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Impact of slurry management strategies on potential leaching of nutrients and pathogens in a sandy soil amended with cattle slurry

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ABSTRACT

For farmers, management of cattle slurry (CS) is now a priority, in order to improve the fertilizer value of the slurry and simultaneously minimize its environmental impact. Several slurry pre-treatments and soil application methods to minimize ammonia emissions are now available to farmers, but the impact of such management strategies on groundwater is still unclear. A laboratory experiment was performed over 24 days in controlled conditions, with undisturbed soil columns (sandy soil) in PVC pipes (30 cm high and 5.7 cm in diameter). The treatments considered (4 replicates) were: a control with no amendment (CTR), injection of whole CS (WSI), and surface application of: whole CS (WSS), acidified (pH 5.5) whole CS (AWSS), the liquid fraction obtained by centrifugation of CS (LFS), and acidified (pH 5.5) liquid fraction (ALFS). An amount of CS equivalent to 240 kg N ha^{-1} was applied in all treatments. The first leaching event was performed 72 h after application of the treatments and then leaching events were performed weekly to give a total of four irrigation events (IEs). All the leachates obtained were analyzed for mineral and organic nitrogen, electrical conductivity (EC), pH, total carbon, and phosphorus. Total coliforms and *Escherichia coli* were also quantified in the leachates obtained in the first IE.

The results show that both acidification and separation had significant effects on the composition of the leachates: higher NO_3^- concentrations were observed for the LFS and ALFS relative to all the other treatments, throughout the experiment, and lower NO_3^- concentrations were observed for acidified relative to non-acidified treatments at IE2. Acidification of both the LF and WS led to higher NH_4^+ concentrations as well as an increase of EC for treatment ALFS relative to the control, in the first IE, and lower pH values in the AWSS. Furthermore, the *E. coli* and total coliform concentrations in AWSS, LFS, and ALFS were significantly higher than in WSI or WSS. In conclusion, none of the strategies generally used to minimize ammonia emissions impact positively on leaching potential relative to the traditional surface application of CS. Furthermore, some treatments, such as separation, might increase significantly the risk of leaching.

1. Introduction

Close to one billion tonnes of animal manure and slurry are produced within the EU each year (Marmo et al., 2009). Consequently, over the last few years, animal slurry management has become a central activity in intensive dairy, beef, and swine farms. Treatments such as solid–liquid separation and anaerobic digestion have been developed to increase the slurry value and improve management but, in most of these treatments, the final product cannot be discharged directly to water bodies and is generally applied to agricultural soils as fertilizer. However, it is well known that slurry application to soil can lead to high emissions of ammonia (NH_3) and greenhouse gases (Chadwick et al., 2011; Webb et al., 2010) and may also result in water pollution due to the leaching of nitrate (NO_3^-) or pathogenic bacteria (Amin et al., 2013; Lee et al., 2007; Mantovi et al., 2006).

Minimization of NH_3 emissions following animal slurry application to soil has been the priority over recent decades (Webb et al., 2005), since they represent not only an environmental problem (Carozzi et al., 2013; Oenema et al., 2012) but also a significant decrease of the fertilizer value of slurry (Sørensen and Amato, 2002). As a consequence, several mitigation measures have been

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proposed to minimize NH_3 emissions during and after slurry application to soil (Ndegwa et al., 2008). Animal slurry injection is considered as one of the most effective solutions to minimize NH_3 emissions at the field scale and is now compulsory in some European countries (Carozzi et al., 2013; Webb et al., 2010). Nevertheless, this technique presents several limitations (cost, not applicable in some arable soils or grassland) and band application of pre-treated slurry could be a good alternative to slurry injection. As slurry pre-treatment, acidification is considered an efficient way to minimize NH_3 emissions at the barn and field scales, although its application is still restricted to a few countries such as Denmark (Kai et al., 2008; Oenema et al., 2012). Solid–liquid separation is another possible pre-treatment for the minimization of NH_3 emissions. Indeed, some authors (Petersen et al., 2003; Sommer and Hutchings, 2001) suggested that the application of the liquid fraction (LF) obtained by solid–liquid separation instead of whole slurry (WS) may also be efficient with regard to minimizing NH_3 emissions, assuming that the LF quickly infiltrates the soil.

All three of these NH_3 abatement strategies have proved to be efficient with regard to the minimization of NH_3 emissions but little is known about their impact on leaching losses and potential water contamination. Several studies focused on the impact of animal production on the environment, in terms of water contamination (Unc and Goss, 2004), but the introduction of new tools for slurry management, namely treatments such as solid–liquid separation or acidification, may alter the leaching of the slurry elements that are affected by such treatments. Also, the leaching potentials of slurry elements will differ according to whether slurry injection or surface application is used. Hence, we believe that the impact of these new technologies needs to be evaluated, to accurately define the best option that minimizes total nutrient losses to the environment and avoids the so-called "pollution swapping". Indeed, the main risk associated with the minimization of NH_3 emissions from slurry amended soil is the high ammonium (NH_4^+) content of the amended soil, that can be quickly nitrified by soil aerobic bacteria (Cavagnaro et al., 2008). If the NO_3^- produced exceeds crop requirements, it can leach down through the soil and into the groundwater.

Our hypotheses are: i) surface application of the LF rather than WS will increase the leaching potential of nutrients and pathogens due to their greater exposure to percolating water, ii) acidification of WS or the LF will increase the leaching potential of nutrients and pathogens due to their potential solubilization and the decrease of dry matter (Fangueiro et al., 2009), iii) injection of WS will increase the leaching potential of nutrients and pathogens relative to surface application due to the position of the slurry in the soil column and/or slurry-soil contact (Bech et al., 2011; Glaesner et al., 2011). We also considered the acidification of the LF since it might prevent NH_3 emissions during storage.

The main objective of our study was to compare the impact of five slurry management strategies on the potential release of nutrients and pathogens into water, in soils amended with cattle slurry. For this, we quantified the leaching potential (proportion of applied contaminant leached) of amended soil after four simulated rain events.

2. Materials and methods

2.1. Soil sampling

Intact columns of a sandy soil were collected from an arable field located at Palmela-Portugal (N 38.57957; W 8.82954) under a typical Mediterranean climate. The soil is classified as Haplic Arenosol (IUSS, 2006). The field has not received any animal slurry in the last 12 years and is used for double cropping maize/ryegrass. For soil sampling, PVC columns (30 cm long, internal diameter 5.7 cm) were pushed into the soil to a depth of 25 cm and were then excavated by removal of the surrounding soil. The soil column was sealed at the bottom by a glass wool layer and a PVC net. The top surface of the column remained undisturbed. The soil columns were taken to the laboratory and weighed. Three of the columns were destroyed for a full characterization of the soil; the main characteristics are shown in Table 1. The soil was analyzed following standard laboratory methods (van Reeuwijk, 2002); cation exchange capacity was determined following method described by Chapman (1965).

2.2. Slurry

The cattle slurry (CS) used was collected from a dairy farm near Palmela (Portugal) and preserved at 4 °C in plastic barrels. The liquid fraction (LF) was obtained by centrifugation of the whole slurry (WS) at 4000 rpm for 10 min. The acidification of both the whole slurry (AWS) and the liquid fraction (ALF), to pH 5.5, was performed by addition of concentrated sulfuric acid (96%) at a rate of 4.5 ml kg^{-1} slurry.

The WS, AWS, LF, and ALF were fully characterized by following procedures described by Fangueiro et al. (2009). Analysis of *Escherichia coli* and fecal coliforms was performed by following a standard procedure (ISO 9308-2, 2012). The main characteristics of the different fractions are presented in Table 2. All slurry samples were stored at 4 °C until soil application.

2.3. Experimental design

Six treatments were considered: injection of the whole CS (WSI), surface application of the whole CS (WSS), surface application of the acidified whole CS (AWS), surface application of the liquid fraction (LFS), surface application of the acidified liquid fraction (ALFS), and a control without slurry application (CTR). Four replicates of each treatment were considered.

The soil columns were placed on a shelf equipped at the bottom with a funnel that allowed the recovery of the leachates. The amount of CS applied to each column was calculated in order to apply 240 kg N ha^{-1} (the maximum allowed legally in Portugal). This application rate is equivalent to 48 kg P ha^{-1} in WSS and AWS, 12 kg P ha^{-1} in LFS and 15 kg P ha^{-1} in ALFS. Slurry injection was simulated by placing the slurry in a slit (10 cm deep, 5 cm long and 2 cm wide) located at the center of the soil column. After slurry application, the slit was covered with the soil removed previously. For surface application, the different fractions were applied in a

Table 1
Soil characteristics – mean values of three replicates.

Characteristic	Unit	Value
Soil composition		
Clay	%	3.3
Silt	%	4.5
Sand	%	92.2
Porosity	$m^3\ m^{-3}$	0.45
Bulk density	$g\ cm^{-3}$	1.457
Cation exchange capacity	$cmol_c\ kg^{-1}$	2.938
Total C	$g\ kg^{-1}$	8.8
pH (H_2O)		5.7
EC	$\mu S\ cm^{-1}$	74.56
NO_3^-	$mg\ kg^{-1}$	43.4
NH_4^+	$mg\ kg^{-1}$	7.5
Total N	$mg\ kg^{-1}$	510.4
Total P	$mg\ kg^{-1}$	287.2
Available P	$mg\ kg^{-1}$	43.3