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RESEARCH ARTICLE

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Leaching of the different forms of nitrogen by the application of poultry litter, swine waste, and mineral nitrogen on corn cultures (*Zea mays* L.)

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Abstract

Agricultural, livestock management, and industrial activities have the potential to cause high levels of contamination to the soil, surface water, and groundwater as a result of accidental or deliberate discharges of pollutants to the environment. In this study, we evaluated the contamination of groundwater by various forms of leached nitrogen (total N, ammonia, nitrate, and nitrite) arising from the application of poultry litter, swine waste, and mineral nitrogen (urea) to the soil. The study was conducted using a set of drainage lysimeters in the experimental area of UFSM, Frederico Westphalen Campus (RS), Brazil. In this study, the use of swine waste and urea as nitrogen sources shows high leaching of ammonia (N-NH_3^+) and total nitrogen (total N) in drainage water in relation to the nitrogen supplied by poultry litter. Comparing the values of ammonia, nitrite, nitrate, and total nitrogen percolates in the soil with the Maximum Permissible Values allowed by Brazilian law, Res.357/2005-–the Brazilian National Environmental Council and Ministry of Health Ordinance 2914/2011, it was observed that all analyzed applications of fertilizers resulted in values that exceeded the maximum allowed waste limits. Therefore, the results obtained in this paper regarding the different sources of nitrogen fertilization used on agricultural soils released potentially toxic concentrations of nitrogenous residues that leached through the soil, creating the potential for serious human and animal health effects, such as methemoglobinemia, as the total nitrogen contents released from each fertilization treatment appeared to percolate through the soil layers and into the groundwater, polluting water sources for both human consumption and agricultural production.

KEYWORDS
environmental pollution, methemoglobinemia, nitrogen sources, public health

1 | INTRODUCTION

The Northwest and North regions of the State of Rio Grande do Sul are characterized by small estates, where pig farming and aviculture are the main economic activities. These activities are also responsible for generating large amounts of effluents, which, in the case of swine waste, and according to the effective Brazilian legislation, should be stored in decantation wells and used in agriculture as a method of organic fertilization, primarily as a source of nitrogen (N).

However, due to the chemical composition of wastes generated from animal farming activities, the practice of spreading them on the soil as a source of nutrients in cultivated areas may contribute to the soil contamination when technical recommendations regarding the appropriate amounts for application are not observed.

Fertilization of the soil with high amounts of nitrogen may cause environmental contamination (Oliveira, 2004, p. 109), in addition to affecting the absorption capacity of plants, favoring its fixation in the soil for further use of subsequent crops. This fact, added to the relatively high storage and application costs of these animal wastes on crops, makes it necessary to develop economically feasible management techniques that minimize environmental risks, most of which are related to water pollution from nitrate, nitrite, and ammonia.

The presence of nitrogen in the soil, whether it occurs naturally or by the application of wastes and effluents, undergoes a transformation upon contact with the soil, water, and microorganisms. Hence, the

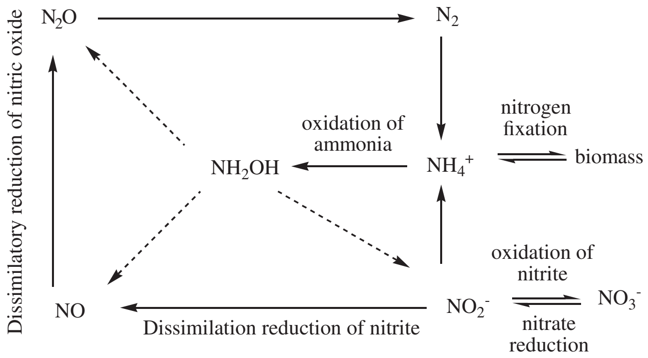

EXHIBIT 1 Integrating reactions of the biological cycle of nitrogen (adapted from Rick & Thomas, 2001)

nitrogenous compounds in the nitrogen cycle, which arise from microbial metabolism, occur due to the processes of nitrification, denitrification, nitrogen fixation, anaerobic oxidation of ammonium (through nitrite), and nitrate reduction. This cycle is shown in **Exhibit 1**.

Ammonia may be naturally present in surface water and groundwater, but its concentration is usually low, due to its easy adsorption by bacteria and soil particles, or through nitrite and nitrate oxidation (Alaburda & Nishihara, 1998).

However, nitrate is one of the ions that are most abundantly found on natural waters. Law number 357/2005 from the Brazilian National Environmental Council (CONAMA) establishes concentrations of 10 milligrams per liter (mg/L) of nitrate ($N\text{-}NO_3^-$), 1.0 mg/L of nitrite ($N\text{-}NO_2^-$), 3.7 mg/L of ammonia ($N\text{-}NH_3^+$), and 2.18 mg/L of total nitrogen (N-total) for lotic environments, as the maximum residue limit (MRL), tolerable for water potability. Nonetheless, the Brazilian Health Regulatory Agency (Anvisa) sets a maximum concentration of 1.5 mg/L for $N\text{-}NH_3^+$ for water intended for human consumption through Decree number 2914 of the Health Ministry, which established the Water Quality Standard (Brazil—Ministry of Health, 2011). Therefore, it is understood that the presence of nitrogen content above the limits established by Anvisa for human drinking water may be associated with adverse health effects and may lead a person, mainly children and babies, to develop methemoglobinemia, also known as “blue-baby” syndrome (Jadoski, Saito, Do Prado, Lopes, & Sales, 2010).

In the area of public health, nitrate, and especially nitrite residues, which are of great toxicity than nitrate residues, have drawn much attention, as they are associated with physiological disturbances and diseases, among them, the establishment of cyanosis (methemoglobinemia), which, under nitrite concentrations around 1 gram per liter (g/L), is extremely lethal to adult humans (Araújo et al., 2011; de Melo Filho, Biscontini, & Andrade, 2004).

Methemoglobinemia (Khanal et al., 2015) is a disease characterized by the abnormality of hemoglobin, which loses its capacity to transport oxygen in the plasmatic system to the cells and tissues, causing tissue hypoxia and cellular anoxia. This hemoglobin abnormality occurs due to the fact that the heme prosthetic group of hemoglobin is in a ferric state (Fe^{+3}) rather than in a ferrous state (Fe^{+2}), as it normally is, due to its presence among other nitrogenous compounds that oxidize the heme group of hemoglobin (**Exhibit 2**), thus originating the aberrant dyshemoglobins known as methemoglobin.

Methemoglobin is unable to fix oxygen, and consequently, it does not transport oxygen within the effected organism, which may even lead to death (Carvalho, Ribeiro, Alves, Gomes, & Sarmento, 2011; Nascimento, Pereira, Mello, & Costa, 2008). According to Nascimento et al. (2008), when the methemoglobin (MeHb) level within an organism reaches a serum concentration above 1.5%, cyanosis has established. This disease is difficult to treat because it does not respond well to oxygen supplementation. Among the symptoms of cyanosis are: dizziness, headaches, anxiety, dyspnoea, reduction of the heart rate, convulsions, and even death when the methemoglobin concentration level reaches above 70%.

Therefore, in animals, when nitrate is ingested in excess, it is reduced to nitrite and enters the blood stream, where it oxidizes the iron ($Fe^{2+} \geq Fe^{3+}$) from the hemoglobin, producing methemoglobin (Exhibit 2), the inactivated form of hemoglobin that is unable to efficiently transport oxygen from the normal breathing processes to the cells and tissues, resulting in hypoxia. Nitrite may also be combined with amines, creating nitrosamines, which are both carcinogenic and mutagenic (Gomes, de Souza, Boeira, & de Toledo, 2008).

The development of methemoglobinemia caused by nitrate will depend on its biological conversion to nitrite during the digestion process in the gastrointestinal tract. Children are more susceptible to the development of this disease due to their low gastric acidity and transitory physiological deficiency of MeHb-reductase or the reduced form

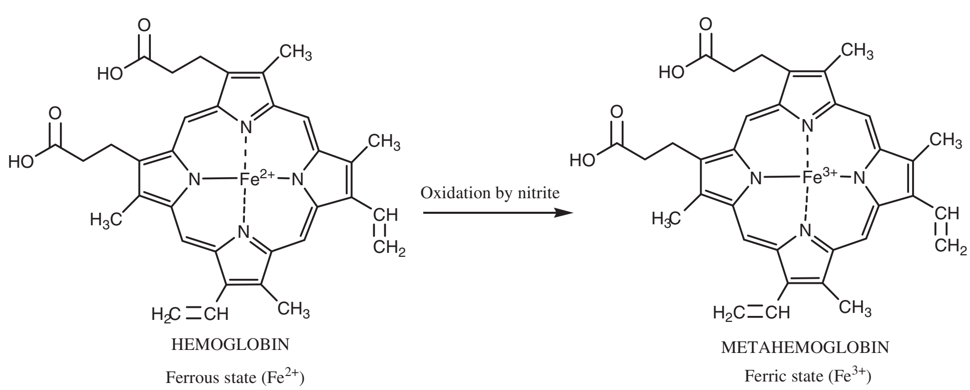

EXHIBIT 2 Hemoglobin molecule oxidized to methemoglobin (adapted from Swann, 1975)

of nicotinamide adenine dinucleotide cofactor (Moreau & Siqueira, 2008).

Nitrite present in water used for human consumption provides a faster and more pronounced toxic effect than does nitrate. According to Araújo et al. (2011), if nitrite is directly ingested, it may cause methemoglobinemia, regardless of the age of those consuming it. In that sense, there is increased concern for monitoring agricultural activities and their impact on the quality of water sources in rural and suburban areas due to the use of inorganic and organic fertilizers. Both nitrate and nitrite are leached by rain water, thus reaching groundwater, streams, rivers, and lakes that constitute the aquatic ecosystems and that serve as water sources for animal production (fish, shrimp, pets) and for human consumption (Baird & Cann, 2011).

de Campos, Miranda Filho, D'Incao, Poersch, and Wasielesky (2012) observed the toxic effects of ammonia, nitrite, and nitrate concentrations on young pink shrimp (*Farfantepenaeus brasiliensis*), obtaining the following mean values for lethal concentration 50% (LC_{50}) tests: for ammonia, 1.99 mg/L over exposure for X number of hours (hr; mg/L/24 hr); nitrite (105.9 mg/L/96 hr); and nitrate (912.05 mg/L/96 hr), concluding that although the Penaeidae species are more resistant to the toxicity effects of nitrate and nitrite, they are sensitive to the ammonia low concentrations.

Ramírez-Rochín et al. (2017) conducted nitrite acute toxicity tests on the shrimp species *Litopenaeus vannamei* (Boone) and observed that the toxic effect of nitrate is reduced by an increase of the saline concentration in the medium. In that sense, the LC_{50} of nitrate concentrations over 24 hr for the young shrimp species were: 19.4 mg/L (in a saline concentration of 2 g/L); 14.4 mg/L (in a saline concentration of 1 g/L); and 8.1 mg/L (in a saline medium concentration of 0.6 g/L).

Within this context, this study was developed to evaluate the residual effect of ammonia, nitrate + nitrite, and total nitrogen on leached water originating from poultry litter, swine waste, and mineral nitrogen (urea) used as fertilizers for corn culture collected from draining lysimeters.

2 | MATERIALS AND METHODS

The study was conducted during the agricultural year of 2013 in the experimental area of Centro de Educação Superior Norte-RS, at Universidade Federal de Santa Maria in Frederico Westphalen (RS), which is located at the following geographic coordinates: latitude 27º 25′ 43″ S, longitude 53º 43′ 25″ W, and at a mean altitude of 488 meters (m).

In order to evaluate water contamination by total nitrogen resulting from treatments with swine waste and poultry litter and from treatments with mineral nitrogen (urea), a set of draining lysimeters was used for the collection of samples. The set of lysimeters consists of 12 boxes, made from glass fiber with the following dimensions: 1.40 m × 0.95 centimeters (cm) and 1.00 m in depth. This set of lysimeters is protected by ethylene-vinyl acetate polyethylene covers, supported by metal structures. The soil used in the study is classified as typical ferric aluminum red latosol (Gomes et al., 2008). Prior to the implantation of the corn crop, soil samples were collected from the lysimeters at depths of 0 to 20 cm in order to analyze the chemical conditions. The following values were noted regarding the soil and water samples:

- pH of water collected: 5.9;
- Organic matter of soil: g/dm^3;
- Clay content of soil: 67%;
- Phosphorus: 16.6 mg/dm^3;
- Potassium: 139 mg/L;
- Calcium: 4.3 cmol$_c$/dm^3; and
- Magnesium: 1.8 cmol$_c$/dm^3.

The interpretation of the results and recommendations of the appropriate nutrient doses were followed in accordance with the value ranges recommended by the Brazilian Soil Science Society (2004, p. 400) for the corn culture (*Zea mays* L.), cultivar AS 1570, based on the grain productivity parameter of 9,000 kilograms per hectare (kg/ha).

The nitrogen fertilizers were applied at the time of sowing at the recommended doses according to the nitrogen sources under study: swine waste and poultry litter (organic nitrogen) and urea (mineral nitrogen).

The nitrogen fertilizers were applied at the time of sowing at the recommended doses according to the nitrogen sources under study: swine waste and poultry litter (organic nitrogen) and urea (mineral nitrogen). The doses were calculated based on the nitrogen–phosphorus–potassium needs of the corn, considering that each lysimeter has an area of 1.3 square meters (m^2). In regard to the treatment with the poultry litter, 1.88 kilograms (kg) of litter and 2.63 grams (g) of triple superphosphate (TSP) were applied; for the treatment with the swine waste, 0.135 cubic meters (m^3) of waste, 28 g of TSP, and 23.33 g of potassium chloride (KCl) were applied; and for the treatment with mineral fertilization, 72 g of urea, 66.52 g of TSP, and 34 g of KCl were applied.

The sowing was done manually and carried out in lines on September 18, 2013, under the no-tillage planting system with a population of 75,000 plants per hectare with spacing between the lines of 45 cm and at a depth of 6 cm. Water was supplied to the plants to maintain the soil moisture at close to 90% of the capacity of the field. Monitoring was conducted to verify the soil moisture using a soil moisture capacitance sensor (FDR). Once a month, a percolated water sample was collected

24 hr after the application of 7 liters (L) of water per irrigation, simulating a rainfall of 5.3 millimeters (mm), which exceeds, on average, 15% of the field capacity of the soil, according to the irrigation strategy used. This allowed the water to infiltrate into the soil, and for the water that has leached through the soil to be collected afterward.

The monitoring of the leached water commenced 10 days before sowing, and extended through the growing season up to harvesting and then for additional 60 days, for a total number of eight sample collection events and analyses.

The leached water collected from the lysimeters had its N-total determined using a micro-Kjeldahl steam distiller according to the method described by Tedesco, Volkweiss, & Bohnen (1985, p. 179). The evaluations were conducted at the Research and Chemical Analysis Laboratory (LAPAQ) located inside the installations of the Frederico Westphalen campus/UFSM. The ammonia, nitrate + nitrite, and N-total concentrations obtained from the analyses were compared to the critical levels of the MRL, established by COMANA under number 357/2005 (Brazil—CONAMA, 2005).

The experiment used a randomized design, with three treatments and four replications. The statistical analyses were performed with the Genes Software, using Tukey's statistical test at a 5% error probability in order to compare the means obtained across the different nitrogen sources.

3 | RESULTS AND DISCUSSIONS

3.1 | Ammonia concentrations

The table in **Exhibit 3** shows the observed values and the statistical variations of nitrogen: ammonia, nitrite + nitrate, and N-total, from the three fertilization treatments. These results are from the analyses of leached water samples collected over eight sampling events conducted at 30-day intervals. Exhibit 3 shows that the nitrogen sources with the highest ammonia concentrations, and, therefore, the sources that are potentially the greatest polluters, derive from swine waste and mineral fertilization with urea. The nitrogen sources showed significant differences in the release of ammonia into the leached water, at 30, 60, 90, 120, and 150 days after sowing (DAS). After the application of the fertilization treatments, all collection dates up to 150 DAS showed ammonia concentrations exceeding the MRL, which is 1.5 mg/L, according to Anvisa. Only the treatment with poultry litter at 180 DAS showed concentrations below the MRL. All treatments after 210 DAS showed concentrations of ammonia below the MRL, but with high total nitrogen concentrations, indicating that all of the nitrogen sources used for fertilization are polluters, and that the concentrations leached into the water, making its quality unsuitable for human consumption. However, if we consider the value of 3.7 mg/L for ammonia established by the CONAMA resolution 357/2005, only the “chemical treatment” and “swine waste” showed ammonia concentrations above the MRL in the water samples collected at 60, 90, and 120 DAS, which were statistically different from the concentrations observed in the water samples associated with the “poultry litter” treatment.

In regard to the treatments using poultry litter and swine waste, the concentration peaks for ammonia for the organic sources occurred at 60 and 90 DAS, respectively. In regard to the chemical treatment, the peak concentration for ammonia was observed at 90 DAS, with the concentrations declining after this period. This indicates that the ammonia levels in the water were higher at the beginning of the development of the corn culture. These results differ from the values observed by Griffin and Honeycutt (2000), in which they verified that the ammonia levels disappeared over the first 28 days after the application of animal manure on the soil. A likely explanation for this greater initial availability of ammonia is that it may have been nitrified due to the oxygenation, humidity, and temperature conditions, which may have been favorable for microbial activities (Ernani, Sangoi, & Rampazzo, 2002).

The results regarding the water collected in the areas subjected to the urea treatment were statistically different from the results of the water samples collected from the poultry litter treatment areas

EXHIBIT 3 Ammonia ($N\text{-}NH_3^+$), nitrate + nitrite ($N\text{-}NO_3^-$ + $N\text{-}NO_2^-$), and total nitrogen (N-total) concentration, on the leaching water of draining lysimeters, during the phenological cycle of the corn culture on different nitrogen sources: poultry litter and swine waste (N-organic) and urea (N-mineral)

Date (DAS)	Ammonia (NH_3^+) (mg/L)					
	N-organic				N-mineral	
	Poultry litter		Swine waste		Urea	
0	0.3133	a	0.3533	A	0.3300	A
30	2.9000	a	2.1000	Ab	1.8333	B
60	3.0667	b	4.8333	A	4.2333	A
90	2.6000	b	6.1000	A	5.5333	A
120	2.1667	b	4.2000	A	4.6000	A
150	1.7000	b	2.5000	B	3.5333	A
180	1.3667	a	1.8667	a	2.0333	A
210	1.0967	a	1.0133	a	0.6267	A
Nitrite + Nitrate (NO_3^- + NO_2^-) (mg/L)						
0	0.0900	a	0.1367	A	0.1033	A
30	0.4667	b	1.6333	A	1.7000	A
60	3.0333	b	4.4333	A	1.8000	C
90	2.5667	a	3.2333	A	2.6000	A
120	3.7333	a	3.0333	A	2.1000	B
150	1.8667	b	2.7333	A	2.1767	Ab
180	1.6667	a	2.1333	A	1.8333	A
210	1.4100	a	1.1800	A	0.6867	A
N-total (mg/L)						
0	0.4033	a	0.4900	A	0.4333	A
30	3.3667	a	3.7333	A	3.5333	A
60	5.633	c	9.2667	A	6.0333	B
90	6.0667	b	9.3333	a	8.1333	A
120	5.9000	a	7.2333	a	6.7000	A
150	3.5667	b	5.2333	c	5.7100	A
180	3.0333	a	4.0000	a	3.8667	A
210	2.5067	a	2.1933	a	1.4267	B

Note. Means followed by the same letter on the row are not statistically different from each other, according to Tukey's test at 5% of error probability.

at 30 DAS, but it did not differ from the water samples collected from the swine waste treatment areas, as it showed numerically lower ammonia release values for this date. This may have happened due to the reduced contact of the fertilizer with the soil; that is, a nitrification delay occurred. This condition was also observed by Ernani et al. (2002), who obtained a greater leached nitrogen concentration right after the application (first week), when the urea was mixed with the soil, when leaching occurred 8 weeks later.

Following a similar length of time in the present study (60 DAS), a greater release of ammonia was observed in the water collected from the chemical treatment (urea) areas compared to the water samples collected from the poultry litter treatment areas at that collection time.

3.2 | Nitrite + nitrate concentrations

The values observed in relation to the nitrate + nitrite concentrations in the leached water samples from the areas treated with organic nitrogen (poultry litter and swine waste) showed significant differences among the collection days 30, 60, and 150 DAS.

The swine waste treatment showed the highest nitrate + nitrite concentrations at 60 DAS.

The swine waste treatment showed the highest nitrate + nitrite concentrations at 60 DAS. On the other hand, a greater concentration of nitrate + nitrite was observed in the water samples collected in the areas treated with urea at 90 DAS. The organic treatments showed higher nitrate + nitrite contents than ammonia in water samples collected at 120, 150, and 180 DAS for the poultry litter treatment and in the water collected at 120 DAS from the swine waste area, respectively.

The highest absolute value for the nitrate + nitrite content was observed for the swine waste treatment at 60 DAS. A similar result was observed on studies conducted by Aita, Giacomini, and Hübner (2007), which indicated that the ammoniacal nitrogen in the liquid swine waste is quickly nitrified on the soil under the no-tillage planting system between 15 and 20 days after application. Furthermore, Aita et al. (2007) also verified that the nitrate concentrations were high at 54 DAS in soil deeper than 1.2 m, indicating continued leaching, probably due to the high level of precipitation that occurred near this period.

For the treatment with swine waste, the nitrate + nitrite value after 120 DAS up to the last collection at 210 DAS was 2.27 mg/L, as the mean value among the observations. These contents were similar to the ones found by Aita et al. (2007), who stated that after 125 DAS, the mean nitrate concentration in the soil profile had practically stabilized at 2.25 mg/L.

The nitrogen source of the swine waste represented a pollution source that releases a larger amount of nitrate + nitrite over time in relation to the other analyzed sources. This is due to the fact that the nitrate anion is broadly retained on the positive loads of colloids, and it tends to remain in solution for a longer period of time. In solution, nitrate leans toward the leaching process, causing the contamination of deep groundwater (Alcântara & Camargo, 2005).

3.3 | N-total concentrations

During the monitoring of leached water, the N-total concentrations (Exhibit 3) exceeded the MRL of 2.18 mg/L defined for lotic environments across all collection dates for all treatments, except at the 210 DAS point for the treatment that used the inorganic nitrogen source (urea). This demonstrates that all nitrogen sources used are potential water polluters.

This fact is extremely important as to its environmental effects. This is shown in studies that attest to the acute toxicity of nitrogenous compounds. For example, some fish and shrimp species show acute toxicity to nitrogenous compounds (ammonia, nitrite, and nitrate), according to de Campos et al. (2012) and de Melo, Ferreira, Braga, and Correia (2016). Within this context, the acute toxicity tests for nitrite, nitrate, and ammonia conducted by de Campos et al. (2012) using young pink shrimp specimens, in agreement with the methodologies of the U. S. Environmental Protection Agency to determine LC_{50}, showed that the lethal concentrations of the evaluated nitrogenous compounds were:

- Ammonia LC_{50} at 5.0 mg/L over 24 hr;
- Nitrite total mortality at 40 mg/L in 72 hr; and
- Nitrate total mortality at 250 mg/L in 72 hr.

Similarly, in a study conducted by de Melo et al., (2016) on organisms from the aquatic environment, the authors observed that the lethal concentrations of nitrite at 24 hr for the shrimp species (*L. vannamei*) ranged from 8.1 to 19 mg/L, according to variation in the acidity of the medium (from 0.6 to 3 mg/L of hydrochloric acid [HCl], respectively), that is, these are toxic nitrite concentrations that are similar to the ones found in the water samples collected from the lysimeters for the areas treated with poultry litter (14.89 mg/L), swine waste (18.37 mg/L), and urea (12.89 mg/L), which were analyzed during this experiment.

In the treatment with swine waste, elevated concentrations of N-total were observed during the beginning of the culture cycle and decreased over time. Analyses of the leached water collected from areas that received the treatments—poultry litter, swine waste, and urea—showed an increasing trend in the release of nitrogenous compounds up to 90 DAS (**Exhibit 4**), with a reduction of the release over time. According to Ernani et al. (2002), this is due to the greater immobilization of nitrogen during the first few days after fertilizer application.

The mobilization of nitrogen after the application of organic residues on the soil may last for a few months, depending on the source used; however, it is most intense during the first days after the fertilization treatment (Trinsoutrot et al., 2000). This phenomenon is

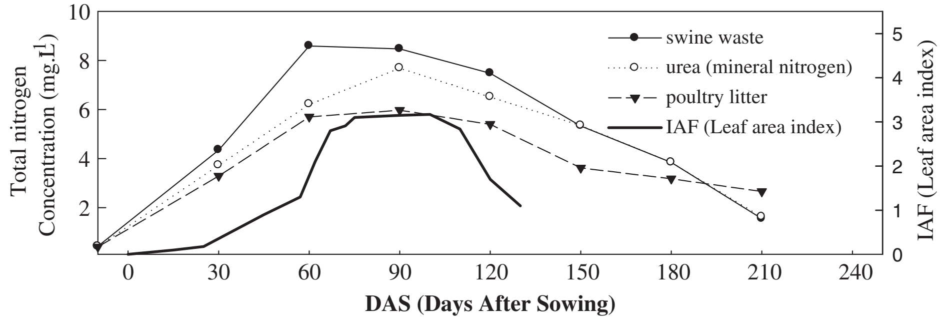

EXHIBIT 4 Total nitrogen concentration (N-total) on the leached water from the draining lysimeters, during the phenological cycle of the corn culture represented by the Leaf Area Index (LAF), on different nitrogen sources: poultry litter, swine waste (organic N), and urea (mineral N)

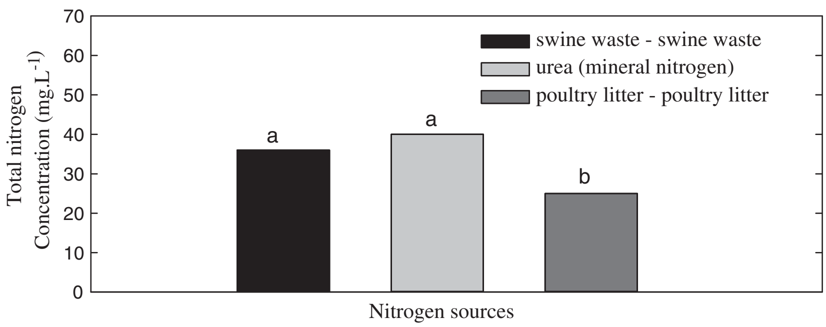

EXHIBIT 5 N-total concentration, leached on draining lysimeters, from different nitrogen sources

particularly important for agricultural crops, as it provides nitrogenous fertilization during the phenological stages with the highest demand for this nutrient. However, in opposition to the beneficial effect on the increased productivity of the cultures, the application of the nitrogen is negative regarding the quality of the leached water.

This is precisely the effect that can be observed in the table in Exhibit 3 for total nitrogen concentrations up to the 8th week after the poultry litter treatment and up to the 12th week after the swine waste and urea treatments. After these dates, the treatments showed a decreasing trend for nitrogenous compound concentrations. However, at times of greater availability of total nitrogen to the leached water, concentrations of total nitrogen were up to 3.5 times higher in the water than the MRL established by CONAMA 357/2005. Concentrations of N-total at 90 DAS were 2.5 times higher than the MRL in the water samples collected from the swine treatment area; for the urea treatment area, also at 90 DAS, concentrations were 2.18 times higher than for the poultry litter treatment.

Exhibits 3 and 4 also show that even after the physiological maturation of the corn culture and after the end of the culture cycle, a large release of total nitrogen still occurs at 210 DAS, and it is 6.21, 4.47, and 3.29 times higher than the time immediately prior to the application of the treatments. In this context, it is obvious that for the adequate use of organic fertilizer, it is necessary to understand the movement of the nutrients from the soil surface, where the fertilizers are applied. The leached N-total levels from the different nitrogen sources are shown in **Exhibit 5**.

Considering the percolated N-total values obtained after the three treatments—poultry litter (25.07 mg/L), swine waste (40.99 mg/L), and urea (35 mg/L), respectively—in addition to the aquatic ecotoxicology studies, it may be inferred that the N-total concentrations found during the present study could reach the environmental compartment of farming waters and would have highly deleterious.

It was observed that there was no statistical difference in the concentrations between the treatment with swine waste and urea. However, both of these treatments displayed a greater residual potential due to the accumulated value of total nitrogen over time. This fact is highlighted by Basso, Ceretta, Durigon, Poletto, and Girotto (2005), who emphasize the importance of using swine waste as the source of nitrogen; however, these authors have warned about the risks of water pollution. On the other hand, the N-total concentration from the treatment with poultry litter was lower than was the case with the other two treatments, showing its reduced residual potential.

Similar values to this were also observed by Pandolfo, Ceretta, Massignam, Veiga, and Moreira (2008) in relation to the use of poultry litter and swine waste. However, in relation to the inorganic nitrogen supplied through urea, Pandolfo et al. (2008) found a lower residual value over time in relation to the poultry litter and swine waste nitrogen sources, which differs from the results observed in this present study, where the nitrogen source through urea was higher in absolute values than the values observed for the poultry litter source.

Furthermore, special attention must be given to animal wastes that usually show unbalanced nutrients (Scherer, Baldissera, & Nunes Nesi, 2007) in addition to the release and transformation of the nutrients into elements that may or may not be more flexible on the soil. This was clear when nitrogen was analyzed (ammonia, nitrite + nitrate, and total nitrogen) after it comes into contact with the soil and undergoes the nitrification processes related to the activities of the microorganisms, and the nitrogen is leached through the soil by rainfall or other water application. This fact was also confirmed by Oliveira, Mattiazzo, Marciano, and Moraes (2001), who observed an increase in the ammonia and nitrate concentrations in the surficial soil layers in periods of low water availability. On the other hand, after rainfall periods, a quick leaching of these nitrogenous compounds occurred into the deeper soil layers.

4 | CONCLUSIONS

The use of swine waste and urea as sources of nitrogenous fertilization showed high leaching of ammonia and total nitrogen in the leached water samples compared to the nitrogenous fertilization offered by poultry litter. The ammonia levels leached into the water were higher at the beginning of the fertilizer application, when nitrogen was supplied through swine waste; for urea, total nitrogen levels increased up to 88 days, reducing after this period.

The lowest values of total nitrogen were observed for treatment with poultry litter, but its presence was higher at 210 days in relation to the other treatments. The N-total values released by leaching into the water samples collected during the corn culture cycle were higher than the 2.18 mg/L limit established by CONAMA number 357/2005 across all treatments (poultry litter, swine waste, and urea), showing the high level of contamination of groundwater by the nitrogenous inputs used for fertilization of the corn cultures.

The experimental results are alarming in regard to public health, as all of the fertilization treatments showed nitrite and nitrate values above the water potability standard, which, in Brazil, is defined by the Decree number 2914 from the Health Ministry from 2011.

The present study's findings indicate that care must be taken in the management of and the technical recommendations for the application of nitrogenous fertilizers for agricultural production, as the use of such fertilizers can negatively affect the quality of water used for human and animal consumption as well as for crops. As this study shows, use of these nitrogen sources produced residues that leach into the soil, creating the potential for high toxicity in groundwater used by humans, animals, and crops.

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