Chemical amendment of dairy cattle slurry to reduce P loss from grasslands

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Abstract
It is estimated that agriculture accounts for 38% of all pollution in Ireland's waterways. In recent years, there have been improvements in water quality in Ireland. The number of rivers in Ireland with good river status increased from 67% in 1997 to 71.4% in 2008. However, more work is needed in order to ensure that Ireland meets the targets set by the Water Framework Directive (WFD). This directive requires that all Irish rivers will have at least 'good status' by 2015. In fresh water environments, algal growth is phosphorus (P)-limited. An increase in soluble P concentration in surface water runoff, resulting from land application of dairy cattle slurry, may result in eutrophication of rivers and fresh water lakes. The aim of this study is to identify chemicals with the potential to reduce P and suspended sediment (SS) loss from agricultural grassland arising from the land application of dairy cattle slurry. An 'agitator test' was used to identify the optimal rates of chemical addition to slurry to reduce soluble P and to estimate associated costs. The best chemical treatments – alum and lime - were then used in laboratory rainfall simulation experiments. Compared to a slurry-only treatment (the study control), alum was best at reducing dissolved reactive phosphorus (DRP) in surface runoff. It reduced mean flow-weighted concentration (MFWC) of DRP by an average of 80% over 3 successive rainfall events, compared to 73% for lime. Lime-amended slurry resulted in greatest reduction in SS and total and particulate P. Lime reduced the MFWC of total P (TP) loss by an average of 85% and particulate P (PP) by over 89%, compared to the study control. Alum reduced TP loss by 53% and PP by over 45%.

Key Words
Phosphorus loss, aluminium chloride, ferric chloride.

Introduction
Repeated application of organic and mineral fertilizer causes soil test phosphorus (STP) to build up in the soil and, during rainfall events, may cause nutrients to be released to surface runoff (Watson *et al.* 2007).Runoff from grassland pastures and meadow fields following slurry application can result in incidental phosphorus (P) and suspended sediment (SS) losses, and has the potential to transport nutrients to surface water (Kleinman and Sharpley 2003; Volf *et al.* 2007). This may result in eutrophication of rivers and fresh water lakes (Carpenter *et al.* 1998). 'Incidental P loss' is the term given to P losses that occur shortly after manure application. Dairy cattle slurry is an excellent source of nutrients and land spreading is the most efficient means of disposal. It is critical that manure is spread effectively and efficiently to minimise P losses. Present agricultural practice in Ireland is governed by The European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2009 (S.I. No. 101 of 2009), which places a responsibility on the individual farmer and the public authority to adhere to the conditions set out within the Nitrates Directive (91/676/EEC; EEC, 1991). The Water Framework Directive (WFD) (2000/60/EC; EC, 2000) requires that all Irish rivers will have at least 'good status' by 2015. Individual farmers are required to maintain records of activities with regard to soil testing, storage capacity, nutrient management, minimum storage period, and periods when application to land is prohibited. Chemical amendment of slurry for the control of P is not currently considered a mitigation method in Ireland. However, the WFD recommends research and development of new pollution mitigation measures to achieve the 2015 target. The objective of this work is to examine – at laboratory scale - the effect of chemical amendments on SS release and P loss from grassland following land spreading of dairy cattle slurry.

Methods
Soil sample collection and analysis
The soil samples used in the flume study were collected from a site on a Teagasc research farm in Athenry, Co. Galway (West Ireland). The site chosen is part of an extensively operated farm with undulating terrain. The site contains poorly-drained soils with an impermeable clay layer beneath the topsoil. The soil has a Mehlich 3-P (MP-3) of 48.85± 1.86 (Mehlich 1984) and a pH of 5.85± 0.04. A laboratory flume was built to

accommodate relatively undisturbed grassed soil samples. Intact grassed sods were cut in 300-mm-wide by 600-mm-long by 80-mm-deep sods using a spade and placed on plastic-covered boards. They were then transported to the laboratory. The grassed soil sods were stored at 11°C in a cold room prior to testing. Immediately prior to the start of each flume experiment, the sods were trimmed and placed in the flume; each slab was butted against its adjacent slab to form a continuous surface. Molten candle wax was used to seal any gaps along the flume. Experiments were conducted in duplicate (n=2) within 10 days of soil collection.

Slurry collection and analysis
Dairy cattle slurry from replacement heifers was used in this study. The slurry tanks were agitated until the slurry was homogenized, and slurry samples were collected in 10-L drums and transported to the laboratory. Slurry samples were stored at 4°C until immediately prior to the start of the test. Total P (TP) of slurry was measured (after Byrne 1979) during the study to allow for any variation. Slurry pH was determined using a pH probe (WTW, Germany). Change in slurry pH and water extractable phosphorus (WEP) (after Kleinman *et al.* 2007), due to chemical amendment, was measured.

Agitator test and rainfall simulation experiment
The agitator test is a simple test that has been be used to investigate the release of P from soil (Mulqueen *et al.* 2004). This test comprises an intact soil specimen, overlain with deionised water, into which a paddle is placed. The paddle is rotated to simulate the movement of water over the soil surface in a runoff event.
A runoff experiment was designed to compare the nutrient loss from chemically-amended dairy cattle slurry subjected to low-energy rainfall. This experiment used two laboratory flumes, 200-cm-long by 22.5-cm-wide by 5-cm-deep with side walls 2.5 cm higher than the soil surface, and 5-mm diameter drainage holes located at 300-mm-centres in the base. Cheese cloth was placed at the base of each flume before placing the sods to prevent soil loss. The packed sods were then saturated using a rotating disc, variable-intensity rainfall simulator (after Williams *et al.* 1997), and left to drain for 24 hr before the experiment commenced. All sod samples were approximately at field capacity prior to the commencement of each treatment. The rainfall simulator consisted of a single 1/4HH-SS14SQW nozzle (Spraying Systems Co., Wheaton, IL) attached to a 4.5-m-high metal frame, and calibrated to achieve an intensity of 11.5 mm/h and a droplet impact energy of 260 kJ/mm/ha at 85 % uniformity. The source water for the rainfall simulations was potable tap water with a maximum dissolved reactive P (DRP) concentration of 0.005 mg/L. During each rainfall simulation, the drainage holes were sealed to better replicate field conditions and to ensure that overland flow occurred at this rainfall intensity. Surface runoff samples were collected in 5-min intervals once runoff began. Each rainfall simulation comprised 3 successive 1-hr rainfall events at time zero (Rainfall 1), after a 1-hr interval (Rainfall 2) and after a 24-hr interval (Rainfall 3) to determine the effect of storm interval on the effectiveness of chemical amendments in reducing P and SS loss via surface runoff.

Chemical amendments
The chemicals being studied in the agitator test were: industrial grade alum ($Al_2(SO_4)_3.nH_2O$), aluminium chloride ($AlCl_3$), ferric chloride ($FeCl_2$) and lime ($Ca(OH)_2$). Alum and lime were the most successful and cost-effective treatments and they were investigated in the rainfall simulation study. Four treatments were examined in the rainfall simulator: (i) dairy cattle slurry (the study control); (ii) alum; (iii) lime and (iv) grassed soil-only (data not shown). Dairy cattle slurry and amended slurries were applied to the soil in the flume at a rate approximately equal to 26 kg TP/ha. Alum (0.68:1 Al: TP stoichiometric rate) and lime (10:1 Ca: TP) were applied to slurry and mixed rapidly (10 min at 100 rpm) before land application. The slurry or chemically-amended slurry was applied to the grass surface using a funnel. The slurry was then spread on the soil surface using a flexible plastic tray. This spread the slurry in a manner similar to what is observed when slurry is landspread using a downwards-facing splash plate.

Runoff analysis
Immediately after collection, runoff water samples were filtered (0.45µm) and analysed colorimetrically for DRP using a nutrient analyser (Konelab 20, Thermo Clinical Labsystems, Finland). A duplicate filtered sample was frozen at -20°C and later analysed for total dissolved P (TDP). Unfiltered runoff water samples were frozen at -20°C until TP was measured. TP and TDP were determined using acid persulphate digestion. Particulate phosphorus (PP) was calculated by subtracting TDP from TP. SS was determined for all samples by vacuum filtration of 50 ml of well-mixed runoff water through Whatman GF/C (pore size 1.2 µm) filter paper. All samples were tested in accordance with the Standard Methods (APHA 2005).

Results

Agitator test results

Chemical aamendments and application rates for the flume experiments were based on results of agitator tests. Alum was the most cost-effective treatment, capable of greater than 90% reduction in soluble P in overlying water. Aluminium chloride and iron chloride were also successful. However, they cost 3 times as much as alum. Lime was also very effective; reducing soluble P in overlying water by 81% at a 10:1 Ca: TP ratio.

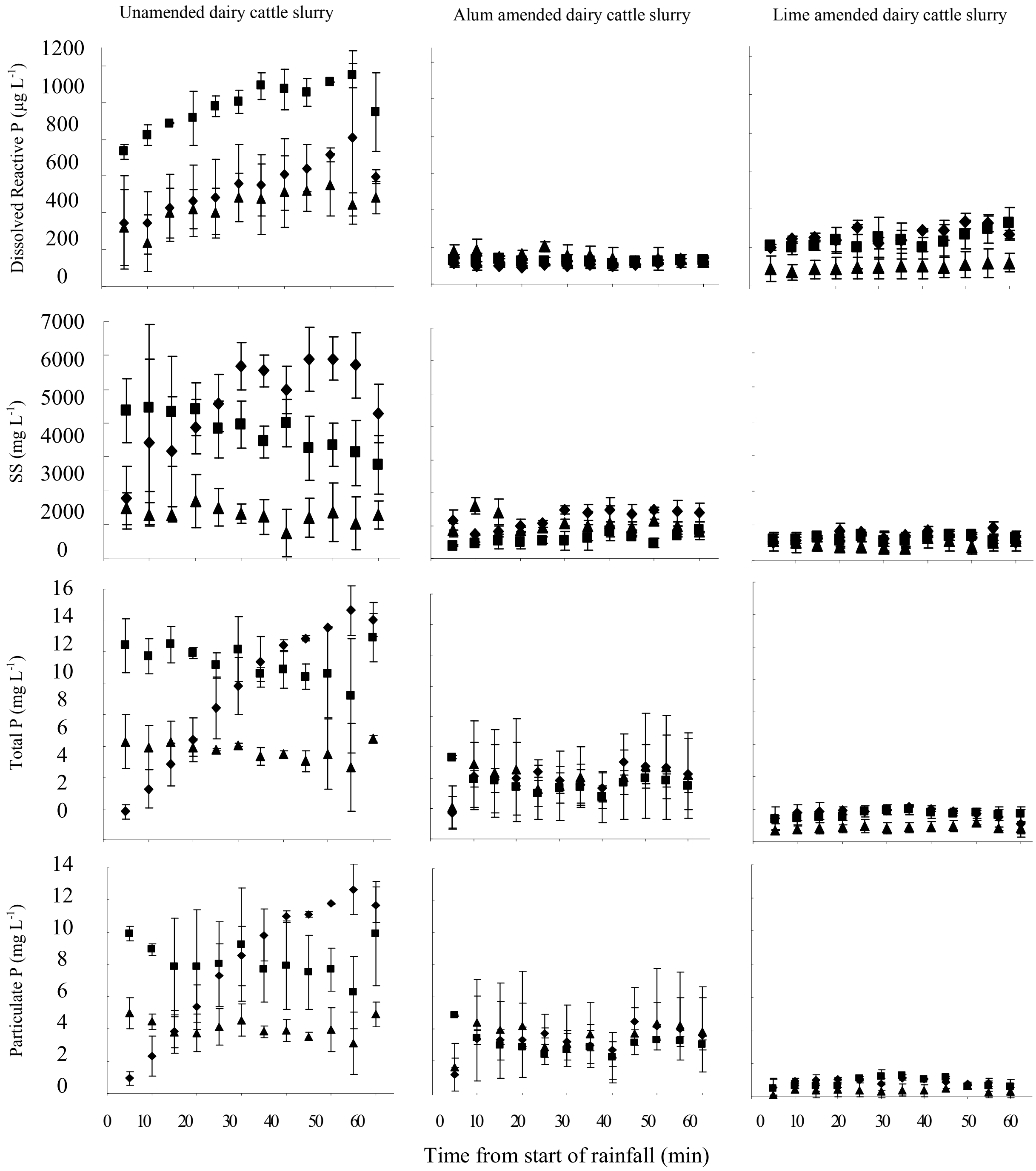

Figure 1. Dissolved reactive phosphorus, suspended sediment, total phosphorus and particulate phosphorus for dairy cow slurry, alum amended dairy cow slurry and lime amended dairy cow slurry. (Rainfall event 1 (♦), Rainfall event 2 (■) and Rainfall event 3(▲)).

Rainfall simulator experiments

The slurry used in this study had a dry matter (DM) of 9.94± 0.2%; TP, 5920± 215 mg/L; WEP, 3.26± 0.76 mg g^{-1}; and a pH of 7.2± 0.2 (n=4). The costs of treatments are estimated based on a dairy farm with 100 cows, or equivalent stock, with a 16-wk winter (average values S.I.101 (2009).) The slurry density was 0.94± 0.2 g cm^{-3}. The change in pH and WEP after 24 hr as a result of chemical addition is shown in Table 1.

Alum addition resulted in best reduction in DRP in runoff. At a rate of 0.68:1 Al: TP, alum reduced the mean flow-weighted concentration (MFWC) of DRP by 87% during Rainfalls 1 and 2, and by 66% during Rainfall 3. Lime addition reduced the DRP MFWC by 67% during Rainfall 1, 76% during Rainfall 2, and by 77% during Rainfall 3. The average of DRP MFWC for the 3 rainfall events was 127 µg/L for alum-amended dairy cow slurry, 203 µg/L for lime-amended dairy cow slurry and 751 µg/L for dairy cow slurry. The DRP MFWC for a grass only was 134 µg/L. Lime was best at reducing SS lost from the flume, lowering it by 83%, 85% and 64% in the 3 successive rainfall events compared to 60%, 86% and 21% with alum. Lime was also best at reducing TP and PP loss from the flume. Lime reduced MFWC of TP loss by an average of 85% and PP by over 89%. Comparatively, alum reduced TP loss by 53% and PP by over 45%.

Table 1. Application rate, cost of treatments, slurry pH and WEP immediately after addition.

Chemical	Cost/tonne € / tonne	% reactive agent	Metal: TP	Cost / cow € / cow	pH slurry	WEP slurry mg/g
Alum	125	4.2	0.68: 1	10.70	5.7± 0.3	0.15± 0.12
Lime	280	53	10: 1	28.10	11.5± 0.4	0.18± 0.15

Conclusion

There is potential for use of alum or lime to reduce P loss resulting from land application of dairy cattle slurry. Alum and lime reduced incidental losses of DRP, SS, TP and PP for each of 3 successive rainfall events. Alum addition resulted in the greater reduction in DRP in runoff. However, it was not as effective as lime at reducing SS, TP and PP. Work is required to investigate long-term effects of these treatments.

Acknowledgments

Authors wish to express gratitude to Teagasc for funding this project through Teagasc Walsh Fellowship.

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