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Impact of chemically amended pig slurry on greenhouse gas emissions, soil properties and leachate

Cornelius J. O' Flynn [a], Mark G. Healy [a,*], Gary J. Lanigan [b], Shane M. Troy [c], Cathal Somers [b], Owen Fenton [b]

[a] Civil Engineering, National University of Ireland, Galway, Co., Galway, Ireland
[b] Teagasc, Environmental Research Centre, Johnstown Castle, Co., Wexford, Ireland
[c] Scottish Rural College, Roslin Institute Building, Edinburgh, UK

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ABSTRACT

The effectiveness of chemical amendment of pig slurry to ameliorate phosphorus (P) losses in runoff is well studied, but research mainly has concentrated only on the runoff pathway. The aims of this study were to investigate changes to leachate nutrient losses, soil properties and greenhouse gas (GHG) emissions due to the chemical amendment of pig slurry spread at 19 kg total phosphorus (TP), 90 kg total nitrogen (TN), and 180 kg total carbon (TC) ha^{-1}. The amendments examined were: (1) commercial grade liquid alum (8% Al_2O_3) applied at a rate of 0.88:1 [Al:TP], (2) commercial-grade liquid ferric chloride (38% $FeCl_3$) applied at a rate of 0.89:1 [Fe:TP] and (3) commercial-grade liquid poly-aluminium chloride (PAC) (10% Al_2O_3) applied at a rate of 0.72:1 [Al:TP]. Columns filled with sieved soil were incubated for 8 mo at 10 °C and were leached with 160 mL (19 mm) distilled water wk^{-1}. All amendments reduced the Morgan's phosphorus and water extractable P content of the soil to that of the soil-only treatment, indicating that they have the ability to reduce P loss in leachate following slurry application. There were no significant differences between treatments for nitrogen (N) or carbon (C) in leachate or soil, indicating no deleterious impact on reactive N emissions or soil C cycling. Chemical amendment posed no significant change to GHG emissions from pig slurry, and in the cases of alum and PAC, reduced cumulative N_2O and CO_2 losses. Chemical amendment of land applied pig slurry can reduce P in runoff without any negative impact on nutrient leaching and GHG emissions. Future work must be conducted to ascertain if more significant reductions in GHG emissions are possible with chemical amendments.

1. Introduction

The European Union Water Framework Directive (EU WFD) (European Commission (EC), 2000) aims to achieve 'at least' good ecological status for all water bodies, including rivers, lakes, groundwater, estuaries and coastal waters, in all member states by 2015. To meet this objective, Programmes of Measures (POM) must be implemented in all EU member states. In Ireland, POM are enacted by the Nitrates Directive (European Economic Community, 1991), which, amongst other measures, limits the magnitude, timing and placement of inorganic fertilizer and organic manure applications to land.

In Ireland, as part of the National Action Programme (NAP) to address the requirements of the EU WFD, the maximum amount of livestock manure that may be spread on land, together with manure deposited by the livestock, cannot exceed 170 kg nitrogen (N) ha^{-1} yr^{-1} and 49 kg phosphorus (P) ha^{-1} yr^{-1}. This limit is dependent on grassland stocking rate and soil test phosphorus (STP; based on plant available Morgan's P (Pm)). Soil P Index categories of 1 (deficient) to 4 (excessive) are used to classify STP concentrations in Ireland (Schulte et al., 2010). Phosphorus losses from P Index 4 soils have the potential to become exported along the transfer continuum within a catchment, and may adversely affect surface and groundwater quality (Wall et al., 2011). The amount by which these limits can be exceeded will be reduced gradually to zero by January 1, 2017. These new regulations will have an impact on the pig industry in particular, as it is focused in relatively small areas of Ireland, and will, in effect, reduce the amount of land available for the application of pig slurry. This may lead to the need for pig slurry export, which is energetically questionable at distances over 50 km (Fealy and Schroder, 2008).

* Corresponding author. Tel.: +353 91 495364; fax: +353 91 494507.
E-mail address: mark.healy@nuigalway.ie (M.G. Healy).

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Landspreading is currently the most cost effective treatment option for pig slurry in Ireland (Nolan et al., 2012). Due to the high concentrations of pig farming in certain areas, in the midlands and south of the country especially, the constant application of pig slurry results in certain fields (those nearest the farm or the most suitable areas for spreading (Wall et al., 2011)) becoming high in STP, which may take years-to-decades to be reduced to agronomically optimum levels (Schulte et al., 2010).

When applications of pig slurry are followed by rainfall events, incidental (short-term), diffuse transfers of P and N may occur in runoff. Losses of both P and N may also occur through leaching, which ultimately could have adverse consequences for water bodies (McDowell and Sharpley, 2001; Fenton et al., 2011; Sophocleous, 2011). Karstified aquifers, which are overlain by free-draining soils, are particularly susceptible to groundwater pollution, as they have less attenuation potential than surface runoff pathways and there is a high potential for macropore flow of dissolved and particulate forms of P (Kramers et al., 2012). In Ireland, karstified limestone covers approximately 20% of the area of the country (Daly, 2005), and much pig farming is conducted in karst-covered areas.

Chemical amendment of pig slurry has been shown to be an effective means of reducing surface runoff of P and suspended sediment (SS) by numerous researchers (Smith et al., 2001, 2004; Dou et al., 2003), but as yet, the role pig slurry amendments have to play in controlling leached losses has not been investigated. O'Flynn et al. (2012a,b) examined the effectiveness and feasibility of different chemical amendments, added to pig slurry, in reducing P, SS and metal concentrations in a series of laboratory studies, conducted first at bench scale (O'Flynn et al., 2012a) and then using a laboratory rainfall simulator (O'Flynn et al., 2012b). In the latter study, O'Flynn et al. (2012b), found additions of alum, ferric chloride ($FeCl_3$) and poly-aluminium chloride (PAC) reduced total phosphorus (TP) and SS losses in surface runoff, without posing a significant risk of metal losses.

Although there has been much work done on the chemical amendment of surface applied pig slurry, there is an absence of work investigating any potential negative impact that this may have on N and carbon (C) losses and on greenhouse gas (GHG) emissions. Brennan et al. (2012) found in a plot study that chemical amendment of dairy cattle slurry with PAC reduced ammonium-N (NH_4^+-N) runoff losses, but alum and lime led to increased NH_4^+-N losses. All amendments reduced P losses in runoff, but had no effect on nitrate (NO_3^--N) runoff losses. The Intergovernmental Panel on Climate Change (IPCC) (2007) estimates that agricultural activities, including land application of animal manures, account for about 20% of the anthropogenic global warming budget, with emissions principally comprised of methane (CH_4) from enteric fermentation and manure management and nitrous oxide (N_2O) from N application to soils. The EU 2020 Climate and Energy Package and its associated Effort-Sharing Decision (Decision No 406/2009/EC; EC, 2009) envisages reducing GHG emissions by 20% by 2020 across the whole of the EU. Whilst previous work has investigated the impact of chemical amendments to pig slurry to reduce P in runoff (O'Flynn et al., 2012a,b), no study has investigated the impact of chemical amendment of pig slurry on GHG emissions.

Therefore, the aims of this laboratory study were to investigate if chemical amendment of pig slurry: (1) reduced leached losses of N, P and C from a low P index soil, (2) resulted in changes to soil properties at different time intervals during the study period and (3) led to a reduction in GHG emissions over 28 d from the time of application.

2. Materials and methods

2.1. Slurry collection and characterisation

Pig slurry was taken from an integrated pig unit in Teagasc Research Centre, Moorepark, Fermoy, Co. Cork, Rep. of Ireland in September 2011. The sampling point was a valve on an outflow pipe between two holding tanks, which were sequentially placed after a holding tank under the slats on which no bedding materials were used. To ensure a representative sample, this valve was turned on and left to run for a few minutes before taking a sample. The slurry was stored in a 25-L drum inside a cold-room fridge at 10 °C prior to testing. The TP and total nitrogen (TN) were determined using persulfate digestion. Ammonium-N was determined by adding 50 mL of slurry to 1 L of 0.1 M HCl, shaking for 30 min at 200 rpm, filtering through No. 2 Whatman filter paper, and analysing using a nutrient analyser (Konelab 20, Thermo Clinical Labsystems, Finland). Total carbon was measured using a nutrient analyser (Biotector, BioTector Analytical Systems Ltd, Ireland). Slurry pH was determined using a pH probe (WTW, Germany). Dry matter (DM) content was determined by drying at 105 °C for 24 h. The physical and chemical characteristics of the pig slurry used in this experiment and characteristic values of pig slurry from other farms in Ireland are presented in Table 1.

2.2. Pig slurry amendment

Amendments for the present study were chosen based on effectiveness of P sequestration and feasibility criterion (cost and potential environmental impediments) determined by O'Flynn et al. (2012a,b). The amendment rates, which were applied on a stoichiometric basis, were: (1) commercial grade liquid alum (8% Al_2O_3) applied at a rate of 0.88:1 [Al:TP], (2) commercial-grade liquid ferric chloride (38% $FeCl_3$) applied at a rate of 0.89:1 [Fe:TP], and (3) commercial-grade liquid PAC (10% Al_2O_3) applied at a rate of 0.72:1 [Al:TP]. Amendments were added to slurry in a 100-mL plastic cup and mixed for 10 s. The compositions of the amendments used are shown in Table 2.

2.3. Soil collection and analysis

A sample of the plough layer (top 0.2 m) of an acid brown earth soil was collected from a tillage farm in Fermoy, Co. Cork, Republic of Ireland. The site is typical of a free draining soil, underlain by a karstified limestone aquifer. Tillage soil was chosen, as this type of

Table 1
Physical and chemical characteristics of the pig slurry used in this experiment and characteristic values of pig slurry from other farms in Ireland.

TP (mg L^{-1})	TN (mg L^{-1})	TC (mg L^{-1})	NH_4^+-N (mg L^{-1})	pH	DM (%)	Reference
620 ± 32	2940 ± 156	5860 ± 80	1739 ± 8	7.51 ± 0.08	3.02 ± 0.24	The present study
800	4200					S.I. No. 610 of 2010
1630	6621				5.77	McCutcheon, 1997,[a]
900 ± 7	4600 ± 21				3.2 ± 2.3	O'Bric, 1991,[a]

TP, total P; TN, total N; TK, total K; DM, dry matter.
[a] Values changed to mg L^{-1} assuming densities of 1 kg L^{-1}.