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Applying different doses of tannin coagulated dairy sludge in soil: Influences on selected pollutants leaching and chemical agronomic attributes

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ABSTRACT

The aim of this study was to evaluate the impact of soil amendment with tannin coagulated dairy industry sludge on fertility chemical attributes and on the release of selected pollutants. To do so, we conducted soil column leaching and soil incubation experiments, with different doses of such residue. Sludge was obtained through thermal dryer or bed drying processes. The results showed that the application of the studied residues did not cause improvement in the release of evaluated pollutants (phenol, NO_3^- and Cl^-). However, for chemical attributes, like pH, value raised from 4.5 in the blank probe to 8.7 and 7.2 in the maximum doses of thermal and bed dried sludge respectively. Based on pH raising, critical doses for application of studied sludges were tested: 11.3 t.ha^{-1}for thermal processed and 64.6 t.ha^{-1}for bed dried sludge. At the critical doses, for thermally dried sludge, we observed improvements in effective cation exchange capacity (ECEC), from 3.61 cmol$_c$. dm^{-3} (in the blank probe) to 6.57 cmol$_c$. dm^{-3}, cation exchange capacity (CEC) at pH 7.0, from 6.65 cmol$_c$. dm^{-3} to 7.85 cmol$_c$. dm^{-3}, decreasing in potential acidity, from 4.23 cmol.dm^{-3} to 1.41 cmol.dm^{-3}and exchangeable aluminium was not detected since the lowest applied dose. For the bed dried sludge, at critical doses, ECEC and CEC were improved to 6.64 cmol$_c$. dm^{-3} and 7.69 cmol$_c$. dm^{-3} respectively. The potential acidity in the critical dose was 1.45 cmol.dm^{-3},and exchangeable aluminium was decreased from 0.95 cmol.dm^{-3}(in the blank probe) to 0.12 cmol.dm^{-3}. Bases saturation and organic matter (OM) content were also increased. The effects over all the studied parameters, except OM, were more perceptible for thermally dried sludge due to lime addition in the drying process. We concluded that the application of the studied residues in agriculture is a feasible option.

1. Introduction

Land application of biosolids often represents the most economic and beneficial way to dispose of these (Lu et al., 2012; Zuba Junio et al., 2015). Biosolid application as soil amender promotes enhancement in physical, chemical and biological properties of the soil (Kabirinejad and Hoodaji, 2012; Lu et al., 2012; Machado and de Barros Trannin, 2015), increasing the fertility and availability of organic matter, macro and micronutrients (Kabirinejad and Hoodaji, 2012; Zuba Junio et al., 2015).

Several studies have been conducted and have reported the feasibility of solid residuals for this application. Biosolids from a municipal wastewater treatment plant were used in banana production, and the authors concluded that these can fully replace mineral fertilization for nitrogen and phosphorus supply (Teixeira et al., 2011). Junio et al. (2015) concluded that sewage sludge compost caused changes in soil chemical properties with enhancement of organic matter (OM) and cation exchange capacity (CEC). Similarly, Kabirinejad and Hoodaji (2012) concluded that both sewage sludge or compost of this residual improved CEC, pH, OM, N, P and other nutrients in the soil.

With respect to industrial biosolids, Guimarães et al.(2012) evidenced an increase in effective cation exchange capacity (ECEC) and levels of N, Ca, Mg, and P. These authors also observed a decrease in soil acidity after application of biosolid from the gelatin industry on the soil. Using industrial sewage sludge from the dairy industry, Machado and de Barros Trannin (2015) concluded that this kind of residue can be employed as a good source of nutrients, mainly N and P, for both annual or perennial crops. They also emphasized that it is necessary to evaluate the nutritional necessities for the crop in which the residue will be applied, as well as environmental safety issues, economic aspects and the necessity for mineral supplementation.

Although the application of wastewater treatment sludges as soil

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amender represents a good option, exploiting an untapped potential, authors have also pointed to risks attached to this activity, such as the presence of heavy metals and organic contaminants in sludge composition that may accumulate in soil layers and travel up the food chain. Additionally, the presence of pathogenic microorganisms has to be considered for both industrial and sanitary sludges (Lu et al., 2012). The possibility of leaching pollutants from biosolids used as soil amenders to water bodies also needs to be taken into account. Pollutants that have high mobility through soil layers, as nitrate, present risks to the environment (Knowles et al., 2011; Lu et al., 2012; Machado and de Barros Trannin, 2015). The high presence of pollutants like N and P in water bodies leads to eutrophication (Carvalho et al., 2013) and causes risks to human health if water is used for drinking purposes (WHO, 2011).

The use of inorganic coagulants in water and wastewater treatment, specifically aluminium and iron salts, presents some drawbacks to its value as a soil amendment, due to the generation of non-biodegradable sludges. The presence of metals such as Al and Fe at certain levels in the generated sludge can causes toxicity to crops (Nava et al., 2016). On the other hand, vegetable tannin used as a coagulant for wastewater generates sludges more suitable for use as soil amender or biologic conversion, due to its organic composition (Junior et al., 2013; Souza et al., 2013)

Dairy industries produce high amounts of wastewater, up to approximately 2.5 l of wastewater per litre of processed milk (Dvarioniene et al., 2012; Slavov, 2017), and organic residues along their productive chain. Such residues are often known as biosolids, due to their predominantly organic composition (Ghimire et al., 2015), although usage of this term was initially restricted to sewage sludges (US-EPA, 1993). In fact, several studies have pointed to the feasibility of the usage of industrial biosolids as a soil amendment and linked its application to the improvement in soil fertility, as shown above. However, environmental aspects must be taken into account.

Based on this premise, the aim of this study was to examine the leaching of selected pollutants from soil amended with solid residues from a dairy industry wastewater treatment plant by conducting a soil column leaching experiment. Moreover, we studied the impact of the application of such residue on fertility chemical attributes of the soil in soil/residue incubation experiments. The applied solid residues were obtained from a dissolved air flotation (DAF) facility that uses tannin for wastewater coagulation.

2. Material and methods

2.1. Soil samples collection and characterization

The soil utilized in the experiments was an Inceptisol, sampled in the Rio Fortuna municipality, Brazil, 28°10′0.051″S 49°07′19.22″W. The sample was collected from the 0–20 cm superficial layer in a corn cultivation area, with the use of a cutting blade. After collection, samples were manually cracked, air dried and conditioned in plastic bags, and an aliquot was sent for characterization. The results of the chemical characterization are shown in Table 1.

The granulometric composition of the soil was 23% sand, 41% silt and 36% clay. Apparent density was 1380 $kg.m^{-3}$, and total porosity was 39.31%.

2.2. Obtention of sludge utilized in experiments

The study was carried out at a dairy wastewater treatment plant composed of a screening step, followed by an equalization tank, after which the wastewater is pumped to DAF equipment designed to treat $25\,m^3\,h^{-1}$. It has a $2.5\,m^2$ surface area and is operated at a $10\ m^3\,m^{-2}\,h^{-1}$ surface application rate. The microbubbles' size is about 20–25 μm diameter, and maximum recirculation rate in the system is 20%.

The coagulation and flocculation process applies a commercial tannin-based coagulant named TANFLOC SL (TANAC, Brazil). The TANFLOC SL is extracted from *Acacia mearnsii* de Wildemann (*Acácia Negra*), and its commercial solution contains 25% (w/w) of total tannin. The coagulation step is performed by the coagulant application at variable concentrations according to the turbidity of the wastewater to be clarified. Additionally, a flocculation adjuvant is applied based on a copolymer of acrylamide and sodium acrylate.

After DAF, the sludge is sent to a dewatering unit, composed of a dewatering press, and then on to a rotative heat dryer facility coupled to aboiler furnace burning gas output. At this stage, the sludge is subjected to exhaust gas temperatures (110.2–163.3 °C) until constant weight (around 6 to 12 h). In order to prevent sludge pasting on dryer walls, lime is added during the drying processes, towards the end. Dry sludge is taken out from the dryer when the moisture is 29.3 ± 12.6% (value means five replicate measurement).

For comparison purposes, we employed sludge obtained through both the heat drying process (previously explained) and the drying bed process. The sample for bed drying was taken from the same lot sent to heat drying, after the press dewatering step. Bed drying was performed in September 2016 for 21 days, under sunlight, on a plastic film at environmental conditions and protected from rainfall water. The average temperature in the region of the experiments during this time of the year was 17.3 °C and average relative air humidity 84.9%.

After the drying processes, two aliquots, one from each kind of sludge, were characterized along the parameters shown in Table 2.

2.3. Soil column leaching experiment

The apparatus for the soil column leaching experiments was constructed according to Skoronski et al.(2017), with some modifications. Our study was carried out in 0.5 m length columns and the leaching period was 12 h. This duration was selected because we aimed to evaluate only the promptly leachable selected pollutants from the residue/soil mixture.

In this experiment, we employed real rainwater from the municipality of Rio Fortuna, Brazil. The volume of rainwater applied to columns was fixed based on the last ten years' average amounts of rainfall, which was 1910 mm (from 1720.40 to 2099.60 mm, in a 95% confidence level interval), representative to the area in which the sludge was studied to be employed as a soilamendment. The rainwater presented pH values ranging from 7.39 to 7.76 and electrical conductivity

Table 1
Chemical characterization of soil utilized in experiments.

pH – H_2O 1:1	SMP[a] index	P $mg.dm^{-3}$	Ca $cmol_c.dm^{-3}$	Mg	K	Al	$H^+ + Al$	ECEC[b]	CEC[c] pH 7.0	OM[d] %
4.8	5.3	91.5	2.03	0.99	0.38	0.14	9.70	3.54	13.10	1.4

[a] Shoemaker, McLean and Pratt buffer test.
[b] Effective cation exchange capacity.
[c] Cation exchange capacity.
[d] Organic matter.