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Nonpoint source pollution by swine farming wastewater in bean crop

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ABSTRACT

In order to verify the environmental impact of the application of swine farming wastewater in bean crop, an experiment was set up in the Experimental Farm of PUCPR – Toledo, PR, Brazil. Runoff and soil samples were collected at the end of the experiment. Four wastewater treatments were utilized during the experiment (50, 100, 150 and 200 m^3 ha^{-1}) and the without wastewater as the control. The results demonstrate that (i) the amounts of potassium, phosphorus, and nitrogen in runoff are exponential, (ii) that phosphorus has a seven-fold polluting potential compared to potassium and three-fold compared to nitrogen, and (iii) that the mobility of potassium in the soil profile is the largest, followed by those of nitrogen and phosphorus.

Key words: water reuse, runoff, environmental pollution

Poluição difusa da água residuária de suinocultura na cultura do feijoeiro

RESUMO

Visando verificar o impacto ambiental da aplicação de água residuária de suinocultura na cultura do feijoeiro, instalou-se um experimento na Fazenda Experimental da PUCPR – Toledo, PR, Brasil; para isto, amostras do solo e do escoamento superficial foram coletadas ao final do experimento e se utilizaram quatro taxas de aplicação de água residuária durante o experimento, 50, 100, 150 e 200 m^3 ha^{-1}, sem aplicação de água residuária como testemunha. Os resultados demonstraram que: (i) as perdas de potássio, fósforo e nitrogênio no escoamento superficial são exponenciais; (ii) o fósforo apresenta potencial poluidor sete vezes maior que o potássio e três vezes maior que o nitrogênio; (iii) a mobilidade do potássio no perfil do solo é maior, seguida do nitrogênio e do fósforo.

Palavras-chave: reúso de água, escoamento superficial, poluição ambiental

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INTRODUCTION

West Paraná has very intense farming and industrial farming activity, which causes environmental problems, particularly related to hydric resources and largely to hydric erosion. These activities make this region a natural laboratory for diffuse pollution studies.

The use of swine farming wastewater in soil is a form of recycling and supplying nutrients to plants. However, the use of large amounts of runoff along with an irregular relief, or even due to rainfall on soil with little cover and low permeability is a factor that greatly contributes to the diffuse pollution of the environment. Thus, significant amounts of wastewater constituents such as nitrogen, phosphorus, and potassium may be lost to runoff. Young & Mutchler (1976) observed the loss of 25-50% nitrogen after the use of swine farming wastewater and due to intense and successive rainfall. However, the nutrient loads depend directly on the amount of wastewater applied and reduce with subsequent rainfall (Edwards & Daniel, 1993).

According to Hatfield (1998), the international literature cites nitrate leaching from the soil profile and the transport of phosphorus by runoff as the two main problems of diffuse pollution, and consequently, of water quality in farming locations. To this end, Chang & Entz (1996) evaluated the effect of the yearly use of cattle farming wastewater over the long term and showed that the levels of application and rainfall affect the concentrations of nitrate in soil. The doses studied (60, 120, and 180 m^3 ha^{-1}) resulted in a significant accumulation of nitrate in the radicular zone of rye with minimal loss of nitrogen under 1.5 m, except in high rainfall years. However, the authors showed that the nitrogen losses to runoff may reach 93-341 kg ha^{-1} under irrigation and application repeated over the recommended rate. Therefore, yearly application over the first estimated dose is not recommended in the long run under the risk of soil and water contamination, as confirmed by Ingrid et al. (1997) after two years of consecutive applications. As a result, the definition of the doses to be used as well as the interval between applications in the same area is important factors to minimize the diffuse pollution potential due to the loss of nitrogen by nitrate leaching.

According to King et al. (1990), a large part of the environmental problems related to phosphorus results from the determination of wastewater application doses based only on nitrogen content. The continued application of wastewater in the same area generally leads to the increase in phosphorus content in soil in excess of the required crop levels. Furthermore, an increase in the concentrations of phosphorus may reduce the soil adsorption capacity (Mcleod & Hegg, 1984), and it may increase the potential of phosphorus loss by lateral and vertical water flow in soil (Reddy et al., 1980).

In general, phosphorus is transported in larger amounts by runoff than by underground flow as it is strongly absorbed by soil particles, which reduces its mobility. Thus, this element tends to accumulate at the application location and is only transferred when the portion of the soil where it is located is moved (Correll, 1998; Ginting et al., 1998). In turn, potassium has larger concentrations and is more soluble and mobile in soil than phosphorus is, and consequently it is leached more easily (Bertol et al., 2004).

Although nitrogen and carbon are essential for the growth of water biota, phosphorus has received special attention in many parts of the world for it water eutrophication potential as it is a growth limiting element. While it has been demonstrated the loss of soil phosphorus to erosion water and/or runoff, phosphorus leaching has received little attention (Heathwaite et al., 2000). Comparatively to nitrate, the mobility of phosphorus in soil is very small and its leaching in farmable land is considered insignificant. Eghball et al. (1990) applied 60 kg ha^{-1} phosphorus in strips and showed that it leached to the depth of 4 cm in three types of soils. Compared to phosphorus leaching under fertilizer and organic residue application, research shows that it increases with the application of organic residues, thus evidencing the large mobility of phosphorus in the organic form in soil (Mozaffari & Sims, 1994; Eghball et al., 1996).

According to Sutton et al. (1982) and Beauchemin et al. (1996), in farming regions, it is common the continued application of wastewater and manure to farmable land, which affords a surplus and may add to the phosphorus leaching as a function of the reduced absorption capacity of soil.

Therefore, the objective of this work was to evaluate the diffuse polluting potential of the use of wastewater treated in bioreactor in bean crop considering the chemical and dynamic aspects of runoff.

MATERIAL AND METHODS

The experiment was carried out at the Experimental Farm of PUCPR – Toledo Campus, PR for 120 days in early jalo beans (75-day cycle) crop under direct plantation without chemical fertilization.

Swine farming wastewater (Table 1) was supplied by the Farming School located in Toledo, Pr after integrated biosystem (on-site bioreactor).

Twenty 2-m^2 parcels were delimited and arranged in 4 blocks and 5 treatments. In the end of the experiment, soil samples were collected in a parcel chosen at random at depths of 0-5, 5-10, 10-15, 15-20, 20-30, 30-40, and 40-60 cm and sent to laboratory for analysis of total nitrogen, phosphorus, sodium, and potassium.

Whenever there was rainfall runoff, it was sampled and kept in plastic bags duly identified and refrigerated after volume measurement. Total nitrogen, phosphorus, and potassium concentrations in runoff samples were measured. The samples were analyzed in PUCPR, Toledo Campus, PR laboratory and in Environmental Sanitation and Hydric Resource laboratory of Universidade Estadual do Oeste do Paraná (UNIOESTE), Cascavel, PR.

Four distinct wastewater treatments were carried out with rates as follows: 50, 100, 150, 200 m^3 ha^{-1} and no wastewater (control). Wastewater treatment was carried out in gradual and increasing amounts (Table 2).

Table 1. Chemical characteristics of swine wastewater

Parameters (mg L^{-1})	Bioreactor In	Bioreactor Out	Sedimentation tank Out	Application			
				1st	2nd	3rd	4th
Total Nitrogen	3200.00	1800.00	1296.00	1296.00	1272.00	1260.00	1282.00
Phosphorus	66.00	47.00	28.00	24.62	26.71	30.54	31.95
Potassium	1.40	0.80	0.51	0.49	0.45	0.51	0.54
DBO5	32425.00	2932.60	483.00	-	-	-	-
DQO	41500.00	8043.00	1967.50	-	-	-	-
Total solids	79390.00	11810.00	3800.00	-	-	-	-

Table 2. Treatment schedule

Treatment	Total Applied Wastewater	Treatment Time[(1)]			
		Sowing	12[(2)]	26[(2)]	39[(2)]
T1 (control)	0	-	-	-	-
T2	50 m^3	X			
T3	100 m^3	X	X		
T4	150 m^3	X	X	X	
T5	200 m^3	X	X	X	X

(1) Each treatment corresponds to 50 m^3; (2) DAS – Days after sowing

Results and Discussion

Rainfall occurred nine times during the experiment (rainfall). However, runoff was observed only in four occasions, at rainfalls 03, 05, 08, and 09. The simplified water balance is given in Table 3.

Table 3. Depths of rainfall, runoff and infiltration accumulation during bean crop cycle

Occurrence	DAS (days)[(1)]	Rainfall depth (mm)	Accumulated depths (mm)		
			Rainfall	Runoff	Infiltration
1	3	18.90	18.90		18.90
2	6	9.00	27.90		27.90
3	10	41.85	69.75	0.35	69.40
4	21	18.00	87.75	0.35	87.40
5	22	102.60	190.35	0.75	189.60
6	35	15.00	205.35	0.75	204.60
7	36	8.00	213.35	0.75	212.60
8	57	83.70	297.05	1.45	295.60
9	60	74.25	371.30	1.85	369.45

(1) Sown on Nov. 26th, 2006.

As shown in Figure 1, total nitrogen, phosphorus and potassium gradually increased in wastewater runoff with the increase in treatment amounts.

Shows in Figure 2 the results of concentrations of total nitrogen, phosphorus and potassium in the soil profile during the experiment.

Considering T2 to T5, the mean nitrogen increase rate in runoff is 1/1, that is, a five-fold increase in treatment leads to an equal increase in its runoff (Figure 1A).

However, it is worth noting that the behavior is exponential in regression analysis in contrast to that observed by Basso (2003), who reported a decreasing quadratic behavior for treatment rates ranging from 0 to 80 m^3 ha^{-1} in forage turnip crops in typically sandy soil with 3% slope.

Coelho (1973) reported that nitrogen, mainly in nitrate form, is soluble in soil water, does not form insoluble compounds and is relatively easy to be transported by runoff and through the soil profile. Thus, nitrogen is one of the nutrients most lost in erosion due to its high concentration in top soil layers, where erosion occurs. However, Smith et al. (2001), acknowledged that nitrogen may be lost in runoff and

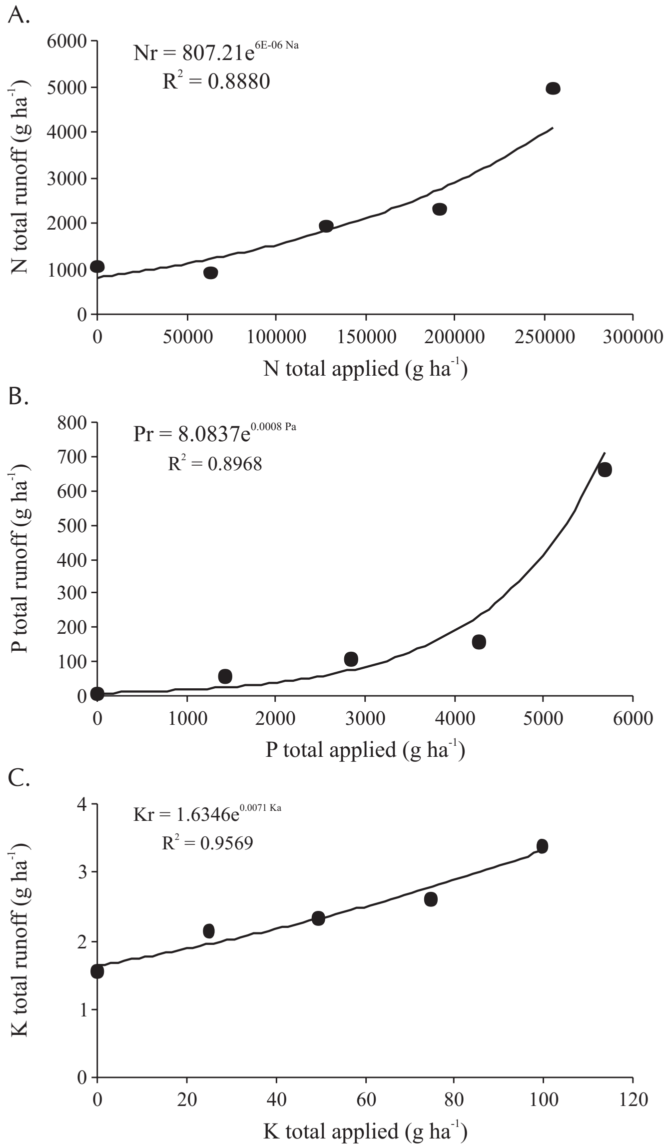

Figure 1. Total nitrogen (1A), phosphorus (1B) and potassium (1C) in runoff as a function of nutrient amounts applied through swine farming wastewater to bean crop

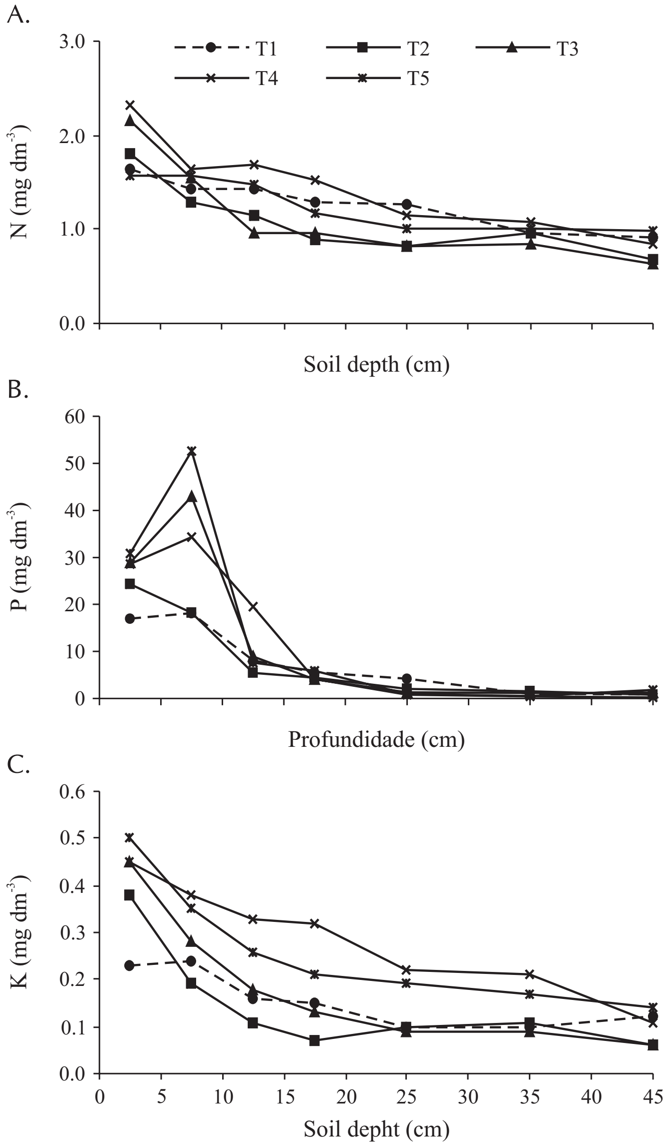

Figure 2. Total nitrogen (1A), phosphorus (1B) and potassium (1C) concentration in soil profile grown with bean crop

represent an even greater potential environmental pollutant in agricultural areas where swine farming wastewater is used, specially in large amounts, in crop fertilization in areas with pronounced slope without proper soil conservation system in association with rainfall exceeding soil water infiltration. The nitrogen losses of 25-50% after swine wastewater treatment followed by heavy and successive rains observed by Young & Mutchler (1976) are illustrative.

The analysis of Figure 2A confirms the polluting potential of swine wastewater treatment concerning its percolation and the nitrogen concentration in deep soil layers of the soil profile analyzed, which was also evidenced by Basso (2003). It is well known that the amount of organic matter in below-surface horizons is very low and that it is constituted mainly by mineral horizons.

Considering that T1 represents the original area concentrations, the hachure represents nitrogen accumulation due to swine wastewater treatment.

It can be observed in Figure 2A that in the 0-5 cm layer, all treatments result in excess total nitrogen. In the subsequent layers, large treatment amounts result in large total nitrogen accumulation to 20 cm deep.

Roth & Fox (1990), Angle et al. (1993), Daliparthy et al. (1994), Jemison & Fox (1994), Sexton et al. (1996) observed that, when the nitrogen addition exceeds the crop requirements and the crop development stage is not physiologically appropriate, a significant amount of nitrogen may leach below the plant root zone and reach ground water.

The amounts and volume of swine wastewater treatment influences the concentration of applied nitrogen directly, leading to runoff to deep soil layers, since most nitrogen in wastewater is in inorganic form (NO3), which has large mobility in soil. To this end, Chang & Entz (1996) evaluated the yearly application of cattle wastewater for a long period and demonstrated that application levels and rainfall affect nitrate concentration in soil. They concluded that applications over the recommended level (60 m^3 ha^{-1} $year^{-1}$) result in a significant accumulation of nitrate in rye crop. Therefore, according to the same authors, the yearly application of wastewater over the recommended levels for a long period is not advisable due to the risk of water and soil contamination, as also observed by Ingrid et al. (1997).

N'Dayegamiye & Côté (1989) observed the increase in organic C and total N in the top layers and small amounts in deep soil layers, probably due to the increased microbial activity resulting from wastewater treatment, as evidenced in Figure 2A. However, as the treatments were followed by rain and the soil had good humidity, it was possible to confirm the percolation of total N to deep layers of the soil under study, which reduces the risk of water and soil contamination.

The evaluation of treatments T2 to T5 showed an increase in the mean total rate of phosphorus in the proportion of 1:2.5.

Figure 2A shows that the profile of the four runoffs. Based on the data obtained, it can be observed a similar behavior for runoff phosphorus in relation to that of nitrogen, which was previously discussed, demonstrating the polluting potential of wastewater in relation to phosphorus concentration as a function of the wastewater amount applied and the environmental hazard of wastewater to water resources. Sharpley (1996) found that the concentration of inorganic phosphorus in surface water in the range 0.01-0.02 mg L^{-1} is critical as eutrophication is accelerated over this range.

Heathwaite et al. (2000) pointed out that the ideal amounts of phosphorus for the good development of commercial crops is between 0.20 and 0.30 mg L^{-1}. However, these amounts are much over the concentrations considered critical for the contamination of water resources by inorganic phosphorus. Although phosphorus is an extremely important element for the development of plants and the most limiting mineral factor in Brazilian soils, its low concentration in surface water pose a large environmental risk.

Heathwaite et al. (2000) also stated that runoff is the main responsible for phosphorus losses, which confirms the observation of Figure 1B that it increases with the increase in the amounts of wastewater applied, corresponding to concentrations of 37.9, 19.9, 16.5, 4.14, and 0.35 mg L^{-1} of total phosphorus.

Bertol (2005) evidenced that the soil treated with swine wastewater is more susceptible to phosphorus loss in relation to the soil treated with the commercial NPK formulation. It also means that the transfer of phosphorus to soil through swine wastewater poses a larger environmental risk than that of an inorganic source. Such behavior may have been due to its transport by torrents of wastewater that remained on the surface and the larger solubility of phosphorus in wastewater than those in NPK formulation and in native soil. Withers et al. (2001) evaluated the losses of phosphorus applied to soil as cattle wastewater, mineral fertilizer, and sewage sludge and concluded that phosphorus is the most soluble in cattle wastewater. This evidences the hazard of light rain on phosphorus losses, particularly in sufficient amounts to produce torrents (Quinton et al., 2001) and shortly after wastewater treatment.

It is possible to see in Figure 2B that the amounts of phosphorus on the profile top layers increases gradually with the amounts of wastewater applied. It is also possible to observe from the control that this amount increases linearly and that from 50 m^3 on, these concentrations become larger with successive treatments comparatively to that of total nitrogen. The hachured area shows a larger accumulation of phosphorus in top layers proportionally to the wastewater treatment amounts.

It is known that phosphorus is not very mobile in the soil profile due to the formation of compounds with other elements in soil such as iron, aluminum, and calcium, resulting in a phenomenon known as fixation. Fixation may occur by isomorphic substitution, adsorption, and double decomposition related to the product solubility, evidencing its concentration in top layers.

While soil phosphorus losses to water by runoff have been demonstrated, little importance has been given to its losses by leaching due to its low mobility in soil profile, as shown in Figure 2B, comparatively to that of nitrogen. Therefore, phosphorus leaching in farmable soil is considered insignificant (Heathwaite et al., 2000).

In the short run, studies by Eghball et al. (1990) evidence that phosphorus mobility of only 0.04 m in three kinds of soils. However, the work of Kao & Blanchar (1973) revealed that after 82 years of continued wastewater and fertilizer application, significant amounts of phosphorus were found at 1.0-1.4 m deep.

Although the application of phosphorus within the recommended amounts is hardly lost under the surface, treatments over crop requirements for a long period may result in phosphorus accumulation in soil. In this condition, the use of manure in amounts over crop requirement may increase phosphorus soil leaching due to reduced adsorption capacity. Sutton et al. (1982), Beauchemin et al. (1986) cited that along the years and with the irrational and unrestrained use of wastewater, the ground water contamination potential exits even with nutrients (phosphorus in this case) so far considered immobile in deep soil layers.

The observation of Figure 1C shows the potassium concentration pattern as a function of amount of wastewater applied as previously observed and discussed for phosphorus and nitrogen in soil wastewater runoff.

Treatments T2 to T5 showed an increase mean total rate of potassium runoff in the proportion of 1:0.45.

Polluting to a lesser degree, potassium may also be a major environmental hazard as it is movable in the soil profile and may leach to soil and pollute water due to unrestrained and improper use of wastewater in farming. Considering the frequently high losses of potassium in wastewater runoff, as shown in Figure 1C, it may contaminate water bodies, making water undrinkable and salinized.

Bertol et al. (2004) stated that, despite the mobility of potassium, “conservative preparation” of soil has contributed to increase the concentration of this element on soil surface, and thus, increase its transport by torrents, specially when adsorbed to sediments. The authors also strengthen that, besides the influence of the land preparation system on the nutrient surface concentration, the origin of its formation in soil also counts. Basaltic soils with frequent NPK mineral fertilization tend to present large potassium amounts along with its formation genesis and thus are more susceptible to losses in wastewater runoff.

Giacomini et al. (2003) also confirmed that the soil preparation system influences the concentration of potassium in soil directly. Bertol (2005) compared the intensity of rainfall and its correlation with potassium losses in torrents in soils treated with swine wastewater and observed that, for a given soil and its “conservative preparation” and for the same potassium concentration, the more intense the rainfall and the disaggregation of surface soil particles are, the larger the potassium runoff loss is. Thus, based on the present data, the environmental risk is directly proportional to the amounts of swine farming wastewater applied under high rainfall.

A larger mobility is observed for potassium in the soil profile comparatively to those of phosphorus and nitrogen as shown by the hachure in Figure 2C for all layers evaluated.

Figure 2C shows that the high levels of potassium in top soil layers result from the amounts of wastewater applied as potassium, as well as phosphorus, presents fixation, but mainly through adsorption in the soil exchange complex. However, as this element is movable in the profile, and according to Ceretta et al. (2003), almost all potassium in swine wastewater is soluble.

High concentrations of potassium in soil may result in its high rates of salts, thus limiting the productivity of crops and making farming unviable. This fact is not only possible but also real, mainly considering its initial concentration in the control, which did not receive wastewater treatment, in all the profile.

Conclusions

1. The behavior of runoff phosphorus, nitrogen, and potassium in response to the treatments evaluated is typically exponential.

2. The treatments demonstrate that phosphorus has a high polluting potential due to a runoff three-times as large as that of total nitrogen and seven-times as large as that of potassium.

3. The treatments demonstrated that the mobility of potassium in soil is the largest, followed by those of nitrogen and phosphorus.

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