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Effects of Land Use on the Diffuse Load of Phosphorus and Nitrogen

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The diffuse load of phosphorus and nitrogen was studied in 23 small drainage basins in different parts of Finland between 1965 and 1974. Total phosphorus and total nitrogen concentrations were analyzed monthly and runoff measured continuously. Mean concentrations and loads for each basin are presented. The mean concentrations of phosphorus varied from 8.3 to 98 μg l^{-1} and of nitrogen from 190 to 2400 μg l^{-1}. The dependence of concentrations on runoff was in most basins rather slight, but the highest concentrations were usually observed during the spring floods. The mean loads of phosphorus varied from 4.0 to 44 kgs $km^{-2}a^{-1}$ and of nitrogen from 79 to 740 kgs $km^{-2}a^{-1}$. The dependence of concentrations and loads on basin characteristics was studied by linear regression analysis. The percentage of cultivated land was found to be the most descriptive variable of the characteristics of the basin. The percentage of cultivated land also reflects the loading caused by sparse population and by domestic animal population because of the strong intercorrelations between these variables.

Introduction

The water quality in 34 small hydrological basins has been studied once a month since 1962. The results of investigations performed in 1962-1968 have been published earlier: for the load of nutrients by Särkkä (1972), for alkali metals by Kohonen (1974) and for organic matter by Kauppi (1975). The findings have been summarized by Kohonen (1976). A study on the effects of meteorological and basin characteristics on runoff has been published by Mustonen (1965 b). The aim of the present investigation was to determine the effect of drainage basin characteristics on the diffuse load of total phosphorus and total nitrogen in 1965-1974.

Observation Basins

Of the 34 drainage basins, 23 representing typical diffuse loading areas were selected for inclusion in the study. The basins were distributed fairly evenly throughout the country (Fig. 1).

The drainage basin characteristics and loading factors have been described in detail by Mustonen (1965 a) and Särkkä (1972). The percentage of cultivated land changed in some basins after 1958. The factors investigated in this study were the percentage of fine particles (clay and silt) in the soil (%), the percentage of cultivated land, *FP* (%), sewage (persons km $^{-2}$), other habitation and livestock (person equivalents km^{-2}). All the factors varied considerably among the different basins (Table 1).

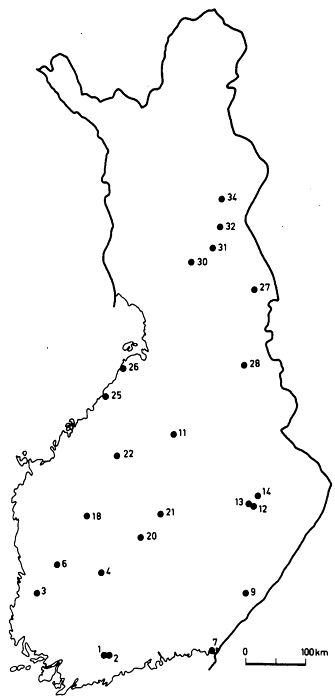

Fig. 1. The location of the observation basins.

Table 1 – Factors defining the characteristics of the basins
($p\ km^{-2}$ = persons km^{-2}, $peq\ km^{-2}$ = person equivalents km^{-2})

Basin	Size (km^2)	Fine particles (%)	Cultivated land (%)	Sewage ($p\ km^{-2}$)	Other habitation + livestock ($peq\ km^{-2}$)
Teeressuonoja	0.7	9	0	0	27
Kylmänoja	4.0	31	27	11.5	164
Löytäneenoja	5.6	43	67	16.3	453
Paunulanpuro	2.0[1]	16[1]	1.7[1]	0.6[1]	24[1]
Katajaluoma	11.2	0	3	0	0
Ravijoki	56.9	13	17	3.7	157
Latosuonoja	5.3	2	14	0.4	2
Korpijoki	122	3	8	1.7	94
Kesselinpuro	21.7	0	3	0.6	38
Kuokkalanoja	2.8	0	11	7.3	280
Mustapuro	11.2	20	11	2.7	120
Kaidesluoma	45.5	4	13	5.5	160
Heinäjoki	9.4	0	8	4.8	171
Ruunapuro	5.4	10	17	7.8	182
Pahkaoja	23.3	0	2	0	25
Tuuraoja	23.5	0	16	0.3	18
Huopakinoja	19.7	1	17	2.7	95
Vääräjoki	19.3	0	0	0	2
Myllypuro	9.9	0	2	1.1	11
Korintteenoja	6.1	2	2	1.7	24
Vähä-Askanjoki	16.4	0	0	0	0
Kuusivaaranpuro	27.6	1	2	0	0
Myllyoja	28.5	0	0	0	0

1. The Paunulanpuro drainage basin decreased in size in 1968 because of ditching; the reported values are means weighted for time.

Material and Methods

A measuring weir with a limnigraph was built in each drainage basin for runoff observations. Water samples were taken once a month.

The mean monthly load of phosphorus and nitrogen was calculated according to Eq. (1)

$$L_m = K_p \frac{1}{n} \sum_{i=1}^{n} c_i q_i \tag{1}$$

L_m = mean monthly load, kg km^{-2} month^{-1}
K_p = coefficient for alteration of dimensions
C_i = concentration in the i'th observation, μg l^{-1}
q_i = mean runoff of the month corresponding to the i'th observation, l s^{-1} km^{-2}

The mean annual load (kg km^{-2}a^{-1}) was calculated by multiplying the mean monthly load by twelve.

Results

Phosphorus and nitrogen concentrations and loads varied considerably among the drainage basins (Table 2). Mean values of total phosphorus concentration varied from 8.3 to 98 μg l^{-1}, and total nitrogen from 190 to 2400 μg l^{-1}.

Annual loads varied from 4.1 to 44 kg km^{-2}a^{-1} total phosphorus and from 79 to 740 kg km^{-2}a^{-1} total nitrogen. The seasonal variation was marked. Thus in some cases half of the total annual load came during one month in the spring. More often, however, the maximum load observed during one spring month was only a third or a quarter of the total annual load. The load of phosphorus deposited in the Korpijoki basin was exceptionally high, presumably because of fertilization of the nearby surrounding forest. Accordingly values for the Korpijoki basin were not included in the calculations for the dependence of phosphorus load on the basin characteristics.

Strong correlations were found between the concentrations and loads of total phosphorus and total nitrogen and the basin characteristics (Table 3). Because the variables are not normally distributed the statistical significance of the correlation coefficients has not been presented here.

The percentage of cultivated land explains best the variance of the dependent variables. The concentration of total phosphorus appears to increase logarithmically with the increase in the percentage of cultivated land (Fig. 2). The correlation with the logarithmic expression of FP, $\log_{10}(FP + 1)$, is 0.84 and the regression function is (2)

$$Y_{P\text{-conc.}} = 46.4 \log_{10}(FP + 1) + 7.2 \quad (n = 23) \tag{2}$$

$Y_{P\text{-conc.}}$ = phosphorus concentration, µg l^{-1}

The function explains the variance in phosphorus concentration quite well, r^2 = 0.71. As the variables were not normally distributed, the weight of the most extreme value (FP = 67) in determining the shape of the curve was very high. With this value excluded the correlation between phosphorus concentration and the logarithmic expression of FP was slightly weaker (r = 0.81) than that between phosphorus concentration and FP itself (r = 0.84).

Table 2 – Mean values of the total phosphorus and total nitrogen concentrations and annual loads in the drainage basins.

Basin	Phosphorus		Nitrogen	
	Concentration ($\mu g l^{-1}$)	Load (kg $km^{-2}a^{-1}$)	Concentration ($\mu g l^{-1}$)	Load (kg $km^{-2}a^{-1}$)
	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
Teeressuonoja	18	5.2	680	180
Kylmänoja	86	25	1400	560
Löytäneenoja	98	34	2400	740
Paunulanpuro	30	8.7	620	160
Katajaluoma	43	11	1100	310
Ravijoki	75	29	1200	540
Latosuonoja	67	26	890	310
Korpijoki	78	44	890	370
Kesselinpuro	39	11	780	230
Kuokkalanoja	33	15	1000	460
Mustapuro	28	13	810	410
Kaidesluoma	43	18	940	350
Heinäjoki	21	6.5	640	200
Ruunapuro	64	19	1100	300
Pahkaoja	35	6.4	740	190
Tuuraoja	79	14	940	210
Huopakinoja	86	27	940	320
Vääräjoki	17	5.6	420	180
Myllypuro	22	9.7	340	130
Korintteenoja	12	5.6	230	89
Vähä-Askanjoki	8.3	4.0	230	130
Kuusivaaranpuro	18	5.6	320	100
Myllyoja	10	4.2	190	79

Table 3 – Correlation of phosphorus and nitrogen concentrations and loads with basin characteristics.

Basin characteristic	Phosphorus		Nitrogen	
	Concentration	Load	Concentration	Load
Fine soil particles (%)	0.50	0.44	0.74	0.74
Cultivated land (%)	0.75	0.65	0.91	0.83
Sewage (p km^{-2})	0.56	0.52	0.81	0.81
Other habitation + livestock (peq km^{-2})	0.51	0.54	0.80	0.83

The dependence of the phosphorus load on the *FP* value is also logarithmic (Fig. 3). The correlation with the logarithmic expression of the percentage of cultivated land (without Korpijoki), $\log_{10}$ (*FP* + 1), is 0.88 and the regression function is (3)

$$Y_{P\text{-load}} = 15.1 \log_{10}(FP + 1) + 1.9 \qquad (n = 22) \tag{3}$$
$$Y_{P\text{-load}} = \text{annual phosphorus load, kg km}^{-2}\,\text{a}^{-1}$$

Eq. (3) explains 77% of the variance in the annual phosphorus load. For purposes of comparison the regression line obtained without the extreme point (Löytäneenoja) has been included in Fig. 3.

The dependence of total nitrogen concentration on the most relevant variable, percentage of cultivated land, is clearly linear (Fig. 4a). The regression function obtained is (4)

$$Y_{N\text{-conc.}} = 30\,FP + 500 \qquad (n = 23) \tag{4}$$
$$Y_{N\text{-conc.}} = \text{nitrogen concentration, µg l}^{-1}$$

The equation explains 82% of the observed variance in the nitrogen concentration. Without the extreme point the degree of explanation is 66%.

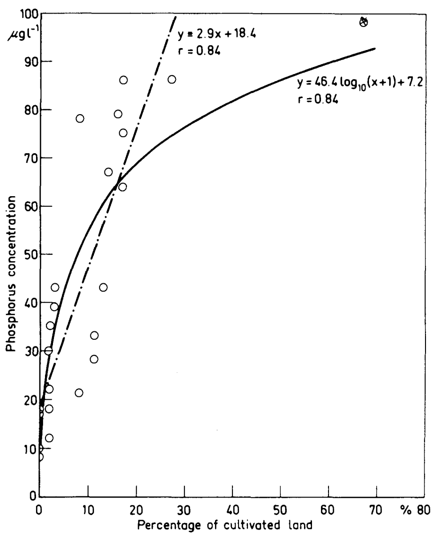

Fig. 2. Dependence of the total phosphorus concentration on the percentage of cultivated land in the basin. —— Value ○ included.—.—.—Value ○ excluded.

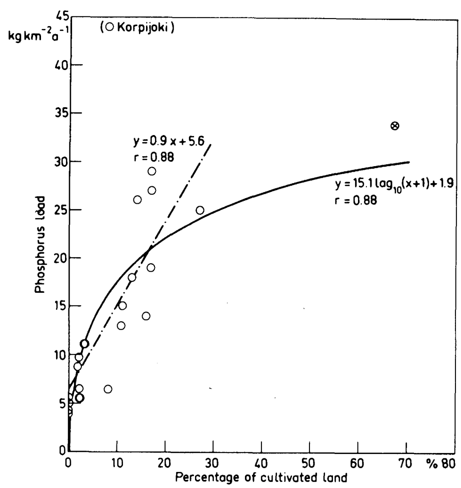

Fig. 3. Dependence of the diffuse phosphorus load on the percentage of cultivated land in the basin. —— Value ○ included.—.—.—Value ○ excluded.

The nitrogen concentrations observed in water from basins in a natural state varied from 190 to 680 $\mu g\ l^{-1}$. Concentrations were lower in the northern basins. This may partly be explained by the fact that movement of nitrogen is largely dependent on biological activity, which itself is partly dependent on ambient temperatures. The soil is frozen for longer periods in Northern than in Southern Finland, and of course the average temperature is lower, too. This is reflected in the observed nitrogen concentrations. The dependence of nitrogen concentration on the percentage of cultivated land was calculated excluding the northern basins, too. A total of 17 basins remains and the correlation is 0.95 (Fig. 4b).

The equation of the regression line is (5)

$$Y_{N\text{-conc.}} = 25\,FP + 650 \qquad (n = 17) \tag{5}$$

This equation explains 89% of the observed variance in nitrogen concentration. Exclusion of the most extreme observations (FP = 67) does not markedly alter the result (6):

$$Y_{N\text{-conc.}} = 22\,FP + 690 \qquad (n = 16) \tag{6}$$

Eq. (5) can be considered as applying only to Southern and Central Finland. As the observations from Northern regions were all from non-cultivated basins, a corresponding method of estimating nitrogen concentrations cannot be presented there.

The nitrogen load (kg $km^{-2}a^{-1}$) correlates almost equally strongly with cultivated land (r = 0.83), sewage (r = 0.81) and livestock (r = 0.83). As the percentage of cultivated land is the easiest of these variables to determine in practice, it was taken into the model as the first variable. The dependence of the nitrogen load (kg $km^{-2}a^{-1}$) on FP is found to be almost linear (Fig. 5a).

The regression function is (7)

$$\begin{aligned} Y_{N\text{-load}} &= 9.8\,FP + 180 \qquad (n = 23) \\ Y_{N\text{-load}} &= \text{annual nitrogen load, kg km}^{-2}\text{a}^{-1} \end{aligned} \tag{7}$$

The equation explains 70% of the variance in the annual nitrogen load. The regression line obtained without the extreme point has been included in Fig. 5a for comparison.

Nitrogen loads in the non-cultivated areas of Southern and Northern Finland differed from each other as in the case of concentrations. In the Southern non-cultivated areas nitrogen load was almost 200 kgs $km^{-2}a^{-1}$, whereas in Northern areas the corresponding load was about 100 kgs $km^{-2}a^{-1}$. The equation (8) of the regression for Central and Southern Finland (Fig. 5b) is (r = 0.82)

$$Y_{N\text{-load}} = 8.4\,FP + 230 \qquad (n = 17) \tag{8}$$

Without the value for Löytäneenoja this becomes (9)

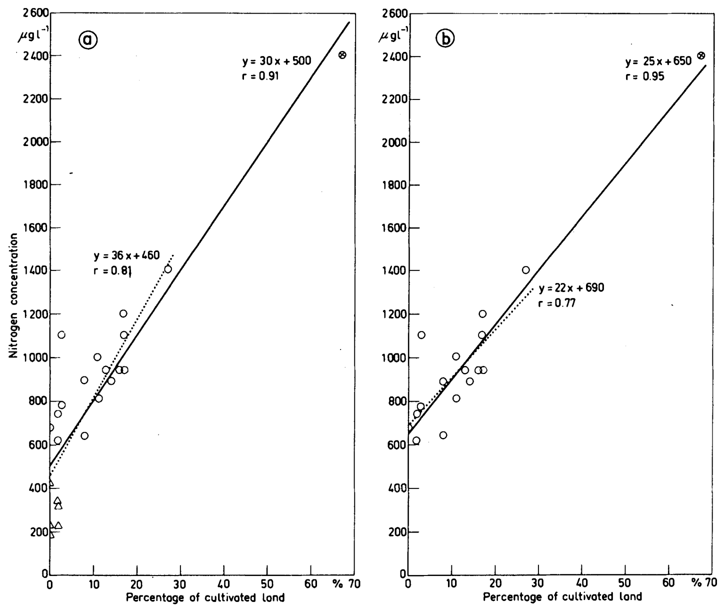

Fig. 4. Dependence of the total nitrogen concentration on the percentage of cultivated land in the basin. a) Including the values for the basins in Northern Finland △ b) Without the values for the basins in Northern Finland. —— Value ○ included- .—.—.—Value ○ excluded.

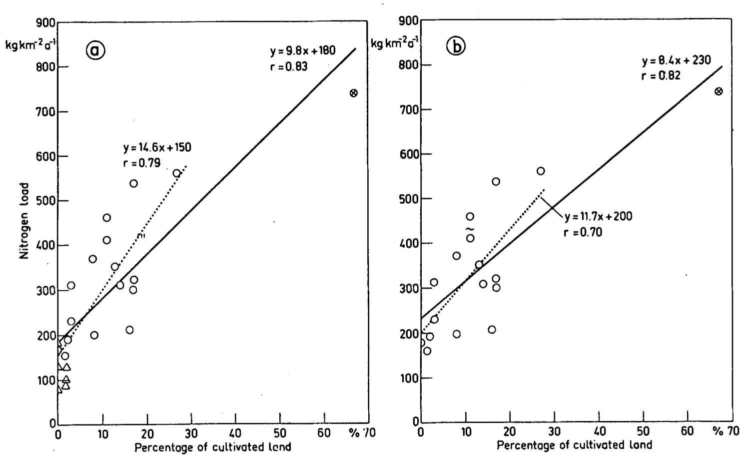

Fig. 5. Dependence of the diffuse nitrogen load on the percentage of cultivated land in the basin. a) Including the values for the basins in Northern Finland △ b) Without the values for the basins in Northern Finland. —— Value ○ included.—.—.—Value ○ excluded.

$$Y_{N\text{-load}} \equiv 11.7\ FP + 200 \qquad (n = 16) \qquad (9)$$

Finding of the best possible equation to describe the actual values would entail further observations in those areas in which the percentage of cultivated land is 20-60%. It was not considered worth-while to include the other variables in the equations, since they did not significantly improve the models.

Discussion

The dependence of nutrient concentrations on runoff was rather weak indicating that the extent of runoff had a basic effect on the size of the load. In many cases a third or a quarter – even a half – of the total annual load came during the spring floods. The amount of cultivated land had the greatest effect on the phosphorus and nitrogen concentrations as well as on the loads in the small drainage basins studied. This agrees well with the results of Kajosaari (1965), Gächter and Furrer (1972), Ahl (1977) and Prochazkova (1977) among others.

In general, cultivated land is situated close to watercourses, but with the increasing percentage of cultivated land in some areas, fields necessarily become more distant. As phosphorus readily adsorbs to soil particles, it is probable that proportionately less phosphorus reaches the watercourse from the more distant fields. For calculation purposes the fields should therefore be weighted for their distance from the nearest watercourse. The need for such weighting is illustrated by the Heinäjoki basin where the mean phosphorus concentration in water was only 21 $\mu g\ l^{-1}$ and the phosphorus load 6.5 kgs $km^{-2}a^{-1}$, although the area of cultivated land amounted to 8% of the total area. The fields in question were near the outskirts of the basin, and there were no running water connections between the fields and the watercourse. The high phosphorus loads obtained for the Korpijoki basin (forest fertilization had been carried out near the measuring station) confirm the theory that areas near to the measuring station have more influence on the phosphorus load than similar areas further away. Kirchner (1975) has found a strong correlation between phosphorus export and the length of stream per unit area (drainage density): correlation coefficient $r = 0.94$. As it was not possible in this study to carry out the required weighting of the areas of cultivated land, the less precise logarithmic dependence of the phosphorus concentration and load on the percentage of cultivated land has had to suffice.

Nutrients dissolved in rainwater also comprise an important part of non-point source loading. Haapala (1977) has presented averages for some of the observation stations for 1971-1976. In Southern Finland the amounts of nutrients arriving dissolved in rainwater were: phosphorus 14.4-15.6 kgs $km^{-2}a^{-1}$ and nitrogen 528-828 kgs $km^{-2}a^{-1}$. The rest of the diffuse loading seems to be more dependent on the basin characteristics according to the present study. In Northern Finland the amounts arriving in rainwater were 6.0-7.2 kgs phosphorus and 144-312 kgs nitrogen per square kilometre and year (Haapala 1977). In non-cultivated areas throughout the country the amounts of phosphorus and nitrogen arriving in rainwater generally exceed the amounts of these nutrients coming from the soil. Soil and vegetation both fix part of the nutrients, and some of the nitrogen is released to the atmosphere by denitrification.

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