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Phosphorus load from equine critical source areas and its reduction using ferric sulphate

Aaro Närvänen1)*, Håkan Jansson1), Jaana Uusi-Kämppä1), Helena Jansson2) and Paula Perälä1)

1) *MTT, Agrifood Research Finland, Plant Production Research, FI-31600 Jokioinen, Finland (corresponding author's e-mail: aaro.narvanen@mtt.fi)*
2) *MTT, Agrifood Research Finland, Animal Production Research, FI-32100 Ypäjä, Finland*

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The increasing number of horses, especially in urban areas has made the phosphorus (P) load of exercise areas (paddocks) more and more obvious but there has been a lack of information regarding how to assess this load and what can be done to lower it. In the surface soil (0–2 cm) of areas that are affected by horse manure, like paddocks, we measured very high extractable P contents. When testing soils from these areas using a rainfall simulator we found a close correlation between the extractable soil P in the surface soil and the dissolved reactive P in runoff water. In a runoff treatment test trial we used ferric sulphate to treat paddock runoff water. The chemical dosage was carried out using a tube doser placed in a well. After ferric sulphate treatment the runoff was discharged into a sedimentation pond and then filtered in a sandbed. The chemical treatment was performed during one year and the reduction of the dissolved P and total P in the runoff was 95% and 81%, respectively. Our Agri-Environmental Programme has not been successful in reducing the total P status in our agriculturally loaded lakes. We suggest that the cost-effective chemical treatment of waters from the high P equine areas should be included in the programme. Also in other countries in the Baltic Sea catchment area reductions of P contents in waters from equine areas should be carried out.

Introduction

The occurrence of algal blooms has been identified as a serious problem in many parts of the world (Ongley 1996). That has motivated research into nutrient exports from different land uses. Phosphorus (P) is one of the critical factors contributing to the development of algal blooms in freshwater systems (e.g., Pietiläinen 1997). Phosphorus enters the aquatic environment from a number of sources within a catchment including forests, urban runoff, sewage treatment plants, industry and agriculture (Barlow *et al.* 2003).

In countries like Finland the P load from industry and municipalities has been reduced to very low levels. Instead, the load from agriculture is now high as compared with that from other sources. It has been estimated to be as high as 60% of the total P load in Finland (Silvo *et* *al*. 2002). The concentration of extractable P in agricultural soils has been commonly tested in Finland using the acid ammonium acetate (AAAc) extraction method developed by Vuorinen and Mäkitie (1955). During the past decades the easily soluble P that this test measures has continuously increased in surface soils (Mäntylahti 2002). It had nearly doubled in the 1960s, and continued to increase at a more moderate pace until the end of the 1990s despite a substantial reduction in fertiliser use in the beginning of the decade. In recent years the P status of surface soils has appeared to be stabilising but, so far, no positive effects on water quality have been observed. Ekholm *et al*. (2004) studied 19 agriculturally loaded lakes during periods before and after the Agri-Environmental Programme, from 1990 to 1994 (MMM 2000) and from 2000 to 2002 (MMM 2002). They found an increase in the total phosphorus in 10 of the lakes, a decrease in 7 of the lakes and equally high total phosphorus content in 2 of the lakes.

There is a danger that the growing horse industry will be excluded in agricultural P load reduction plans, as horse keeping is not always considered a part of the agricultural sector. Often the P load from agriculture is considered a problem of non-point source pollution, and the P load from point sources such as paddocks are forgotten. When studying ditch sediments in different agricultural and forest areas, Jansson *et al*. (2000) noticed high P content in runoff from horse stable areas. This high P content in water corresponded well to the high extractable contents of P in ditch sediments where this water flowed.

It has been noted that in areas of high domestic animal traffic the water infiltration is much slower and precipitation will thus often form surface runoff. In a Finnish trial with different stages of cattle trampling, Pietola *et al*. (2003) measured an infiltration rate decrease from 7 cm h^{-1} to 1 cm h^{-1} in a trampled area. On a sandy soil the decrease from 15 cm h^{-1} to 3 cm h^{-1} was observed.

As pointed out by Airaksinen *et al*. (2006), accumulation of horse dung in paddocks is a problem, especially in countries with snowy winters. In their study the P concentration in surface water from a paddock area that was cleaned daily was compared with water from an uncleaned paddock area. They found that the cleaning of paddocks lowers the P content, especially during the summer, when horses were not kept in the paddocks but a residual effect remained. In their trial they collected the dung from the paddock of three adult horses during seven winter months. The horses spent on average 6 hours per day in their paddocks. The total content of P in the dung collected from the cleaned paddock during these seven months amounted to eight kilograms. As pointed out in their report these nutrients would be usable for crop production after composting (Airaksinen *et al*. 2001, Airaksinen *et al*. 2006).

According to official registers, the number of horses in Finland in 2006 was 64 000 (http://www.hippos.fi/hippos/tilastot/jalostus_ja_kasvatus/hevoskannan_kehitys.php). During recent years, an increase of more than 1000 horses per year has been measured. However, the number of horses has previously been much higher. In 1950, the number of horses was as high as 408 800. In those days horses were mostly used in agricultural and forestry work and were usually not kept year-round in paddocks.

Pikkarainen (2005) made a study of 70 stables in southwestern Finland (Häme). The horses were kept in paddocks for 7.2 hours on average. The average size of these horse paddocks was 1100 m^2. In her study, there was an average of 1.9 horses kept in a paddock. When these figures are used it can be estimated that approximately 34 000 horse paddocks are present in Finland. As the increase in the number of horses in Finland is currently about 1000 per year, these horses will need an additional 500 paddocks per year.

In Sweden the amount of P in faeces and urine from a horse is reported to vary from 22 to 44 g per day (Steineck *et al*. 2000). With varying diets van Doorn *et al*. (2004) found widely varying, but relatively low (0 to 1 g day^{-1}), urinary P excretion by mature horses. The faecal excretion varied from 18 to 37 g day^{-1}.

In a study on faecal P excretion from yearling geldings Hainze *et al*. (2004) found water-soluble P contents varying from 3.0 to 7.9 g day^{-1}. Faecal output of total P, water-soluble P, and insoluble P was 8.4, 3.0, and 5.4 g day^{-1}, 10.1, 3.9, and 6.9

g day^{-1}, 14.9, 5.3, and 9.6 g day^{-1}, and 19.0, 7.9, and 11.1 g day^{-1}, respectively for diets containing whole oats, alfalfa cubes, commercial 'sweet feed' and pelleted concentrate (Hainze *et al*. 2004). The water-soluble P varied between 36% and 42% of the total P in the faeces. Thus feed ingredients commonly used to meet digestible-energy and crude-protein requirements can be expected to differ markedly with respect to the quantity and solubility of P returned to the environment in faeces.

Our earlier studies have suggested that ferric sulphate could be used to reduce the concentrations of both dissolved reactive P and total P in waters from equine areas (Närvänen *et al*. 2001, Jansson and Närvänen 2005). In this study, we wanted to analyze in more detail the soil P concentrations in areas in equine use. In the three first parts of the study we investigated the concentrations of extractable P at different soil depths with the aim to study the influence of different equine use on different soil layers. The layers examined were 0–2 cm, 0–20 cm, and 0–100 cm. In the fourth part we tested the relation between the extractable P and dissolved reactive P in the runoff water in a rainfall simulation study. The fifth part we tested how effectively ferric sulphate treatment in a tube doser can reduce the P load from a horse paddock.

Material and methods

Soil and water sampling

Soil sampling

In the first trial the soil sampling was carried out at Ypäjä, southwestern Finland. The soil samples were collected at the premises of Ypäjä Equine College and Equine Research of MTT in Ypäjä. Thirty soil samples were taken from the surface layer (0–2 cm).

In the second trial, samples from the surface soil layer (0–2 cm) at twelve equine sites, were compared with samples from the normal field sampling depth (0–20 cm). This sampling was carried out at a stable in Rehtijärvi catchment area. This stable is situated at Jokioinen in southwestern Finland. Soil and ditch water nutrient contents have been well-monitored in this catchment area (Uusitalo and Jansson 2002).

In the third trial, soil samples were taken from 17 stable sites to a depth of one meter, and divided into 20-cm subsamples (0–20, 20–40, 40–60, 60–80 and 80–100 cm). These samples were taken from the stables of Ypäjä Equine College and the Equine Research of MTT. Sampling was also carried out at the above-mentioned stable in the Rehtijärvi area as well as at a newly established stable in Kuuma, Jokioinen.

Rainfall simulation tests

In the fourth trial, 26 surface soil samples (0–5 cm) were taken from paddocks and other areas of widely varying horse-related use, for a rain simulation study. These samples were taken at the stable areas of Ypäjä Equine College and Equine Research of MTT as well as at the above-mentioned stable in Kuuma, Jokioinen. These samples were used in a rain simulation test in a laboratory. In this rain simulation test the artificial rainwater was sampled as surface flow only. The samples were cut to fit into plates with a diameter of 24 cm and edges of 5 cm. Twenty-one mm h^{-1} of rain was simulated and the surface flow water was sampled. A more detailed description of the rain simulation equipment used can be found in Uusitalo and Aura (2005). The rain intensity in our study was higher than in their rainfall simulation treatment (5 mm h^{-1}). This was done by increasing the bypass height of the water from 40 to 104 mm.

We collected half a litre of water for determining the concentration of dissolved reactive phosphorus (DRP). This was done after a 0.5–1.5-hour rainfall simulation, and the collecting of water started after a measured flow of half a litre. To get this amount of water half an hour of rainfall simulation was needed during this steady state period. By collecting water during the steady state period in the water flow we could have water representing a runoff from a saturated soil as is typical for our main surface flow periods in spring and autumn. The collected water was used for comparison with the soil P

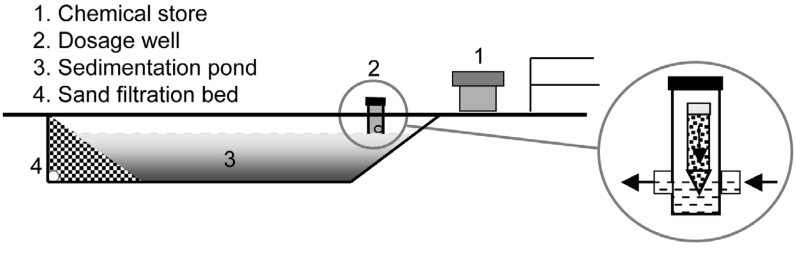

Fig. 1. The treatment system for runoff waters from the equine areas.

content and in estimating the P load in different paddocks. After the rain simulation treatment of these soils the top layer (0–2 cm) was used for soil testing.

Treatment of paddock runoff water with ferric sulphate

In the fifth trial of this study, a runoff treatment unit was constructed beside a paddock of a run-in shed at Ypäjä Equine College. The run-in shed has been in use from 1981. The number of horses kept in this stable is usually about ten but the number has varied from 5 to 20. During the winter of 2003/2004 seven young stallions were kept in the stable. They were fed with hey or silage under the open sky. The outdoor area was 5000 m^2. The horses were fed outdoors using a hay feeder and, during recent years, also using a hay feeder wagon. For minerals and concentrated feeds there was a feeder with a roof. The area with the feeders was properly cleaned once a year. This was done in summer when the horses were not staying in the run-in shed. The droppings and the top layer were taken away and a new sand cover was spread out. The droppings were also taken away from other parts of the yard a few times a year.

The surface flow water from this 5000 m^2 yard was collected in an open ditch leading to a well. The untreated water was sampled from this well (Fig. 1). From the well the water flowed through a pipe to pass a doser of ferric sulphate. The granulated ferric sulphate (http://www.kemira.com/NR/rdonlyres/99D642FD-410D-4351-8DFE-730033E9B82A/0/Ferix_3.pdf) was dosed in a small well where a pipe with a cone-shaped bottom was placed. There were holes in the bottom of the doser allowing the chemical to dissolve in the water. The pipe was filled with the chemical and, through the holes, the chemical dissolved in the water. When a large flow raised the water level in the well, more holes came into contact with the water, and thus more chemical was dissolved. It was possible to calibrate the dosing amounts by measuring the pH of the water flowing out from the outlet pipe of the doser and adjusting the number of holes and their location on the cone accordingly. After the dosing, the water flowed into a constructed pond (100 m^2) and was filtered through a sandbed. The sandbed filter was made by filling the first layer around the effluent pipe with 9 m^3 of sieved sand (grain size > 2.0 mm) and the second layer with 9 m^3 of unsieved sand.

As the sedimentation pond was 100 m^2 and the water came from the 5000 m^2 paddock yard this means that the pond to watershed area ratio is 2%. This is a ratio recommended as a minimum for constructed wetlands in Finland (Koskiaho 2006). Our pond had a theoretical water residence time of 8.7 h and a water volume of 63 m^3. Typical annual maximum of (daily mean) runoff was expected to be 400 l s^{-1} km^{-2} and for our pond 2 l s^{-1}. The pond was 10-m long and 10-m wide. The maximum water depth was 1 m and the size of this deep area was 5 m × 5 m. The hydraulic loading rate (HLR) was 0.07 m h^{-1}. The water amount to be treated in this pond would be 1500 m^3 year^{-1} and the yearly use of ferric sulphate would be 100 to 200 kg year^{-1}. The expected retention of P would be 1.5 to 2 kg year^{-1}.

The sampling of water was a combination of high hydraulic loading rate (HLR) and few grab samples. The sampling of the effluent water was usually done from the water that had filtered through the sand bed, but when the water flow was higher than the filter capacity the sampling was done from a mixture of both the filtered water and the water leaving the pond as overflow. The flow water rates of the effluent water were measured. The effluent flows could not be measured throughout the test period, as the flow during the snow–thaw period was higher than the capacity of the (frozen) sandbed.

Soil sampling from this paddock was carried out at three sites from five different layers down to a depth of one meter. In addition, composite samples (12–15 subsamples), one surface (0–2 cm) sample from the feeding area, and one surface sample (0–2 cm) from the other area of the paddock were taken.

Soil and water analyses

The soil samples were air-dried and passed through a 2-mm sieve. To assess the P load in the study areas, the soil was extracted using the routine field soil testing method (Vuorinen and Mäkitie 1955) using a soil acid ammonium acetate (AAAc) extraction (0.5 M ammonium acetate, 0.5 M acetic acid; pH 4.65). In the AAAc extraction, 25 ml air-dry soil was shaken end-over-end (37 rpm) with 250 ml of AAAc solution for 60 min, whereafter the suspension was passed through a S&S 5893 blue ribbon paper (Schleicher & Schuell, Dassel, Germany), and the filtrate analysed for P using stannous chloride reduction of the phospho-molybdate complex.

In addition to soil extractable phosphorus (AAAc-P), soil pH and electrical conductivity were also determined. Electrical conductivity was measured from a soil:water (1:2.5) suspension after letting the suspension settle overnight. Soil pH (H_2O) was measured from the same suspension after stirring. Volume weight of soil was determined by weighing a 40 ml sample of air dried soil. Concentration of total phosphorus (TP) was determined in unfiltered water samples according to the Finnish standard method (SFS 3026 1986). For the determination of dissolved reactive phosphorus (DRP), water samples were filtered through a membrane filter (Nuclepore®, Polycarbonate, pore size 0.2 μm) before analysis. DRP was determined by means of a molybdate blue method, using ascorbic acid as the reducing agent (Murphy and Riley 1962; SFS 3025 1986).

Results and discussion

Soil AAAc-P concentrations

The highest extractable soil P contents (AAAc-P) in surface soil (0–2 cm) were found in areas where the horses were regularly fed with hay or in areas where the horses defecated (Table 1). The run-in shed areas were also high in AAAc-P. When interpreting these results using the seven P classes in use for field soils in Finland (Viljavuuspalvelu 2000), almost 50% of the samples fell into the highest class, i.e., their P contents were alarmingly high. The lowest P contents were found in areas of minor equine use. However, the P content of the surface soil was also not especially high in some areas with quite high equine use. In these cases the explanation seemed to be that most of these sites were affected by erosion, and the sampled layer contained unaffected soil exposed by erosion. The AAAc-P in the surface soils of the studied paddocks always exceeded the mean content reported for fields (Mäkelä-Kurtto *et al*. 2002).

The high or extremely high AAAc-P contents in the surface soil from the paddock areas were not expected as the surfaces of these paddocks had been replaced frequently, in most cases every year. Paddock areas used by horses in run-in sheds were also all extremely high in AAAc-P. In ungrassed areas in larger paddocks the concentration of extractable P varied significantly. These areas included steep slopes, susceptible to erosion, and flows of surface water passing directly through the critical source areas.

As compared with the paddocks, the other equine areas studied were relatively low in AAAc-P (Table 1). The extractable P from the trotting course was of the average level of Finnish fields. However, the field P level in Finland is high enough to be a big contributor to the dissolved reactive phosphorus (DRP) load. In Finland a typical field water DRP concentration is 0.13 mg l^{-1} and amounts to 0.4 kg ha^{-1} per year (Rekolainen 1993). DRP is directly available for algal growth so reducing DRP levels is important.

On average, the AAAc-P in the surface layer was three times as high as in the topsoil layer (Table 2). The highest amount of AAAc-P was found in the muddiest paddock. In this paddock, however, the difference in P content between layers was not as distinct. This may be due to mixing of the topsoil layer by the horses' hooves. When examining the depth distribution of AAAc-P down to one meter, we observed that high AAAc-P was typical in the topsoil layer (0–20 cm), and strongly decreased with depth (Fig. 2).

Soil pH in the surface layer (0–2 cm) did not differ from that of the topsoil (0–20 cm) (Table 2). Conductivity in the surface layer was much higher than in the topsoil layer. Conductivity in soil showed a strong positive correlation with the AAAc-P in both the topsoils and the surface soils: the correlation coefficients were as high as 0.92 and 0.86, respectively. Although a high soil

Table 1. General soil properties and AAAc-extractable soil phosphorus in surface layers (0–2 cm) of soil from sites of different equine use.

Sampling site	pH (H_2O)	Conductivity (10^{-4} S cm^{-1})	Volume weight (g cm^{-3})	P (mg l^{-1} soil)
Constructed paddocks, no vegetation				
Western side of stable I	6.76	1.33	1.14	50.55
North western side of stable I	6.54	0.85	1.23	46.01
Between stables I and II	6.68	0.73	1.04	53.15
Paddock with roofed area (stable I)	6.79	1.71	0.55	104.13
Equine hospital paddock	6.71	0.78	0.8	45.51
Stable III paddock area close	6.78	1.88	0.99	46.95
Stable III paddock area close	6.71	0.94	1.03	44.69
Stable III paddock area far off	7.02	3.57	0.96	43.34
Mean	6.75	1.47	0.97	54.29
SD	0.14	0.95	0.21	20.39
Paddocks, not constructed, no vegetation				
South of stable I lower paddock	6.64	2.12	0.95	41.73
Stable III paddock area far off	6.66	4.85	0.46	93.06
Stable III paddock area far off	6.73	3.24	0.68	36.78
Stable IV paddock (slope)	6.63	1.28	1.09	46.63
Mean	6.67	2.87	0.80	54.55
SD	0.05	1.54	0.28	25.99
Not established paddocks, varying vegetation				
Birch area, defecating area	6.71	2.7	0.83	187.31
Behind the restaurant gate area	6.05	1.14	0.95	27.53
Behind the restaurant in middle	5.9	1.55	0.72	23.48
Birch area, feeding area	6.86	3.15	1.02	32.31
Karrinmäki area	6.29	1.65	0.81	51.53
Trotting course paddock	6.45	0.89	0.86	25.34
South of stable II and III (slope)	6.33	3.02	0.69	23.16
Päivärinne, feeding area	6.92	5.16	0.50	227.06
Päivärinne, gate area	6.66	3.06	0.78	43.6
Mean	6.46	2.48	0.80	71.26
SD	0.35	1.33	0.15	78.29
Paddocks with run-in sheds				
Run-in shed A	6.78	5.5	0.53	122.92
Run-in shed B	6.49	2.06	0.78	71.69
Run-in shed C	6.9	5.25	0.78	102.84
Mean	6.72	4.27	0.70	99.15
SD	0.21	1.92	0.14	25.81
Other equine areas				
Trotting course	6.65	14.3	1.40	11.49
Dressage arena	6.61	5.85	1.18	9.16
Driving course	6.46	0.32	1.41	6.57
Watering place, pasture	5.6	1.49	0.74	14.29

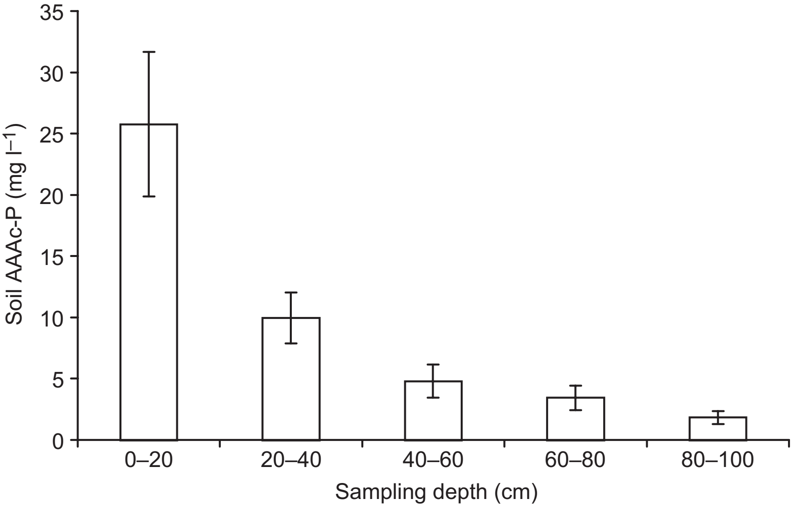

Fig. 2. Average and SE acid ammonium acetate (pH 4.65) extractable phosphorus (AAAc-P) in different soil layers of paddocks.

conductivity in equestrian areas generally indicated a high soil P it was not so in all the studied areas. In the material from the first part of the study, including the surface soils from thirty sites, the places with the two highest conductivities (the racetrack and the dressage arena) were not exceptionally high in P. The likely explanation is that in these areas salt, usually magnesium chloride, is used for dust prevention, raising the electric conductivity but not the P content of the soil (*see* Table 1).

Rainfall simulation tests

After the rain simulation treatment of the top layer (0–2 cm) was used for soil testing. The AAAc-extractable P concentrations of these surface soil from the 26 sampled sites of various equine use varied from 6.39 to 169 mg l^{-1} soil. The P concentration (DRP) in the surface flow water collected in the simulation test varied relatively much more widely as the lowest measured concentration was 0.02 mg l^{-1} and the highest

Table 2. Soil general properties and acid ammonium acetate (pH 4.65) extractable content of phosphorus of the surface layer (0–2 cm) and in top soil layer (0–20) of different areas of a horse farm.

	Soil layer 0–2 cm			Soil layer 0–20 cm		
Sampling site	pH (H_2O 1:2.5)	Conductivity (10^{-4} S cm^{-1})	P (mg l^{-1} soil)	pH (H_2O 1:2.5)	Conductivity (10^{-4} S cm^{-1})	P (mg l^{-1} soil)
Paddock	6.62	5.3	70.8	6.6	2.95	42.5
Paddock	6.13	2.65	37.36	5.89	1.24	5.4
Paddock	6.11	2.65	39.71	5.74	0.76	7.1
Paddock	5.88	2.35	14.67	5.53	0.62	2.9
Free running stable yard	6.1	3.51	41.3	6.12	2.42	17.1
Pasture	6.17	2.8	20.6	5.72	0.67	2.3
Pasture	5.9	2.67	13.7	5.73	0.46	1.0
Pasture	5.68	1.44	6.08	5.74	0.55	2.4
Area used as manure storage	5.91	2.69	23.6	5.94	0.9	2.4
Pasture	5.8	2.86	9.27	5.6	0.56	1.6
Exercise road	5.83	1.4	16.4	5.99	0.89	7.9
Pasture	5.74	1.48	4.01	5.82	0.74	2.4
Average	6.0	2.7	24.8	5.9	1.1	7.91
SD	0.26	1.06	19.32	0.28	0.79	11.77

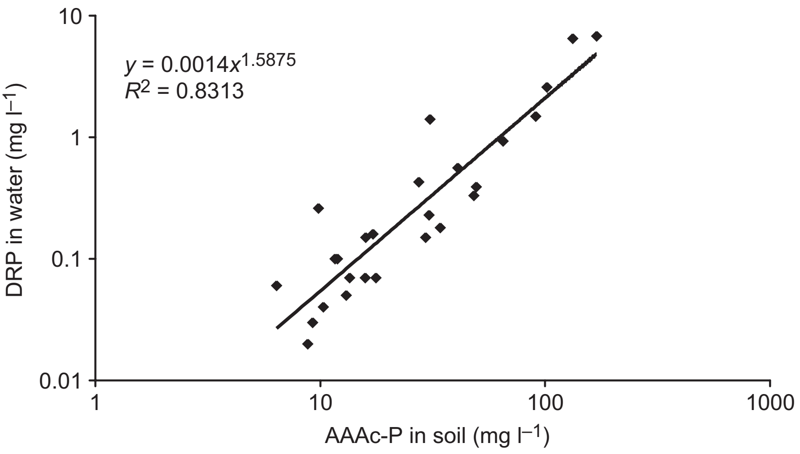

Fig. 3. Regression of dissolved reactive phosphorus (DRP) contents in runoff waters on AAAc soil extractable soil phosphorus in an artificial rainfall treatment test.

was 6.81 mg l^{-1} water The correlation between the AAAc-P in the soil and the DRP in the surface flow water was good (Fig. 3) and thus AAAc-P in the 0–2 cm surface soil layer is a very good indicator of the P load.

When comparing the results from a runoff study in two horse paddocks reported by Airaksinen *et al*. (2006) with the results in this study it can be seen that their extractable soil AAAc-P contents were much lower as compared with those measured in this study. One reason for this could be that they sampled the soil to a depth of 12 cm. Also, in their experiment the sand layer in the paddocks was replaced before the experiment started.

Treatment of paddock runoff water with ferric sulphate

The AAAc-P in the topsoil (0–20 cm) layer of the test site varied from 23 to 99 mg l^{-1}. The surface soil samples showed somewhat higher soil P levels in the feeding area (102 mg l^{-1}) than in the soil sample representing the whole area (72 mg l^{-1}). These concentrations were high as compared with the normal concentrations in Finnish fields (*see* Mäntylahti 2002). The high P concentrations were reflected in high P concentrations in the surface flow water from this paddock. The DRP was especially high, being ca. 15 times the concentration in runoff water from our field areas (Fig. 4).

The reduction in TP concentration achieved with ferric sulphate was generally good (Fig. 4) but at the end of March 2004 also low reductions were noted. The reduction in DRP was high throughout the test period (*see* Fig. 4). The effluent flows could not be measured throughout the entire test period as the flow during the snow melting period was not filtered through the frozen sandbed. We used the mean of all observations made for calculating the mean reductions in P. Had it been possible to use flow weighted averages, the one-year reductions would probably have been lower, as the poorest reductions could be noted in the spring with high flows when the reduction in total P was low. The mean reduction in TP was 81% and in DRP 95%. During the test period 160 kg of ferric sulphate was used (320 kg $Fe_2(SO_4)_3$ ha^{-1} of paddock area).

Conclusions

The extractable P contents in surface soil samples (0–2 cm) in comparison with those in deeper soil samples (0–20 cm) were on the average three times higher. The deep sampling showed that overall, the highest extractable soil P in equine areas would be find in the surface soil. In this study it could be shown that, when estimating the dissolved reactive phosphorus (DRP) load, the inexpensive routine P analysis from the surface soil (0–2 cm) was a very good indicator of this load. The method for chemical treatment of paddock surface water tested in this project was very effective in reducing the P load.

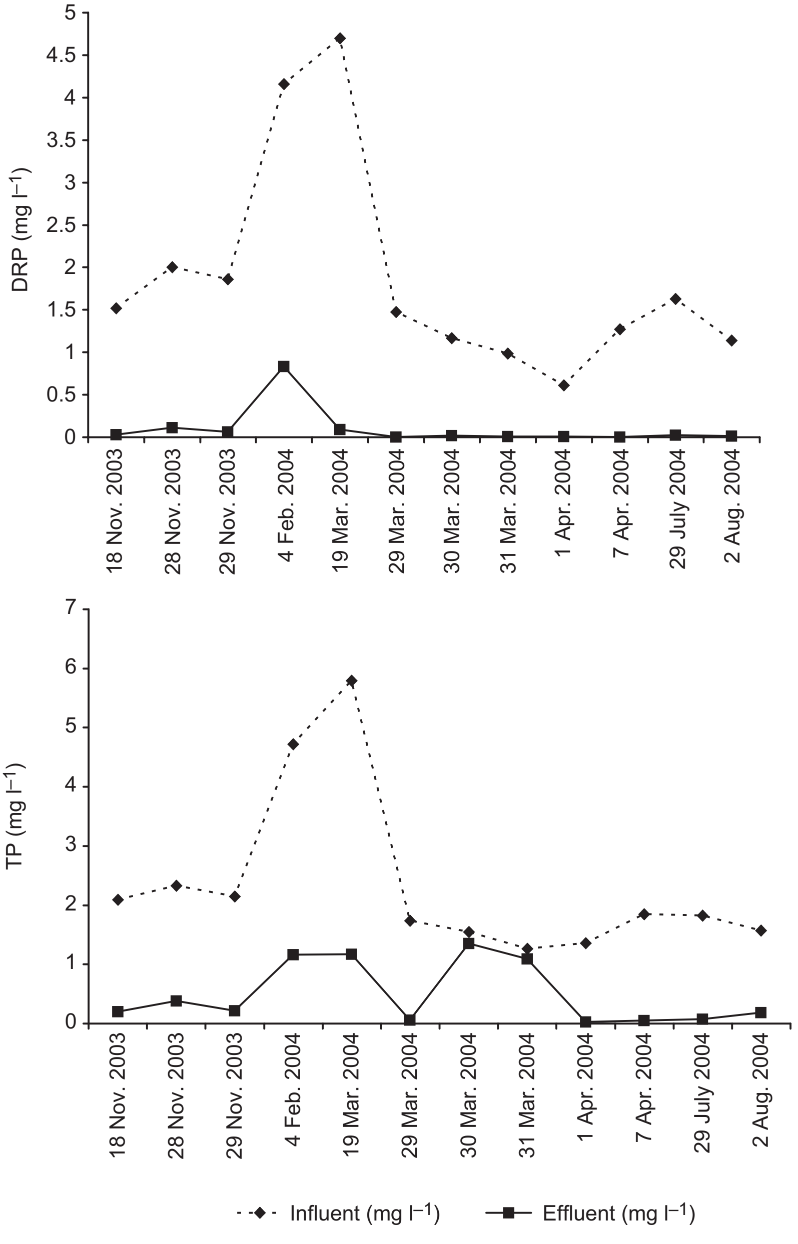

Fig. 4. Concentrations of dissolved reactive (DRP) and total phosphorus in the influent and effluent (treated) equine area water at the Ypäjä treatment site.

It has been estimated that in Finland there are nearly 1000 lakes suffering from eutrophication (Turunen and Äystö 2000). We have not been successful in reducing the total phosphorus levels in our agriculturally loaded lakes (Ekholm *et al*. 2004). One reason may be our increasing horse industry with its high P load. Therefore the waters from equine critical source areas very high in P should be treated chemically in the future.

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References

Airaksinen S., Heinonen-Tanski H. & Heiskanen M.-L. 2001. Quality of different bedding materials and their influence on the compostability of horse manure. *Journal of Equine Veterinary Science* 21: 125–130.

Airaksinen S., Heiskanen M.-L. & Heinonen-Tanski H. 2006. Contamination of surface run-off water and soil in two horse paddocks. *Bioresource Technology* 98: 1762–1766.

Barlow K., Nash D., Turral H. & Grayson R. 2003. Phosphorus uptake and release in surface drains. *Agricultural Water Management* 63: 109–123.

Ekholm P., Virtanen J. & Mitikka S. 2004. Agricultural nutrient loading and its impact on surface waters — an assessment based on monitoring data. Water quality in lakes. *Maa- ja elintarviketalous* 59: 84–96. [In Finnish with English abstract].

Hainze M.T.M., Muntifering R.B., Wood C.W., McCall C.A. & Wood B.H. 2004. Faecal phosphorus excretion from horses fed typical diets with and without added phytase. *Animal Feed Science and Technology* 117: 265–279.

Jansson H., Mäntylahti V., Närvänen A. & Uusitalo R. 2000. Phosphorus content of ditch sediments as indicator of critical source areas. *Agricultural and Food Science in Finland* 9: 217–221.

Jansson H. & Närvänen A. 2005. Reducing the phosphorus load and the algae blooms in Finnish lakes and the Baltic Sea. *Agrifood Research Reports* 68: 190–200.

Koskiaho J. 2006. *Retention performance and hydraulic design of constructed wetlands treating runoff waters from arable land*. Acta Universitatis Ouluensis, Series C, Technica.

MMM 2000. *Ympäristötukiopas*. Maa- ja metsätalousministeriö, Helsinki.

MMM 2002. *Horisontaalinen maaseudun kehittämisohjelma*. Manner-Suomi. Maa- ja metsätalousministeriö, Helsinki.

Murphy J. & Riley J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27: 31–36.

Mäkelä-Kurtto R., Sippola J. & Grek K. 2002. Peltomaiden viljavuus ja helppoliukoiset raskasmetallit. *Maa- ja elintarviketalous* 13: 30–46.

Mäntylahti V. 2002. Peltojen ravinnetilan kehitys 50 vuoden aikana. *Maa- ja elintarviketalous* 13: 5–13.

Närvänen A., Jansson H. & Jansson H. 2001. Saostus puhdistaa hevosten juoksutarhojen valumavedet. *Koetoiminta ja käytäntö* 58: 2.

Ongley D.O. 1996. Control of water pollution from agriculture. *FAO irrigation and drainage paper* 55. Food and Agriculture Organization of the United Nations, Rome.

Pietiläinen O.P. 1997. Agricultural phosphorus load and phosphorus as a limiting factor for algal growth in Finnish lakes and rivers. In: Tunney H., Carton O.T., Brookes P.C. & Johnston A.E. (eds.), *Phosphorus loss from soil to water*, CAB International, UK, pp. 354–356.

Pietola L., Yli-Halla M. & Horn R. 2003. Cattle trampling increases risk for surface runoff. In: Niemeläinen O. & Topi-Hulmi M. (eds.), *Proceedings of the NJF's 22nd Congress "Nordic Agriculture in Global Perspective", July 1–4, 2003, Turku, Finland*, MTT Agrifood Research Finland, Jokioinen, p. 30.

Pikkarainen M. 2005. *Hevosten hyvinvointi ja lajinmukainen käyttäytyminen sekä niiden toteutuminen suomalaisilla talleilla*. Opinnäytetyö, Maaseutuelinkeinojen koulutusohjelma, Hämeen ammattikorkeakoulu, Mustiala.

Rekolainen S. 1993. *Assessment and mitigation of agricultural water pollution*. Publications of the Water Environment Research Institute 12, National Board of Waters and the Environment, Helsinki.

SFS 3025 1986. *Veden fosfaatin määritys*. Finnish Standards Association SFS, Helsinki.

SFS 3026 1986. *Veden kokonaisfosforin määritys*. Finnish Standards Association SFS, Helsinki.

Silvo K., Hämäläinen M.-L., Forsius K., Jouttijärvi T., Lapinlampi T., Santala E., Kaukoranta E., Rekolainen S., Granlund K., Ekholm P., Räike A., Kenttämies K., Nikander A., Grönroos J. & Rönkä E. 2002. *Päästöt vesiin 1990-2000. Vesiensuojelun tavoitteiden väliarviointi 1990–2000*. Suomen ympäristökeskuksen moniste 242.

Steineck S., Svensson L., Jacobsson C., Karlsson S. & Tersmeden M. 2000. *Hästar — gödselhantering*. Teknik för Lantbruket 82, Institutet för jordbruks- och miljöteknik, Uppsala.

Turunen A. & Äystö V. 2000. *Selvitys vesistöjen kunnostusttarpeista*. Suomen ymparistökeskuksen moniste 180.

Uusitalo R. & Aura E. 2005. A rainfall simulation study on the relationships between soil test P versus dissolved and potentially bioavailable particulate phosphorus forms in runoff. *Agricultural and Food Science* 14: 335–345.

Uusitalo R. & Jansson H. 2002. Dissolved reactive phosphorus in runoff assessed by soil extraction with an acetate buffer. *Agricultural and Food Science in Finland* 11: 343–353.

van Doorn D.A., Everts H., Wouterse H. & Beynen A.C. 2004. The apparent digestibility of phytate phosphorus and the influence of supplemental phytase in horses. *Journal of Animal Science* 82: 1756–1763.

Viljavuuspalvelu 2000. *Viljavuustutkimuksen tulkinta peltoviljelyssä*. Viljavuuspalvelu Oy, Mikkeli.

Vuorinen J. & Mäkitie O. 1955. The method of soil testing in use in Finland. *Agrogeological Publication* 63: 1–44.