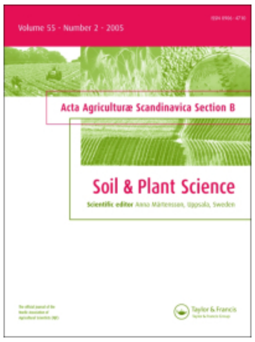

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Losses of phosphorus, potassium and nitrogen from horse manure left on the ground

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ABSTRACT
In this five-month Swedish field study, we examined losses of nutrients from horse manure over time, in order to examine how regularly manure should be cleared from paddocks in order to minimise the risk of nutrient leaching. Small heaps of manure (400 g) were placed in open cylinders outdoors and samples (five replicates) were taken on 12 occasions from December 2020 to May 2021. The samples were analysed for weight, dry matter content and concentrations of total nitrogen (N), ammonium N, total phosphorus (P), water-extractable P (WEP), potassium (K) and carbon (C). There was a fast decline in P and K concentrations and a strong correlation between accumulated precipitation and losses from the manure into the soil. The mean reduction in total-P was 11 mg P kg−1 manure dry weight per mm accumulated precipitation. Manure N was retained in the manure over the five-month period. In conclusion, this study demonstrated high mobility of P and K, indicating a need for strategies for rapid removal of manure from paddocks. Daily removal of manure from paddocks used year-round would, approximately, save 1.7 kg P and 5.5 kg K per horse per year, which could be recycled to replace non-renewable mineral fertilisers.

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Horse manure; nutrient losses; horse paddock; phosphorus leaching; eutrophication

Highlights

- This study showed the importance of frequent removal of manure from horse paddocks under wet conditions.
- P and K in manure left on the ground are very mobile when exposed to rain or melting snow.
- After five months in the field, about 80% of N, 30% of P and 10% of K in manure remained.
- Strategies and development of methods for collection of manure in paddocks and pastures are needed.
- Manure collected from paddocks is a resource if recycled and used to replace mineral fertilisers.

Introduction

Nitrogen (N) and phosphorus (P) losses from arable land, animal husbandry, households and other human activities world-wide are leading to eutrophication and water quality degradation in freshwater and saltwater bodies (Hilton et al. 2006; Shigaki et al. 2006; Dubrovsky et al. 2010; EEA 2021). At the same time, P is categorised as a critical raw material, i.e. economically important and at high supply risk, within the European Union (EU) (European Union 2020). It is therefore important to minimise nutrient losses in order to protect water quality, increase nutrient use efficiency in food production and improve nutrient recycling.

Keeping domestic animals outdoors can have negative impacts on water quality due to deposition of manure on land which results in leaching and/or surface runoff of nutrients, e.g. found in studies of heifers (Salomon et al. 2015), poultry (Aronsson et al. 2021), pigs (Eriksen and Kristensen 2001) and horses (Airaksinen et al. 2007). Nevertheless, according to animal protection regulations in Sweden, horses must spend a minimum of one hour per day outdoors where they can move freely. According to Keskinen et al. (2017), the horse population within the EU produces manure corresponding to 300 million kg N and 48 million kg P annually. Scientific studies on the environmental impact of horse keeping are still scarce, but recent studies indicate that the problem is greater than

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previously believed (Parvage et al. 2015; Kumblad and Rydin 2018).

Horse paddocks differ widely in size and vary in how they are utilised over the course of the year. Paddocks close to stables are commonly intensively used year-round, and thus are often affected by trampling and erosion and frequently lack plant cover to bind soil and nutrients. If manure is not removed, horse paddocks can act as a diffuse source of N and P losses. These losses can occur as direct losses in surface runoff from manure deposited on the ground or by leaching through the soil to tile drains or groundwater. The dominant pathway for losses to waters will depend on factors such as weather, soil type, topography and vegetation cover (Sharpley et al. 2015). For N, gaseous losses also occur through ammonia volatilisation from manure and denitrification in the soil (Fowler et al. 2013).

Continuous addition of manure loads from horses in paddocks increases the soil P content and P saturation of the soil. For example, a Swedish study found considerable accumulation of P in intensively used horse paddocks over long time, especially in areas used for feeding and defecation (Parvage et al. 2013), and concentrations of P in drainage water from a horse paddock were also considerably higher than in drainage water from reference area (Parvage et al. 2011). Similarly, Airaksinen et al. (2007) found that P concentrations in surface runoff from horse paddocks were 10–50 times higher after horses used the paddocks than before. Several studies have revealed a correlation between increasing soil P saturation and amount of water-soluble P in the soil, i.e. an increased risk of P leaching losses when P accumulates in the soil (Heckrath et al. 1995; Torbert et al. 2002). Thus, there is some evidence that long-term use of horse-paddocks may constitute a risk of nutrient losses both to air and water, and that strategies for efficient clearing of manure from paddocks would decrease the losses, provided that manure is removed before losses have occurred from the manure heaps into the paddock soil. Removal of manure is especially important for P, since P is almost exclusively found in the faeces (Ögren et al. 2013), with the total amount and soluble fraction both being positively correlated to P intake. Removal of manure can also improve recycling of P and other nutrients if the collected manure is used as a fertiliser or soil amendment after composting (Bernal et al. 2009).

Saastamoinen et al. (2020) estimated that adult horses (550 kg live weight) excrete on average 7.6 kg P annually. If a horse paddock is used daily, considerable amounts of manure will be deposited on the soil surface. In a study by Airaksinen et al. (2007), in which a paddock with three horses was cleaned daily, a total of 2500 kg manure (8 kg P) was collected over a seven-month period. Manure left on the ground in a paddock may be exposed to trampling, rainfall and decomposition processes, which will affect the amount of manure that can be collected physically and its composition. A Swedish study investigated different frequencies of manure removal from real horse paddocks (Malmer 2020). In that study, ordinary tools (grip and bucket) were used for removal of manure once a day ($n = 14$), once a week ($n = 2$) or once a month ($n = 1$) in a paddock with two horses (900 m^2). The results showed that 78% of the total amount of manure deposited could be collected when applying a daily removal regime, 47% with weekly removal and only 36% when removal was on a monthly basis. Regular removal of manure from paddocks is also widely recommended for horse health issues, since it decreases the pressure from faecal parasites (Corbett et al. 2014). In the present field study, we examined the decrease of nutrient content of horse manure over time, in order to assess the losses of N, P and potassium (K) nutrients from manure heaps under natural weather conditions. The objective was to gain insights into how regularly manure should be cleared from horse paddocks in order to minimise the risk of negative environmental impacts.

Materials and method

Experimental design

Fresh horse manure was placed as heaps in open cylinders on the ground and manure samples were extracted over time for determination of residual mass and residual contents of different elements, in order to assess the losses of mass and nutrients from the manure. The study was conducted between 18 December 2020 and 21 May 2021 at a site 25 km north of Uppsala, Sweden (59.981546, 17.940091), situated in a cold temperate climate region, with periods of snow cover during winter. The water surplus (runoff) is normally highest in autumn and winter, with a peak in the early spring (February–March), and lowest in the summer (May-September). The fresh horse manure (30 kg) was collected in the box of one adult horse on two consecutive days and mixed gently but thoroughly by hand before the start of the experiment. It consisted mainly of faeces, referred to hereafter as manure. Fresh bedding straw and any traces of hay were removed. The initial composition of the manure (null samples) is presented in Table 1. A 400 g portion of the fresh manure (23% dry weight) was placed in each of 60 cylinders (19 cm high, 20 cm in diameter) on a piece of land

Table 1. Initial composition of dry matter (%) and nutrients (g kg^{-1} dry weight) in the fresh manure used in the field study (average values and standard deviation, SD).

	Dry matter %	Total-N	NH_4-N	Total-*P*	WEP	K	C	C:N ratio
		------------------mg kg^{-1} dry weight------------------------						
Average	23	10	0.77	3.7	2.2	12	430	43
SD	0.52	0.23	0.08	0.26	0.08	0.31	8.8	1.4

Note: WEP: water-extractable P.

with sparse vegetation, to imitate a trampled paddock. The cylinders, made from standard black damp proofing membrane, were placed in three pallet collars covered with chicken wire to exclude birds and vermin. Precipitation and melted snow were able to run out at the base of the cylinders. Weather data for the study period were obtained from stations in the Swedish Meteorological and Hydrological Institute (SMHI, https://www.smhi.se), with precipitation data from Vattholma (13 km northwest of the study site) and temperature data from Uppsala (22 km southwest).

Sampling regime and analyses

Five null samples were taken at the start of the experiment (Day 0). On 12 subsequent sampling occasions during the 154-day study period, five cylinders (representing replicate samples) were chosen randomly on each occasion. Samples (including the whole heap) were taken weekly when possible (not frozen to the ground), or otherwise at melting after frozen conditions. Towards the end of the experiment (April–May), sampling was performed bi-weekly. The cylinders were emptied by hand, avoiding getting any vegetation or soil in the sample. The tiny fragments of manure that were not possible to pick up were left in the cylinder. In April and May, insects, plants and fungi were found in the samples and were removed.

All manure from each cylinder was weighed in the field (instrument accuracy 1 g) and then mixed by hand before a sample (100 g) was taken for further analysis. These samples were stored frozen. After thawing, the samples were dried at 105°C for 24 h and analysed for dry matter content. Dried and milled samples were analysed for total-N and total-C with a LECO CN928 after combustion (Modified methods of Swedish Standards SS-ISO 13878:1998 and SS-ISO 10694:1996 for total-N and total-C, respectively), where the ammonium N (NH_4-N) was assumed to have been lost through ammonia volatilisation during the drying process. For determination of NH_4-N content, fresh thawed samples (20 g) were extracted with 2M KCl (150 ml) and analysed by flow-injection analysis (FOSS TECATOR FIAstar 5000 Analyzer) according to International Standard, EN-ISO 11732:1997. Total-N presented onwards is the sum of these two analyses. Total-P and K were analysed with ICP-OES (Spectro Blue ICP) according to Swedish Standard, SS-ISO 028311:2017, with a modified method including heat extraction of 1 g manure with 20 ml 7 M HNO_3. Water-soluble P (WEP) was analysed on four occasions by ICP-OES, after extraction of 5–15 g of manure with 100 ml deionised water.

Comparison of this study and a complementing study

The current study, performed during winter-spring 2020–2021, was designed very similar, and as a complement, to a field study performed in the same region of Sweden during two months in spring 2020 (Malmer 2020). In that study manure was collected from two horses, and cylinders with manure (three replicates, 400 g manure in each cylinder) were placed on the ground outside the paddock fence. Samples were collected on 5 occasions (day 7, 14, 21, 28 and 56), for analyses of remaining manure mass and total-P content. That study also included a laboratory experiment with simulated rainfall to study explicitly the impact of precipitation on P losses from horse manure, which was assessed as the difference between initial content and content after irrigation. In the laboratory study, manure from the same horses were placed in steel cylinders (three replicates) were water percolating through the manure was drained away. The remaining P content and manure dry matter was analysed after exposure to three rain events during six days, with artificial rainwater. The irrigation equipment consisted of a sprinkler system (described by Liu et al. 2012), where irrigation was applied at an intensity of 5 mm h^{-1} during 5 h every second day, where manure was sampled on the day after irrigation. The manure used in that study had a P content of 4.6 g kg^{-1} dry weight. We used these two datasets, together with new data obtained in the present study, to examine correlations between total-P concentrations and precipitation.

Statistical analyses

The correlation between total-P concentration in manure and accumulated precipitation was examined with both linear and nonlinear regression (StataSE 16). The analysis included the current dataset (65 data points) together with the two datasets produced in the study by Malmer (2020) described above (19 data points in field study and 10 in the lab study). In linear regression, concentration was set as the dependent variable and dummy variables were used for each value of accumulated precipitation. This was done to examine differences in P concentration between different precipitation values, with consideration of which value belonged to which dataset, since initial values of manure P concentration differed between the studies. The correlation between total-P concentration and temperature was also tested with the linear model.

The relationship between P concentration and accumulated precipitation displayed clear nonlinearity, so nonparametric kernel regression was used to better show the functional form. This method uses kernel functions as weights to estimate the mean function and the effects of the mean function. The bandwidth of the kernels was selected using a cross-validation criterion based on mean squared leave-one-out residuals. This allowed for visualisation of the nonlinear relationship function while maintaining the lowest possible distance from the residuals. The standard error and the confidence interval were generated through bootstrapping with 200 replicates. The nonparametric kernel regression allowed for approximation of the general effect of accumulated rainfall on P concentration (change in P concentration per mm of precipitation) based on the data from the three datasets. Linear regression was used to check for significant changes ($p < 0.01$) in concentrations and total amounts of N, P, K and C over time in the present dataset, where concentrations and amounts were treated as dependent variables and 'day' as a continuous variable.

Results

Temperature and precipitation

In total, 218 mm of snow and rain fell over the 5-month study period (Figure 1), which was slightly above the long-term average precipitation for this period of the year in the region (194 mm), and about 40% of the average annual precipitation (SMHI, https://www.smhi.se). The precipitation was mainly in the form of snow from December until February, and the manure was then frozen on the ground. When the horse manure was placed in the field on December 18, the temperature was above zero but declining. The next two months were cold with frozen conditions, except for a few days in January (Figure 1). Sampling on Days 12, 21 and 35 was confined to periods with melting, when it was possible to separate the manure from the soil.

Changes in manure amount and composition over time

The amount of manure that was retrieved from the soil surface decreased over time under exposure to biotic and abiotic processes, such as freezing-thawing, rainfall and in-growing vegetation (from late March). At the last sampling occasion, Day 154, 67% of the initial amount of manure remained (Table 2). The final recovery of nutrients was 77% for N, 31% for P and 12% for K, with a significant decreasing trend over time ($p < 0.01$), because of reduced amount of manure and changes in concentrations over the period.

Concentrations of all elements except total-N decreased significantly over time ($p < 0.01$) as water from rain and melting snow drained through the manure heaps. Total-N concentration increased ($p < 0.01$) towards the end of the experiment (Figure 2(a–d)), and the C/N ratio decreased from 43 in the fresh manure (Table 1) to 35 at Day 154. For both K and P, there was a stepwise decline in concentrations (Figure 2(b,c)), with a first step at the first sampling (Day 12), after 46 mm accumulated precipitation, and a second step at sampling number 5 on Day 69, after an additional 84 mm of precipitation. There were frozen conditions for almost four weeks in January-February, which meant that precipitation accumulated as snow that melted just before sampling on Day 69. On Day 12, after 46 mm of rain, the concentrations were 70% (P) and 54% (K) of initial values. After 130 mm of rain or melting snow (Day 69), the concentrations of the manure stabilised at 46% (P) and 15% (K) of initial values, and remained there until the end of the experiment. The proportion of WEP of total-P in manure was 59% at the beginning of the experiment and 38% at the end. Only a minor part of the N was in the form of NH_4-N, which constituted 8% of total-N at the start of the study and 2% at the end in May.

Impact of precipitation – comparison of studies

Total-P concentrations in relation to accumulated precipitation from the three datasets are presented in Figure 3. A negative correlation of P concentration in manure and accumulated precipitation was indicated with both linear ($p < 0.001$) and non-linear regression ($p < 0.001$). Linear regression ($R^2 = 0.88$) showed that, except for two occasions (at 34 and 41 mm accumulated precipitation), all nutrient concentrations were significantly lower than at the start (precipitation = 0).

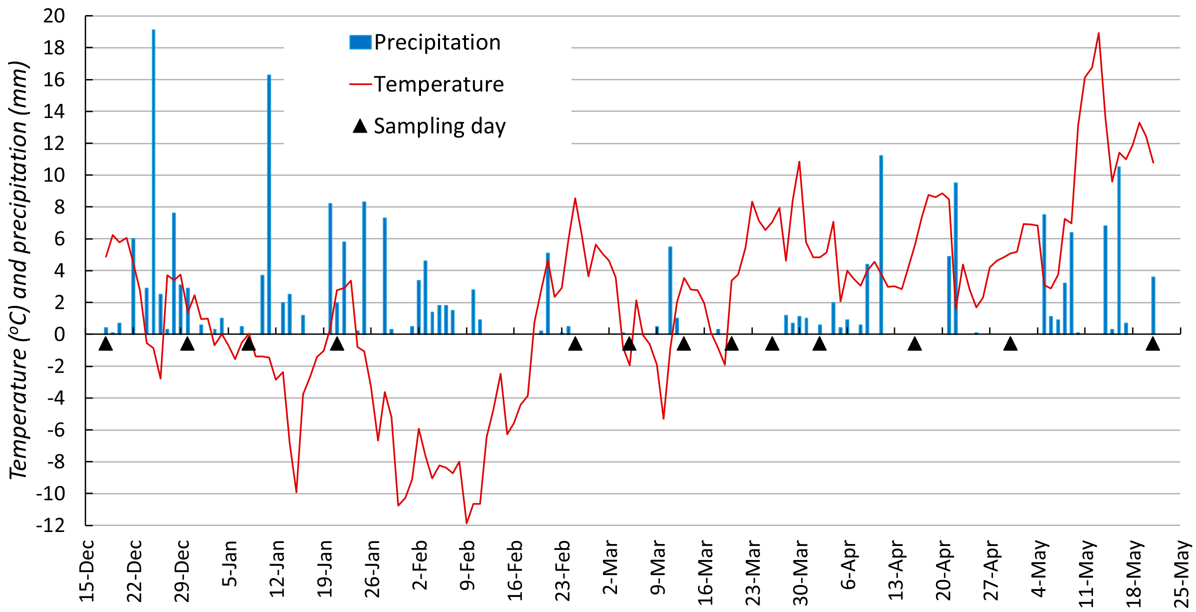

Figure 1. Daily precipitation as snow or rain (Vattholma weather station) and daily mean temperature (Uppsala weather station) (https://www.smhi.se). Sampling days are indicated on the x-axis.

According to nonlinear kernel regression ($R^2 = 0.85$), the mean reduction in total-P was 11 mg P kg^{-1} dry weight per mm accumulated precipitation.

Discussion

This study and an earlier study of Swedish paddocks by Malmer (2020) (in total three datasets) showed a strong correlation between accumulated precipitation and decreasing P concentrations in manure heaps placed on the ground. Rainwater or melting snow draining through the manure appeared to be one of the main factors governing losses of mobile nutrients from manure to the soil. After about 130 mm of accumulated precipitation, the concentrations of total-P and K stabilised at 46% and 15% of the initial values, respectively, and remained at that level until the end of the five-month experiment. In a study of horse manure compost piles exposed to large rainfall amounts during six months, Landry et al. (2018) found that concentrations of total-N did not decrease, while P and K concentrations decreased by 35–65% and 83–93%, respectively. Another study, by Keskinen et al. (2017), estimated losses of N and P from fresh manure after about 20 mm rainfall to be 5–15% of the initial concentrations. The water-extractable P (WEP) in manure in our study, which comprised 59% of total-P, seemed to be lost easily. The losses of P were somewhat larger than the initial WEP content and the proportion of WEP in manure was still substantial (38%) at the end of experiment. This shows that organic P in manure entered the WEP pool, although it is also possible that also some particulate-P was lost from the manure. The initial P content of the manure used in the experiment (Table 1) was similar to that in a review by Liu et al. (2018a), who reported a mean value of 4.9 P g kg^{-1} dry weight, with 55% as WEP. Keskinen et al. (2014), who measured nutrient losses from manure, both in demonstration paddock and in an irrigation study, found that P was mainly lost in inorganic form while N was lost mainly as organic N.

Our study covered a relatively long period (five months) and there is reason to believe that biological degradation processes during the period affected manure composition, nutrient transition and nutrient losses, but this was not investigated directly. For C, losses mainly occurred from April and were most probably in the form of CO_2 emissions due to microbial degradation. The N concentration in manure increased over time and the C/N ratio decreased from 45 at the start to 35 at the end of the experiment. The manure had a low initial content of NH_4-N, with N mainly occurring in organic forms. Obviously, N was preserved over winter, and when C was respired mineralised N was probably immobilised in microbial biomass, since NH_4-N remained low. However, nitrate was not measured, so nitrification of NH_4-N is unknown, but the increase of total-N concentration indicated that there were no substantial gaseous or water-related losses of N. In the long-term, net mineralisation of N, P and K would be expected.

Table 2. Initial values for fresh horse manure in cylinders at the start of the experiment (Day 0) and changes over time in manure dry weight (g) and total amounts (g) of different elements in the manure heaps (average ($n = 5$), standard deviations in brackets).

Day	Acc prec mm	Manure dry weight	Total-C	Total-N	NH_4-N	Total-*P*	WEP	K
0	0	92 (2)	40 (1)	0.93 (0.04)	0.071 (0.008)	0.34 (0.03)	0.20 (0.01)	1.1 (0.02)
12	46	79 (2)	35 (1)	0.74 (0.02)	0.035 (0.003)	0.20 (0.01)		0.56 (0.05)
21	48	83 (3)	36 (1)	0.79 (0.04)	0.034 (0.004)	0.21 (0.01)		0.55 (0.06)
35	84	78 (6)	34 (3)	0.75 (0.09)	0.025 (0.003)	0.19 (0.03)	0.094 (0.01)	0.45 (0.08)
69	130	74 (3)	32 (2)	0.72 (0.04)	0.021 (0.002)	0.13 (0.01)		0.19 (0.04)
77	131	77 (2)	33 (1)	0.74 (0.04)	0.014 (0.002)	0.13 (0.01)		0.16 (0.04)
85	138	76 (3)	33 (2)	0.74 (0.03)	0.009 (0.003)	0.13 (0.01)		0.16 (0.03)
92	138	75 (3)	32 (1)	0.71 (0.05)	0.006 (0.001)	0.12 (0.01)	0.047 (0.01)	0.18 (0.04)
98	138	76 (3)	32 (1)	0.75 (0.02)	0.008 (0.002)	0.13 (0.01)		0.17 (0.02)
105	142	74 (3)	32 (1)	0.76 (0.04)	0.011 (0.003)	0.14 (0.01)		0.19 (0.03)
119	162	69 (4)	29 (2)	0.70 (0.06)	0.006 (0.003)	0.13 (0.02)		0.18 (0.04)
133	176	67 (9)	28 (3)	0.71 (0.10)	0.011 (0.004)	0.11 (0.01)		0.14 (0.01)
154	218	62 (6)	25 (2)	0.71 (0.09)	0.010 (0.002)	0.10 (0.02)	0.039 (0.01)	0.13 (0.03)
Observations		64	64	64	64	64	20	64
R-squared		0.63	0.29	0.74	0.70	0.98	0.73	0.73
Effect day^{-1}		−0.14	$-0.70\ 10^{-1}$	$-0.10\ 10^{-2}$	$-0.38\ 10^{-3}$	$-0.13\ 10^{-2}$	$-0.15\ 10^{-2}$	$-0.58\ 10^{-2}$
		$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$

Note: Results of linear regressions for correlation between amount and time are presented at the bottom of the table. WEP: water-extractable P. Acc prec: accumulated precipitation.

The manure used in this study was collected indoors and it is possible that some urine and bedding material were also included, although this was not the intention. A considerable part of excreted N is found in urine, 37% at medium protein intake according to a study by Weir et al. (2017). The N, and probably also K, content of the fresh manure could have been somewhat overestimated compared with faeces excreted by a horse directly onto paddock soil. However, the low NH_4-N content indicated that little urine N was included or that N was lost as NH_3 in the stable before collection. For P, which is present almost solely in the faeces (Ögren et al. 2013), any additional urine would not have influenced the result.

The experimental period had varying weather conditions, with several freezing-thawing events over

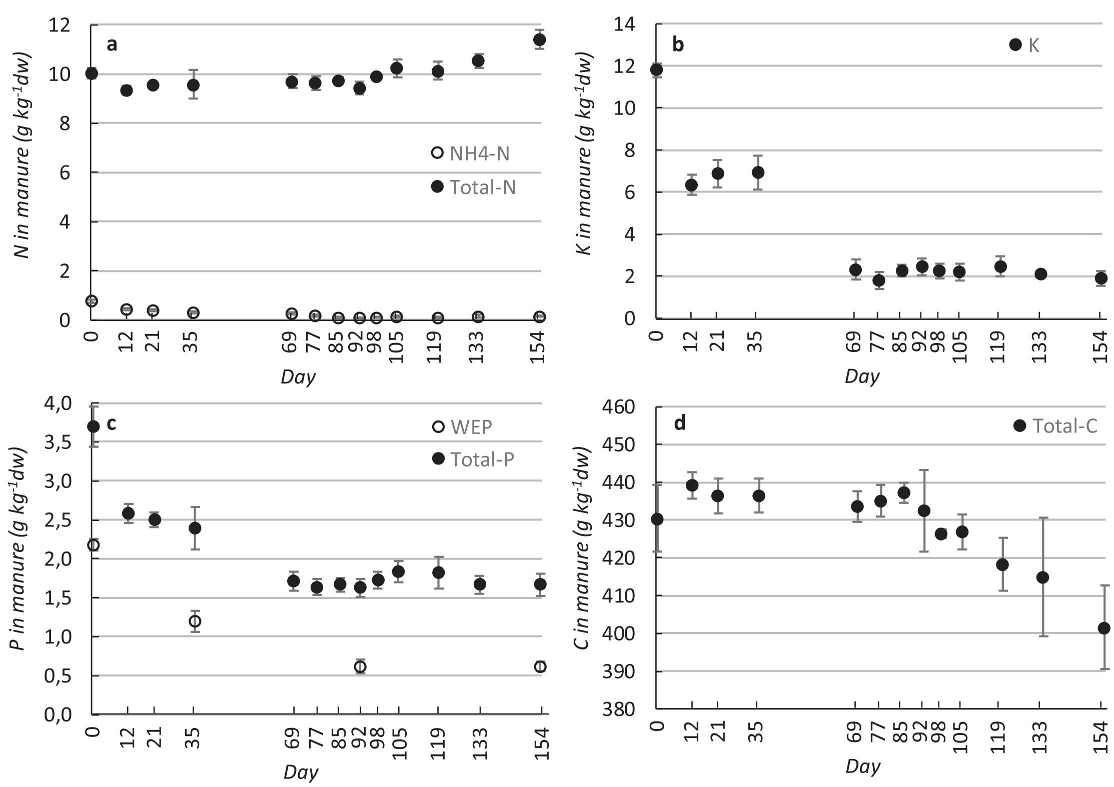

Figure 2. Concentrations (g kg^{-1} dry weight) of (a) total-N and NH_4-N, (b) K, (c) total-P and water-extractable P (WEP), and (d) total-C in horse manure on different sampling occasions. Standard deviations presented for each mean value ($n = 5$).

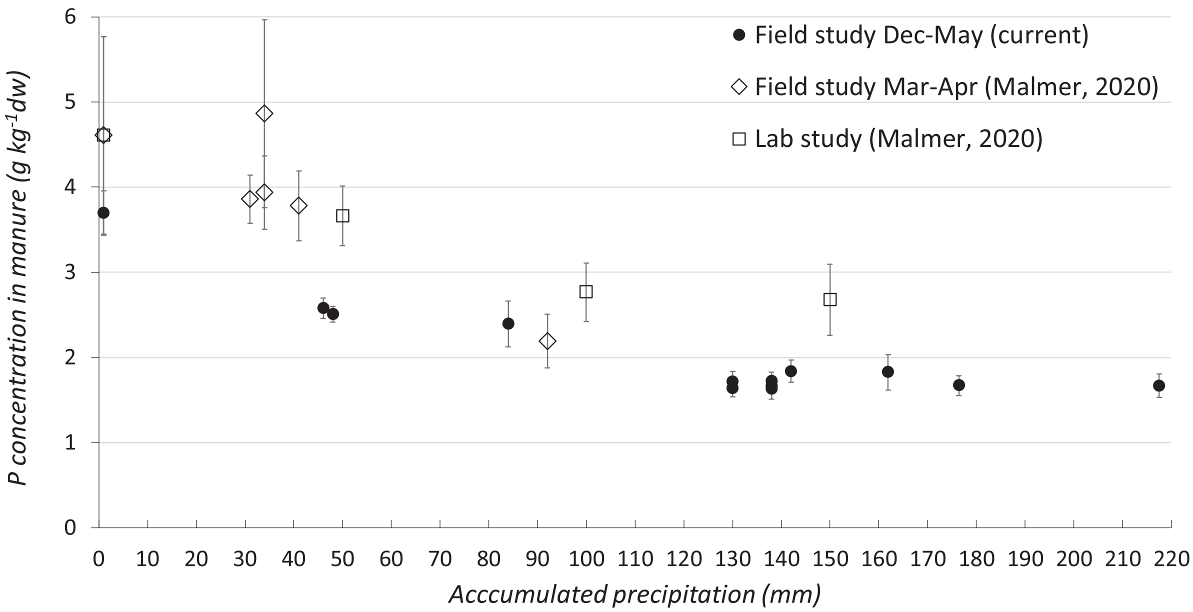

Figure 3. Concentrations of total-P in relation to accumulated precipitation in the present study (Field study Dec-May (current)) and in studies by Malmer (2020) (Field study Mar–Apr, Lab study).

winter and then a warmer spring period from mid-March. Repeated freezing-thawing has been shown to break down cell structures rapidly and to increase losses of WEP from plant material placed on the ground (Riddle and Bergström 2013; Liu et al. 2014). A similar mechanism for manure could reasonably be expected, i.e. that thawing after freezing would contribute to increased amounts of WEP and thereby also washout of P. However, there are no obvious indications of this in Figure 3, which also includes data from a study during a warmer spring period with more stable temperature conditions above zero. It could also be the case that cold conditions prevented biological degradation and related release of nutrients by mineralisation. Although alternating freezing-melting did not seem to increase the risk of losses from manure to soil compared with other weather conditions, it may have strongly affected other transport pathways of P draining from the manure heaps, thereby increasing the risk of losses of nutrients from the paddock where manure was left on the soil surface over winter. Frozen or partly frozen soil conditions generally hamper infiltration of water into the soil due to water saturation, and instead cause surface runoff (Liu et al. 2018b). The P lost from manure can thereby be transported over the soil surface quickly, without passing through the soil, where adsorption to soil particles would otherwise occur. The risk of negative impacts on water quality will then be determined by e.g. proximity to water bodies.

This study, which was performed in the absence of horses, found that recovery of manure placed on the ground was 67% after five months, while the rest was degraded or incorporated into the soil. Under real paddock conditions and using ordinary tools available for cleaning the paddock, the situation would be rather different. The proportion of the manure that could be collected would then depend on factors such as soil conditions, weather and the distribution of horses in the paddock. Horse trampling would make it more difficult to collect manure as time passes. This means that the interval between manure removals would greatly affect nutrient removal, due to less manure being collected and due to out washing by rainfall. In the previous field study by Malmer (2020) investigating different frequencies of manure removal from real horse paddocks with grip and bucket, 78, 47 and 36% of the manure was removed with daily, weekly and monthly manure removal, respectively. Based on this, it is obvious that a less frequent rate than daily removal will considerably reduce the possibility of collecting manure P for physical reasons, even under dry conditions.

Collecting manure from paddocks not only reduces the risk of negative environmental impact, but may also provide an important resource if the manure is properly channelled into crop production. The N fertiliser value of horse faeces is low (Keskinen et al. 2017). However, when used as a soil conditioner, e.g. after composting, horse manure can help to increase soil fertility (Bernal et al. 2009). All P excreted by horses is found in the faeces, with more than 50% in soluble form according to this study and others. Malmer (2020) estimated that 5.6 kg manure (fresh weight) were removed with daily removal of faeces from one horse that spent about 30% of its time outside. With the manure composition in our study, on an annual basis this would save 1.7 kg P and 5.5 kg K per horse, which could be recycled and used to replace non-renewable mineral P and K fertilisers. These savings correspond to approximately 10% of the P and 30% of the K in harvested grain per hectare from a cereal crop in Sweden (Aronsson et al. 2007).

Conclusions and recommendations

This study demonstrated high mobility of P and K in manure heaps and a strong impact of precipitation on losses of these two nutrients from manure in the field. However, N was retained in the manure over the five-month period. Since leaching of P may constitute a risk of negative impact on water quality, strategies for regular removal of manure from paddocks are required, especially under wet or expected wet conditions. Losses of P may occur within the first few days if manure is exposed to precipitation conditions or snow-melting events.

Frequent manure removal is especially important in paddocks used year-round, since horse trampling impedes collection of manure from paddocks and thereby shortens the acceptable interval between manure removal needed to reduce the risk of negative environmental impacts. Therefore, greater awareness among horse-keepers about the environmental effects, strategies and development of technical methods for collection of manure are important to reduce the risk of nutrient losses from horse paddocks to soil and water. Moreover, collecting manure from paddocks may also provide an important resource if the manure is properly recycled into crop production.

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Disclosure statement

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Linda Kumblad (associate professor) is a senior researcher in systems ecology with focus on eutrophication management in coastal areas.

Camilla Winqvist has a PhD in ecology, and has worked on horses and eutrophication as both a researcher and as a municipal environmental strategist.

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