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Are horse paddocks threatening water quality through excess loading of nutrients?

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A B S T R A C T

The Baltic Sea is one of the most eutrophied water bodies in northern Europe and more than 50% of its total anthropogenic waterborne phosphorus (P) and nitrogen (N) loads derive from agricultural sources. Sweden is the second largest contributor of waterborne N and the third largest contributor of waterborne P to the Baltic Sea. Horse farms now occupy almost 10% of Swedish agricultural land, but are not well investigated with regard to their environmental impact. In this study, potential P, N and carbon (C) leaching losses were measured from two representative horse paddock topsoils (0–20 cm; a clay and a loamy sand) following simulated rainfall events in the laboratory. Results showed that the leachate concentrations and net release of P, N and dissolved organic C (DOC) from paddock topsoils were highest in feeding and excretion areas and considerably higher from the loamy sand than the clay paddock topsoil. Leaching losses of dissolved reactive P (DRP) were significantly ($p < 0.05$) correlated with concentrations of water-soluble P and ammonium acetate lactate-extractable P (P-AL) in the soil, while leaching losses of dissolved organic P and total organic N were significantly correlated with DOC concentration in leachate. Leaching loads of P and N from paddock topsoils greatly exceeded average figures for Swedish agricultural topsoils. It was concluded that: i) horse paddocks pose a potential threat to water quality via leaching of excess P and N, ii) feeding and excretion areas are potential hotspots for highly enhanced leaching losses, and iii) paddocks established on sandy soils are particularly susceptible to high N leaching losses.

1. Introduction

Eutrophication is a problem in many freshwater and marine aquatic systems world-wide and different agricultural sources are major contributors of nutrient loads to water. Within the northern hemisphere, the Baltic Sea is one of the most eutrophied water bodies (Swedish Environmental Protection Agency, 2013), with agriculture alone contributing over 60–70% of diffuse and 50% of total anthropogenic waterborne loads of phosphorus (P) and nitrogen (N) (HELCOM, 2013a). As a result, reducing nutrient losses from arable land and management of animal manure by the Baltic States are a high priority.

Among the Baltic countries, Sweden has the longest coastline (>13,500 km) and contributes 19% of total waterborne N loads (second largest contributor) and 13% of total waterborne P loads (third largest contributor) to the Baltic Sea (HELCOM, 2011). The recently allocated national environmental target for Sweden is to reduce its nutrient loads to the Baltic Sea by 530 tons P and 9240 tons N by 2021 (HELCOM, 2013b). In the period 1995–2005, flow-normalised losses of P and N from Swedish agricultural soils decreased by an estimated 5% and 11%, respectively, but remained unchanged thereafter (Blombäck et al., 2011). Therefore, to meet the HELCOM goals further improvements are needed, including identification of all possible sources of losses from agriculture.

Horse farms now occupy almost 10% of Swedish arable land (300,000 ha) (European Pari Mutuel Association, 2009), but have so far not been included in national nutrient reduction plans. Guidelines for horse farms in the Baltic Sea Action Plan are also lacking (HELCOM, 2013c), despite the fact that many of the other Baltic countries use 3–6% of their total agricultural land for horses (European Pari Mutuel Association, 2009). Furthermore, horse farms are not included (no specific guidelines) in the EU Water Framework Directive (European Commission, 2013a), although such farms currently occupy about 4% of total European agricultural land and horses are becoming increasingly numerous in many European countries (European Horse Network, 2012). For example,

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there are about 1 million horses in Great Britain, 0.6 million in Spain, 0.4 million in Sweden, and 0.3 million in Belgium (European Pari Mutuel Association, 2009), representing about 56%, 72%, 105% and 60%, respectively, of the number of dairy cows (DairyCo, 2013).

A large proportion of the total agricultural area used for horses comprises intensively managed outdoor paddocks, which are often situated close to the stables. Of the 300,000 ha used for horses in Sweden, an estimated 34,000 ha consist of paddocks (Parvage et al., 2013). A high horse density and feed imports to paddocks are common. Feed remnants and faeces deposited inside the paddocks are often not removed, which can result in nutrient build-up in the soil (Airaksinen et al., 2007; Närvänen et al., 2008). High soil P and N concentrations in paddocks can lead to high runoff and leaching losses and thereby can act as 'hotspots', contributing a significant proportion of N and P loads to nearby water bodies. After only one year of paddock management, Airaksinen et al. (2007) measured an eighteen-fold increase of P in surface runoff from non-cleaned feeding areas. Eight years of field observation of drainage water, Parvage et al. (2011) measured three-fold higher P leaching losses from paddocks than the adjacent arable field with similar annual P input. However, a general assessment of soil P (and other elements) status of the paddocks could not well explain such high losses. This led to a detailed survey including identification of nutrient-enriched zones dominated by different horse activities within paddocks (i.e. feeding, grazing/winter exercise and excretion) (Parvage et al., 2013). Quantification of losses under controlled conditions from each specific zone of the paddocks should be the next step in order to understand the potential threat to water quality in this type of land management system.

Losses of P and N from extensively grazed paddock soils can occur in both water-soluble and particle-bound form, including inorganic and organic entities. Measurements of dissolved reactive P (DRP) or total P in leachate or runoff water have been used previously to quantify P losses from grazing pastures (Sharpley et al., 2001, 2004; Monaghan et al., 2002; Hart et al., 2004) and measurements of nitrate–N ($NO_3^- - N$), ammonium–N ($NH_4^+ - N$) and total N for estimation of N losses (Hooda et al., 2000; Monaghan et al., 2002; Airaksinen et al., 2007). Measurements of dissolved organic carbon (DOC) in leachate water, together with P and N, have also been used to assess water quality in grazing systems (Fleming and Cox, 2001; McTiernan et al., 2001; Ghani et al., 2010).

In Sweden and other European countries, most horse farms are located near towns and cities, where vulnerable water bodies used for drinking water extraction can be affected. Despite this, the effect of horse paddocks on water quality has not been sufficiently investigated to date. Therefore this study examined whether horse paddocks with a high animal density, combined with outdoor feeding, significantly contribute to water pollution via excess leaching losses. Although nutrient losses in surface runoff can be considerable (Hooda et al., 2000; Airaksinen et al., 2007), we considered leaching via field drains. The main objectives of the study were to: (i) identify potential hotspots of P, N and C leaching losses within the paddock by measuring leaching losses from feeding, grazing and excretion areas of paddock topsoil with contrasting soil texture; (ii) compare the losses with those from nearby unfertilised and ungrazed grassland soils (reference area); and (iii) discuss potential P and N leaching losses from paddock soils with those from common agricultural soils in Sweden.

2. Materials and methods

2.1. Horse farms and paddock soils

Two farms with contrasting soil texture (a clay soil (*Eutric Cambisol*), code UPS; and a loamy sand (*Dystric Cambisol*), code UKB) near Uppsala, Sweden, were studied based on information obtained in a survey of horse paddock soils (Parvage et al., 2013). A general description of management practices of the investigated sites were given in Table 1. In brief, the clay soil had been used as a paddock for 23 years, with a horse density of 5.9 livestock units (LSU) ha^{-1} (1 horse = 0.8 LSU; European Commission, 2013b) and an annual input of 27 tons ha^{-1} of fresh manure, equivalent to 38 kg total P ha^{-1} and 159 kg total N ha^{-1}. The loamy sand soil had been used as a paddock for 18 years, had a two-fold higher horse density (12.7 LSU ha^{-1}) and a mean annual input of fresh manure to the paddock of 60 tons ha^{-1}, equivalent to 85 kg total P ha^{-1} and 360 kg total N ha^{-1}. The feeding, grazing and excretion areas within the paddocks measured on average 55, 1221 and 72 m^2, respectively, at the clay soil site and 35, 1157 and 65 m^2, respectively, at the sandy soil site (see Table 1).

Nutrient status in topsoils (0–20 cm) of the paddocks and reference fields varied widely (Table 2). Full details of the sampling procedures, sample preparation and methods of chemical analysis can be found in Parvage et al. (2013). Soil pH values were higher (6.5–7.6) in the clay paddock than in the corresponding reference soil (5.5). The highest concentrations of soil water-soluble P (WSP), total N and organic C were found in the excretion area, followed by the feeding area and grazing area. The mean concentrations of plant available P (P-AL), total P and degree of P saturation percentage (DPS%) were higher within the paddock than in the reference soil. Compared with clay soil, soil pH was slightly lower (6.3–6.7) in the loamy sand paddock, whereas the reference area was slightly alkaline (7.3). The highest concentrations of WSP, P-AL and total P were found in the feeding and excretion areas of the loamy sand soil, followed by the grazing and reference areas. The DPS% was generally high in both paddock soils and highest (40–49%) in the excretion area.

2.2. Soil monolith collection and leaching study

Undisturbed soil columns were collected in September 2011 from the topsoil in plastic cylinders (20 cm long, 18.8 cm diameter) at points close to the spots used for composite soil sampling in April 2011. Soil columns were kept in a cold room at 5 °C for about two weeks until the simulated rain event was applied in mid-October 2011. In total, 16 monoliths were collected from each horse paddock (four columns each from feeding, grazing, excretion and reference areas). During sampling of feeding and excretion areas, soil surfaces with visible fresh feed residues and fresh manure were avoided or these contaminants were removed before sampling. The reference UPS clay soil was taken from a meadow not used for agriculture. Reference columns for the UKB loamy sand soil were taken from a fallow area approximately 20 m away from the actual sampling site, at a place that had been grazed by dairy cows for several decades and left undisturbed for the previous 7–10 years. All soil columns were moved to an indoor rain simulation station where a sprinkler system with hydraulic atomising nozzles created artificial rain. The nozzles had a capacity of 7 L h^{-1}, with drop diameter 0.07–0.10 mm. The sprinkler system was positioned 80 cm above the soil columns. More details of the rain simulator and soil columns preparation for the leaching experiment can be found in Liu et al. (2012a).

Tap water containing 0.004 mg total P L^{-1} and 1.07 mg total N L^{-1} (pH 8.3) was used as rainwater. One day prior to the leaching study, the soil columns were wetted with 7 mm of simulated rain and drained water (if any) was discarded. Soil columns were exposed to four simulated rainfall events (equivalent to 80% of total soil volume), each comprising 40 mm rain applied over 3 h and with 72-h intervals between consecutive events. Leachate was collected in glass jars, the volume of water leached per column was