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CONTRIBUTION OF AGRICULTURAL LOADING TO THE DETERIORATION OF SURFACE WATERS IN FINLAND

Lea Kauppi

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Agriculture accounts for 9 per cent of the total land area of Finland. Since agricultural activity is scattered throughout the whole country its effects in lakes are less pronounced and have traditionally received less attention to than those of domestic and industrial effluents. However, the use of fertilizers in agriculture has more than doubled since 1960 thus increasing potential pollution. Structural changes in agriculture — such as a move towards larger and more specialized production units — may also cause water pollution problems. In addition, point source phosphorus loading of lakes and rivers has decreased during the nineteen-seventies, thus increasing the relative importance of non-point loading. The aim of this study was to evaluate the contribution, i.e. amounts and effects, of agricultural phosphorus and nitrogen loading to the deterioration of Finnish lakes. Since phosphorus is the nutrient which primarily limits production in most Finnish lakes, the evaluation of eutrophying effects was concentrated on phosphorus. In the case of nitrogen the results were viewed mainly from the point of view of harmful concentrations of inorganic nitrogen. Agriculture comprises the greatest single source of nutrients released into Finnish watercourses. Approximately 31 000 t of nitrogen and 1 400 t of phosphorus enter the watercourses annually due to agricultural activity. These estimates were based on the specific loads of 12 kg $ha^{-1}a^{-1}$ nitrogen and 0.57 kg $ha^{-1}a^{-1}$ phosphorus for cultivated land. Although most of the nitrogen coming from agricultural fields was in the form of nitrate, the amounts were so low that the concentrations remained well below the harmful level. A major fraction of the phosphorus in agricultural runoff enters the watercourses adsorbed to soil particles and the crucial question is its availability to algae. Experimental results indicated that 60—70 per cent of the total phosphorus was available for algal growth. However, the concentrations of available P remained so low that they could be achieved in Finnish lakes of low ionic concentration through chemical desorption without the assistance of the metabolic activities of algae. The utilization of runoff phosphorus in lakes would thus not depend on the concurrence of the maxima of loading and algal growth.

Index words: Agriculture; pollution: phosphorus; nitrogen; algal-available P; nitrate; eutrophication; diffuse loading

1. INTRODUCTION

During the nineteen-seventies point source loading of lakes and rivers decreased in Finland due to the measures undertaken for pollution control. Particularly phosphorus and organic loading in domestic effluents decreased (Fig. 1). As a result the recovery of polluted areas has already started, e.g. in Lake Vesijärvi (Keto 1982). However, in some cases even the diversion of effluents to another recipient has not reversed the eutrophication trend. In these cases it has often been found that nonpoint loading, together with loading from sediments, is sufficient to maintain high production levels. For example in Lake Tuusulanjärvi diffuse loading was almost as high as sewage loading

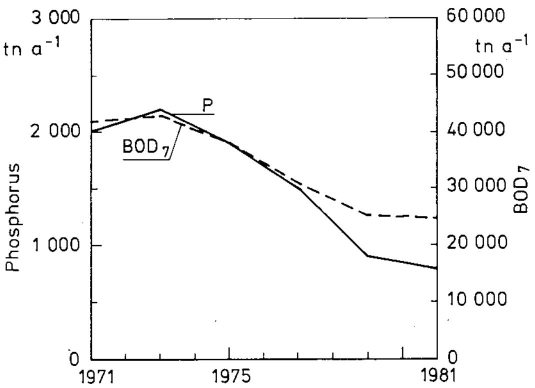


Fig. 1. Loads of phosphorus and organic matter from domestic effluents in Finland 1971–1981.

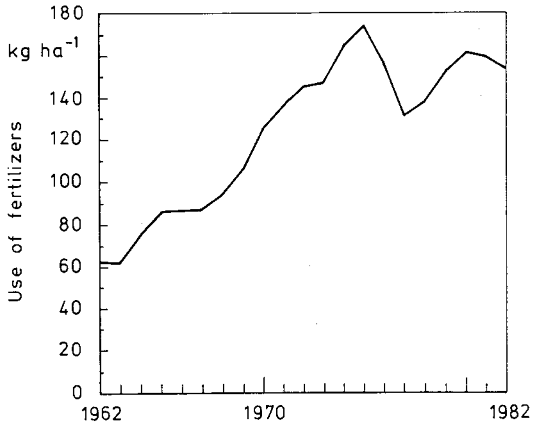


Fig. 3. Use of fertilizers in Finland 1962–1982.

during the period 1974 — 1977 (Ojanen 1979). After the diversion of sewage no rapid recovery was observed. Ojanen (1979) calculated that even the diffuse load was greater than the critical loads reported by Vollenweider (1970).

Agriculture accounts for 9 per cent of the total land area of Finland. In the most intensively cultivated region in southwestern Finland arable land totals 30 per cent of the surface area (Fig. 2). This is also the area in which the most severe water pollution problems due to agriculture occur. For example in the river Aurajoki agricultural loading has caused problems for water supply. The odour and taste of drinking water has been unsatisfactory, particularly during the melting period in spring. The same is also true for some other neighbouring rivers in south-western Finland. Generally, however, slow eutrophication is typical for waters under agricultural influence.

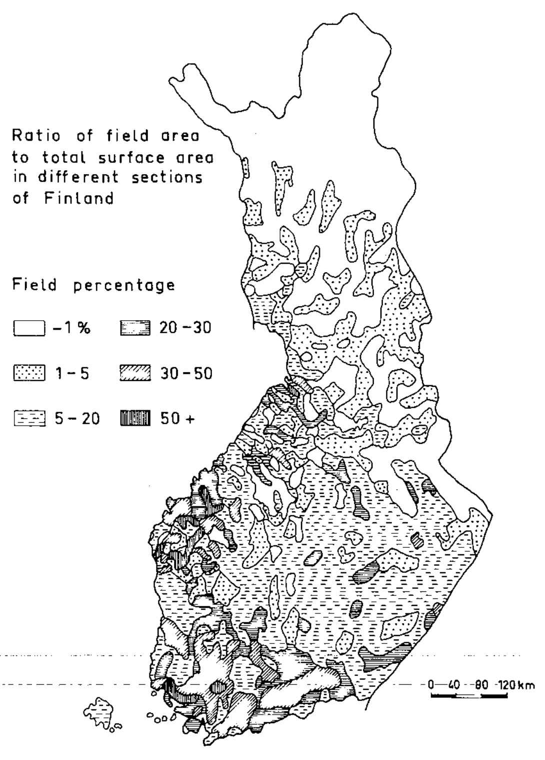


Fig. 2. Percentage of agricultural land of the total surface area in Finland.

It is not surprising that agricultural loading has increased during the last few decades. Fertilizer use more than doubled between 1960 and 1980 (Fig. 3). Structural changes in agriculture — especially the change towards larger production units — have also contributed to water pollution.

Phosphorus is the primary limiting nutrient in Finnish lakes. The question of the availability of non-point phosphorus is therefore important in evaluating the impact of non-point loading in lakes. In the case of nitrogen the problem arises from high concentrations of inorganic nitrogen — nitrate, nitrite and ammonia — which are detrimental to fish and also to human health.

In addition to nutrient input there are other factors which affect the response of the recipient in the case of agricultural loading, i.e. the characteristics of the recipient (hydrography, physicochemical factors) and, particularly important in connection with agricultural phosphorus loading, the temporal distribution of loading.

The primary objective of this study was to improve the basis for assessing the significance of agricultural nutrient loading in the deterioration of fresh waters in Finland. First, methods for quantifying loads were developed and secondly the actual contribution of these loads to the alteration of watercourses was studied.

2. MATERIALS AND METHODS

Calculations of non-point loading were based on the hydrological network consisting at present of 60 small drainage basins (Fig. 4). In 1962 monthly monitoring of water quality started in 34 of these basins. At present 27 basins are included in the monitoring network of water quality. The dependence of phosphorus and nitrogen loads on the characteristics of the drainage basin was studied using data from 23 basins in 1965 — 1974. The basins were selected by the criteria that loading was derived from agriculture and sparse population and that the soil did not include high concentrations of alum (Kauppi 1979a). Specific phosphorus and nitrogen loads of cultivated land and sparse population were calculated using observations from six southern basins in 1962 — 1976 (Kauppi 1979b). The totally cultivated basin, Hovi, situated in Vihti in southern Finland, was used in two case studies: first in the study on the effects of subdrainage on the quantity and quality of runoff (Seuna and Kauppi 1981) and secondly in the application of the CREAMS model for simulation of nitrogen and phosphorus losses from agriculture (Kauppi 1982). Nitrate concentrations and their changes in runoff and rivers waters during the nineteen sixties and seventies were examined in 31 drainage basins and 19 rivers (Kauppi 1984). The evaluation of the role of runoff water phosphorus in eutrophication was based on an experimental study in which algal assays were used to measure the potential effect of non-point phosphorus on the algal growth of the lake water (Kauppi and Niemi 1984).

3. LOADS OF NITROGEN AND PHOSPHORUS FROM AGRICULTURE

On the basis of observations in 23 small hydrological basins in 1965 — 1974, Kauppi (1979a) calculated the dependence of phosphorus and nitrogen loads on the percentage of agricultural fields (FP, %) in the basin. For phosphorus (Fig. 5) the equation was of the form

$$\text{P-load (kg km}^{-2}\text{a}^{-1}) = 15.1 \log_{10}(\text{FP} + 1) + 1.9 \quad (1)$$

and for nitrogen (Fig. 6)

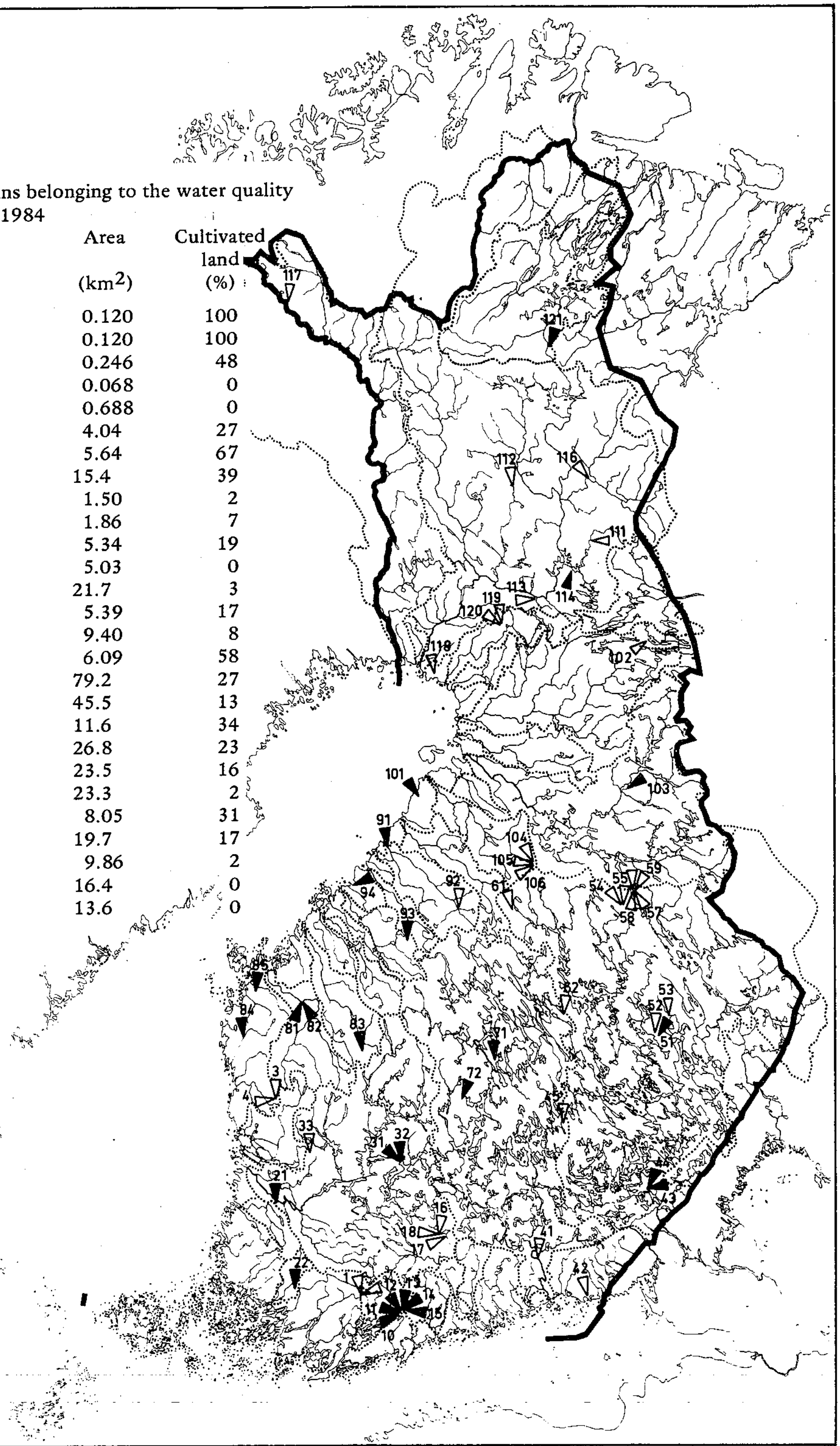
$$\text{N-load (kg km}^{-2}\text{a}^{-1}) = 9.8\,\text{FP} + 180 \quad (2)$$

On the basis of observations in six southern basins during the period 1965 — 1976, estimates were presented of specific nutrient loads per hectare of cultivated land (Kauppi 1979b). These were 0.57 kg $ha^{-1}a^{-1}$ for phosphorus and 12 kg $ha^{-1}a^{-1}$ for nitrogen and thus of the same order of magnitude as in other Nordic countries (Ahl 1977, Holmen 1977, Larsen 1977). The losses were equivalent to 1 % and 13 %, respectively, of the amounts of P and N given in fertilizers. According to these specific loads, the nutrient loading from Finnish agriculture would be on average 1 400 t a^{-1} phosphorus and 31 000 t a^{-1} nitrogen. This implies that agriculture comprises the most important single nutrient input to the watercourses (Table 1).

The loads given above are based on average values over twelve years. There are, however, indications of increasing input of nutrients from rural basins to watercourses. An increasing trend in total phosphorus concentration over the period 1965—1974, was found in three out of 23 basins and for total nitrogen the respective number was five (Kauppi 1979a). Concentrations of nitrate, which is easily mobile in the soil, increased statistically significantly in 15 of the 31 basins over the period 1966 — 1980 (Kauppi 1984). The increasing trends largely developed during the first ten years, when the use of fertilizers also increased.

In addition to fertilizer use sub-drainage strongly influences the leaching of nitrate. After the subdrainage of the small cultivated basin in southern Finland, maximum nitrate concentrations as high as 90 mg l^{-1} were recorded in the runoff water, whereas before the drainage the corresponding values were 10—20 mg l^{-1} (Seuna and Kauppi 1981). The difference was even greater in the annual means. The strongest effect lasted for about 5 years. The annual changeover from open-ditched to sub-drained farmland is over 30 000 ha in the whole country. According to these results this should be reflected in the nitrate concentrations of agricultural runoff.

Other physiographic factors, such as slope steepness and soil particle size, also have a strong influence on nutrient losses. The agricultural nutrient loads depend strongly on hydrological factors and thus vary from year to year. In order to describe the processes associated with nutrient losses in more detail several models have been proposed. Haith (1982) has reviewed the existing models. One of the models is the CREAMS (Chemicals Runoff and Erosion from Agricultural Management Systems) model (Knisel 1980), which was developed by the US Department of Agriculture. This model has been applied in many European countries within the context of the IIASA (International Institute for Applied Systems Analysis) research project on the environmental prob-



Small hydrological basins belonging to the water quality monitoring network in 1984

		Area (km²)	Cultivated land (%)
10	Hovi, sub-drains	0.120	100
11	Hovi	0.120	100
12	Ali-Knuutila	0.246	48
13	Yli-Knuutila	0.068	0
14	Teeressuonoja	0.688	0
15	Kylmänoja	4.04	27
21	Löytäneenoja	5.64	67
22	Savijoki	15.4	39
31	Paunulanpuro	1.50	2
32	Siukolanpuro	1.86	7
43	Latosuonoja	5.34	19
44	Huhtisuonoja	5.03	0
51	Kesselinpuro	21.7	3
71	Ruunapuro	5.39	17
72	Heinäjoki	9.40	8
81	Haapajyrä	6.09	58
82	Kainastonluoma	79.2	27
83	Kaidesluoma	45.5	13
84	Norrskogsdiket	11.6	34
85	Sulvanjoki	26.8	23
91	Tuuranoja	23.5	16
93	Pahkaoja	23.3	2
94	Kuikkisenoja	8.05	31
101	Huopakinoja	19.7	17
103	Myllypuro	9.86	2
114	Vähä-Askanjoki	16.4	0
121	Laanioja	13.6	0

Fig. 4. Location of the small hydrological basins. Basins belonging to the present water quality monitoring network are shown darkened.

lems of agriculture (Svetlosanov and Knisel 1982).

One of the case study areas was a small cultivated basin in southern Finland (Kauppi 1982). Simulation of monthly and annual runoff values was successful, whereas the soil and nutrient losses calculated by the model deviated considerably from the observed values. This may have been due to the rough approximation of the parameter values. In particular, the nutrient contents of the soil should be measured in the basin being investigated, because considerable variation may occur even between basins situated near to each other.

In principle, the CREAMS model seemed to be potentially suitable as a model for the estimation of agricultural pollution in Finnish conditions. However, its use is restricted to field scale. Furthermore, the number of parameters in the model is large and for many of them it is difficult to find a reliable value from the literature. It would therefore be necessary to carry out field measurements before applying the model. As long as the use of the model is restricted to field scale it seems that in most cases the information needed for water protection planning would be easier to obtain by other, simpler methods. Models like the CREAMS, however, have the potential of comparing different agricultural management practices from the point of view of erosion and nutrient losses. Thus they may prove very valuable for future water protection planning.

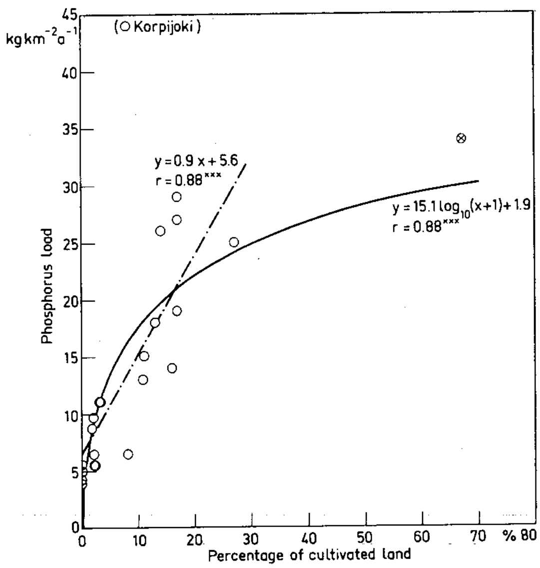


Fig. 5. Dependence of the diffuse phosphorus load on the percentage of cultivated land in the basin. —Value ⊗ included ---Value ⊗ excluded (Kauppi 1979a).

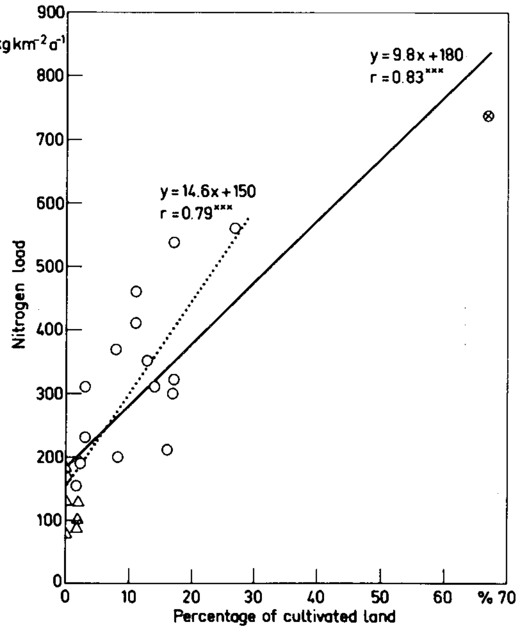


Fig. 6. Dependence of the diffuse nitrogen load on the percentage of cultivated land in the basin. — Value ⊗ included ... Value ⊗ excluded.

Table 1. Phosphorus and nitrogen loads from point and non-point sources in Finland in 1980 (Kauppi 1979b, National Board of Waters 1981, 1983).

	Nutrient load (t a $^{-1}$)	
Source	Phosphorus	Nitrogen
Industrial effluents	770	7 200
Domestic effluents	800	13 000
Agriculture	1 400	31 000

4. EFFECTS IN LAKES

High nitrate concentrations in surface and ground waters are not yet as serious a problem in Finland as in some other European countries. In general, the concentrations in runoff and river waters were well below the drinking water standards. Agriculture was an important contributor to the nitrogen budget of the drainage basins, whereas atmospheric deposition played a minor role. The increases in runoff water nitrate concentrations during the observation period 1966 — 1980 were mainly found in agricultural basins and during the first ten years, when the use of fertilizers also increased. This indicates that if fertilizer use continues to increase in the future water pollution problems due to high nitrate concentrations may occur.

The question of the availability of non-point phosphorus has gained importance during recent years since the loading from point sources has been reduced. Phosphorus transported by particles is often the most important component of the non-point P loading of lakes, whereas algae mainly utilize P in a soluble form. This means that adsorbed P must become soluble before algae can use it.

The fraction of runoff P that could be taken up by algae was studied by algal assays using Selenastrum capricornutum as test organism. Nonfiltered runoff water was also mixed with oligotrophic lake water in different proportions (0, 10, 50, 100 %) and the algal growth potentials (AGP) of the mixtures were measured.

The highest AGP values (74 — 76 mg l^{-1} f.w.) were measured in the spring samples from the totally cultivated basin. In autumn the AGP was rather small in all the samples, possibly because plants had taken up most of the available P from the soil during the summer. Filtration of samples decreased the AGP by 5 — 82 %, indicating the significance of adsorbed P to the growth of algae.

Spring runoff waters flowing from cultivated areas clearly increased the AGP of lake water. The relative increase was strongest with the most dilute (10 %) additions. In these mixtures, 27 — 100 % of the added total P became available for algal growth, the mean value being 64 %. In autumn samples the percentage availability was even higher, but because the absolute values of the total P concentrations in runoff were low, only a slight effect on the lake AGP was recorded. In general the lower the total P concentration in the culture solution, the more efficient was the utilization of runoff P. This may reflect more favourable conditions for desorption and in any case implies that the availability of runoff P in lakes might be quite high, perhaps 60 — 70 %, because runoff waters become diluted by lake waters.

There are, however, other factors which might limit the utilization of runoff P in Finnish lakes. The most important of these would be the time delay in spring from the maximum loading to the attainment of the optimum water temperature for algal growth.

If desorption as a merely chemical process is capable of transforming P into a bioavailable form to the degree found in this study, then the time delay would not be important. Most of the desorbed P would simply remain in solution until the temperature increased to allow algae take it up. If, however, it is assumed that algae are needed to enhance desorption by removing P from solution or that they utilize particulate P through direct contact with particles, then the time delay is a key factor. During the delay of one or one and a half months, particles have sufficient time for sedimentation, which would remove the adsorbed P from the water. In this case non-point P would have much less effect on the productivity of the lake.

The capability of chemical desorption to transform P into a soluble form was evaluated by comparing the concentrations of available P in our study with the equilibrium P concentrations obtained in desorption studies by Hartikainen (1979). On the basis of this comparison it appeared that desorption could account for the transformation of P into a bioavailable form at the concentration observed in this study. If this is in fact the case, the availability estimates obtained in this study can be applied to spring loading despite the fact that the peak of P loading does not coincide with that of algal growth. This conclusion should be verified by monitoring the development of soluble phosphate concentrations in lakes during spring.

LOPPUTIIVISTELMÄ

Maatalousmaan osuus Suomen pinta-alasta — 9 prosenttia — on paljon pienempi kuin useimmissa muissa Euroopan maissa. Vain rajoitetuilla alueilla peltoprosentti yltää yli kolmenkymmenen. Näin ollen on luonnollista, että aktiivisen vesiensuojelun alkuaikoina ei juurikaan puhuttu maatalouden vesistökuormituksesta, vaan päähuomio kohdistettiin asutuskeskusten ja teollisuuden jätevesikuormituksen vähentämiseen. Tämän ansiosta asumajätevesien fosforikuormitus väheni 1970-luvun loppuun mennessä alle puoleen siitä, mitä se oli vuosikymmenen alussa. Toisaalta maataloudessa tapahtuneet muutokset, lannoitteiden käytön kaksinkertaistuminen viimeisen kahdenkymmenen vuoden aikana ja rakennemuutos kohti suurempia tuotantoyksiköitä, ovat lisänneet ainakin maatalouden potentiaalista kuormitusta. Tämän tutkimuksen tarkoituksena oli arvioida maataloudesta aiheutuvan vesistöjen fosfori- ja typpikuormituksen suuruutta ja merkitystä Suomen järvien tilan muuttajina. Koska fosfori on useimmissa suomalaisissa järvissä ensisijaisesti tuotantoa rajoittava ravinne, rehevöittävän vaikutuksen arviointi perustui fosforikuormitukseen ja sen käyttökelpoisuuteen. Typen osalta tuloksia tarkasteltiin lähinnä haitallisen korkeiden nitraattipitoisuuksien kannalta.

Maatalous on vesistöjemme suurin yksittäinen ravinnekuormittaja. Normaalisateisena vuonna noin 31 000 tonnia typpeä ja 1400 tonnia fosforia joutuu vesistöön maatalouden harjoittamisen seurauksena. Arvio perustuu pieniltä valuma-alueilta laskettuihin ominaiskuormituslukuihin, jotka ovat typelle 12 kg $ha^{-1}a^{-1}$ ja fosforille 0,57 kg $ha^{-1}a^{-1}$. Lähtöolettamuksena on myös, että kaikki karjatalouden jätteet käytetään hyväksi peltojen lannoituksessa. Suurin osa peltovalumavesien typestä on nitraattimuodossa. Kuitenkin nitraattipitoisuudet olivat selvästi juomavesille asetettujen pitoisuusrajojen alapuolella. Valumavesien fosforista jopa yli puolet saattaa tulla vesistöön kiintoaineeseen adsorboituneena. Sen rehevöittävä vaikutus riippuu siten voimakkaasti siitä, missä määrin desorptiota maahiukkasista järviveteen tapahtuu. Laboratoriossa tehdyissä levätesteissä havaittiin, että 60—70 % kokonaisfosforista oli levien käytettävissä, kuitenkin käyttökelpoisen fosforin pitoisuudet olivat niin pieniä, että voidaan olettaa tällaisia liukoisen fosforin pitoisuuksia saavutettavan suomalaisissa järvissä puhtaasti kemiallisen desorption kautta ilman levien läsnäoloakin. Näin ollen valumavesien fosforin rehevöittävä vaikutus ei välttämättä edellyttäisi kuormitus- ja leväbiomassamaksimien yhtäaikaisuutta.

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