

Release of soil phosphorus during runoff as affected by ionic strength and temperature

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Dissolved reactive phosphorus (DRP) from two cultivated clay soil samples (Vertic Cambisols) was extracted under conditions simulating the variation in the properties of surface runoff water in the field. DRP was extracted at three temperatures (5, 15 and 25°C), and at different ionic strengths by using deionized water and CaCl₂ solutions (0.00005–0.005 M) as extractants. The solution-to-soil ratio varied from 50 to 2000 l kg⁻¹. Sorption to and desorption from the soils were studied at different temperatures and ionic strengths by determining quantity-intensity (Q/I) plots at the solution-to-soil ratio of 50 l kg⁻¹, and the results were fitted to a modified Langmuir equation:

$$Q = Q_{\max} I / (1/K + I) - Q_0$$

where Q is P sorbed or desorbed, Q_{max} = maximum P sorption, I = P concentration in the equilibrium solution, K = sorption/desorption equilibrium constant, and Q₀ = instantly labile P. The desorption of DRP was depressed by increases in the CaCl₂ concentration of the extractant and promoted by widening of the solution-to-soil ratio. At the solution-to-soil ratio of 50 l kg⁻¹, the increase in the temperature from 5 to 25°C raised the DRP release to water from 12.6 to 20.7 mg kg⁻¹ in the Aurajoki soil and from 1.8 to 3.4 mg kg⁻¹ in the Jokioinen soil. In the Aurajoki soil, the constant Q₀ of the Langmuir equation responded to the changes of ionic strength and temperature in the same way as did DRP extracted at wide solution-to-soil ratios. However, the P release capacity of both soils was underestimated by the constant Q₀.

Key words: water extraction, CaCl₂ extraction, solution-to-soil ratio, modified Langmuir equation, phosphorus loading of surface waters

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Introduction

Surface runoff water transports phosphorus (P) from soil to watercourses in the dissolved form

and in the particulate material. In areas of frozen soil and snow coverage in winter, the volume of surface runoff water peaks in spring during the thaw, another peak often occurring in autumn. Erosion and removal of dissolved P are

also most intensive during these periods (Turto-la and Jaakkola 1995). The equilibrium P concentration (EPC) in the solution where the particulate material collected from river water neither released or adsorbed P was shown to be lower than 0.010 mg P l⁻¹ which is decisively below the EPC obtained for cultivated soils (e.g. Hartikainen 1982b, Yli-Halla 1991, Yli-Halla et al. 1995). Pietiläinen and Ekholm (1992) showed that 90% of particulate material in a small agriculturally loaded river in southern Finland was recently eroded from the surface soil of the fields of the drainage basin. Comparison of the results above thus reveals that P must be effectively desorbed during the erosion process.

Dissolved P in the runoff water originates partly from the bulk of the soil remaining in the field and partly from suspended particles. Soil P status, to some extent, explains the average dissolved reactive P (DRP) concentration in runoff water but not the temporal variation of DRP (Yli-Halla et al. 1995). The temperature during the runoff peaks in autumn and particularly in spring is much lower (between 0 and 5°C) as compared

to temperatures prevailing during the occasional summer rainstorms (commonly around 15°C) and to room temperatures at which laboratory experiments are usually done. There is also a marked seasonal variation in other external conditions (ionic strength and volume of runoff water) prevailing during runoff events.

In this study, a set of desorption tests was carried out to quantify the impact of environmental factors on the P loading risk due to the surface runoff from cultivated soils. The temperature as well as ionic strength and solution-to-soil ratio were varied to simulate their changes during the runoff and erosion process and material transport in watercourses. The impact of temperature and external ionic strength on the dynamic equilibrium between solution and solid material was investigated by means of the quantity-intensity (Q/I) plots. The instantly labile P derived from these graphs was used as one estimate for the P loading risk due to runoff water. The suitability of the Q/I plots to predict P release from soil was also evaluated.

Table 1. Properties of the experimental soils.

Characteristic	Aurajoki soil	Jokioinen soil
Clay, %	60.1	58.5
Organic C, %	2.8	1.4
Soil pH(CaCl ₂)	5.72	5.14
Al _{ox} , g kg ^{-1*}	1.05	2.22
Fe _{ox} , g kg ^{-1*}	7.23	7.03
P _w , mg kg ^{-1**}	27.5	3.6
P _{Ac} ^{***} , mg dm ⁻³ of soil	27.1	5.1
NH ₄ Cl-P, mg kg ^{-1****}	5.2	0.2
NH ₄ F-P, mg kg ^{-1****}	132	80
NaOH-P, mg kg ^{-1****}	527	423
H ₂ SO ₄ -P, mg kg ^{-1****}	475	172
Sum of fractions, mg kg ^{-1****}	1139	675

* Extracted with 0.05 M ammonium oxalate, pH 3.3 (Niskanen 1989)

** P extracted with water, solution-to-soil ratio 50 l kg⁻¹

*** P extracted with an ammonium acetate solution, pH 4.65 (Vuorinen and Mäkitie 1955)

**** Chang and Jackson fractions of inorganic P (Hartikainen 1979)

Material and methods

Soil samples

The soil samples of Aurajoki and Jokioinen (Table 1) were taken from experimental fields set up for studies on surface runoff. They represent fields with high and low level of P concentration in runoff, respectively (Yli-Halla et al. 1995). Both soils, located in southwestern Finland, are classified as Vertic Cambisols (FAO 1988). The soil samples were taken from the 0–10 cm layer. After air-drying and homogenization, the samples were rewetted to a moisture content of 20% and stored at 5°C for several weeks before the analyses. Air-dry samples were analyzed for pH in a 0.01 M CaCl₂ suspension and for water-extractable P (1 g of soil, 50 ml of deionized water, 17 hours of equilibration; Hartikainen 1982a).

Desorption tests

To study the effect of ionic strength on P desorption from soil, deionized water, 0.0005 M and 0.005 M CaCl₂ were used as extracting solutions at room temperature (25°C). The selection of CaCl₂ is based on the dominance of Ca among the exchangeable cations of the experimental soils (results not presented). For the extractions, moist soil samples (four replicates) were weighed to give dry soil concentrations of 0.5, 1, 2, 5 and 20 g l⁻¹ of the extractant (solution-to-soil ratio 2000–50 l kg⁻¹). The soil suspensions were shaken for 17 h in an orbital shaker at a speed of 250 rotations min⁻¹. According to preliminary experiments, this reaction time was well sufficient to reach a semi equilibrium. The supernatant solutions were filtered through a membrane filter (0.2 µm, Nuclepore polycarbonate) and analyzed for dissolved reactive P (DRP) by a molybdenum blue method using ascorbic acid as the reducing agent. The effect of temperature on P desorption was studied by extracting soil with deionized water at 5, 15 and 25°C. At each temperature, the extractions were carried out at solution-to-soil ratios from 50 to 2000 l kg⁻¹. The soil samples and the solutions to be added were adapted to the respective temperatures before the extraction. Phosphorus was determined as mentioned above.

Q/I plots

The Q/I plots were applied to express the sorption or desorption as a function of the P concentration in the equilibrium solution. They were determined in three replicates by adding 50 ml of KH₂PO₄ solution (0–4 mg P l⁻¹ for Aurajoki samples, 0–5 mg P l⁻¹ for Jokioinen samples) to moist samples corresponding to 1 g of dry soil (solution-to-soil ratio 50 l kg⁻¹, or concentration of suspended solids 20 g l⁻¹). The extracts were obtained as described above and analyzed for DRP. The Q/I plots were determined at three temperatures: 5, 15 and 25°C. At 25°C, the plots were also determined using 0.005 M, 0.0005 M

and 0.00005 M CaCl₂ as the supporting electrolytes. The ionic strengths of soil extracts were estimated from the electrical conductivity according to Griffin and Jurinak (1973).

Sorption to or desorption from soil (Y) in mg P kg⁻¹ was calculated from the changes in P concentration of the contacting solution and fitted to a modified Langmuir equation (Hartikainen and Simojoki 1994):

$$Q = Q_{\max} I / (K + I) - Q_0$$

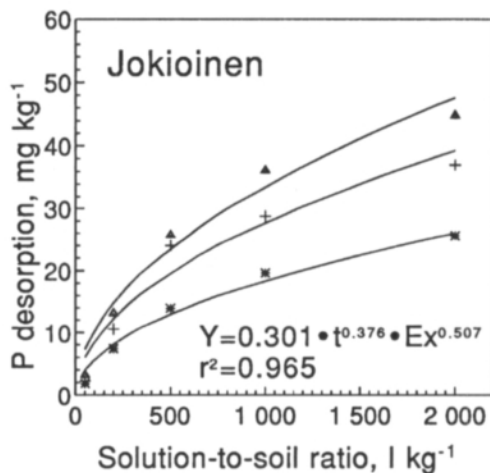
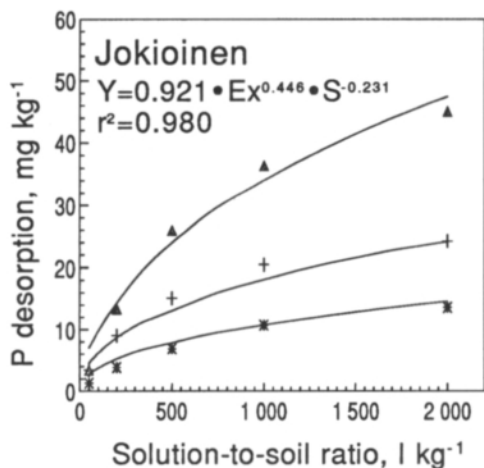
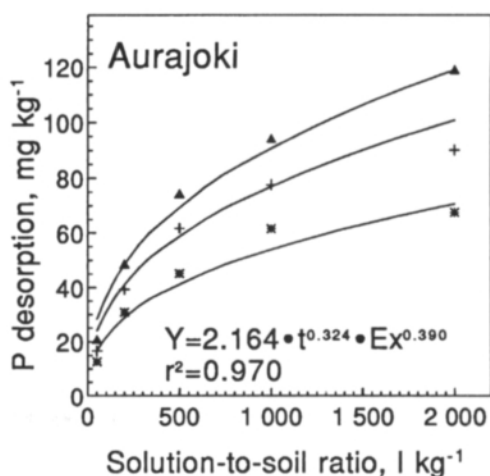
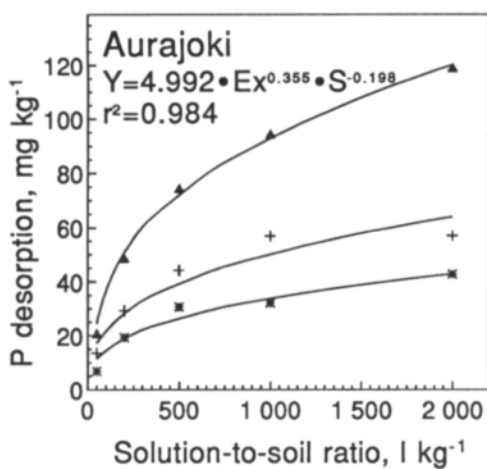
where Q is P desorbed or sorbed, Q_{max} = maximum P sorption, I = P concentration in the final equilibrium solution, K = sorption/desorption equilibrium constant, and Q₀ = instantly labile P. Mathematically, the isotherm will intersect the y-axis when I = 0. According to Beckett and White (1964), the intercept (term Q₀ in the equation) represents what was termed instantly labile P that would have to be removed from the soil to reduce I to zero at a given solution-to-soil ratio. The intersecting point of the graph on the x-axis (Y = 0), the equilibrium phosphate concentration (EPC), represents the zero point of P exchange at which no net desorption from or sorption to soil occurs. The slope of the sorption-desorption curve at the EPC was referred to by Holford and Mattingly (1976) as the equilibrium buffer capacity (EBC).

Results

Desorption tests

At every solution-to-soil ratio, the two CaCl₂ solutions extracted much less P than did water (Fig. 1). At the solution-to-soil ratio of 50 l kg⁻¹ the P concentration in the extract was lowered from 0.42 to 0.14 mg l⁻¹ in the Aurajoki soil and in the Jokioinen soil from 0.068 to 0.015 mg l⁻¹ when the ionic strength of the soil extract, shown in Table 2, increased from 0.3–0.5 mmol l⁻¹ (water extract) to 16 mmol l⁻¹ (0.005 M CaCl₂ extract). Relatively, the decrease in P desorption

Yli-Halla, M. & Hartikainen, H.: Phosphorus desorption to runoff water



Extractant
▲ Water
+ 0.0005 M
* 0.005 M

Temperature
▲ 25 °C
+ 15 °C
* 5 °C

Fig. 1. Phosphorus extracted from the Aurajoki and Jokioinen soil with deionized water, 0.0005 M and 0.005 M CaCl₂ solutions at different solution-to-soil ratios (Ex). In the calculation of the equations, the ionic strengths (S, mmol l⁻¹) estimated from the measured electrical conductivities of the soil extracts were used.

Fig. 2. Phosphorus extracted from the Aurajoki and Jokioinen soil at three temperatures (t) with deionized water at different solution-to-soil ratios (Ex).

was equal in both soils. If desorption to water is denoted as 100, the relative desorption to 0.0005 M and 0.005 M CaCl₂ was 66 and 33 in the Au-

rajoki soil, and 68 and 30 in the Jokioinen soil, respectively.

Table 2. Ionic strengths of water extracts and the CaCl₂ extracts at the solution-to-soil ratio 50 l kg⁻¹.

Extractant	Ionic strength, mmol l ⁻¹	
	Aurajoki	Jokioinen
Water	0.51	0.29
0.0005 M CaCl ₂	2.13	1.94
0.005 M CaCl ₂	15.92	15.70

At the solution-to-soil ratio of 50 l kg⁻¹, elevation of temperature from 5 to 25°C enhanced P desorption markedly. The DRP concentration in the water extracts increased in the Aurajoki soil from 0.25 to 0.42 mg l⁻¹ (by 68%) and in the Jokioinen soil from 0.037 to 0.068 mg l⁻¹ (by 84%). The quantities of P desorbed (mg kg⁻¹) with water at the three temperatures and the honest significant differences at P=0.05 (HSD_{0.05}) were:

	<u>Aurajoki</u>	<u>Jokioinen</u>
5°C	12.6	1.8
15°C	16.6	2.2
25°C	20.7	3.4
HSD _{0.05}	3.5	0.3

Increasing the volume of water around the soil particles lowered the ionic strength and the DRP concentration in the extract (Table 3). Owing to the strong P buffer power of the soil, however, the decrease of DRP concentration was even less linear than that of the ionic strength.

Consequently, the desorption of P, expressed as mg kg⁻¹, was strongly promoted (Fig. 2). Desorption increased from 20.7 to 119 mg kg⁻¹ in the Aurajoki soil and from 3.4 to 45.0 mg kg⁻¹ in the Jokioinen soil at 25°C when the solution-to-soil ratio increased from 50 to 2000 l kg⁻¹.

Q/I plots

The Q/I plots crossed from net desorption to net sorption, and the results conformed accurately to the modified Langmuir equation (r²>0.99) (Fig. 3 and Fig. 4). However, for Jokioinen soil, the graphs intersected the x-axis close to the origin and the desorption remained very small at the solution-to-soil ratio of 50 l kg⁻¹ at which the Q/I plots were determined. In both soils, sorption increased and desorption decreased when CaCl₂ solutions were used as extractants (Fig. 3). The EPC values obtained in 0.005 M CaCl₂ were less than one fifth of that measured with out a supporting electrolyte (i.e., in water), and the EBC increased substantially upon increase of the ionic strength (Table 4). Despite the similar level of ionic strengths (0.3 mmol l⁻¹ in water extracts, 0.5 mmol l⁻¹ in 0.00005 M CaCl₂ extracts) in the Jokioinen soil, the Q/I plot in the CaCl₂ solution was markedly steeper.

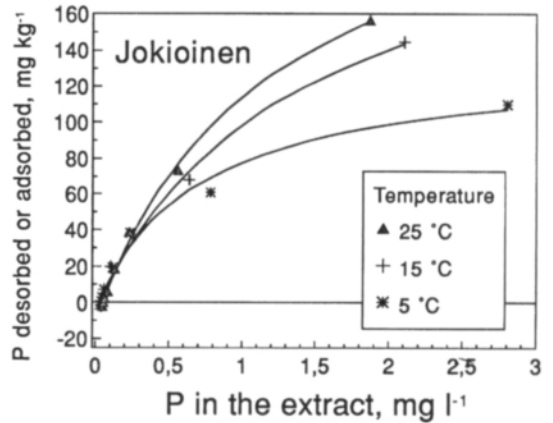
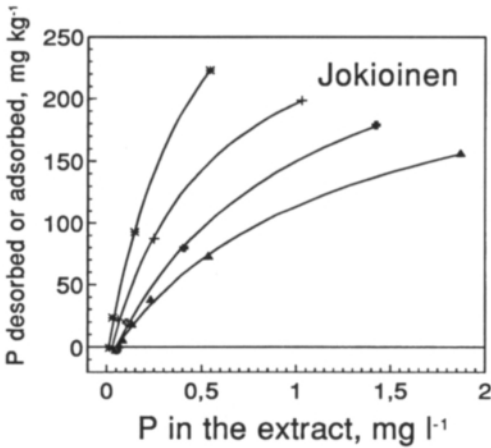
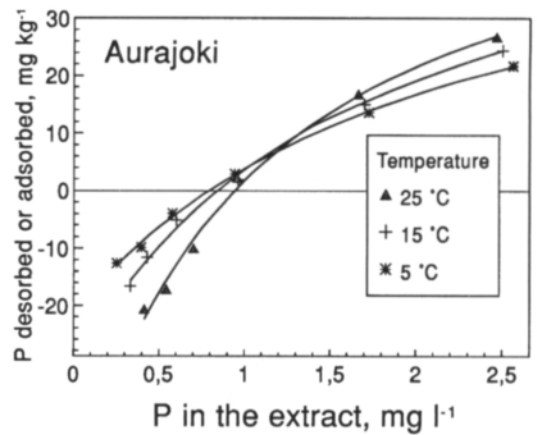
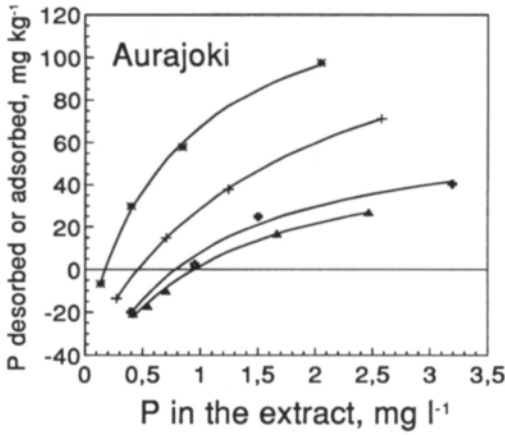
The Q/I plots determined at 5, 15 and 25°C (Fig. 4) showed that both desorption and sorption of P were promoted by gradual elevation of temperature. Both EBC and EPC increased upon

Table 3. DRP concentration and ionic strength of the water extracts obtained at different solution-to-soil ratios at 25°C.¹

Solution-to-soil ratio, l kg ⁻¹	DRP, mg l ⁻¹		Ionic strength, mmol l ⁻¹	
	Aurajoki	Jokioinen	Aurajoki	Jokioinen
50	0.415 ^a	0.068 ^d	0.51 ^c	0.29 ^c
200	0.243 ^d	0.065 ^d	0.23 ^b	0.19 ^b
500	0.149 ^c	0.052 ^c	0.15 ^{ab}	0.12 ^a
1000	0.094 ^b	0.036 ^b	0.09 ^{ab}	0.10 ^a
2000	0.060 ^a	0.023 ^a	0.09 ^a	0.09 ^a
HSD _{0.05}	0.030	0.011	0.12	0.05

¹ Each column was tested separately. Means marked with the same superscript do not differ at P = 0.05.

Yli-Halla, M. & Hartikainen, H.: Phosphorus desorption to runoff water



Solution

- * 0.005 M
- + 0.0005 M
- ◆ 0.00005 M
- ▲ Water

Fig. 3. Q/I plots of the Aurajoki and Jokioinen soil determined in deionized water and in CaCl₂ solutions at the solution-to-soil ratio of 50 l kg⁻¹. The molarities in the legend refer to the concentration of CaCl₂ in the extractant. The curves displayed are calculated using the modified Langmuir equation. The constants of the equations of the curves are presented in Table 4.

Fig. 4. Q/I plots of the Aurajoki and Jokioinen soil determined in deionized water at three temperatures at the solution-to-soil ratio of 50 l kg⁻¹. The curves displayed are calculated using the modified Langmuir equation. The constants of the equations of the curves are presented in Table 4.

increase in temperature (Table 4). The plots intersected at 1.2 and 0.2 mg P l⁻¹ in the Aurajoki and Jokioinen soil, respectively, i.e. clearly

above the respective EPC values (see Table 4). In Jokioinen soil, dominated by a marked sorption tendency, the effect of temperature on the P exchange was small at the low P concentrations in the equilibrium solution. Therefore the graphs

Table 4. Constants of the Q/I plots calculated from a modified Langmuir equation.

	EPC mg l ⁻¹	EBC l kg ⁻¹	Q ₀ mg kg ⁻¹	Q _{max} mg kg ⁻¹	K l mg ⁻¹
<u>Equilibration without a supporting electrolyte at 5, 15 and 25°C:</u>					
<i>Aurajoki</i>					
5°C	0.793	19.6	21.3	79	0.47
15°C	0.845	24.4	30.9	92	0.60
25°C	0.945	31.1	55.3	118	0.93
<i>Jokioinen</i>					
5°C	0.024	186	4.6	140	1.42
15°C	0.025	168	4.4	248	0.71
25°C	0.050	212	11.0	272	1.18
<u>Equilibration in water or CaCl₂ at 25°C:</u>					
<i>Aurajoki</i>					
H ₂ O	0.945	31.1	55.3	118	0.93
0.00005 M ¹	0.790	41.1	59.5	131	1.06
0.0005 M ¹	0.460	66.0	38.5	183	0.58
0.005 M ¹	0.174	150.3	31.7	179	1.24
<i>Jokioinen</i>					
H ₂ O	0.050	212	11.0	272	1.18
0.00005 M ¹	0.051	309	16.6	324	1.06
0.0005 M ¹	0.028	567	16.9	322	1.96
0.005 M ¹	0.010	888	9.4	430	2.16

¹ CaCl₂ concentration of the extractant.

are very close to each other and the cross-over points cannot be clearly seen in the scale used in Fig. 4.

In the Aurajoki soil, the constant Q₀ increased upon elevations of temperature and in general decreased upon increasing ionic strength (Table 4). The changes of Q₀ were thus in accordance with the influence of temperature and ionic strength on desorption obtained in the desorption tests. In the Jokioinen soil, on the contrary, the response of Q₀ to the changes of temperature or ionic strength was less consistent. In both soils, the values of Q₀ of the Q/I plots determined without a supporting electrolyte were less than half of the observed desorption to water at the widest solution-to-soil ratio. The values of Q₀ determined in CaCl₂ were 56–94% of the measured maximum desorption to the respective CaCl₂ solution (0.005 M or 0.0005 M; 0.00005 M not used in the desorption test).

Discussion

The quantity of labile adsorbed P on soil particles is the ultimate reserve of P which can be desorbed, but the DRP concentration in runoff water is also controlled substantially by ionic strength and temperature, and to some extent by the solution-to-soil ratio. The P buffer power of soil tends to maintain a constant DRP concentration in water, and therefore more voluminous runoff markedly increases the total quantity of DRP removed from the field.

The ionic strength of the water extracts at the solution-to-soil ratio 50 l kg⁻¹ corresponded to that of rain and snowmelt water (0.3 mmol l⁻¹) while those of the extracts obtained at wider solution-to-soil ratios were even lower in salts. As for ionic strength, the soil extracts obtained with 0.0005 M CaCl₂ were similar to the surface

runoff waters of the Jokioinen and Aurajoki fields (Yli-Halla et al. 1995), and those obtained with 0.005 M CaCl₂ corresponded to soil solution (Wiklander and Andersson 1974). As for the solution-to-soil ratio, it was observed in an earlier study that the average DRP concentration in the surface runoff in these particular fields was the same as that of soil extracts obtained at the solution-to-soil ratio between 250 and 500 l kg⁻¹ (Yli-Halla et al. 1995) but according to Ekholm (1994) the concentration of suspended solids in coastal river waters of Finland is lower than was applied in the present study. The equations in Fig. 1 describing the dependence of P desorption on ionic strength and solution-to-soil ratio thus cover the range of these factors occurring in the hydrologic environment in the field.

On the ionic strength scale used, the decrease in the salt concentration proved to effectively promote the P release from soil. In the water extracts, all dissolved salts originated from the soil sample, resulting in the decrease of the ionic strength of the extracts upon widening the solution-to-soil ratio. At a constant solution-to-soil ratio, decreasing ionic strength promotes P desorption (Hartikainen and Yli-Halla 1982). Therefore, it can be concluded that upon widening the solution-to-soil ratio the decrease of DRP concentration (mg l⁻¹) may have been more substantial and the increase of P desorption (mg kg⁻¹) less marked if the ionic strength had been kept constant. The present results thus give the net effect of two factors promoting P desorption: widening solution-to-soil ratio and decreasing ionic strength.

Besides DRP released in the field, surface runoff water transports P which is adsorbed onto the suspended soil material and which can be released as DRP in the recipient watercourse. As for the total DRP loading from the eroded material, the temperature during the runoff event may be unimportant because in the water body, the eroded material is subject also to higher temperatures during the summer months. Therefore, results obtained at a low temperature are needed to assess the DRP release in the field during the cool and wet season, while those obtained at

higher temperatures are applicable to DRP release by the summer rains and to desorption taking place in a watercourse during the warmer period of the year.

Increased speed of diffusion at elevated temperatures explains the cross-over of the Q/I plots. Below the EPC, net diffusion occurs from soil to solution, resulting in a higher P concentration in the extract when the temperature is elevated. Above the EPC, net diffusion is from solution to soil, and an elevated temperature leads to a higher sorption. If diffusion were the only factor affected by the temperature, the curves should cross at the EPC. However, in both soils, elevation of the temperature seemed to shift the EPC to a higher concentration. At higher temperatures, a higher P concentration was required for sorption to start, or, vice versa, desorption continued to a higher P concentration. As a consequence, the crossing of the curves occurred at a P concentration above the EPC. At the EPC the net diffusion is zero. Based on the shift of the EPC, conclusions can be made on the temperature-dependency of the P exchange equilibrium. The shift of EPC to a higher concentration indicates that a high temperature favors desorption. This suggests sorption to be an exothermic reaction, as presented by Barrow (1979), and desorption to be an endothermic one. The parameter Q_{\max} stands for P sorption sites available. Its increase as a response to the elevated temperature can be taken to indicate that the saturation of the sorption sites is kinetically controlled.

The Q/I plots can in principle be utilized to quantify the instantly labile P of the soil (Pionke and Kunishi 1992). The physical relevance of the constant Q_0 as a measure for instantly labile P can be assessed by comparing it with the observed desorption at wide solution-to-soil ratios, e.g. at 2000 l kg⁻¹ and with other estimates of P release from soil. Phosphorus bound to hydrous oxides of Al and Fe are the major reserves of bioavailable P in the watercourse (Dorich et al. 1985), and they control the level of water-extractable P in soil (Hartikainen 1982a). Maximum desorption in this study (solution-to-soil

ratio 2000 l kg⁻¹, 25°C) corresponded to 9 and 18% of the secondary P fractions (NH₄Cl-P + NH₄F-P + NaOH-P, see Table 1) in the Jokioinen and Aurajoki soils, respectively, while the constant Q₀ of the respective Q/I plots amounted to only 3 and 8% of the secondary P reserves.

In an exhaustive pot experiment with one soil, Yli-Halla and Renlund (1990) measured a 30% decrease in these P fractions. If this decrease is taken to represent a measure of the maximum bioavailability of soil P reserves, the Q₀ values markedly underestimate the potential P loading. Even the desorption measured at the widest solution-to-soil ratio (2000 l kg⁻¹) at 25°C may be smaller than the P amount that can be released from eroded soil in a watercourse. However, it should be mentioned that, particularly in the Aurajoki soil, Q₀ and the P release in the desorption tests responded similarly to changes of ionic strength and temperature. This shows that

the Q/I plots qualitatively reflect the dynamic P exchange even though quantitative interpretation of the Q₀ values may be questionable.

The present results show that depending on prevailing experimental conditions, a wide variation of P desorption results can be measured in a given soil, leading to different estimates for P loading. In most studies on soil samples, the Q/I plots have been determined using a 0.01 M supporting electrolyte (e.g. Barrow 1979). The information obtained from those Q/I plots is applicable to P fertilization and the nutrition of plants. Phosphorus release to surface runoff or water bodies needs to be assessed by experiments performed at a low ionic strength and a wide (above 200 l kg⁻¹) solution-to-soil ratio.

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SELOSTUS

Ympäristöolosuhteiden vaikutus maan fosforin liukenemiseen pintavalunnan aikana

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Pellolla kulkevaan pintavaluntaveteen liukenee fosforia (P) sekä paikalleen jäävästä maasta että veden mukana kulkevasta eroosioaineksestä. Aurajoen ja Jokioisten huuhtoutumiskentiltä otettujen savimaanäytteiden P-luovutuskykyä tutkittiin laboratoriotuokkein. Kokeissa pyrittiin simuloimaan pintavalunnassa vallitsevia olosuhteita uuttamalla maasta P:a eri lämpötiloissa (5, 15 ja 25 °C), eri suolakonsentraatioissa (deionisoitu vesi tai 0,00005–0,005 M CaCl₂) ja käyttäen erilaisia vesi-maasuhteita (50 – 2000 l kg⁻¹). Maa-aineksen kykyä sitoa ja luovuttaa P:a tutkittiin myös sorptio-desorptioisotermien avulla. Isotermi määritettiin ravistelemalla maata erivahvaisissa P-liuoksissa eri lämpötiloissa ja suolakonsentraatioissa. Kun uuttolämpötila nousi 5 °C:sta 25 °C:een, vesi-maasuhteella 50 l kg⁻¹ Aurajoen maasta veteen uuttuneen P:n määrä kasvoi arvosta 12,6 mg kg⁻¹ ar-

voon 20,7 mg kg⁻¹ ja Jokioisten maassa arvosta 1,8 mg kg⁻¹ arvoon 3,4 mg kg⁻¹. Kun maata uutettiin deionisoitun veteen asemesta maaveden suolapitoisuutta jäljittelevällä 0,005 M CaCl₂:lla, uuttuneet P-määrät Aurajoen maasta pienenevät 6,8 mg kg⁻¹:aan ja Jokioisten maasta 0,7 mg kg⁻¹:aan. Vesi-maasuhteen väljentäminen 2000 l kg⁻¹:aan puolestaan lisäsi P:n uututumista veteen Aurajoen maassa kuusinkertaiseksi (119 mg kg⁻¹:aan) ja Jokioisten maassa 14-kertaiseksi (46 mg kg⁻¹:aan). Lämpötilan ja suolapitoisuuden kohotessa pidättyi maahan lisätystä P:sta yhä suurempi osuus. Saatujen tulosten perusteella voidaan päätellä, että pellolta tulevan pintavalunnan liukoisen P:n pitoisuuteen ja vesistökuormituksen suuruuteen vaikuttavat oleellisesti maan helppoliukoisen P:n pitoisuuden ohella myös valumaveden määrä, sen lämpötila ja suolapitoisuus.