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Recession of phosphorus and nitrogen concentrations in tile drainage water after high poultry manure applications in two consecutive years

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ABSTRACT

High application rates of poultry (*Gallus gallus domesticus*) manure can impair drainage water quality through enhanced leaching of phosphorus (P) and nitrogen (N). In two years with application rates of broiler chicken manure corresponding to 99 and 79 kg P ha^{-1} year^{-1} to a tile-drained field with loamy soil in SW Sweden, mean concentrations of dissolved reactive P (DRP) were significantly higher ($p < 0.05$) elevated in peak water flows in the two winter periods than in 19 previous years without manure application of any kind. With the water sampling strategy used, this effect was observed 5 and 4 months after application, when 160 and 140 mm of water, respectively, had discharged. Flow recession of distinct peak flows was illustrated as exponential decay to time, with half-life 48 h, while recession of elevated DRP concentrations had approximately 2 h half-life. In the following 12 years, only moderate amounts of mineral P were applied (on three occasions) to this topsoil with 11% degree of P saturation measured in acid soil extract (DPS-AL). Mean DRP concentrations in peak, base and intermediate flow in that period were moderate, i.e. similar to those before manure application. In contrast, high concentrations of nitrate N (NO_3-N) in peak, base and intermediate flows occurred in the 8-year period following manure application. Mean NO_3-N concentration in peak flows decreased approximately linearly, by 5.6 μg L^{-1}, for every mm of total water discharge. Thus poultry manure should not be applied in repeated high loads in order to avoid the risk of enhanced P leaching losses during subsequent peak flows. Furthermore, N leaching losses during peak and base flow conditions can persist for longer than a 5-year crop rotation and were shown here to recede at a slower relative rate than P.

1. Introduction

The highly eutrophied state of the Baltic Sea and implementation of the EU Water Directive have focused attention on the need to control phosphorus (P) and nitrogen (N) losses to water from agricultural land and identify possible solutions to mitigate such losses. In Sweden, leaching of P and N in drainage water has been identified as the primary pathway of emissions from agricultural land and it mainly takes place in October–April. Once soil P concentrations become elevated by excessive fertilisation or manure application, high levels of P leaching losses may follow (e.g. Kleinman et al., 2005; Kang et al., 2011) and can continue for many years (e.g. Buda et al., 2012).

Excessive application of poultry manure to cropping systems can result in nitrate-nitrogen (NO_3-N) leaching and contamination of groundwater, as shown, e.g. on a sandy loam in the US (Bitzer and Sims, 1988). Significant leaching may also occur from the manure itself, with tracer experiments showing that 25% of N was leached from ^{15}N-labelled poultry manure applied at a rate of 100 kg N ha^{-1} (Bergström and Kirchman, 2004). Elevated leaching of N several years after incorporation of solid manure into the soil at the wrong time for the crop has frequently been demonstrated (e.g. Thomsen, 2005). Application of moderate loads of manure to recently drained clay soils also carries a risk of P leaching (Hodgkinson et al., 2002). Bypass or preferential flow via soil macropores represents one of the major transport mechanisms of P leaching through structured clay soils (Flury et al., 1994; Stamm et al., 1998) and is commonly suggested as an explanatory factor for high leaching of P, in dissolved reactive (DRP) form, from manure-amended structural soils (e.g. Schelde et al., 2006). Such flows may also be a major concern in loamy soils (Van Es et al., 2004; Kleinman et al., 2009).

After peak flows, P concentrations in tile drain discharge generally decrease depending on the flow, while nitrate concentrations may be depleted more as a dilution effect (Hergert et al., 1981). In laboratory lysimeter experiments, the recession of P concentration over time after poultry manure application to a silty loam has been

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described as a power function (McDowell and Sharpley, 2004). In that experiment, the decline in DRP concentration was faster in high flow than low flow conditions and after three years fast flow DRP was predicted to fall below 0.01 mg L^{-1}. However, Leytem et al. (2005) stress the importance of biomass activity in the topsoil for reducing the soluble P content in the topsoil. A long-term high risk of P leaching is also created by high P saturation of the subsoil, causing subsoil desorption of P (e.g. Brock et al., 2007). This factor is especially important for sandy soils with less preferential flow, but a long water residence time in the subsoil. As an example of this risk, application of broiler manure in litter form (sawdust bedding) at a rate of 100 kg P ha^{-1} $year^{-1}$ for four consecutive years to a sandy loam was found to result in a degree of P saturation in the soil exceeding the threshold value of 30% (Butler and Coale, 2005).

Since 1988, Sweden permits a maximum application of 22 kg P ha^{-1} $year^{-1}$ with animal manure over a 5-year period (average for the farm). This load corresponds approximately to the P content in the manure produced annually by 1.6 dairy cattle or by 470 slaughter chickens (7 batches per year) (SJVFS, 2013:40). In practice, farmers apply animal manure depending on choice of crops grown, other competing work tasks and distance between fields and manure storage. On farms with the maximum permissible livestock density in particular, this strategy can result in high loads of P being applied to certain fields. In the plains district of southern Götaland, 5% of fertilised arable land receives a mean dose of 40 kg P ha^{-1} with animal manure (SCB, 2006; Djodjic and Kyllmar, 2011). In order to reduce the risk of NO_3-N leaching, spring application before sowing is recommended for animal manure when a large part of the N present may be in ammonium form. In practice, farmers apply animal manure in autumn to winter crops, especially winter wheat. About half the area of winter crops on livestock farms in Sweden receives manure slurry in autumn (SCB, 2006). Based on the EU Nitrate Directive, this practice has been questioned in view of the increased risk of nitrate leaching, but should also be questioned concerning P leaching. Distinct and frequent rain episodes are usually followed by peak flows from tile drains, and several studies have demonstrated the importance of not applying manure in conjunction with these peak flows in order to avoid increased P leaching (e.g. Van Es et al., 2004). Previous studies on the timing of manure application have usually been conducted with liquid manure. In one of the few studies using solid manure, separated from liquid pig manure and applied to sandy soil, it was suggested not to increase the risk of P leaching (Sørensen and Rubæk, 2012). However, there is a need to analyse nutrient leaching following repeated high applications of all types of solid manure, especially to soils with a risk of preferential flow. For such soils, P sorption conditions in the subsoil are less important, but other influencing factors need to be identified. These factors should then be considered in fertilising strategies in all types of livestock production and for all types of soils, in order to decrease the risk of eutrophication.

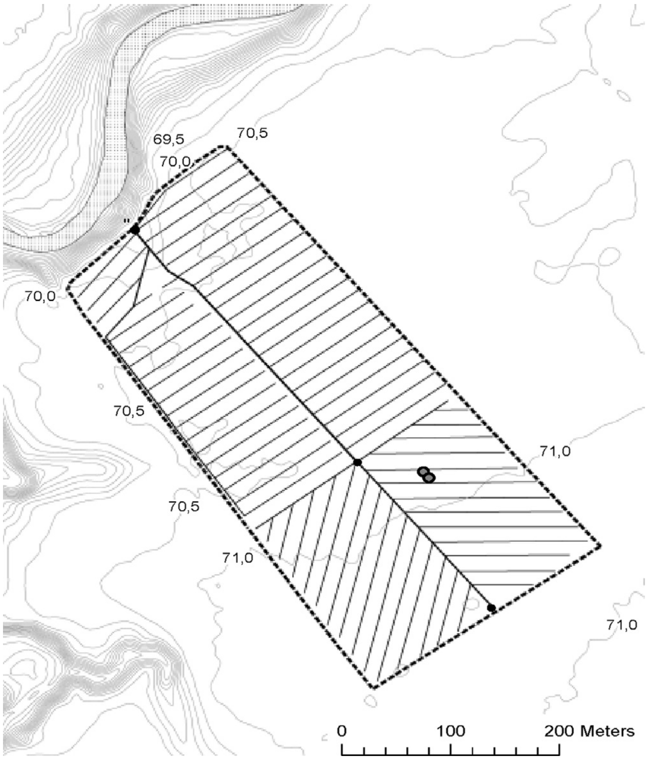

Fig. 1. Map of the field with the tile drainage system, connecting wells (black-filled circles) and two piezometers (grey-filled circles).

The aim of the present study was to quantify and characterise nutrient leaching before and after two consecutive years of application of high loads of solid chicken manure to a tile-drained field in Sweden with loamy soil and with a history of only mineral fertilisation. The starting hypotheses were that concentrations of P and N at the drain outlet are elevated in peak flows following manure application; and that the elevated N concentrations persist for several years, while the elevated P concentrations decline more rapidly.

2. Materials and methods

2.1. Study field and management

The study field is situated on the largest agricultural plains area in Sweden (Västgöta plain), SW of the towns of Skara and Skövde and close to a stream (Fig. 1). The field (national code 5O) has an area of 10.9 ha and a mean slope of 2% towards a stream. The average clay content in the topsoil is less than 6% and the average soil texture class is loam (Ulén et al., 2012). Soil P analyses using the standard Swedish procedure with acid ammonium lactate (P-AL) (Egnér et al., 1960) and inductively coupled plasma (ICP) techniques for determination of P in the extract (Ulén, 2006) demonstrated moderate soil P levels in 1999, 2001 and 2005 (Table 1). There were no significant changes in the soil P status over time. Degree of P saturation in the extract was relatively moderate in topsoil (11%) and subsoil (16%) when analysed in 2005 (Ulén et al., 2012).

Drainage pipes were installed in a herringbone pattern in early 1975, at a spacing of 16 m and a depth of 1 m. The field has three connecting open inlets which also collect surface runoff to the tile drainage system. In two piezometers (Fig. 1), groundwater samples are collected at 2 and 4 m depth. Drain water flows to a Thomson weir in an underground measuring station established in 1975 and situated 30 m from the river bank. Water level over the Thomson weir has been measured continuously since 1975 with a water stage recorder. The chart is digitalised on an hourly basis and water flow calculated. During recent years the chart has been complemented with a data logger (Thalimedes). The discharge is expressed in mm day^{-1} in order to make it comparable with daily precipitation. The drainage system was repaired in 1998 to ensure that all drainage water would pass through the measuring system. As a consequence, recorded water discharge before 1998 is not comparable with that measured in or after 1998.

Mean annual temperature at the site is 5.9 °C (Skara municipality), but for four months per year mean temperature is below 0 °C (Alexandersson et al., 1991). Annual precipitation is 556 mm (Skara) and estimated annual evapotranspiration according to the Penman–Monteith equation (Penman, 1948; FAO, 2014) is 523 mm (Skövde municipality). From observations of the water levels in the two piezometers and from the general location and topography, it