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Research article

Influence of soil structure on contaminant leaching from injected slurry

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ABSTRACT

Animal manure application to agricultural land provides beneficial organic matter and nutrients but can spread harmful contaminants to the environment. Contamination of fresh produce, surface water and shallow groundwater with the manure-borne pollutants can be a critical concern. Leaching and persistence of nitrogen, microorganisms (bacteriophage, *E. coli*, and *Enterococcus*) and a group of steroid hormone (estrogens) were investigated after injection of swine slurry into either intact (structured) or disturbed (homogeneous repacked) soil. The slurry was injected into hexaplicate soil columns at a rate of 50 t ha^{-1} and followed with four irrigation events: 3.5-h period at 10 mm h^{-1} after 1, 2, 3, and 4 weeks. The disturbed columns delayed the leaching of a conservative tracer and microorganisms in the first irrigation event compared to the intact columns due to the effect of disturbed macropore flow paths. The slurry constituents that ended up in or near the macropore flow paths of the intact soil were presumably washed out relatively quickly in the first event. For the last three events the intact soil leached fewer microorganisms than the disturbed soil due to the bypassing effect of water through the macropore flow path in the intact soil. Estrogen leached from the intact soil in the first event only, but for the disturbed soil it was detected in the leachates of last two events also. Leaching from the later events was attributed to higher colloid transport from the disturbed soils. In contrast, NO_3-N leaching from the intact soil was higher for all events except the first event, probably due to a lower nitrification rate in the disturbed soil. A week after the last irrigation event, the redistribution of all slurry constituents except NO_3-N in most of the sections of the soil column was higher for the disturbed soil. Total recovery of *E. coli* was significantly higher from the disturbed soil and total leaching of mineral nitrogen was significantly lower from the disturbed soil. Results demonstrate how manure-borne constituents injected into undisturbed soil columns respond more as expected in the field, in terms of leaching and persistence, than do the same constituents injected into typically constructed columns of disturbed soil.

1. Introduction

Soil amendment with animal slurry, a mixture of urine, feces and water, is an economical and viable option for replenishing nutrients and organic matter in cropped soils (Hjorth et al., 2010). It is also a sustaining option for recycling nutrients at the farm level. Application of animal slurry into soil, however, can potentially introduce harmful slurry-borne contaminants into the environment (Lee et al., 2007). The contaminants of land-applied slurry may take different pathways to groundwater and/or surface water bodies via direct runoff, subsurface flow, leaching and percolation depending on the local hydrology (Bech et al., 2014; Kjaer et al., 2007). Inappropriate handling of manure can cause nitrate pollution to groundwater (Mantovi et al., 2006), eutrophication to surface water (Norring and Jorgensen, 2009), pathogenic

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contamination of ready-to-eat type crops and untreated water facilities (Franz and Van Bruggen, 2008), and aquatic ecology degradation by organic pollutants like steroid hormones (Sumpter and Johnson, 2008).

Identifying the best management practices in relation to animal slurry application to agricultural fields has become very important in the effort to reduce nutrient loading to the stream, contamination of the surrounding environment, and nuisance odor (Hjorth et al., 2010; Lee et al., 2007). Reduced tillage or no-till agriculture has been increasingly practiced worldwide as a soil and water conservation practice. No-till practice reduces the opportunity of incorporation of surface-applied manure with soil, which can augment the runoff loss of nutrient and manure-borne contaminants. Slurry injection on no-till agricultural land is therefore a slurry management technique recognized as a best management practice (Dell et al., 2012). It is important to know whether soil structural condition, disturbed or non-disturbed, prior to slurry injection makes any difference in the leaching and transport susceptibility of different manure-born constituents.

Both intact (non-disturbed monolith-type) and disturbed soil (repacked columns) have been used to study transport of contaminants in soil (Das et al., 2004; Lucas and Jones, 2009). Both methods have some advantages and disadvantages as reviewed by Lewis and Sjostrom (2010). Disturbed soil is more homogeneous than intact soil. Macropore structure generated through weathering and biogeochemical activities is generally destroyed during the repacking process, altering the transport paths of water, solutes, and suspended colloids (Lewis and Sjostrom, 2010). Structural changes in the soil can crucially influence the filtering functions that reduce direct groundwater contamination (Robinson et al., 2012). Flow through macropores exerts non-equilibrium solute transport that shifts the sorption/attachment or retardation of contaminants, and, thereby, reduces the filtering effect of the soil and the time available for degradation (Jarvis, 2007; Laegdsmand et al., 2009). Presence of macropore flow under field conditions has been identified to augment manure-borne estrogen transport (Kjaer et al., 2007; Laegdsmand et al., 2009). Macropore flows are also known to influence the leaching of microorganisms (Safadoust et al., 2011).

Understanding how the environmental fate of a range of slurry-borne contaminants responds to a change in soil structure is important for soil and manure management options. A leaching experiment using both intact and disturbed soil can show the comparative effects on the environmental fate of different slurry-borne constituents. Soil sampled from a plough layer represents the critical zone of contaminant transport under field conditions because this part of the soil is the most biologically, physically and chemically active. The objective of this study was to determine if disturbing field soil structure, when constructing laboratory soil columns, significantly impacted leaching patterns of common pig slurry constituents. To this end, we quantified the leaching patterns (percent leached, retention in soil and total recovery) for intact and disturbed soil columns of commonly found contaminants in pig slurry: total organic carbon (TOC), mineral nitrogen (N), *Salmonella enterica* serovar Typhimurium bacteriophage 28B (phage) as a representative organism for viruses, *Escherichia coli* (*E. coli*) and *Enterococcus* spp. as representative organisms for pathogenic bacteria, and the summation of three types of estrogen (estrone, 17α-estradiol and 17β-estradiol) to represent steroid hormones.

2. Materials and methods

2.1. Soil and slurry

The study location was at Foulum Experimental Station (56° 29′ N, 9° 34′ E), Denmark. Fifteen intact soil columns, 20-cm long and 20-cm diameter, were collected from a crop field in a spring barley-winter wheat-spring barley rotation, as described previously in Amin et al. (2013). Soil at location is a Typic Hapludult loamy sand with a visible humic A-horizon, influenced by tillage and ranging as deep as 44 cm. Three repacked columns were prepared using soil from a single field and maintaining a consistent bulk density. Soil moisture content during repacking was at field capacity, and repacking was in accordance with the general guidelines of soil column preparation (Lewis and Sjostrom, 2010). All soil columns were saturated slowly and then drained to a soil water potential of −100 hPa (i.e., field capacity) to achieve uniform soil moisture.

To allow greater application under phosphorus-restricted nutrient management practices, the phosphorous-rich solid part of the raw animal slurry is usually separated out before land application (Hjorth et al., 2010; Liu et al., 2016). Thus, only the liquid fraction of mechanically separated swine slurry was collected from a farm near Åbøl, Denmark and stored at 2 °C until applied to the soil columns. *E. coli* and *Enterococcus* spp. in the slurry acted as model organisms for bacteria. The slurry was spiked with 1.5×10^6 PFU mL^{-1} of phage and 2 g L^{-1} of 2,6-difluorobenzoic acid (FBA; CAS RN 385-00-2; Sigma-Aldrich, Germany) before soil application to provide a model organism for pathogenic viruses and a nonreactive tracer, respectively. No significant toxicity effect of FBA on the microorganisms studied was found in a toxicity test before starting the main experiment, which agreed with the findings of McCarthy et al. (2000).

2.2. Experiment procedure

The experiment was conducted in a climate-controlled room at 10 °C. Each soil column was placed on a glass filter disc of 60–100 μm pore size and 1.6 cm thickness (ROBU, Glassfiltergerate GMBH, Germany), on top of a stainless steel plate (Fig. 1). Suction of −12.5 hPa was maintained on each soil column's lower boundary by a water-filled space between the glass filter disc and stainless steel plate and by a hanging water column in a hypodermic needle attached to the stainless steel plate (Fig. 1) (Laegdsmand et al., 2005). The filtering effect due to the combination of filter disc, steel plate and hypodermic needle was tested, and the differences in contaminant concentrations entering and leaving the below-column setup were insignificant.

The mechanically separated liquid slurry fraction was added to hexaplicate intact and triplicate disturbed soil (repacked) columns by subsurface injection at a rate of 50 t ha^{-1} (145 kg ha^{-1} mineral N and 215 kg ha^{-1} total N) as described by Amin et al. (2013). A slit was created at the center of the column surface to inject the slurry and then backfilled with soil loosely after slurry application, resulting in an injection shape, depth, and closure similar to a shallow-disk field coulter (Fig. 1). A rainfall simulator was calibrated to apply artificial rainwater (0.1 mM NaCl, 0.01 mM $CaCl_2$ ($2H_2O$), and 0.01 mM $MgCl_2$ ($6H_2O$); supplied by VWR, Denmark) to the columns at a uniform intensity of 10 mm h^{-1} (Laegdsmand et al., 2009). Four 3.5-h long separate irrigation events were applied to each of the slurry injected columns 1, 2, 3 and 4 weeks after slurry application. Triplicate soil columns without slurry injection, as control, were also exposed to similar irrigation events. The control columns were undisturbed to study the background concentration of contaminants. We used acid-washed and sterilized equipment to avoid any contamination during experiment period.

Leachates were collected in sterilized blue cap laboratory glass bottles until percolation from each irrigation event had ended. Subsamples of leachates of the first irrigation event were collected at 15, 30, 60, 120, 180, 240 min for tracer breakthrough analysis.

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