Managing slurry applications to minimise nitrogen and phosphorus losses in drainage waters from clay soils

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Introduction

An estimated 47 million tonnes of livestock slurry supplying *c*.210,000 tonnes of nitrogen (N) and *c*.50,000 tonnes of phosphorus (P) are applied to agricultural land in the UK each year (Williams *et al*., 2000). These applications are a valuable source of plant available nutrients, however, they also pose a significant risk of diffuse pollution of surface and ground waters. It has been estimated that agriculture contributes around 60% of nitrate and 25% of P entering water systems in England (Defra, 2007).

On clay soils, manures are commonly applied in the autumn when soils are dry and can carry the weight of heavy application machinery, without causing damage to the soil structure. However, autumn application timings are widely recognised as presenting the greatest potential risk of diffuse nitrate pollution, as crop N uptake is generally low and over-winter drainage means that applied manure readily available N (after nitrification from ammonium-N to nitrate-N) can be washed out of the soil. Later manure application timings (i.e. in winter and spring) will reduce nitrate leaching losses compared with autumn applications, as the volumes of over-winter drainage following application are lower and colder winter temperatures inhibit the nitrification of ammonium-N to nitrate-N. However, on drained land (which covers *c*.6.4 million hectares of England and Wales) the rapid transfer of water from the soil surface to field drains, via soil macropores ('by-pass flow'), could potentially lead to high nutrient concentrations and losses (particularly of ammonium-N and P) following slurry application.

This paper reports results from a three year study to quantify the effects of different cattle slurry application timings on N and P losses in drainage waters from a drained clay soil under arable cropping and grassland management.

Materials and Methods

The experiment was undertaken at the Brimstone Farm hydrologically isolated plot facility, near Faringdon in Oxfordshire (England). The site consists of 18 hydrologically isolated plots (40 m x 48 m) on a heavy clay soil of the Denchworth Association (54% clay). The site had been in continuous arable cropping for over 20 years, before grass was established on 9 of the plots in August 2001. The soils are drained with pipe drains at 1 m depth and 48 m spacing, and have gravel backfill to within 30 cm of the soil surface, with secondary mole drains (at 2 m spacing and 50 cm depth) periodically drawn at right angles to the pipe drains.

Cattle slurry was applied to the arable and grass plots in autumn (August-October), winter (November-January) and spring (February-April) in the 2003/04, 2004/05 and 2005/06 cropping years, with 3 replicates of each application timing. The cattle slurry was applied using an 11 m^3 Joskin tanker fitted with a 12 m trailing hose boom, at a rate of *c*.45 m^3/ha, supplying *c*.120 kg/ha total N (*c*.60 kg/ha ammonium-N) and *c*.20 kg/ha total P (of which *c*.20% was water soluble). Drainflow volumes were measured continuously and drainage water samples were collected on a flow proportional basis, using automatic water samplers, and analysed for nitrate-N (NO_3-N) ammonium-N (NH_4-N) and total dissolved P (TDP).

Results and Discussion

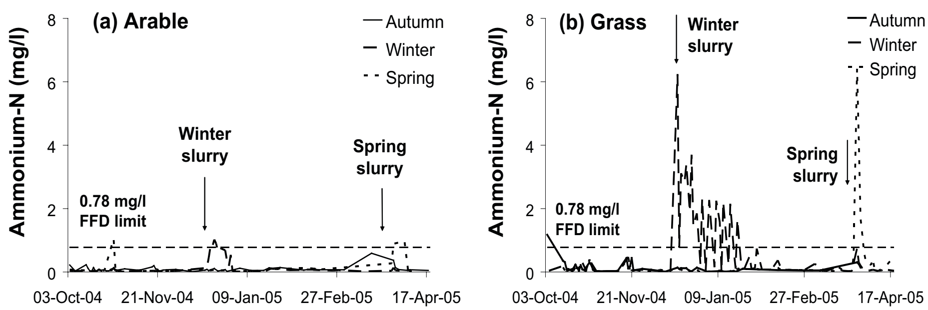
Nitrogen losses

The autumn slurry application timings to the arable plots resulted in the highest (P<0.05) drainage water NO_3-N concentrations (with peak concentrations 20-30 mg/l NO_3-N greater than from the control plots). There was no effect (P>0.05) of slurry application timing on drainage water NO_3-N concentrations from the arable reversion grassland plots, which were generally close to or below the 11.3 mg/l NO_3-N EC limit.

The autumn slurry application timings, which were applied before the soil reached field capacity (i.e. before the soil began to drain), generally did not increase NH_4-N concentrations in drainage waters at the start of drainflow (concentrations <0.2 mg/l NH_4-N, with the exception of a 1.2 mg/l peak NH_4-N concentration from the grassland plots in 2004). However, on both the arable and grassland plots following slurry applications in winter and spring, there were large peaks in NH_4-N concentrations (up to 6.3 mg/l NH_4-N), where slurry was applied to 'wet' soils (<20 mm soil moisture deficit) and significant rainfall (typically >10 mm) followed soon afterwards.

In 2003/04, heavy rainfall (c.20 mm) 9-12 days following the spring slurry application resulted in peak NH_4-N concentrations of 3.9 and 4.5 mg/l from the arable and grassland plots, respectively. The winter slurry application had no effect on NH_4-N concentrations, reflecting the 'dry' soil conditions when the slurry was applied in December 2003 and lack of drainflow soon after application. In 2004/05, heavy rainfall soon after both the winter (21 mm 1-2 days following application) and spring (30 mm 6-7 days after application) slurry applications to 'wet' soils (i.e. soil moisture deficit <20 mm) resulted in peak NH_4-N concentrations of 6.3 mg/l from the grassland plots (c.8-fold greater than the EC Freshwater Fish Directive limit of 0.78 mg/l NH_4-N) and 1.0 mg/l from the arable plots (Figure 1). Similarly in 2005/06, heavy rainfall (c.20 mm) 1-2 weeks after the winter slurry application timing resulted in peak NH_4-N concentrations of 2.8 and 5.2 mg/l from the arable and grassland plots, respectively, and following the spring slurry application in late April 2006 (10 mm of rain fell 5-6 days after application) peak NH_4-N concentrations of 4.5 mg/l were measured from the arable plots. In contrast on the grassland plots, the spring slurry application did not increase drainage water NH_4-N concentrations, which was most probably a reflection of the greater soil moisture deficit under the actively growing grass sward which did not generate drainflow, compared with 'wetter' soil conditions (and drainflow generation) under the immature winter wheat crop.

Figure 1. Ammonium-N concentrations in drainage waters (2004/05) from (a) arable and (b) grassland plots following autumn, winter and spring cattle slurry application timings



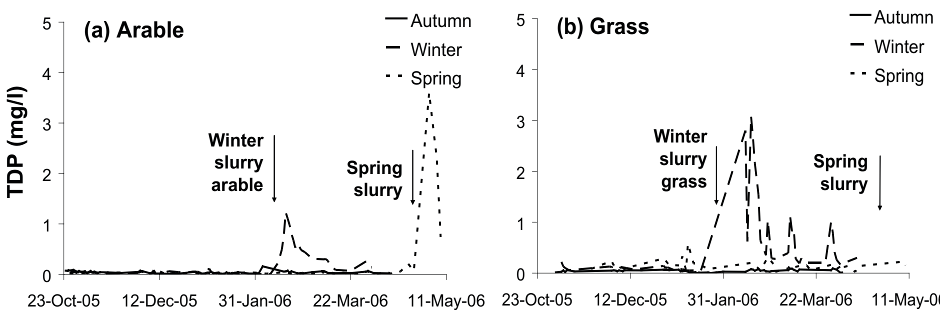
Ammonium-N is usually strongly adsorbed to soil colloids and is relatively immobile within the soil. Following the autumn slurry application timings, NH_4-N is likely to have been either adsorbed onto the soil matrix and/or transformed (within a few days) to NO_3-N, via the microbially mediated process of nitrification. The elevated NH_4-N concentrations in drainage waters, where heavy rainfall (typically >10 mm) followed soon after slurry application to 'wet' soils in the winter and spring (i.e. soil moisture deficit <20 mm), indicates that slurry NH_4-N moved rapidly from the soil surface to field drains, via 'by-pass' flow in cracks/mole drains, with little interaction with the soil matrix. There was some evidence (particularly in 2004/05) of higher NH_4-N concentrations in drainage waters from the grassland than the arable plots, which was most probably a reflection of greater connectivity on the grassland plots between the soil surface and field drains, as a result of 'by-pass' flow in cracks/mole channels, than on the cultivated arable plots.

Phosphorus losses

The autumn slurry application timings had no measureable effect on TDP concentrations in drainage waters from both the arable and grassland plots. However, on both the arable and grassland plots following slurry applications in winter and spring, there were large peaks in TDP concentrations (of up to 7.3 mg/l TDP), where slurry was applied to 'wet' soils (i.e. soil moisture deficit <20 mm) and rainfall (typically >10 mm) followed within 10-20 days of application (Figure 2).

TDP concentrations in drainage waters followed a similar pattern to the NH_4-N concentrations. In 2003/04, following the spring slurry application timing, drainage waters TDP concentrations peaked at 1.3 and 1.6 mg/l from the arable and grassland plots, respectively, when *c*.20 mm of rain fell 9-12 days after the slurry was applied. In 2004/05, 21 mm of rainfall 1-2 days following the winter slurry application resulted in peak drainage water TDP concentrations of 2.0 mg/l from the arable plots and 7.3 mg/l from the grassland plots. Similarly, 30 mm of rainfall 6-7 days following the spring slurry application resulted in peak drainage water TDP concentrations of 0.68 mg/l from the arable plots and 5.2 mg/l from the grassland plots. In 2005/06, heavy rainfall (*c*.20 mm) 1-2 weeks after the winter slurry application resulted in peak drainage water TDP concentrations of 1.2 and 3.1 mg/l from the arable and grassland plots, respectively (Figure 2). Similarly, following the spring slurry application at the end of April, 10 mm of rain fell 5-6 days after application and resulted in a peak TDP concentration of 3.6 mg/l from the arable plots. However, as observed for NH_4-N, there was no measureable increase in TDP concentrations from the grassland plots following the spring slurry application. Again, this was most probably a reflection of the greater soil moisture deficit under the actively growing grass sward, compared with 'wetter' soil conditions (and drainflow generation) under the immature winter wheat crop.

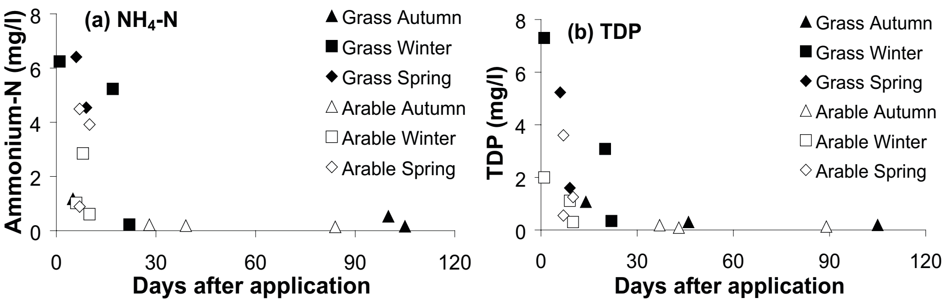
Figure 2. Total dissolved phosphorus concentrations in drainage water (2005/06) from arable (a) and grassland (b) plots following autumn, winter and spring cattle slurry applications



TDP concentrations in drainage waters were greater from the grassland than arable plots in all three years. This was most probably a reflection of greater connectivity on the grassland plots between the soil surface and field drains, as a result of 'by-pass' flow in cracks/mole channels, than on the cultivated arable plots.

The highest drainflow NH_4-N and TDP concentrations were measured where slurry was applied to 'wet' soils (soil moisture deficit <20 mm) and significant rainfall (typically >10 mm) followed, usually within 10-20 days of slurry application (Figure 3). These data indicate that following slurry application a soil 'residence time' of 10-20 days is required to guard against elevated drainflow NH_4-N and TDP concentrations.

Figure 3. Relationship between peak (a) NH_4-N and
(b) TDP concentrations in drainage waters and the number of days after slurry application



Conclusions

The autumn slurry application timings which were made before the soil reached field capacity generally had no measureable effect on drainage water NH_4-N or TDP concentrations. However, slurry application timings to 'wet' soils (in winter and spring) resulted in elevated drainage water NH_4-N and TDP concentrations. The highest NH_4-N and TDP concentrations were measured where slurry was applied to 'wet' soils (soil moisture deficit <20 mm) and significant rainfall (typically >10 mm) followed, usually within 10-20 days of slurry application. These data indicate that winter slurry application timings are likely to pose the greatest risks of elevated NH_4-N and TDP concentrations in drainage waters, as during this period soils are typically 'wet', and slurry derived NH_4-N and TDP can be transported rapidly from the soil surface to field drains, via cracks/mole drains, with little interaction with the soil matrix. And conversely, spring slurry application timings to soils with a moisture deficit of >20 mm (when significant rainfall does not occur in the following 10 days), are not likely to result in elevated drainage water NH_4-N and TDP concentrations.

References

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