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A survey of soil phosphorus (P) and nitrogen (N) in Swedish horse paddocks

Mohammed Masud Parvage*, Barbro Ulén, Holger Kirchmann

Department of Soil and Environment, Swedish University of Agricultural Sciences, Box 7014, SE-750 07 Uppsala, Sweden

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ABSTRACT

Of the EU countries, Sweden utilizes the highest proportion (10%) of its total agricultural land for horses. Horse paddocks commonly hold horses on a limited space, in the present study at a rate of 5–14 livestock units ha^{-1}. Thus these paddocks receive significant amounts of phosphorus (P) and nitrogen (N) through feed residues and deposition of faeces and urine, which can lead to nutrient build-up in the soil. This study examined soil P and N status in different parts of horse paddocks (feeding, grazing and excretion areas) and compared it with that in adjacent, unmanaged reference soils. The paddock areas were then categorized with respect to environmental risk using the threshold concentrations of plant-available P extracted with ammonium acetate lactate solution at pH 3.75 (P-AL) and total N set by the Swedish Environmental Protection Agency. In total, seven horse farms, covering different grazing densities and soil textures representative of Swedish horse paddocks, were examined. The results showed that concentrations of water-soluble P (WSP), P-AL, and total N were highest in feeding and excretion areas within the paddocks. Weighted concentrations of soil P for the whole paddocks amounted to 2.9–10.5 mg WSP (kg^{-1}) and 35–224 mg P-AL (kg^{-1}), and were higher than in the corresponding reference fields (0.8–4.9 mg WSP (kg^{-1}) and 17–102 mg P-AL (kg^{-1})). The WSP concentration in the paddocks was strongly correlated with horse density ($R^2 = 0.80^{***}$[1], $n = 13$) and P-AL with years of paddock management ($R^2 = 0.78^{***}$, $n = 13$). Total organic C was significantly correlated with P-AL, total P and total N in the feeding and excretion areas. The degree of soil P saturation (DPS) concentrations was important soil parameters determining WSP concentration in the paddocks ($R^2 = 0.63^{***}$, $n = 110$), whereas total P concentration in soils was determining P-AL concentrations ($R^2 = 0.82^{***}$, $n = 112$). According to Swedish environmental guidelines, two of the seven farms studied posed a high risk and three a moderate risk of extensive P leaching losses, but the risk of extensive N losses was moderate for all farms studied. As regards the specific sections of the paddock, the feeding and excretion areas had the highest risk of P leaching losses. Thus paddock soils can be high-risk areas for P leaching comprising about 3.85% of the total high-risk land area in Sweden.

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1. Introduction

The equine industry is a growing sector in the EU countries and the popularity of horse riding and racing has increased over recent decades. Today, more than 6 million hectares of permanent grassland, equivalent to about 4% of the total agricultural land in the EU, are used for 6 million horses (European Horse Network, 2012). Some of these 6 million hectares are intensively managed as paddocks for outdoor keeping, feeding and grazing, often situated close to stables. Horse farms in the Nordic countries occupy a larger fraction of the total agricultural area than in other European countries, namely 10% in Sweden, 6% in Norway and 5% in Finland (European Pari Mutuel Association, 2009).

According to the Swedish Board of Agriculture (2013), the numbers of most farm animals (e.g. cattle, pigs, dairy cows) have decreased over the past two decades in Sweden, while the number of horses has increased by more than 300%, from 88,621 horses in 2000 to 362,700 in 2010. Today, horses occupy around 300,000 ha of Swedish land including 17,509 farms with an area of ≥5 ha (Swedish Board of Agriculture, 2013).

Under Swedish climate conditions, horses usually are kept in paddocks for at least 8–12 h per day, including during snow-covered winter periods, and are supplied with feed. As a result, horse paddocks receive significant amounts of phosphorus (P), nitrogen (N) and carbon (C) through feed residues and deposition of faeces and urine (Caselles et al., 2002; Parkyn and Wilcock, 2004). The current recommended maximum horse density at farm level on Swedish pastures is 3 horses or 2.4 livestock unit (LSU) ha^{-1} [1

* Corresponding author. Tel.: +46 018671223; fax: +46 0672795.
E-mail addresses: masud.parvage@slu.se, parvage.ss_ku@yahoo.com (M.M. Parvage).

[1] $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

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horse = 0.8 LSU (European Commission, 2013)] which is based on the amount of nutrients can be added (especially P, 22 kg ha^{-1} y^{-1}) through manure to soil (Swedish Board of Agriculture, 2012). However, the recommended density is often exceeded when horses are kept in comparatively small, fenced-off paddocks near stables (Parvage et al., 2011). Furthermore, as feed not eaten by the horses remains on the soil and decomposes, and as horses do not excrete randomly but prefer an excretion zone mainly in the corners of the paddock and/or along fences, the potential exists for much larger stocks of P, N and other nutrients to build up within the paddocks (especially in feeding and excretion areas) than in other agricultural areas.

Studies have shown that grazed land can receive high inputs of nutrients, leading to significant losses of P and N (Hooda et al., 2000; Nash et al., 2000; Uusi-Kämppä, 2002; Ebeling et al., 2002; Hart et al., 2004; Airaksinen et al., 2007; Bilotta et al., 2007). It can therefore be assumed that horse farms with a high animal density can have a negative impact on the quality of surface water and groundwater through excess loading of nutrients, especially P and N. However, information on the environmental impact of horse keeping is still scarce and this sector has so far not been included in environmental planning (Närvänen et al., 2008).

The main objectives of the present study were to determine the P and N status in paddock soils, to quantify the nutrient build-up over time, and to categorize these soils with respect to their environmental risk using the threshold soil concentrations for P and N set by the Swedish Environmental Protection Agency (Swedish EPA, 2012). Soils from adjacent unmanaged fields were used as reference. The following hypotheses were tested: (a) the soils in horse feeding and excretion areas of paddocks are enriched with P and N through accumulation of feed residues, dung and urine, (b) the concentrations of soil P and N in paddocks as a whole are higher than in reference fields and (c) nutrient enrichment in paddock soil is correlated with paddock age and horse stocking density.

2. Materials and methods

2.1. Horse farms and paddocks

A total of seven horse farms established more than 10 years ago within a radius of 50 km of Uppsala city were chosen for the study. The selected farms represented different animal densities, soil textures (clay content from 1.8 to 45.6%) and paddock ages (Table 1). Data collection was conditioned so as not to disclose farm names and locations. Codes are therefore used in the following text.

The paddock area per horse varied from 550 m^2 to 1498 m^2 (mean 1063 m^2), which corresponded to a density of 14.5–5.3 (mean 8.6) LSU (ha^{-1}). The duration of grazing and/or outdoor keeping of horses was dependent on the season, with the year usually being divided into two main seasons: winter (October–April), with around 7 h of outdoor stay, and summer (May–September), with around 18 h. Due to these differing durations of outdoor stay, horse density was recalculated and the actual mean density was found to range from 7.4 to 2.6 (mean 4.1) LSU (ha^{-1}) (Table 2).

The feeding and excretion areas within paddocks were relatively small, amounting to only 3–5% of the total (measured during site inspections and soil sampling), and the remaining area was used for grazing. Per horse, the feeding area ranged from 18 to 55 m^2 (mean 33 m^2), the excretion area from 24 to 72 m^2 (mean 51 m^2), and the grazing area from 509 to 1394 m^2 (mean 979 m^2).

The horses kept in the paddocks were supplied with hay, oats and granules (blended commercially available horse feed) in both summer and winter months. Hay was put on bare soil and residues remained on the soil. Oats and granules were placed in a feeding bowl. There were no dung removal practices from five of the studied farms whereas one farm cleans the paddock every year and another every second year.

2.2. Sampling and sample preparation

Soil samples were collected from one paddock on each farm. Sampling was carried out at a representative site with respect to size and management practices. After visual observations, each paddock was divided into three distinct sections, i.e. feeding area, grazing area and excretion area. Undisturbed and non-grazed natural grass land either located inside a forest adjacent to the paddock, fallow areas between two adjacent paddocks, or nearby grass lands were selected as reference areas for soil sampling. In some cases, it was difficult to find suitable reference areas as the previous land use for most of the reference areas was undiscovered. Samples were collected from the topsoil (0–20 cm). Samples from the feeding and excretion areas were collected in grids at 1-m intervals. At each sampling point, five sub-samples were collected within a radius of 15 cm using an auger, thoroughly mixed and pooled to one composite sample. Grazing areas were much larger than feeding and excretion areas. However, to avoid influences of previous dung or fodder waste deposits along the borders samples were collected only from the middle of the grazing area. A cross section within the grazing area was sampled. Sampling distance between two composite samples varied between 2 and 4 m depending on the size of the paddock. Composite samples were made of five sub samples collected within a radius of 20 cm, thoroughly mixed and pooled. The number of composite samples taken and analyzed for each section of the paddock (feeding area, grazing area and excretion area) was 4 and additionally 4 composite samples were taken from each reference area. Soil samples were air-dried at 50 °C, milled and sieved through a 2-mm mesh. Soil particles that passed through the sieve were retained for further analysis.

2.3. Chemical analysis

Soil pH was determined in distilled water using a glass electrode pH metre where the ratio of soil to water was 5:1. Water-soluble phosphorus (WSP) in soils was extracted according to Self-Davis et al. (2000), applying a ratio of 3:1 for soil to water, and the concentration was determined colorimetrically (Murphy and Riley, 1962) using a Shimadzu UV-1201 spectrophotometer. Plant-available P, aluminium (Al) and iron (Fe) were extracted with ammonium acetate lactate (AL) solution at pH 3.75 (Egnér et al., 1960) and were analyzed by ICP-AES Optima 5300. Concentrations of total P were determined after 7 M HNO_3 acid digestion and measured by ICP-AES (SIS, 1997). The degree of P saturation (DPS) was calculated as the ratio of the elements on a molar basis in the AL extract using the equation:

$$\mathrm{DPS} = \frac{\mathrm{P-AL}}{\mathrm{Fe-AL+Al-AL}} \times 100 \qquad \text{(i)}$$

Concentrations of total organic C and N were determined after combustion of 1 g air-dry soil at 1250 °C for 5 min with a LECO CN2000 analyser (LECO Cooperation, 2003). Soil particle size distribution was measured using the pipette method (Ljung, 1987) and soil texture was classified according to the guidelines of the Food and Agricultural Organization of the United Nations (FAO, 2006).

2.4. Statistical analysis

Sample means and standard deviations (SD) were calculated in Excel 2010. Weighted means for each paddock were calculated by multiplying the sample mean for each section by the size of the section in relation to the total paddock area (see Table 1). These values were then summed up to represent the total paddock area. Nutrient

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