer. The excess may remain in the soil, available for subsequent crops, or be lost through various mechanisms, such as volatilization, denitrification and leaching.

Conclusions

After 14 years of successive applications of liquid swine manure, nitrate concentrations are below the maximum values established by environmental guidelines (Conama 396), indicating that soil and water contamination are under low polluting potential.

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