JULKAISUJA 74 • 1994

CONTROLLING NONPOINT SOURCE POLLUTION OF NITROGEN FROM AGRICULTURE THROUGH ECONOMIC INSTRUMENTS IN FINLAND

JOHN SUMELIUS

MAATALOUDEN TALOUDELLINEN TUTKIMUSLAITOS
AGRICULTURAL ECONOMICS RESEARCH INSTITUTE, FINLAND

RESEARCH PUBLICATIONS 74 • 1994

JULKAISUJA 74, 1994

CONTROLLING NONPOINT SOURCE POLLUTION OF NITROGEN FROM AGRICULTURE THROUGH ECONOMIC INSTRUMENTS IN FINLAND

John Sumelius

MAATALOUDEN TALOUDELLINEN TUTKIMUSLAITOS
AGRICULTURAL ECONOMICS RESEARCH INSTITUTE, FINLAND
RESEARCH PUBLICATIONS 74

ISBN 952-9538-45-6
ISSN 0788-5393

Vammala 1994 Vammalan Kirjapaino Oy

Preface

In recent years the importance of decreasing agricultural nonpoint source pollution has become obvious. While research on the biological-physical factors, which determine nitrogen and phosphorus leakages, has been conducted, economic analysis of this issue has been scarce, at least in Finland. The current publication is an effort to deepen the analysis of economic instruments to decrease agricultural nonpoint source pollution of the waterways and the Baltic sea. The study was initiated in Finland but the major part was carried out while I was a visiting scholar at the University of California, Davis. I wish to thank the persons from whom I received assistance so that the work could be completed. *Douglas M. Larson* provided me with valuable help in deriving the theoretical model for marginal abatement costs. *Quirino Paris* was very helpful in guiding me in the estimation of production functions. *Garth Holloway* and *Jim Wilen* also helped me in the work. *Lauri Kettunen* has given constructive criticism of the study. *Jyrki Aakkula*, *Jukka Peltola* and *Reijo Pirttijärvi* all read and commented on the manuscript, and made valuable corrections on the texts. *Jaana Ahlstedt* drew the figures and assisted in editing the text. The study has been supported by grants from Kyösti Haataja Foundation, the Foundation of Ella and Georg Ehrnrooth, The Academy of Finland, and the ASLA/ Fulbright Program. To all these person and institutions I wish to express my gratitude.

Helsinki, May 2, 1994

John Sumelius

AGRICULTURAL ECONOMICS RESEARCH INSTITUTE
Research Publications, No. 74, 1994, 66 p.

CONTROLLING NONPOINT SOURCE POLLUTION OF NITROGEN FROM AGRICULTURE THROUGH ECONOMIC INSTRUMENTS IN FINLAND

JOHN SUMELIUS

Abstract. In this study agricultural nonpoint source pollution in Finland has been reviewed and the intensification of Finnish agriculture after 1950 has been described. The advantages and disadvantages of various economic instruments for abating nitrogen leakages have been examined. On the basis of a farm level theoretical model the cost efficiency of four optional economic instruments for reducing one kg of nitrogen was estimated. The marginal abatement cost (*MAC*) was estimated on the basis of two components: 1. barley and wheat response to nitrogen 2. nitrogen leakages as a function of nitrogen fertilizer intensity. Doubling fertilizer prices exhibited the lowest *MAC*, followed closely by a fertilizer quota of 50 kg N/ha. A producer price tax of 50 % was the least cost efficient incentive. The order of *MAC* for the economic instruments was insensitive to changes in the specification of the production function. *MAC* for N-leakages on high initial leakage levels (40 kg N/ha) were 13 times lower than for low initial leakage levels (3 kg N/ha). The order of the instruments was insensitive to changing the form of the production function, but absolute costs varied depending on the functional form of the nitrogen response curve. Overestimation of *MAC* proved to be substantial, when a quadratic response function was used instead of a Mitscherlich specification. Measures directed towards high initial leakage levels, such as filter strips and best management practices, may, however, be more cost efficient than any of the economic instruments described.

Index words: abatement, economic instruments, environmental policies, fertilizer taxes, incentives, marginal abatement costs, marginal control costs, nitrogen, nonpoint pollution

Contents

1. Introduction

1.1. Background

Finnish agriculture is facing new challenges these days. Agriculture is under pressure from the general public to reduce its load on the environment. In particular, the polluting of waterways and the Baltic sea has become an important issue in Finland. Agriculture is the major source of both phosphorus (P) and nitrogen (N) emissions into the waterways, as compared to industry and municipalities.

According to a decision made by the Finnish government in 1988, P-emissions should be reduced by a third in 1995, combined with a significant reduction of the N-loading. A joint project "Agriculture and the loading of waters" by the Ministry of Agriculture and Forestry and the Ministry of Environment was started in 1988. The final report from this project was published in April 1992 (Rekolainen et al. 1992). According to this report, the total P-load into the waterways from agriculture is between 2,000 and 4,000 tons per year (25 % dissolved P), and the N-load is between 20,000 and 40,000 tons. These loads are higher than the combined loads from industry (700 tons of P and 5,700 tons of N) and municipalities (460 tons of P and 15,000 tons of N). Consequently, different P-emission abatement strategies are being considered. N-leaching abatement has not yet in practice been given a particularly high priority, while P-leaching has received a lot more attention.

Excessive levels of N-fertilization may increase nitrate leakages. The negative effects of excessive N-leakages are well documented: N is a plant nutrient which causes eutrophication and, consequently, undesired plant growth. Plant species that flourish in low-nutrient waters are displaced by species that tolerate a high N-load. In some cases the undesired addition of fertilizers to surface waters lead to growth of algae and possible oxygen starvation in fish. As a consequence, the recreational value of the waters will decrease. Rising nitrate levels in drinking water is another principal side-effect (Hanley 1990, Netherlands Scientific Council for Government Policy 1992).

Environmental policy in Finland has focused mainly on eutrophication of the waterways. Since the Second International Conference on the Protection of the North Sea (London 24.-25.11.1987) more emphasis has been laid on reduction of nutrient leakages to the sea. The concern of the leakages has grown in all Nordic countries, and plans for action to reduce both N and P in marine environments has been created in two of the countries. A compilation of nutrient leakages from all the countries around the Baltic sea is presented in Table 1 (Nordic Council of Ministers 1993)

The figures in Table 1 should be read with caution because of possible data deficiencies. For instance, the Polish figures may be exaggerated with respect to nutrient leakages. Also the figures from the former USSR seem small with regard to the big watershed area. Anyhow, the table shows the importance of international cooperation in trying to reduce the leakages. For the Nordic countries the Nordic

Table 1. Aggregate leakages to the Baltic sea and Skagerak (Nordic Council of Ministers 1993)[1].

Country	N-leakages (tons/year)	%	P-leakages (tons/year)	%	Watershed area km²
Finland[2]	80,000	12	5,100	10	303,400
Sweden[2]	138,000	21	5,400	11	445,300
Denmark[2]	92,000	14	6,500	13	32,204
Norway[2]	25,000	4	900	2	-
USSR[3]	52,000	8	8,300	16	594,600
Poland[3]	245,000	37	21,500	42	312,683
Germany[4]	29,000	4	3,000	6	23,390

[1] Does not include Danish leakages to Skagerak or the North Sea.
[2] Annual averages corrected for precipitation.
[3] Figures from former USSR 1987-1989 and Poland 1988-1989, not corrected for precipitation.
[4] Figures from 1987.

Council of Ministers (1993) made a rough approximation of agricultures' share of the nutrient leakages, according to which the share of agriculture in the N-leakages was 25-35 % in Finland, 20-30 % in Sweden, 25-30 % in Norway, and approximately 65 % in Denmark.

The Nordic Council of Ministers pointed out the greater need for integration of agricultural and environmental policies in the report cited above. The Committee for a Rural Environmental Program (Ministry of Environment, Committee report 68/1992, Maaseudun ympäristöohjelmatyöryhmän muistio) also pointed out the need for increased research on methods to reduce the soluble P- and N-load from agriculture. One area where knowledge is lacking is the cost efficiency of different measures and instruments to reduce these nutrient loads. In order to reduce N-leakages, knowledge on the effects of various policy alternatives and their farm level cost implications is needed.

This study provides some information on the economic efficiency of such policy alternatives.

1.2. Objective and methods

The objective of this study is to analyze the cost efficiency of various economic instruments for controlling agricultural nonpoint pollution of nitrogen. This is done by formulating theoretically a farm level model for estimating the cost efficiency of fertilizer taxes, product price taxes (i.e. reductions in producer prices of agricultural products) and fertilizer quotas for reducing one kilogram of N. The application of the analysis is based on estimations of N-response curves (crop response curves) for barley and wheat and a simulation of a generalized N-leakage function. The aim of the empirical part is to acquire a measure of *marginal abatement cost, (MAC)* for one kilogram of reduced N-leakages for the various instruments applied. The instruments include:

1. N-fertilizer tax of 112 % (doubling the N-price 1991).
2. Output tax of 50 % (halving the producer price 1991).
3. Combination of instruments 1 and 2.
4. Fertilizer quota of 50 kg N/ha.

In addition to this general objective, this study also has a more specific purpose: to evaluate how the specification of the N-response function affects the *MAC*. Three different specifications will be compared: a quadratic polynomial, a square root polynomial and a Mitscherlich specification of the N-response curve.

To start with, the intensification of Finnish agriculture is described and the literature on economic instruments for controlling nonpoint source pollution is reviewed. At first sight, the reason for this review may not be obvious. It is, however, beyond doubt that the intensification of agriculture and the change in agricultural practices connected with this account for a huge part of the increase in nutrient leakages from agricultural nonpoint sources. A description of this intensification process may illustrate the potential for reducing agricultural nonpoint source pollution by adopting successful extensification strategies, such as those, stipulated within the European Union, for instance, by the EC regulation No 2078/98 (Anon 1992).

2. Effects of intensification of Finnish agriculture

2.1. Growth of intensity in Finnish agriculture

The development of Finnish agriculture after 1950 is characterized by a substantial increase in the intensity of production, especially in the use of fertilizers and pesticides. The increased consumption of purchased inputs has contributed to the substitution for labor. It also compensated for the loss of agricultural land in 1939-1944, which represented approximately 10 % of the cultivated land. The most important technological breakthroughs have been mechanization, increased fertilizer use, and the adaptation of placement fertilization practices.

The total sold volume of nitrogen (N) fertilizers increased over six times between 1955 and 1990. The sold volume of phosphorus (P) fertilizers increased between 1955 and 1970 and declined after this. Measured on a per hectare basis, the N-fertilizer consumption multiplied twenty times between 1950 and 1990. The P-doses increased until the end of the 1980s, measured on a per hectare basis, and then evened out or decreased slightly. The development of fertilizer consumption per hectare is illustrated by Figure 1 (Fertilizer consumption 1950-1990, Kemira).

In four decades the consumption of N-fertilizers has increased from 5.5 kg N/ha to 111.5 kg N/ha. The consumption of N-fertilizers decreased temporarily at the end of the 1970s because of price increases due to the oil crisis. N-application doses continued to grow until 1992, when the N-fertilizer tax was raised substantially to FIM 2.90/kg N. Then the consumption of N-fertilizers decreased to 94.3 kg N/ha in 1993.

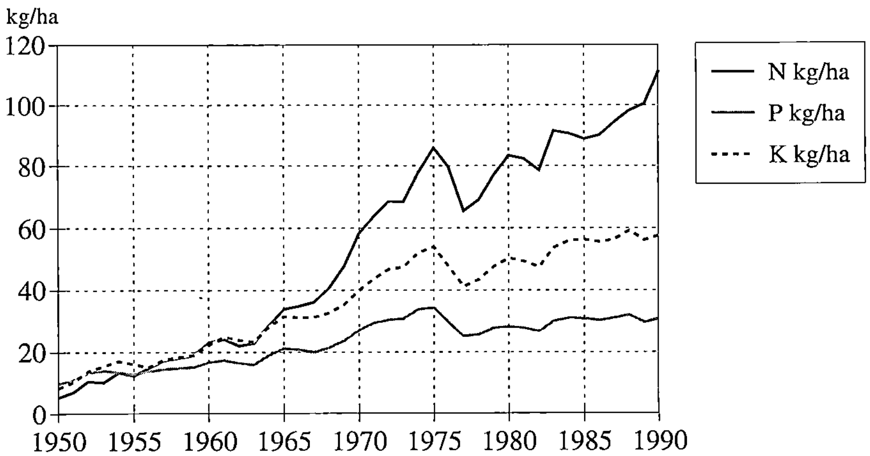

Figure 1. Fertilizer consumption 1950-1990.

The P-fertilizer doses per hectare have increased from 9.9 kg P/ha in 1950 to 30.7 kg P/ha in 1990 and then decreased to 19.4 kg P/ha in 1993. The potassium (K) fertilizer doses has increased from 8.5 kg K/ha to 57.6 kg N/ha in 1990 and has fallen again to 39.8 kg K/ha in 1993. The P-content in Finnish soils has been built up during the last two decades and is considered good. Fertilizer recommendations for P depend upon soil type and the amount of soil soluble P, which in turn depends on the acidity of the soil. The average P-application doses can be limited to 15-20 kg P/ha with only marginal or no economic losses (ELONEN 1991, SAARELA 1991). The development towards lower P-doses the recent years is therefore in harmony both with nature and with economic principles.

The total consumption of pesticides in 1953-1987 in Finnish agriculture and horticulture was presented by MARKKULA et al. (1990) in a report from the Agricultural Research Center in Finland. According to the report, the consumption of effective ingredients increased seven times between 1953 and 1987. After this the amount of consumption has decreased, and was one-quarter lower in 1988 than in 1980.

As a result of this, yields of wheat, rye, barley and oats doubled in 1988-1990 as compared to the average yields in 1947-1956 (MONTHLY REVIEW OF AGRICULTURAL STATISTICS NO. 12, 1957, YEARBOOK OF FARM STATISTICS 1990). The productivity of dairy cows measured as annual milk production per cow doubled in the same period. The intensive production has led to surplus production especially of milk, later eggs, meat and feed grains.

The increase in intensity and in the loading on the waterways resulting from animal production has resulted from three trends in Finnish agriculture 1955-1990:

1. Change in the number of animals.
2. Change in the regional distribution of animals.
3. Change in the composition and amount of feed.

The Institute of Animal Science at the University of Helsinki reports the total N-content in manure for the year 1990/92 to have been 45.842 mill. kg N or approximately 24 kg N/ha of the harvested area. The total P-content in the manure reported by the same source was 15.977 mill. kg P or approximately 8.3 kg P/ha of the harvested area.

As was already mentioned, the leakages of nutrients have increased to a total N-load from fields which according to recent approximations varies between 20,000 and 40,000 tons per year. Per ha the N-leakages are estimated at 15 kg N/ha (KAUPPI 1993).

The increase in the leakages of nutrients from agriculture has partly been a result of the increased intensification of agricultural production, partly a result of stronger regional and farm specialization, which has led to a change in cropping pattern. In certain regions the negative effects have been more pronounced. The waterways in

Table 2. Indicators of changes in Finnish agriculture 1955-1990.

	1955	1960	1970	1980	1990
Total arable land area, 1,000 ha[1)]	2,566	2,654	2,667	2,563	2,544
Cultivated land area, 1,000 ha[5)]	..	2,600	2,506	2,290	1,919
Sold volume of main fertilizer nutrients, 1,000 tons[2)]					
- Nitrogen	30	64	169	197	202
- Phosphorus	33	46	78	65	49
Sold volume of main fertilizer nutrients, per ha[2)]					
- Nitrogen	12.4	23.1	58.3	83.3	111.5
- Phosphorus	12.8	16.7	27.2	28.0	30.7
Sold volume of pesticides, content of active ingredients, tons[3)]	412	451	1291	2,402	1,839
Number of cows, 1,000 pcs[4)]	1,155	1,153	889	720	497
Number of pigs, 1,000 pcs[4)]	523	483	1,047	1,451	1,291[7)]
Number of hens > 6 months, 1,000 pcs[4)]	3,945	3,457	4,471	6,041	4,923[7)]
Number of tractors on farms, 1,000 pcs[6)]	..	45	74	155	212
Crop yields[4)]					
- Barley, kg/ha	1,480	2,070	2,310	2,880	3,540
- Wheat, kg/ha	1,526	2,036	2,330	2,870	3,483
Average milk yield per cow, liters	..	2,955	3,680	4,478	5,547

1) Including fallow, pasture and other arable land, Statistical Yearbook of Finland, Agricultural Census 1991.

2) Figures for fertilizer years 1954-55, 1960-61, 1970-71, 1980-81, 1990-91. Kemira.

3) Agricultural fungicides, insecticides and herbicides. Markkula et al. 1990, Yearbook of Farm Statistics 1990.

4) Statistical Yearbook of Finland.

5) AERI statistics.

6) Yearbook of Nordic Statistics 1992. The figure for 1955 is an average of the figures for 1950 and 1960.

7) The figure is from the year 1989.

southern and western Finland are generally more loaded than central and eastern Finland. The regional specialization and the declining role of grass in the crop rotation has contributed to the increase of nutrient loading. The nutrient runoff from cattle production may be important, especially if manure facilities are not adequate.

The change in the intensity of Finnish agriculture is illustrated by some main indicators in Table 2. The cultivated area decreased by approximately a fourth between 1960 and 1990, whereas the change in the total arable area is much smaller.

2.2. External costs of intensification

It can be concluded that intensification, especially with reference to the fertilizer input, has been an important source of productivity growth in Finnish agriculture. However, the growth of intensity, in combination with changes in cultivation and animal husbandry practices, has had unintended side-effects on the environment. In other words, the growth in intensity has resulted in external costs. Society as a whole is to an increasing degree concerned about this development, the most important being the leakages of phosphorus and nitrogen to the waterways. In order to reverse this trend, extensification of agriculture has been suggested.

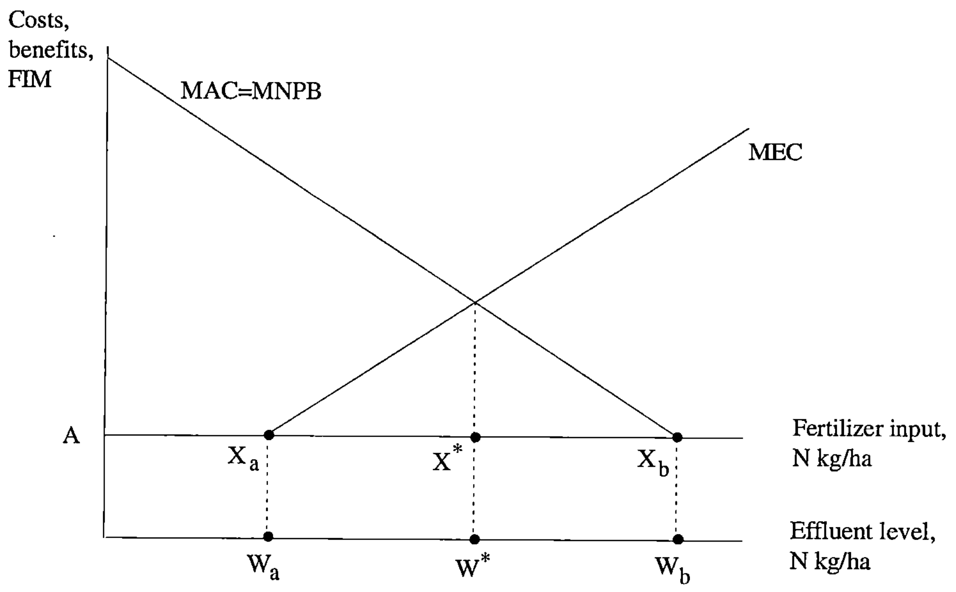

Figure 2. Relation between intensification, marginal control cost and marginal external cost.

An external cost exists when two conditions prevail (PEARCE and TURNER 1991):

1. An activity by one agent causes a loss of welfare to another agent.
2. The loss of welfare is uncompensated.

The relation between external costs and intensification of the fertilizer input is illustrated by Figure 2.

In the figure costs are represented by the vertical axis, while effluent levels are represented by the horizontal axis. Fertilizer intensity level is represented by a straight line above the effluent level axis suggesting a linear relationship between intensity and effluent level.

The external costs are represented by the *marginal external cost* curve (*MEC*). The *MEC* curve can be understood as a leakage function which shows the social damage caused by leakages. Since $\partial MEC/\partial w > 0$ the marginal external costs from an increase in intensity are rising more rapidly than the effluent increase. The *marginal abatement cost* curve *(MAC)* is decreasing ($\partial MAC/\partial w < 0$) with higher intensity because of the law of diminishing returns. If output reduction is the only way to reduce leakages, then the *MAC*-curve is equal to the marginal private net benefit curve (*MNPB*), which shows benefits from increasing intensity.

As long as the fertilizer intensity is below x_a, the assimilative capacity of waterways is not exceeded. In other words, the waterways are able to selfpurify the effluent level below W_a. Consequently, for intensity levels below x_a no external costs exist.

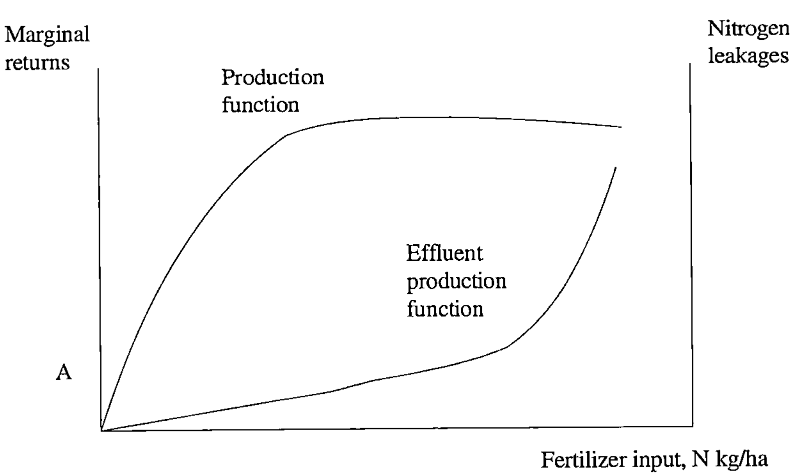

Figure 3. Relation between the production function and leakage function.

Below the intensity level x^* marginal private net benefits exceed the external cost. Above that point the marginal external costs exceed private marginal benefits. Consequently, x^* will be the optimal intensity level, where the welfare of society is at the maximum. At this point the effluent level is W^*, implying there is a certain amount of effluent which affects the welfare of people, but this marginal external cost is exactly equal to the marginal private net benefits to farmers.

The effects of extensification of nitrogen fertilization on the production function is illustrated in Figure 3.

In Figure 3 a production function $y = f(x)$ has been drawn, where x = nitrogen fertilizer input. Below that profit function an effluent production function of nitrogen leakage (also called a leakage function) $h = g(x)$ as a function of fertilization level has been depicted. The production function $f(x)$ is characterized by the law of diminishing returns, i.e. $\partial y/\partial x < 0$. A sufficient condition for this is that the production function exhibits decreasing returns to scale, $f(tx) < tf(x),\ t \geq 1$. Instead the marginal increase in leaching of nitrogen grows, i.e. $\partial h/\partial x > 0$. The leaching function therefore exhibits increasing returns to scale, i.e $f(tx) > tf(x),\ t \geq 1$. From this follows that $\partial MAC/\partial w < 0$, like has been depicted in Figure 2.

Figures 2 and 3 illustrate graphically the essential relations in evaluating the environmental benefits of extensification from the economic point of view. The purpose of these pictures is to give some intuition to the model formulated in chapter 4. Before deriving the formal model, different economic instruments for nonpoint pollution are examined by means of theoretical analysis in the next chapter.

3. Economic instruments for controlling nonpoint source pollution

3.1. Point source pollution and nonpoint source pollution

Water pollution can be classified according to the source of effluent. *Point source* pollution refers to discharge with a specific location through a pipe, outfall or ditch. *Nonpoint source* pollution, or simply nonpoint pollution, on the other hand, affects water in a more diffuse way. Point source pollution can be traced to a precise, defined source whereas nonpoint source pollution is difficult to trace back to a precise source (Tietenberg 1992, Libby and Boggess 1990). In the literature *diffuse loading* is used synonymously with nonpoint source pollution. Effluent discharges from arable land or from fallow are examples of nonpoint source pollution since the exact location of the discharge is difficult to locate. Discharges from a particular point at a farm, like a manure storage facility can be classified as point source pollution. If no measurement of effluent discharges is done, nonpoint source pollution includes all those small points of pollution from where the discharges emanate. The majority of pollution from agriculture can be classified as nonpoint pollution. Discharges from factories and municipal sewage treatment plants represent the major point sources.

The *effluent production function* refers to a function with an undesirable substance in the runoff water from fields or in the disposal from factories (for instance nitrogen). In the literature there is a large number of terms which essentially describe the same thing. Leakage function, nonpoint production function, pollution production function, externality generating function, and emissions are more or less synonymous, depending on the context.

3.2. Voluntary extensification of nitrogen fertilizer intensity

The potential for extensification of nitrogen fertilizer doses by voluntary measures seems to be limited. On the basis of one study (Sumelius 1994), the potential to extensify production in a profitable way seemed to be limited, assuming that price relations between inputs and outputs would not change. The majority of the farms did not seem to be able to save in production costs by saving fertilizer expenditure since the marginal returns were higher than marginal costs. Only in the subsample with the highest fertilizer expenditure/ha, accounting for 18 % of the examined grain producing book-keeping farms, some farmers were likely to have used fertilizers excessively. It seemed that, without a change in technology (for instance a change to integrated farming systems), only part of the farmers in this subsample were using excessive fertilization since the marginal returns for the whole subsample was higher than the marginal fertilizer cost.

Judging from this particular set of data, voluntary measures based on extension and education are not likely to bring about a sharp decrease in fertilizer consumption, which may be necessary for abatement of nutrient leakages. This conclusion is in accordance with the general skepticism of economists that moral persuasion and extension would suffice for introducing environmentally favorable production practices in order to protect the environment. In fact, as agricultural markets internationalize and import barriers will become lower, it is unrealistic to assume that farmers will adopt pollution abating activities voluntarily if they are costly. Therefore extensification through lower fertilizer input doses or through best management practices has to be promoted by means of specific instruments, if this is considered desirable. In this chapter the specific instruments analyzed in the literature are surveyed briefly. Concerning point source pollution, it has been established that incentive based instruments can generally achieve a *predetermined target* of an allowed leakage level at a lower cost than regulation (BAUMOL and OATES 1988). Given the complexities of the biological systems that characterize nitrogen leakages, it has not been possible to establish that this would also hold in most cases for nonpoint source pollution.

In chapter 4 a theoretical model for analyzing some of the available instruments for nonpoint pollution control will be presented. The reader has to bear in mind that the focus is in particular on instruments which are abating N-leakages.

3.3. Definition of economic instruments for controlling point source and nonpoint source pollution

A simple definition of economic instruments to control water pollution can be presented as follows: *Economic instruments to control environmental nonpoint source pollution are policy tools which create financial ex ante incentives for producers to contain effluent leakages.* Applied to agriculture, economic instruments would be instruments which create financial incentives for farmers to contain leakages of nitrogen or phosphorus. SEGERSON (1990) makes a distinction between *incentive policies* and *regulatory policies* for the control of agricultural water pollution. Regulatory policies force the polluter, by law or regulation, to comply with certain restrictions on the level of polluting activities. There is no mechanism to separate between different firms in this approach. Farms are considered uniform. Incentive policies can be divided into ex post and ex ante policies. Ex ante policies are designed to prevent pollution before it has occurred, or prevent pollution from increasing before it has increased. These policies are in Segersons' definition equal to *economic instruments* as defined in this work. Ex post policies are mainly policies applied when pollution is detected, which assign rules for *liability for pollution* damages. Such liability could, for instance, be a penalty for nitrate concentrations in wells above a set level, when the increase has been caused by another party. Both ex ante and ex post policies rely upon the price system for creating incentives.

Economic instruments and policy options for controlling nonpoint source pollution have not been analyzed theoretically in great detail, but the means for controlling point source pollution have been analyzed extensively. The major instruments for the control of point source pollution are environmental fees and subsidies, changes in producer prices, quotas, tradeable permits, and standards. As far as nonpoint source pollution is concerned, theoretical analysis is much more scarce. GRIFFIN and BROMLEY (1982) as well as SHORTLE and DUNN (1986) have modelled effects of four distinct policies for dealing with nonpoint externalities: nonpoint incentives (e.g., taxes applied to effluent), nonpoint standards (i.e. effluent standards), management incentives (e.g. fertilizer taxes or subsidies for abating inputs) and regulated management practices (e.g. mandatory use of no-till). The authors conclude that the effects of each of these policies are dependent on whether the effluent production function is known or not. STEVENS (1988) has formulated a constrained model for comparing the effects of effluent and input taxes. SEGERSON (1988) has formulated a probabilistic model where the ambient pollutant level and a standard for that level are decisive for the introduction of a general tax scheme.

The various instruments for both point source and nonpoint source pollution are described in the next sections and their advantages and disadvantages are discussed briefly.

3.4. Standards and fertilizer quotas

Standards are a noneconomic form of a pollution control instrument which, according to SHORTLE and DUNN (1991), may be divided into *performance standards* (maximum leakage allowed) and *design standards*. As such, standards are not an economic instruments since they do not rely upon the price system. They are by far the most common means relied upon in practice for reducing pollution, so that an understanding of standards is necessary in order to evaluate economic instruments.

Performance standards are based on a maximum leakage allowed. Usually a government agency sets this standard which all firms are supposed not to exceed. This implies monitoring the leakages. Performance standards have been used as a means of controlling point source pollution, but not nonpoint pollution, since monitoring of nonpoint pollution is impossible by definition. In order for standards to be efficient, a different standard would have to be set for each firm. Since abatement costs differ across firms, it is virtually impossible to set an efficient standard. This is the traditional argument for the preference of effluent taxes over performance standards.

HELFAND (1991) claims that by standards economists usually mean uniform restrictions on pollution emissions (i.e. performance standards), which in practice may take many forms. She makes a distinction between five different (performance) standards: standards set as a level of emission, standards per unit of output, standards per unit of input, standards per total level of output, and standards as a set of a specified input (i.e. input quota).

Design standards, on the other hand, are a form of direct regulation specifying the particular technology to be used, or the ways farmers should produce and manage their land. Design standards impose a rule of behavior on the farmer. Therefore it is a form of command-and-control policy, or, in other words, direct regulation of production methods. Examples of design standards are mandating the use of certain best management practices, the timing of the inputs of certain agricultural practices and minimum storage capacity of manure. Design standards have been the most common approach in the efforts to decrease phosphorus and nitrogen leakages Finnish agriculture. Design standards have often been connected with increased extension efforts aiming at attitude change and voluntary control (SHORTLE and DUNN 1991).

In contrast to a system of standards monitored by leakages, it is possible to conceive of N-fertilizer quotas, which actually correspond to a standard. A fertilizer quota would involve a directive not to use more than a fertilizer quantity of a certain specified level per area and crop. While in principle avoiding monitoring leakages, such a scheme would be difficult and costly to implement since no regulating authority could possibly collect all information on the spatial variation (soil type, crop, nutrient contents, etc.) needed to establish such quotas. Monitoring such a quota scheme would necessarily also imply high costs. The possibility of a black market for N-fertilizers is also evident.

For the purpose of agriculture a tradable N-fertilizer quota, instead of actual government determined quotas, could be established. Instead of fixing fertilizer fees, the market would determine where the most economic use of fertilizer would take place. This would be one way to overcome both the need to monitor and to collect information on all factors contributing to leakages.

3.5. Environmental taxes and fees

Environmental taxes are the oldest instrument, initially proposed by Pigou in the 1920s. Consequently, an environmental tax may also be called a Pigouvian tax. By means of the theory of externalities it has been shown that this tax represents the optimal first-best solution when markets are competitive and when the sources of an externality (effluent) or social damage can be measured with certainty (BAUMOL and OATES 1988).

When sources of effluent are not measurable (which is the normal case, especially in the case of nonpoint source pollution) effluent charges do not represent a first-best solution, and taxes may be inappropriate for addressing nonpoint pollution problems. Even if farms were identical, uncertainty about the *marginal abatement cost*

(MAC) makes the efficiency of environmental taxes uncertain. The efficiency of standards versus taxes will mainly depend on the slopes of the marginal abatement cost curves (which are usually called *marginal control cost curves* in a more general context) (WEIZMAN 1974, ADAR and GRIFFIN 1976, BAUMOL and OATES 1988).

If an effluent production function can be estimated with certainty, effluent charges may represent an optimal second-best solution. The only market failure must be the one that defines the nonpoint externality (WEINBERG 1991).

We may therefore conclude that, in spite of appealing properties at first sight, an environmental tax in the form of an effluent tax (or as an input tax) imposes severe problems of analysis because of lack of information on several points.

Since the social marginal cost is not known, nor is it possible to estimate, a second-best solution is the most efficient one that theoretically could be achieved. BAUMOL and OATES (1988) have shown that if the production function possesses the normal second-order properties, i.e. are continuous, twice differentiable and separable with respect to inputs, then a tax rate set at the level which achieves the desired reduction will satisfy the least cost conditions of the society for achieving that reduction level. This means that if a tax is implemented properly, information on marginal control cost for each firm is needed. This would imply a tremendous amount of information to be collected, since marginal control costs vary with marginal returns, which differ from factory to factory, from farm to farm, and from field to field. Uncertainty of marginal control costs are also due to uncertainty about the effluent production function. The effluent production function is affected by spatial and temporal nonuniformities due to variation in the soil type and weather. Variation in topographical conditions and year-to-year variations in weather conditions affect the availability of inputs for crops (see e.g. BABCOCK and BLACKMER 1992). Taking all these uncertainty factors together the only way left to determine whether standards, effluent taxes or input taxes are the most efficient seems to be through simulation processes.

STEVENS (1988) has shown that the relative efficiency of effluent or input taxes for polluting inputs as measured by the cost of reducing effluent depends on the returns to scale of the leaching function. If the leaching function characterized by increasing returns to scale (i.e. is homogenous of degree r, $r \geq 1$, then an effluent tax will be more efficient (leads to less income loss for farmers as measured by money/kg reduced N). If the leaching function is characterized by decreasing returns to scale (i.e. is homogenous of degree r, $r \leq 1$), then an input tax will be more efficient. A consequence of this will also be that an input tax, which is not site-specific, will cause too little reduction in input levels in highly leaking areas and too much in areas with small leakages. The tax on effluent and input must be site-specific to be efficient. This causes again an overwhelming amount of information collection.

In spite of the lack of information on environmental taxes on nonpoint source pollution, some taxes have been implemented. The taxes applied have been directed to the polluting input, which in most cases has been artificially produced nitrogen or phosphorus fertilizers. In the light of Stevens' analysis, it seems likely that, while giving the right signal, this instrument may be relatively costly if soils are easily leaching or precipitation is heavy.

In this context it may be of interest to note that taxes on nitrogen fertilizers have been collected for several years in Finland. They were initially considered a means to raise funds for export subsidies. In 1990 an environmental tax on phosphorus fertilizers was introduced. From Jan. 1st, 1992 the fertilizer taxes were raised substantially, but they were lowered again in 1993. From June 15, 1994 the fertilizer taxes were abolished in order to facilitate a Finnish membership in the European Union. The development of fertilizer taxes per kg of nutrient is presented in Table 3.

Taking into account the long history of nitrogen taxes applied to Finnish agriculture, one may ask whether they have had any effect on the nitrogen leakages or not.

A collective *ambient concentration of pollutant tax*, as suggested by SEGERSON (1988), may be easier to implement than effluent taxes, and it may be more accurate. Segerson makes a distinction between emission levels and ambient pollution level. She recognizes that monitoring of individual polluting action is difficult as far as non-

Table 3. Fertilizer taxes 1976-1994, p/kg N (1 p = USD 0.002).

Period	Tax
July 1st 1976 - June 30th 1977	5
July 1st 1977 - June 30th 1978	11
July 1st 1978 - June 30th 1982	11
July 1st 1982 - June 30th 1983	6
July 1st 1983 - June 30th 1984	10
July 1st 1984 - June 30th 1985	12
July 1st 1985 - Aug. 31st 1985	20
Sept. 1st 1985 - Aug. 31st 1986	23
Sept. 1st 1986 - June 30th 1987	19
July 1st 1987 - Sept. 30th 1988	3
Oct. 1st 1988 - June 14th 1990	5
June 15th1990 - Dec. 31st 1990	15
Jan. 1st 1991 - June 15th 1991	20
June 16th 1991 - Aug. 31st 1991	35
Sept. 1st 1991 - Dec. 31st 1991	60
Jan. 1st 1992 - Aug. 31st 1992	290 (p/kg N)
" "	170 (p/kg P)
Sept. 1st 1992 - June 15th 1994	260 (p/kg N)
" "	170 (p/kg P)

point pollution is concerned, and actions cannot generally be inferred from observed ambient pollution since several polluters contribute to the loads. The level of abatement undertaken cannot therefore be separated from the observations. In other words, individual emissions cannot be observed at reasonable costs. Ambient pollutant levels for a particular watercourse can, however, be monitored rather easily. A collective tax for each firm equal to the social marginal damage as measured by ambient quality reduction could therefore be implemented. In Segerson's analysis the tax comes into force when ambient pollution levels reach a standard, S, set by an environmental agency. A range of ambient pollutant levels is represented by a probability density function with a mean that depends on abating activities undertaken by farmers. Segerson shows that, if farmers adopt a probabilistic framework for profit maximization, such an ambient concentration of pollutant tax is likely to reduce leakages. Thus, in addition to effluent taxes and input taxes an ambient concentration of pollutant tax has been proposed for reducing nonpoint source pollution. The proposal of Segerson overcomes the difficulties connected with monitoring of effluent charges from each discharge source. Furthermore, it concentrates on ambient quality, not on effluent levels. A disadvantage is, according to Segerson, that information is needed in order to set the tax approximately right. Furthermore, this tax addresses primarily surfacewater problems, but not groundwater problems.

Environmental taxes have some positive qualities as compared to product price taxes, or standards. First of all, environmental input taxes tend to tax activities which actually are polluting. Therefore this instrument is in accordance with the Polluters Pay-Principle set up by OECD (which principally states that those who use societys' environmental resources must compensate the owners, i.e. the public, for any degradation). The costs of enforcement and administration are very low as compared to design or performance standards, which require monitoring to be effective.

Furthermore, in the long environmental taxes create incentives for research and development activities aiming at less polluting production methods. They also provide incentives for farmers to shift to products that are less intensive in the polluting input.

The ambient concentration of pollution tax as proposed by Segerson overcomes some of the most difficult problems with input and effluent taxes, i.e. monitoring effluent in order to target taxes correctly for each firm, imperfect knowledge of effluent production function, and ambient quality focus instead of emission focus.

3.6. Environmental subsidies

An environmental subsidy seeks to induce environmental quality protection through positive incentives. An environmental subsidy is usually a subsidy paid in order to lower the cost of reducing an undesired externality. In the case of water pollution this would be a subsidy paid in order to reduce the cost of abating measures. At first thought, an environmental subsidy should, work like a negative environmental tax. A subsidy for measures aiming at emission reduction should therefore establish the same incentive for abatement activity as a tax. Theoretically the subsidy per unit of reduction in emissions should be equal to the marginal damages from pollution (SEGERSON 1990). Of course, the problem is again that the marginal damages are not known.

So, at first sight taxes and subsidies are identical. In the tax approach the firm pays the government, whereas in the subsidy case the government pays the firm. However, in the case of point source pollution under conditions of perfect competition (and uncertainty) it has been shown quite convincingly that environmental taxes and subsidies are *not* substitutes. The reason is that a subsidy works quite differently on the industry level and has different implications for the exit/entry decisions in the long run. To obtain the correct number of firms in the industry in the long run firms should pay, not only the cost of marginal damage, but also the total cost arising from waste emissions (SPULBER 1988, CROPPER and OATES 1992). In the case of perfect competition BAUMOL and OATES (1988, chapter 14) made the following proposition:

> "If emissions rise monotonically with industry output, the more effective the subsidy program is in inducing the individual firm to reduce its emissions, the larger is the *increase* in total industry emissions that can be expected to result from the subsidy".

Note that this proposition is limited to competitive industries. SEGERSON (1990) claims, however, that one might conceive of subsidies not affecting entry/exit decisions. To take a concrete example, she mentions subsidies paid to particular parcels of land (e.g. filter strips), which may be capitalized into land values in the long run. Since the number of acreage next to waterways are fixed, excessive entries are not possible.

A difficulty with the use of environmental subsidies applied to abating inputs in agricultural nonpoint pollution, such as leakage reducing crops, is how to determine the optimal level of the subsidy. Since a subsidy for an abating input creates an incentive to use it more, normal first order conditions prior to the subsidy do not apply. Therefore, it might be difficult to determine the optimal level of subsidy and optimal level of abatement on an a priori basis. In fact, WEINBERG (1991) has shown that, when an abating input enters the production function, there is no way to derive optimality by imposing negative or positive taxes on that input. An intuitive explanation to this fact is that, the larger a subsidy of an input is, the larger will the amount applied be. Finding the appropriate subsidy level is therefore subject to a trial and error process.

Subsidies could, in principle, be paid for abating inputs. Environmental subsidies do not, however, work according to the Polluters-Pay-Principle advocated by the

OECD. They do not impose any penalty on the polluter. The inducement for technological change is therefore missing.

Environmental subsidies in agriculture are, in practice, mostly cost-sharing subsidies. Examples include green fallow premium as applied to filter strips (eg. Finland), subsidies for manure storage facilities, which are used in several countries, or cross-compliance schemes in USA in order to reduce erosion, or premiums for switching to organic farming.

3.7. Product taxes

Product taxes imply lowering the prices for polluting activities. This should in theory reduce profit maximizing fertilizer doses. Deriving the first order conditions for profit maximization shows that the the marginal product equals the ratio between input and output prices, assuming that both prices are homogenous of degree one. Therefore, in a theoretical firm level model halving the product price will result in the same physical reduction in profit maximizing fertilizer application doses as doubling the fertilizer price. Consequently, a 50 % product tax will have the same effect on N-leakages as doubling of N-fertilizer prices, assuming that the product mix and cultivated area do not change. In practice, the last assumption is not very realistic since crops differ with respect to the product price and nitrogen requirement.

A disadvantage with product taxes as compared to environmental taxes or subsidies is that a product price decrease does not make it possible to discriminate between polluting and nonpolluting farms, or between polluting and nonpolluting technologies. While changing the optimal intensity level, a product tax does not give any incentive to change technology. Removal of price subsidies works basically in the same way as imposing a tax on the product price. However, the degree of nutrient abatement achieved in this way must be carefully analyzed before conclusions about the degree of nutrient abatement can be drawn.

3.8. Tradable permits

In the 1970s tradable emission permits for point source pollution were analyzed in a series of papers starting with a seminal paper by Montgomery (1972). The major conclusions are summarized below.

The use of environmental fees implies regulation of input prices. However, it would also be possible to try to regulate the *aggregate* level of emissions by fixing quotas for emissions or by issuing tradable emission permits. Under a system of tradable emission permits, the regulatory authority determines an aggregate level of emissions and issues an amount of emission permits corresponding to that level. The permits can, for instance, be auctioned out, and are freely tradable. In other words, any producer is free to buy or sell the number of permits he wants.

The basic idea with tradable permits is that the regulator do not know what it will cost to achieve the basic output level. Therefore, he is not able to estimate the costs of production or set an optimal emission fee. By establishing an amount of emissions permitted and letting the firms buy and sell these permits, the level of emission abatement can be established, while the market ensures that it will be cost effective. Each firm, it is thought, will buy a number of permits corresponding to the amount in which the marginal return from the production activity equals either the price of that permit or the marginal abatement cost. The problem shifts from establishing a proper effluent fee to an adequate number of permits to be issued. In some respects it combines many features of both the environmental tax system and the standards approach.

Tradable emission permits are in principle appealing. However, the whole context is more complex than it appears to be at first sight. In an environment of complete knowledge and perfect certainty marketable emission permits are, in principle, equivalent to taxes on point source emissions. In such an environment the marginal social benefits curve as well as the marginal control cost curve is known, and the optimal point from society's point of view is the point where marginal costs and benefits are equal. Using a system of tradable emissions will lead to exactly the same results as using a system of fertilizer fees (BAUMOL and OATES 1988).

However, WEITZMAN (1974) showed that, in the presence of inadequate knowledge or uncertainty concerning marginal costs of abatement and cost functions, the outcomes of the two instruments differ considerably. In such a second-best world the preferred policy instrument will depend upon the steepness of the marginal cost function. Under some circumstances price control is preferred, whereas under other circumstances quantities are preferred.

In such a world of imperfect knowledge the regulator will be able to achieve the total reductions in emissions he had decided upon beforehand, but he may greatly overestimate or underestimate the costs of accomplishing this. If, on the other hand, the regulator knows the marginal costs, he may employ an emission fee, but he will be uncertain about the level of the emissions reduction. In general, when the marginal cost curve is lower than expected, emissions reductions will be inadequate under a system of tradable permits and excessive under an emission fee if both are set at what appear to be optimal levels. If the marginal cost curve is higher than expected the reverse is true (BAUMOL and OATES 1988)

The preceding results have been obtained basically with point source pollution in mind. Estimates of marginal social costs and marginal damage costs are far more difficult for nonpoint pollution. Because of this, the relative benefits of tradable permits as compared to environmental fees are almost exclusively of theoretical interest when dealing with nonpoint pollution.

3.9. Policy mix

A mixture of instruments is also possible. ROBERTS and SPENCE (1976) proposed a mixture of licenses, effluent fees, and a subsidy for point source pollution in the case of uncertainty of the marginal control cost curves of firms. Licenses and fees can bee used together to protect against the failings of the other. It is also possible to consider a mixture of instruments for the purpose of reducing nonpoint source pollution. Formulation of such mixtures must, of course, be made with care.

It is possible to draw the conclusion that, in absence of information on the social cost function, it is impossible to point out a general first-best instrument to be recommended from society's point of interest. In practice, various instruments have been used in order to try to reduce nonpoint source pollution from agriculture. Since there is no first-best way of reducing the leakages, and since no second-best policy has been proved to be superior, a policy mix involving several instruments may well reduce leakages. There is, of course, a danger that leakage reduction programs involving environmental taxes *and* subsidies may be cost inefficient if formulated without regard of the interconnections. In order to determine the relative merits of each instrument, an empirical analysis is needed. In the next chapter a theoretical model for such analysis is specified. In chapter 8 it is applied to agricultural N-leakages in Finland.

3.10. Summary of the economic instruments

The key economic criteria in evaluating the different economic instruments for abating nonpoint source pollution should be their cost-efficiency. Standards are easy to evaluate. Their major disadvantage is that a separate standard (for instance, a N-fertilizer quota) should be set for each firm, which would imply an excessive amount of information to be collected. Monitoring costs would also be high. From the viewpoint of a single firm, a fertilizer quota standard need not be less efficient than the other economic instruments. From the viewpoint of the whole society, fertilizer quotas are not likely to be very efficient. Environmental taxes are effective when they can be directed toward the externality. N-fertilizer taxes do not fulfill this requirement since taxes are not based on the N-load, nor on the leakages, but on the use of an input. An advantage of N-taxes is that monitoring them does not require a lot of information. Since leakages and loads vary according to biological and physiological factors, the lack of information on the firm level makes N-taxes less attractive. The incentives to change technology is an advantage. Product price taxes do not need to be monitored. Their cost efficiency is probably smaller than the cost efficiency of N-fertilizer taxes from the firms' point of view. Environmental subsidies applied to abating inputs in agricultural nonpoint pollution, such as leakage reducing crops, are in principle one option. However, it is difficult to establish the optimal level of subsidy and optimal level of abatement on an a priori basis. Tradable permits have not been developed for nonpoint sources. A policy mix of the different instruments, on the other hand, needs to be formulated with care.

Evidently the superiority of different instruments needs to be evaluated from case to case. In the next chapter a model for evaluating the cost efficiency of four different instruments is formulated.

4. The theoretical model

4.1. Derivation of the marginal abatement costs

To understand the effects of financial incentives to decrease nonpoint pollution theoretically, an unconstrained farm model for profit maximization is formulated. The aim with the analysis is, in particular, to compare the efficiency of input taxes, fertilizer quotas, and producer price changes in reducing N-leakages. More specifically, a model is formulated for the estimation of the *marginal abatement cost (MAC)* of four different economic instruments for reducing N-leakages in grain production. The instruments include:

1. N fertilizer tax of 112 % (doubling the N price 1991).
2. Output price tax of 50 % (halving the producer price 1991).
3. Combination of 1 and 2.
4. Fertilizer quota of 50 kg N/ha.

The farms' product/input relation is represented by the production function. We assume that the objective of the farmer is to maximize profit, and that the farmer knows his production function with full certainty:

$$y = f(x_1 \ldots x_n, s, r) \tag{1}$$

where y = production
x_i = production inputs $(i = 1, 2, \ldots, n\text{-}1, n)$
s = soil type
r = precipitation

We also assume that the production function y is homothetic and concave, and that the feasibility set is convex. It is argued that this case represents the most typical production function. Furthermore, we note the effluent production function (i.e. the leakage function or the nonpoint production function) as a function of part of the arguments in y:

$$z = g(x_z, s, r) \tag{2}$$

where x_z = a polluting input
r = precipitation

The effluent production function is also assumed to be known with full certainty. This assumption is clearly unrealistic, since the source of nonpoint pollution is by definition unknown. We can estimate an effluent production function and assume that it is representative. If s and r are kept constant in this effluent production function, the effects of increasing or decreasing x_z can be separated.

It should be emphasized that the results from the theoretical analysis will depend on the assumptions made concerning the form of both production functions $y = f(x_i, s, r)$ and $z = g(x_z, s, r)$ as well as prices. The assumption of a concave production function implies that the function is subject to decreasing returns to scale, whereas the assumption of a convex leakage function implies that the leakages are subject to increasing returns to scale.

Since the profit function is the dual of the production function $y = f(x)$, the latter can be derived from the former. Starting from the assumption of profit maximization, the model is therefore specified as

$$(3) \qquad \pi(p,w) = \underset{x \geq 0}{Max}\{py - wx \mid y = f(x)\}$$

where
π = profit
p = price of y
$f(x)$ = production function
x = quantity of nitrogen fertilizer input
w = price of nitrogen fertilizer input

and the optimization problem of the farmer can be written

$$(4) \qquad \underset{x \geq 0}{Max}\, \pi = pf(x) - wx$$

Differentiating with respect to the input x gives the first order conditions for profit maximization:

$$(5) \qquad \partial\pi / \partial x = p\partial f(x) / \partial x - w = 0$$

or

$$(6) \qquad \partial f(x) / \partial x = w / p$$

which states that at the profit maximum the marginal product equals the ratio between the input and output price. x^* can be solved for

$$(7) \qquad x^* = x(p,w)$$

As inputs can be assumed to be nonnegative, we can impose the constraint $x \geq 0$. In order to guarantee that this optimum is a local maximum for (3), the second order sufficient condition $\partial^2\pi/\partial x\partial x < 0$ must hold.

An economic instrument or financial incentive, denoted k, is introduced. If the financial incentive is an input tax, input prices can be written $w^k_1 = w_1 + k$. If the financial incentive is an output tax, output price can be written $p^k_1 = p_1 + k$. The marginal effect on the profit function of the economic instrument will be $\partial\pi/\partial k$.

Profit maximizing input levels in (7) will adjust to a new level $x(p,w^k_1)$ in the case of input taxes. The effluent production function (2) can now be written as

$$(8) \qquad z = g(x(w_1^k, p), s, r)$$

and the effects of the financial incentive on the leakage will be

$$(9) \qquad \partial z / \partial k = g(\partial x(w_1^k, p) / \partial k)$$

The marginal control cost of different economic instruments as measured by the *marginal abatement cost MAC* will be

$$(10) \qquad MAC = \frac{\partial(pf(x^*) - w_1^k x^*)/\partial k}{\partial g(x(w_1^k, p)/\partial k} = \frac{\partial\pi/\partial k}{\partial z/\partial k}$$

which means that the marginal abatement cost *MAC* for reducing nitrogen leakage by applying economic instruments is equal to the relation between marginal profits lost *($\partial\pi/\partial k$)* and the marginal amount of reduced nitrogen leakage $\partial z/\partial k$. The *MAC* of a fertilizer quota x_q can be derived by imposing a restriction $x \leq x_q$ on both functions. In the case of a product tax, (8), (9) and (10) can simply be written as functions of $x(p^k_1,w)$ instead of $x(p,w^k_1)$.

The *MAC* in (10) takes the firms' profits as the criteria for measuring the cost efficiency of reduced nitrogen leakages. Obviously, it is different from a social efficiency measurement.

4.2. The form of the nitrogen response function

Since the form of the nitrogen response function will affect the empirical estimates of the *MAC* stipulated by (10), different forms of the nitrogen response will lead to different *MAC*s. Crucial for the analysis is the *form* of the nitrogen response curve. In the estimation the main emphasis has been laid on the estimation of the right form of this curve, and less emphasis has been given to the estimation of right absolute profit maximizing nitrogen application doses.

The results from the estimation of the nitrogen response curves is briefly summarized here (a more detailed analysis can be found in Sumelius 1993).

Table 4. Alternative functional forms of the nitrogen response curves and corresponding profit maximizing nitrogen application doses (FOC).

Functional form		*FOC*
Quadratic[1)]	$y = \beta_1 + \beta_2 x + \beta_3 x^2 + \delta_i D_i + \delta_t D_t$	$x^* = \dfrac{\frac{w}{p} - \beta_2}{2\beta_3}$
Square root	$y = \beta_1 + \beta_2 x^{1/2} + \beta_3 x + \delta_i D_i + \delta_t D_t$	$x^* = \left[\dfrac{\frac{w}{p} - \beta_3}{\frac{1}{2\beta_2}}\right]^{-2}$
Mitscherlich[2)]	$y = m(1 - ke^{-\beta x})e^{\delta_i D_i} e^{\delta_t D_t}$	$x^* = \dfrac{\ln\left(\frac{pmk\beta}{w}\right)}{\beta}$

1) D_i = annual dummies
D_t = technology dummy
β_1, β_2, β_3, δ_i, δ_t = parameters
x = nitrogen fertilization

2) m = asymptotic plateau
k = a parameter

The estimation is based on experimental data on barley and wheat production from the Agricultural Research Centre in Finland in 1969-1980 (Esala and Larpes 1984). In the estimation the following three specifications of the nitrogen response were compared: a quadratic polynomial form, a square root polynomial form, and a Mitscherlich's specification (also known as a Spillman function). All these functional forms exhibit decreasing returns to scale $f(tx) \leq tf(x),\ t \geq 1$. Annual dummies and a technology dummy were included. The functional forms and their First Order Conditions for the three functional forms are presented in Table 4.

4.3. Derivation of net output supply functions

From the viewpoint of production it may be of interest to see how the applications of economic instruments will affect output supply. Fertilizer fees, producer price decreases, and fertilizer quotas are likely to affect the output supply negatively, and therefore decrease overproduction. This leads to reduction in the costs for overproduction. A decrease in output supply could, if it is substantial, decrease the need to fallow land, as is currently done in Finland.

Table 5. Net supply functions (yield level for alternative functional forms of the nitrogen response curve).

Quadratic	$y' = \beta_1 + \beta_2 x^* - \beta_3 (x^*)^2 + \delta_i D_i + \delta_t D_t$
or	$y' = \beta_1 + \beta_2 \left(\dfrac{\frac{w}{p} - \beta_2}{2\beta_3} \right) + \beta_3 \left(\dfrac{\frac{w}{p} - \beta_2}{2\beta_3} \right)^2 + \delta_i D_i + \delta_t D_t$
Square root	$y' = \beta_1 + \beta_2 x^{1/2*} + \beta_3 x^* + \delta_i D_i + \delta_t D_t$
or	$y' = \beta_1 + \beta_2 \left[\left(\frac{w}{p} - \beta_3 \right) 2\beta_2 \right]^{-1} + \beta_3 \left[\left(\frac{w}{p} - \beta_3 \right) 2\beta_2 \right]^{-2} + \delta_i D_i + \delta_t D_t$
Mitscherlich	$y' = m(1 - ke^{-\beta x^*}) e^{\delta_i D_i} e^{\delta_t D_t}$
or	$y' = m(1 - ke^{-\beta[\ln\left(\frac{pmk\beta}{w}\right)/\beta]}) e^{\delta_i D_i} e^{\delta_t D_t}$

The effect of changes in the product price or input price on output can be estimated by means of duality theory. Through the envelope theorem (Hotelling's lemma) it is possible to derive the output supply function from the short-term profit function.

If the demand elasticity is also known, this offers a possibility to calculate the changes in the economic surplus of the society, caused by the different economic incentives. This would offer an additional piece of information in order to compare the advantages of the different instruments. No effort to estimate changes in the economic surplus was made, however, since no good estimates of demand elasticities were readily available.

Let the production function (1) be written as

$$(11) \qquad y = f(x, V)$$

where y = physical output of grain, kg/ha
x = N fertilizers
V = a vector of other inputs

Suppose the vector *V* is a constant, and the production function can be represented by any specification of the nitrogen response curve and the corresponding profit maximizing nitrogen application dose x^* in Table 4.

By substituting the profit maximizing fertilizer demand x^* into the production function $y = f(x^*, V)$ we obtain the net supply function for y' according to Table 5.

By altering the nitrogen price w and the product price p, the output supply functions can be estimated for nitrogen fertilizer taxes or lower product prices.

As a conclusion it can be summarized that, by using the dual approach, it has been possible to derive the net supply function (yield level). The conditions for the analysis being correct are that the form of the production function is correct, and that net output prices p^* are held fixed at the optimal choice.

By means of the dual approach it is equally possible to derive the cost minimizing *cost function* $c(w,y)$ and the *conditional factor demand* for fertilizers. In this context no attempt to estimate them was made. It is useful to keep this in mind, since the analysis of effects of economic instruments could easily be broadened by using the envelope theorem.

5. Model applications

5.1. General outline

On the basis of the theoretical model specified in chapter 4, some estimation results will be presented in this chapter. The analysis is organized as follows: first, some results from the response analysis of wheat and barley to nitrogen are briefly reported in section 5.2. Optimal nitrogen fertilization levels according to (7), and corresponding yield levels estimated according to (11) by the three different specifications of the production function are presented.

The arguments for the specification chosen are briefly summarized, and some remarks on the accuracy of the form of the production function chosen are made. In section 5.3. results from Finnish experiments on leakages from arable farming are surveyed and applied to a Danish leakage function (SIMMELSGAARD 1991). The marginal abatement costs, *MAC,* for reducing N-leakages for various economic instruments according to (11) are reported.

5.2. Results from crop response analysis

The theoretical model in chapter 4 was formulated under the assumptions of concavity and differentiability concerning the production function. It was also assumed to be known by the farmer with full certainty. Since the influence of the crop production function on farm income is critically dependent on the form of the function, this restriction has to be motivated. The specifications compared were presented in Table 4.

The estimates for the three functional forms are presented in Tables 14 and 15, appendices 1 and 2. The parameter estimates which determine the yield level (and nitrogen application doses) were significant at $\alpha = 0.005$ for all three functional forms for both barley and wheat.

The estimate of the error term $\hat{\alpha}^2$ was substantially smaller and R^2adj was higher for the Mitscherlich function. In order to determine which of the three specifications is the most appropriate model, they were tested against each other, using a nonnested hypothesis test. A simple way to test two nonnested alternative, possibly nonlinear models, $f(x)$ and $g(x)$, is the following J-test proposed by DAVIDSON and MACKINNON (1981), where a compound model of $f(x,\delta)$ and $g(x,\phi)$ is tested:

$$(12) \qquad \begin{aligned} & y = (1-\alpha)\ f(x,\delta) + \alpha\hat{g}(x,\phi) \\ & H_0 : \alpha = 0 \end{aligned}$$

$\hat{g}(x,\phi)$ is simply the estimate of $g(x,\phi)$. $\hat{g}(x,\phi)$ is, in other words, the fitted value of the function $g(x,\phi)$ estimated by OLS for the polynomial functions and by MLE for the Mitscherlich function. In the testing procedure y is regressed on $(1-\alpha)f(x,\delta)$ and $\alpha\hat{g}(x,\phi)$. If H_0: $\alpha = 0$ is rejected by a conventional asymptotic t-test (i.e. the J-test statistic α is significant), this implies that $f(x)$ is rejected over $g(x)$. If H_0: $\alpha = 0$ is not rejected (i.e. α is insignificant), $f(x)$ is not rejected. The order of both functions should be reversed. It is possible for both functions to reject each other.

Therefore, all three rival models, quadratic, square root, and Mitscherlich are tested against each other, which implies six different tests for each crop and soil, 24 tests altogether. A description of the J-test can be found in econometrics textbooks, e.g. KMENTA (1986) or GREENE (1993).

The J-tests were carried out by the SHAZAM computer program, version 7.0. The results from the J-test are presented in Table 6.

Based on the J-test, the performance of the Mitscherlich functional form seems to be preferred in the barley response analysis, followed by the square root and, in the last place, by the quadratic form. The analysis of spring wheat response is not as clear. The Mitscherlich functional form is rejected for wheat on fine sand clay (at

Table 6. Results from nonnested hypothesis testing based on a J-test, J-test statistic.

	Wheat		
	Null hypothesis		
	Quadratic	Squareroot	Mitscherlich
Alternative hypothesis			
Quadratic		2.193*	0.774
Square-root	2.813***		-1.103
Mitscherlich	0.084	-1.109	
	Barley		
	Null hypothesis		
	Quadratic	Squareroot	Mitscherlich
Alternative hypothesis			
Quadratic		11.315***	0.302
Square-root	16.208***		-0.250
Mitscherlich	-1.892*	-1.915*	

[1] ***: Null hypothesis rejected at 0.5 % level ($t_{.005} = 2.58$)
** : Null hypothesis rejected at 1 % level ($t_{.01} = 2.33$)
* : Null hypothesis rejected at 5 % level ($t_{.05} = 1.65$)

a 5% and a 1% risk level). Remarkable is that the Mitscherlich functional form does not reject either of the polynomial forms for wheat.

If both crops are considered, the quadratic form is rejected in six out of eight cases. The square root form is also rejected in six out of eight cases. The Mitscherlich functional form is only rejected in two out of eight cases. It must be added that the polynomial forms both reject each other in all cases. The Mitscherlich form, however, rejects the quadratic and the square root forms in all barley cases. The Mitscherlich form is not rejected in any case for the barley response.

Consequently, the hypothesis of the Mitscherlich functional form being superior to the quadratic functional form seems to be confirmed in the barley crop response by the nonnested hypothesis testing. However, the results from the spring wheat nitrogen response do not lead to the same conclusion. The nonnested hypothesis testing does not establish the Mitscherlich functional form as superior to the polynomial form on the basis of the spring wheat analysis, since the Mitscherlich function was not able to reject the polynomial forms. The square root form is, on the other hand, rejected by the quadratic form, and vice versa. A more detailed account of the response analysis is found in Sumelius (1993b).

The optimal fertilizer level for profit maximization stipulated by the first order conditions of profit maximization (7) and the corresponding yield level according to (11) for all three functional forms are presented in Table 7.

It is evident from Table 7 that the estimated profit maximizing nitrogen application doses vary between 154.7 kg N/ha and 217.2 kg N/ha for wheat, and between 161.9 kg N/ha and 352 kg N/ha for barley, depending on the specification of the production function. The application doses presented in Table 7 are rather high compared to the levels recommended by crop scientists for grain production in southern Finland. (120-150 kg N/ha). The yield level of wheat varies between 3,497 kg/ha and 3,716 kg/ha. The yield level of barley varies between 4,572 kg/ha and 5,129 kg/ha depending on the specification. The experimental data is from 1969-1980.

Table 7. Profit maximizing N-fertilization doses, kg N/ha and the corresponding yield level, kg/ha on loam clay.

	Wheat N-fertil. doses	Yield level	Barley N-fertil. doses	Yield level
Mitscherlich:	154.6	3,497	210.0	4,572
Quadratic:	148.2	3,671	161.9	4,559
Square root:	217.0	3,716	352.0	5,129

5.3. Economic effects of applying economic instruments

In the analysis, four different measures based on economic incentives were compared:

1. 100 % increase in the price of N (which already included a N-fertilizer tax of approximately 6%) or a 112 % N-tax.
2. Output tax of 50 % (halving the producer prices by 50 %).
3. Combination of both 100 % increase in the price of N and a 50 % reduction of producer prices.
4. Maximum N-fertilizer application quota of 50 kg N/ha.

Increasing the N-fertilizer price by 100 % or decreasing the producer price by 50 % resulted in the same optimal N doses, since the profit function is linearly homogenous: $\pi(tp, tw) = t\pi(t, w), t > 0$. The reductions in profit maximizing nitrogen application doses as a result of the three first economic instruments are presented in Table 8. The fourth policy alternative is a given nitrogen application dose equal to 50 kg N/ha. All three specifications of the production function are presented.

According to the Mitscherlich form of the production function, a 100 % nitrogen fertilizer price increase or a 50 % reduction of producer prices will lower optimal fertilizer application doses 38.4-45.1 kg N/ha or 21-25 %. Implementing both

Table 8. Reductions in optimal N-fertilizer level as a result of 100 % increased input prices, 50 % decreased producer prices, or both a 100 % input price increase and a 50 % producer price decrease.

	Initial situation Optimal N-appl. kg N/ha	w increase or p decrease Optimal N-appl. kg N/ha	Reduction kg N/ha	%	Both w increase and p decrease Optimal N-appl. kg N/ha	Reduction kg N/ha	%
Barley							
Mitscherlich	210.0	165.1	-45.1	-21	120.0	-90.1	-43
Quadratic	161.9	151.5	-10.3	-6	130.1	-31.0	-19
Square root	352.0	227.9	-124.7	-35	117.6	-235.0	-67
Wheat							
Mitscherlich	154.7	116.3	-38.4	-25	77.9	-76.7	-50
Quadratic	148.2	133.8	-14.4	-10	105.0	-43.2	-29
Square root	217.2	132.6	-84.6	-39	64.13	-152.9	-70

measures will lower nitrogen application doses by 76.7-90.1 kg N/ha or 43-50 %. If one assumes a quadratic form of the production function, a 100 % nitrogen fertilizer price increase or a 50 % producer price decrease will lower optimal nitrogen application by 10.3-14.4 kg or 6-10 %. The reductions are both relatively and absolutely much higher for the square root form. It is easy to see that, if a (less appropriate) quadratic functional form is chosen instead of the Mitscherlich specification, the reduction in profit maximizing N-fertilization levels is underestimated.

On the other hand, if a square root functional specification is chosen, the reduction in profit maximizing N-fertilization seems overestimated, as compared to the Mitscherlich specification.

If a Mitscherlich specification is assumed, the yield level is reduced 121.9 kg/ha

Table 9. Initial profits (net revenue/ha) in barley production and reductions in profits and yield level as a result of applying economic instruments 1-4.

	Optimal kg nitrogen/ha	Profit FIM/ha	Reduction FIM/ha	Yield kg/ha	Reduction kg/ha
Optional policies					
Barley:					
1. Current policy. Full producer prices, initial fertilizer prices (N-tax 6%)	210.2	9,140		4,572	
2. Full producer prices, fertilizer prices doubled (N-tax 112%)	165.1	8,234	-906	4,429	-142
3. Halved producer prices, initial fertilizer prices (N-tax 6%)	165.1	4,117	-5,023	4,429	-142
4. Halved producer prices, fertilizer prices doubled (N-tax 112%)	120.0	3,431	-5,709	4,142	-430
5. Fertilizer quota of max. 50 kg N/ha	50.0	6,501	-2,639	3,032	-1,540

(3.5 %) for wheat and 143.2 kg/ha (3.1 %) for barley by either doubling fertilizer prices or halving producer prices. If both measures are implemented, yield will decrease by 365 kg/ha (10.5 %) for wheat and 430 kg/ha (9.4 %) for barley. A fertilizer quota will reduce yields the most, 686 kg/ha (19.6 %) for wheat and 1539 kg/ha (33.7 %) for barley.

In the econometrical analysis, the Mitscherlich form of the production function produced statistically the most appropriate estimates by a J-test for barley, as was noted in the preceding section. Therefore, this specification of the production function is probably the most appropriate for analyzing the effects of applying economic instruments. Since no functional form could be established as superior for the wheat response analysis, it will be dropped.

When the four economic instruments are applied to the profit maximization model, profits for barley are reduced. The initial profits (net revenue/ha) as well as the profit reductions after the optional polices have been applied are presented in Table 9. The results in Table 9 are conditional upon the Mitscherlich form of the production function.

An increase of the fertilizer prices by 100 % will lower profits by approximately FIM 906/ha (9.9 %). A 50 % decrease of producer prices will be much more costly for the farmer; it will lower profits by approximately FIM 5,023/ha or 54.9 %. Both measures will decrease optimal nitrogen application by around 45 kg N/ha. Applying both a 100 % tax on nitrogen and a 50 % price reduction at the same time will reduce profits by FIM 5,709/ha or 62.5 %, and the optimal application doses by approximately 90 kg N/ha. A fertilizer quota of 50 kg N/ha only reduces profits by FIM 2,639/ha (28.9 %) while nitrogen application doses are reduced by approximately 160 kg N/ha.

Therefore it can be concluded that a nitrogen fertilizer tax will lower the profit maximizing nitrogen application doses with much smaller effects on the net revenues of the farmer than a product price decrease. This result holds not only for the Mitscherlich function but for all functional forms which are homogenous of degree one, such as the quadratic and the square root form. Yield level is affected only to a small degree, except in the case of fertilizer quotas, for which the effect seems to be substantial. Since the farmer can substitute for nitrogen by cultivating more legumes, or by using more animal manure, the effects on yield level may be much smaller in practice.

5.4. Nitrogen leakages

5.4.1. Marginal abatement costs of reduced nitrogen leakages

In the preceding section some effects of economic instruments on farmers' net revenue were estimated. This is, however, not enough to establish the cost efficiency for reduced leakages of nitrogen (N). In this and the following section such an estimate, based on equation (10) will be estimated. It should be kept in mind that that the *MAC* in (10) was formulated as the marginal cost of reduced N-leakages in terms of profit loss for the farmer due to the application of financial incentives (i.e. economic instruments).

$$(10) \qquad MAC = \frac{\partial(pf(x^*) - w_1^k x^*) / \partial k}{\partial g(x(w_1^k, p) / \partial k} = \frac{\partial \pi / \partial k}{\partial z / \partial k}$$

In (10) the numerator is the derivative of the profit function with regard to the financial incentive, whereas the denominator is the derivative of the N-effluent production function with regard to the financial incentive. The measure is, therefore, a marginal efficiency measure from the firms' point of view; it measures the profit loss for one unit of reduced N-leakages. In order to estimate the *MAC*s a N-effluent production function is needed.

5.4.2. Results from leaching experiments in Finland

Estimates of N-leakages at different levels of fertilization are needed in order to compute the cost efficiency of different economic instruments, as specified by (10). The effluent production function, or more simply, the leakage function, (2) ($z = g(x_z, s, r)$) represents the last link in the chain between fertilization, yield, and leakages.

Experimental studies on leaching of N and P in Finland have been carried out by Turtola and Jaakkola (1985,1987), Myllys (1992), Vakkilainen and Paasonen-Kivekäs (1992), Yläranta et al. (1992) and by Yläranta et al. (1993). None of these studies has estimated or specified any effluent production function. In most of the

Table 10. Annual NO_3-N leakages in drainage and surface water for barley and grass at Jokioinen 1980-1982 (Turtola and Jaakkola 1985).

	N-fertilization level kg N/ha	NO_3-N leakages drainage water	surface water
Grass	100	1.5	3.1
	200	3.1	3.1
Barley	50	6.3	4.8
	100	6.3	4.8

experiments the N-leaching has been found dependent on the crop, soil type, precipitation, and fertilizer intensity. Precipitation and the soil type generally seem to account for a greater part of the variation in leakages, at least for fertilizer intensity levels of 100 kg N/ha or below. The soil type, crop and annual precipitation are more important than fertilizer intensity in explaining overall N-leaching at low N-fertilizer levels. Fertilizer intensity level becomes the dominant source of nitrogen leakages when N-intensity levels reach 400 kg N/ha (VAKKILAINEN and PAASONEN-KIVEKÄS 1992).

Results from leaching experiments at the Agricultural Research Centre in Jokioinen reported by TURTOLA and JAAKKOLA (1985) indicate that nitrate leaching does not increase much in the case of fertilizer intensities which are less than 100 kg N/ha for barley and 200 kg N/ha for grass. Experiments were conducted in 1980-1982 at two different fertilizer intensity levels. The average annual leaching amounts of N are presented in Table 10.

TURTOLA and JAAKKOLA (1987) reported results from leaching experiments with grass-grain crop rotation at the Agricultural Research Centre in Jokioinen for the period 1983-1986. The average annual leakages were 9.2 kg N/ha and 1.1 kg P/ha. The annual precipitation influenced the leaching amounts substantially. Ploughing down grass ley as well as fallowing increased the leaching. The crops examined included grass, barley, winter wheat and spring wheat. Nutrients added to the soil in the fertilizers as well as leakages in the drainage water (not including leakages in the surface water) are presented in Table 16, appendix 3. In continuous grain cultivation the annual N-leakage in drainage water varied from 2.1 kg N/ha to 9.3 kg N/ha. After fallow the leakage from grain fields was substantially higher, 16 kg N/ha.

In the study by YLÄRANTA et al. (1992) and YLÄRANTA et al. (1993), leaching of N was studied through lysimeter experiments on different soil types over a period of four years at the Agricultural Research Centre in Jokioinen. The soil types included clay, silt, sand, and peat. Crops included barley, grass ley, and fallow. N-leaching seemed to be the highest on fallowed mineral soils, especially silt. A modest degree of N-fertilization (100 kg N/ha on mineral soils, 50 kg N/ha on turf) did not seem to cause much leaching. Of the N-labelled 100 kg N/ha applied in 1983 on irrigated barley, only 0-2.3 kg N/ha had leached by the end of the experiment in 1987. While the total leaching and surface runoff is higher (in the range of 15 kg/ha according to KAUPPI 1993) the researchers conclude that "almost all of the nitrate at risk to leach over the winter period comes from mineralization of organic N, not from fertilizers used in the spring". The experiments did not include N-fertilizer levels over 100 kg N/ha. Leaching was generally the highest on sand soil. The results from this study indicate that only a minor part, in this case at the most 2.3 % of the N-fertilizers applied at the most, actually leached during the four subsequent years.

A summary of the results of these experiments would probably be that precipitation, soil and fallow are the most important factors which increase N-leakages in drainage and surface water. Crop rotation and ploughing down of grass also affect

N-leakages. The effects of fertilization seem difficult to isolate from the factors mentioned above. If fertilization increases above 100 kg N/ha, nitrogen fertilization is likely to increase N-leakages.

5.4.3. The effluent production function

Annual variation in precipitation and the soil type seem to account for a big part of the variation in N-leaching (Turtola and Jaakkola 1987, Yläranta et al. 1992, 1993). Bergström (1987) reported that rainfall clearly affected leaching of N in three- year experiments in central Sweden. Precipitation influences the N-leaching to a much higher degree than fertilizer intensity. The N-leaching experiments reported have in many cases concerned only one level of fertilization. A reliable N-leaching function explaining differences in leaching with fertilizer intensity as one explaining variable is therefore not easy to estimate on the basis of Finnish data.

However, such a leaching function has been estimated by Simmelsgaard (1991) on the basis of Danish leakage research. This leakage function is a semilog function (which Simmelsgaard calls a relative exponential function):

$$(13) \qquad \ln(y / y_n) = b_0 + bx$$

where
x = Relative N-fertilization in relation to normal fertilizer intensity for the crop, $0.5 \leq x \leq 1.5$
y = Leakage at fertilizer intensity level x
y_n = Leakage at normal fertilizer intensity
b_o = a constant
b = a parameter

The leakage function measures changes in N-leakages solely as a function of fertilization intensity level. The function is contingent upon that y_n, the leakage from "normal levels" (x = 1) of fertilizer intensity, is known. The function was found unreliable for fertilizer intensities greater than 150 % of the normal level (x = 1.5), or for intensities less than 50 % of the normal level (x = 0.5).

Equation (13) can be transformed to the following linear form:

$$(14) \qquad \ln y = b_0 + bx + \ln y_n$$

If b is given, then the effect of a marginal change in fertilizer use on N-leakages is also given. This is important to point out, since it implies that the empirical content of the function is based on the estimation of b. In this study b is taken to be 0.7, based on Danish leakage experiments. The MAC calculated on the basis of (10) is therefore a simulated expression based on applying production and leakage functions estimated earlier.

On the basis of the Danish leakage experiments, b was found to be in the interval 0.64-0.75, with an average of 0.7 (SIMMELSGAARD 1991). Values of b higher than 0.7 were found to be representative for easily leaking sandy soils, while clay soils had b-values below 0.7. The function has been estimated on the basis of Danish experiments with 14 crops on 2 different mineral soils, sand (1978-1989) and clay (1973-1986). Normal intensity in Danish barley production was considered 120 kg N/ha. Fertilizer levels in the experiments were 0, 1/2, 1 and 1/2 times the normal level of fertilization to each crop. The interpretation of this leakage function is based on the assumption of fertilizer level being the only varying factor while all other factors (precipitation, soil, temperature etc.) are fixed. During the period when the data was collected the annual precipitation varied between 55 mm and 800 mm. The model allows for correction of N-leakages when precipitation varies. This correction possibility is omitted here.

N-leakages seem to be an outcome of a complex interaction between the soil, precipitation, crops, and cultivation. The use of simple equations does not account for these complexities. Therefore, a leakage function like (13) should not be used for the calculation of leakages in a particular year or on a particular field. A function like (13) should rather be regarded as representing averages. It can be used to approximate average changes in leakages as a consequence of a change in fertilizer application over a number of years (see e.g. SKOP 1993).

As was noted in section 4.1., effluent production functions are likely to exhibit increasing returns to scale, i.e. the leakages are low at initial input levels. but increase proportionally more than the input. The effluent production function in (13) is characterized by increasing returns to scale. A production function exhibits increasing returns to scale if $f(tx) > tf(x),\ t \geq 1$ (CHAMBERS 1988). Accordingly, the function in (13)

(15) $$\ln(y+t)/y_n = \ln(y+t) - \ln(y_n)$$

or $$\ln(y+t) - \ln(y_n) > t \ln y / y_n, \quad y > 0.5$$

exhibits increasing returns to scale with respect to fertilizer intensity when $y > 0.5$, which is a realistic assumption for high fertilizer intensities.

In order to apply the formula (13) to Finnish conditions, two parameter estimates for each crop are needed:

1. Normal intensity level, N
2. N-leakage for the normal intensity level, y_n

In the Finnish experimental data N-fertilization level for barley and wheat has usually been 100 kg N/ha (also 50 kg N/ha in TURTOLA's and JAAKKOLA's study (1985)). This fertilization intensity is considered to approximate normal fertilizer intensity for grain production. The combined surface and drainage N-leakages at this level typically vary between 10-20 kg N/ha, but levels up to over 100 kg N/ha have also been recorded. YLÄRANTA et al. (1993) recently reached a conclusion in a 4-year leaching experiment: only a minor part of the N-leakage was derived from N-fertilization. If N-lekages deriving from fertilizers are as low as >3 kg N/ha a year we also need to look at low levels of N-lekages. Therefore, at the N-fertilization level of 100 kg N/ha, the N-leakage values applied to y_n are allowed to vary between 1 kg N/ha and 40 kg N/ha.

Applying these parameter values to the leakage function (13) gives the nitrogen leakages at different fertilizer intensity levels. The estimated leakages for barley production are summarized in Table 11 and Figure 4. A more detailed table is found in appendix 4, Table 17.

It can be concluded from Table 11 that if the parameter value of y_n is altered, the leached N-amount at normal fertilizer intensity affects estimates of leaching far more than altering the fertilizer intensity level. The reason for this is the great influence of weather and soil factors. As precipitation and soil are assumed constant for each value of y_n, the N-leakages increase with increasing fertilizer intensity.

From Figure 4 is easy to see that, given the form of the effluent production function, the elasticity of N-leakage is characterized by increasing returns to scale.

Assume that N-leakages are initially 5 kg N/ha at the fertilizer level of 100 kg N/ha. If fertilization intensity is decreased to 50 kg N/ha, leakages will decrease approximately 1.48 kg N/ha (to the level of 3.52 kg N/ha). If fertilizer intensity is increased to 150 kg N/ha, leakages increase by 2.1 kg N/ha. If leakages are initially

Table 11. Simulated N-leakages from barley at different levels of N-fertilization when b = 0.7, kg N/ha.

	y_n [1)]						
	1	3	5	10	20	30	40
N[2)]							
50	0.70	2.11	3.52	7.04	14.09	21.14	28.19
70	0.81	2.43	4.05	8.10	16.21	24.30	32.42
100	1.00	3.00	5.00	10.00	20.00	30.00	40.00
130	1.23	3.70	6.16	12.34	24.67	37.01	49.35
150	1.42	4.26	7.10	14.19	28.38	42.57	56.76

[1)] y_n = Leakage at normal fertilizer intensity level
[2)] N = Relative nitrogen fertilization in relation to normal fertilizer intensity for the crop

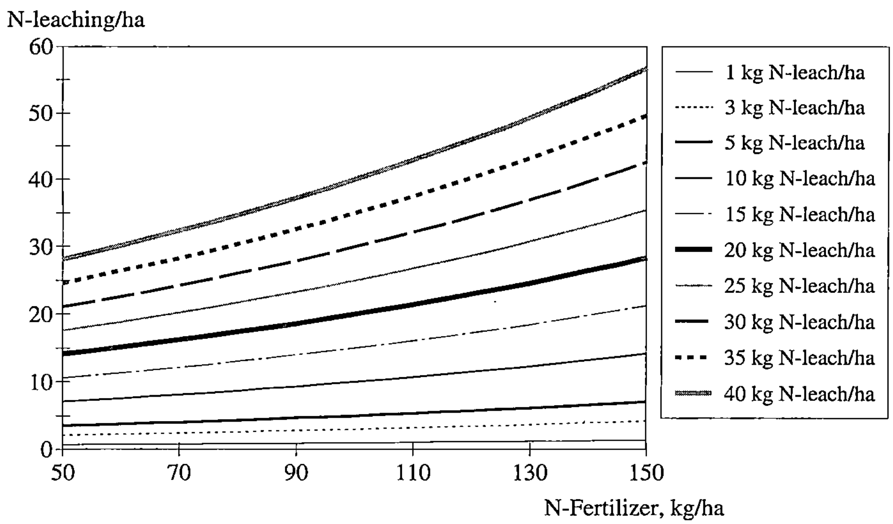

Figure 4. Approximated N-leakages at different fertilizer intensity levels according to (13).

high, for example 30 kg N/ha at the fertilizer level of 100 kg N/ha, decreasing fertilizer intensity to 50 kg N/ha will decrease leakages by 8.86 kg N/ha (to the level of 21.14 kg N/ha). If leakages, on the other hand, are initially around 1 kg N/ha at the fertilizer level of 100 kg N/ha, decreasing fertilizer intensity to 50 kg N/ha will only decrease leakages by 0.3 kg N/ha.

The results mentioned above are based on the assumption that the estimated parameter value $b = 0.7$ is correct. Altering the b-value from 0.7 to 0.75 or 0.64 (the spread of b estimated by Simmelsgaard) had only small effect on the estimated leakages. For instance, at y_n = 10 and a fertilization intensity of 50 kg N/ha of changed the leakages by only -2.5 % to 3.0 % (from 7.04 kg N/ha to 6.87 kg N/ha or to 7.26 kg N/ha)

It can be concluded that, given the semilog form of effluent production function, the soil type and the slope of the field are likely to play a major role in determining the N-leakages from agriculture. If these parameters are taken as given, changing the fertilizer intensity between 0.5 and 1.5 of the normal intensity level will cause the N-leakages to vary between 70 % and 140 % of the initial level. This is a significant reduction in leakage. But next we have to answer the question at what cost such a leakage reduction can be accomplished.

5.5. Marginal abatement cost of economic instruments in abating nitrogen leakages

The *MAC* calculated should be seen as approximated leakage values assuming a particular functional form of the leakage and production function. Therefore the estimates of the *MAC* reported in the following should explicitly be considered simulations rather than empirical estimates.

In Table 12 the *MAC* in the case of barley for the four optional economic instruments is presented, assuming that the Mitscherlich specification is appropriate. In the case of barley this specification proved to be superior to both other specifications. The simulated values in Table 12 are presented in Figure 5.

The column to the far left in Table 12 represents the initial N-leakage y_n at the fertilizer level of 100 kg N/ha. In the four following columns to the right the *MAC*s

Table 12. Simulated loss of profit per kg of abated N-leakage by optional economic instruments in barley production, FIM/kg N. USD 1 = FIM 5.8. y_n = leakage at fertilizer level 100 kg N/ha.

	Profit loss under optional policies			
	1. Profit reduction/ abated kg N	2. Profit reduction/ abated kg N	3. Profit reduction/ abated kg N	4. Profit reduction/ abated kg N
y_n=1	1,550.1	8,587.4	5,641.1	1,810.7
y_n=3	516.7	2,862.5	1,880.4	603.6
y_n=5	310.0	1,717.5	1,128.2	362.1
y_n=10	155.0	858.7	564.1	181.1
y_n=15	103.3	572.5	376.1	120.7
y_n=20	77.5	429.4	282.1	90.5
y_n=25	62.0	343.5	225.7	72.4
y_n=30	51.2	286.3	188.1	60.4
y_n=35	44.3	245.4	161.2	51.7
y_n=40	38.8	214.7	141.1	45.3

[1] 1. a 100 % increase in the price of N (which already included a N-fertilizer tax of approximately 6 %).
2. a decrease in producer prices of grain by 50 %.
3. a combination of both a 100 % increase in the price of N and a 50 % reduction of producer prices.
4. a maximum fertilizer application quota of 50 kg N/ha.

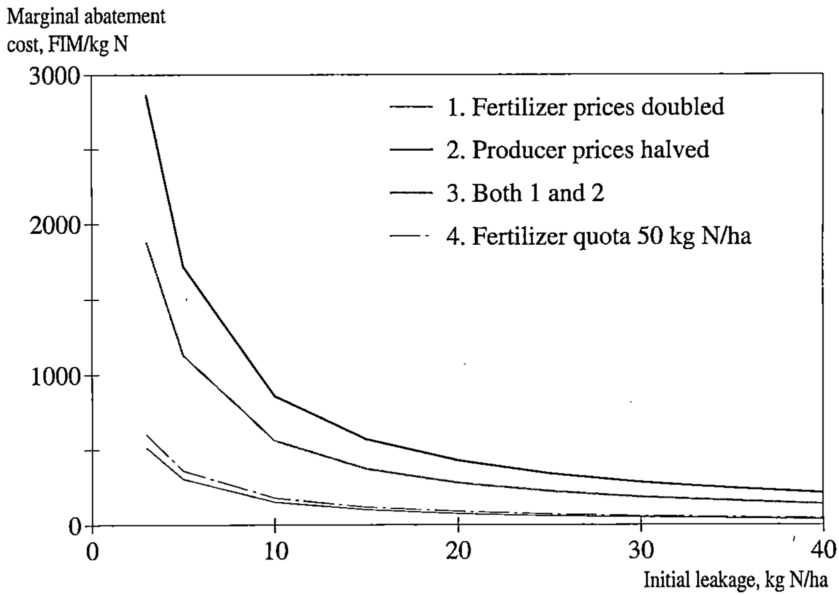

Figure 5. MAC of abating 1 kg N-leakage by a Mitscherlich specification.

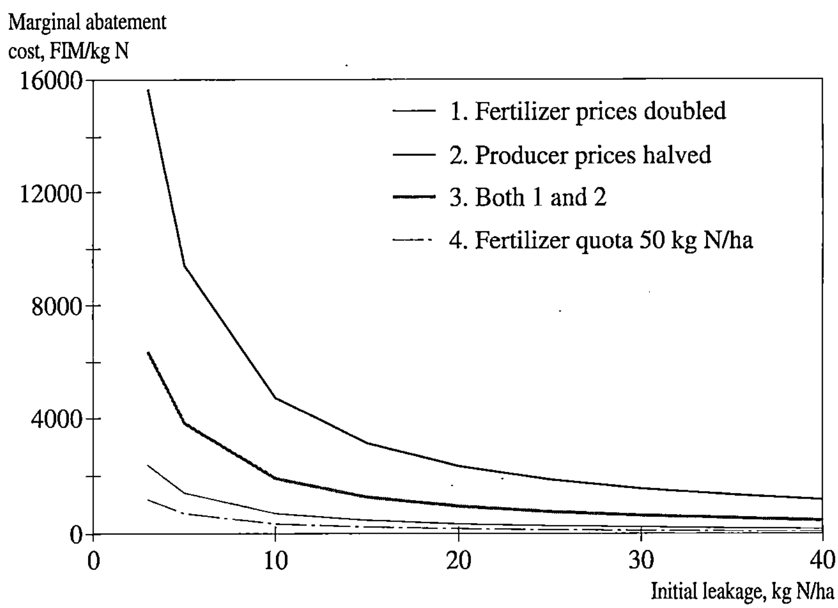

Figure 6. MAC of abating 1 kg N-leakage by a quadratic specification.

for the four different instruments are presented. The following conclusions can be made:

1. The *MAC*s depends most of all on the initial leakage, which is determined by physical and biological factors. At a low initial N-leakage level the *MAC* is high. If the initial leakage is e.g. 3 kg N/ha, the abatement of one kg N will cost 13 times more (FIM 517-2,863 or USD 89-494, if USD 1 = FIM 5.8) than on the initial leakage level, 40 kg N/ha, where the *MAC* is only FIM 39-215/kg N (USD 7-37/kg N).

2. Of the four instruments, the N-fertilizer tax system shows the lowest *MAC,* and the N-quota system the second lowest *MAC.* Decreasing leakages through decreased producer prices is the least cost efficient way to decrease N-leakages from the farmers point of view. To exemplify: assume initial leakages are 20 kg N/ha, which is close to the estimated average leakages from Finnish soils. The *MAC* for 112 % N-taxes are approximately FIM 78/kg N (USD 13/kg N), for N-quotas FIM 90/kg N (USD 16/kg N), for a combination of N-taxes and product taxes FIM 282/kg N (USD 49/kg N) and for 50 % product taxes FIM 429/kg (USD 74/kg N).

3. Yields are reduced the most by N-quotas, which reduced yields by 33.6-37.1 %, depending on the specification. If only 112 % N-taxes or 50 % product price taxes are applied, yields are reduced by 0.75 % and 7.7 %. Applying both 112 % N-taxes and 50 % producer price taxes decrease the yields between 3.75 % and 21.2 %.

How does the *MAC* change if one assumes a quadratic or square root specification of the N-response? Basically, the form of the *MAC* is the same. The absolute level of the *MAC* is, however, different.

In Figure 6 the estimates of the *MAC* are presented, assuming a quadratic form of the production function. It can be seen that the form of the *MAC*-curve is almost identical. The absolute levels of the *MAC* for all four instruments are substantially higher.

In Figure 7 the *MAC*s of one particular economic instrument, doubling the N-price (a 112 % N-tax) for all three specifications are presented. In Figure 8 the same is illustrated for 50 % producer price taxes.

Based on the J-test, it was shown that the Mitscherlich form of the nitrogen response is the most appropriate specification.

The quadratic specification produced estimates determining optimal yield level which were all significant on $\alpha=0.005$.

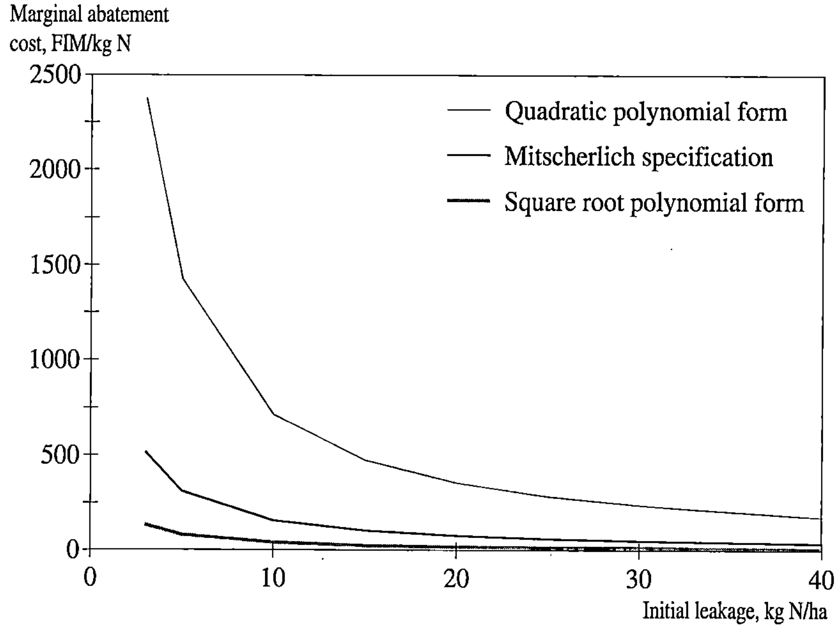

Figure 7. MAC of doubling fertilizer prices (112 % N-taxes) by different specifications of the production function for barley.

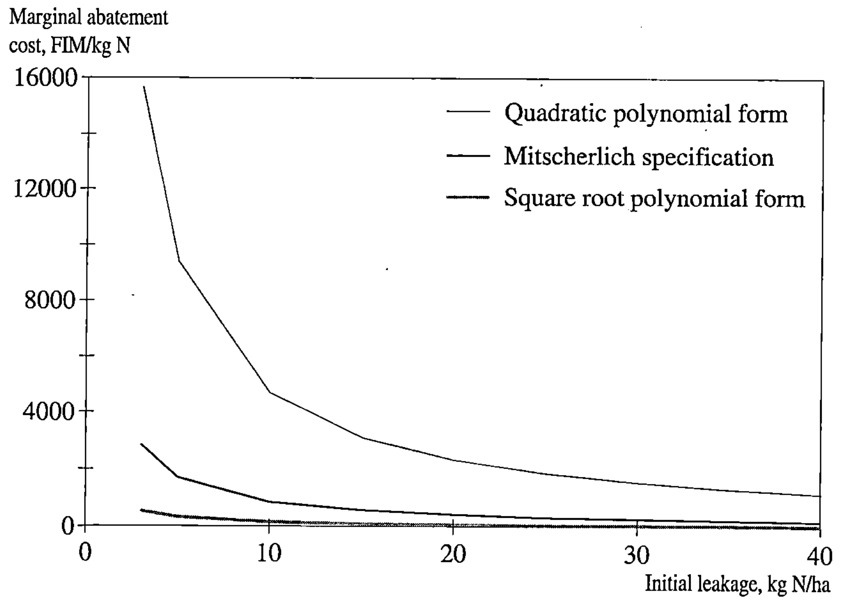

Figure 8. MAC of a 50 % product price tax by specifications of the production function for barley.

Table 13. Cost of the wrong specification if Mitscherlich specification is right, overestimation of profit loss FIM/abated kg N-leakage.

	Optional economic instruments			
	1.	2.	3.	4.
Quadratic specification:				
y_n=1	5,581.4	38,188.5	13,462.1	1,730.8
y_n=3	1,860.5	12,796.2	4,487.4	576.9
y_n=5	1,116.3	7,677.7	2,692.4	346.2
y_n=10	558.1	3,838.9	1,346.2	173.1
y_n=20	279.1	1,919.4	673.1	86.5
y_n=30	186.1	1,279.6	448.7	57.7
y_n=40	139.5	959.7	336.6	43.3
Square root specification:				
y_n=1	-1,143.1	-6,965.3	-4,301.1	-1,276.7
y_n=3	-381.0	-2,321.8	-1,433.7	-425.6
y_n=5	-228.6	-1,393.1	-860.2	-255.3
y_n=10	-114.3	-696.5	-430.1	-127.7
y_n=20	-57.2	-348.3	-215.1	-63.8
y_n=30	-38.1	-232.2	-143.4	-42.6
y_n=40	-28.6	-174.1	-107.5	-31.9

It is therefore interesting to note that the *MAC* estimated by the quadratic function is substantially higher. In Table 13 the cost of the wrong specification is presented.

Table 13 shows clearly that the cost of assuming a quadratic functional form is quite high. If one assumes a square root functional form, the *MAC* will, however, be underestimated. This is also illustrated in Figure 9 and Figure 10.

The same analysis and the same type of results were also obtained for the wheat time series, the only difference being that no functional form could be established superior by nonnested hypothesis testing.

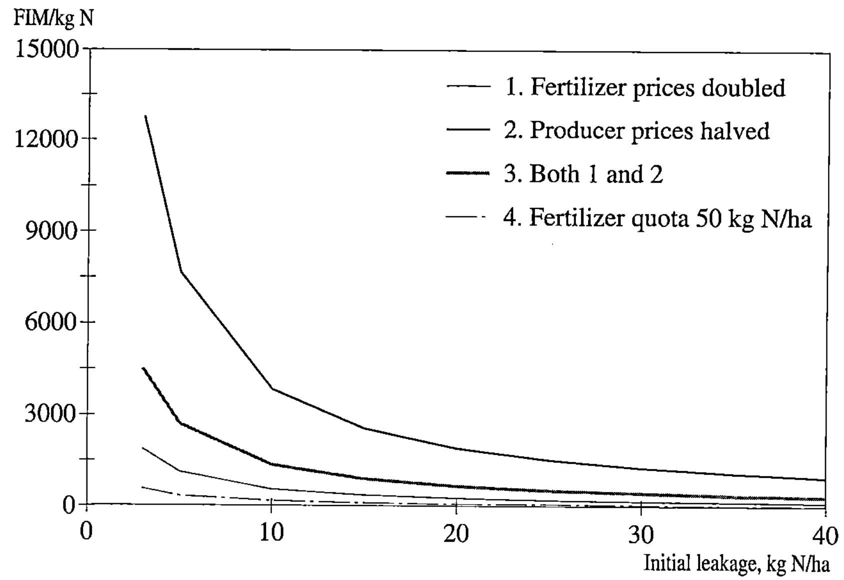

Figure 9. Cost of wrong specification for the quadratic function.

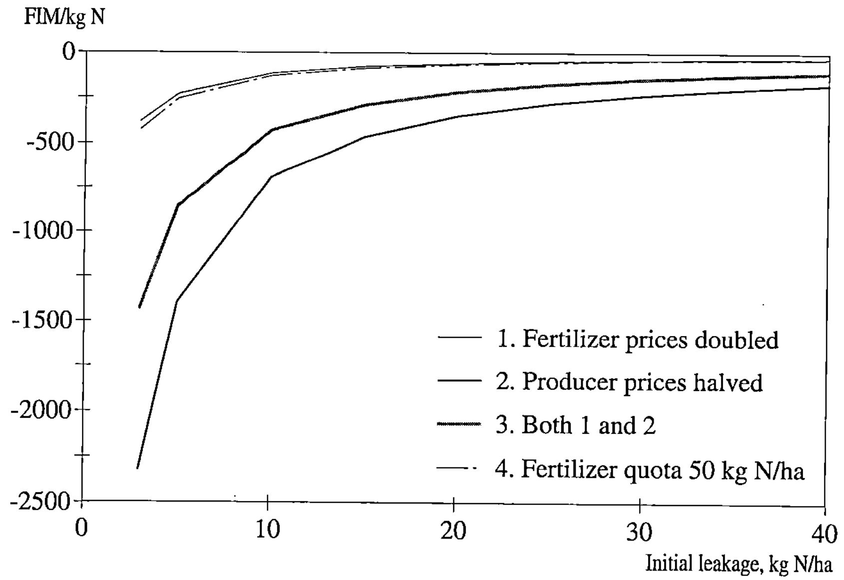

Figure 10. Cost of wrong specification for the square root function.

6. Summary and conclusions

As a consequence of the intensification of farming, the regional specialization in certain crops, and the change in practices related to farming, agriculture has become the major source of nonpoint source pollution in Finland. Reversing this trend necessitates a deliberate agri-environmental policy. Such a policy could imply intensified use of voluntary measures to abate leakages, use of economic instruments (financial incentives), or a large-scale effort to change agricultural practices according to the code of good agricultural practices (best management practices). Economic instruments, which have been analyzed in this study, include standards, such as fertilizer quotas, environmental taxes and fees, environmental subsidies, product taxes, tradable permits, or a policy mix of several instruments.

The *cost efficiency* of different measures and instruments to reduce the nutrient loads should be a central criterion in deciding upon policy issues. In order to reduce N-leakages, knowledge on the effects of various policy alternatives and their farm level cost implications is needed. Standards, like N-fertilizer quotas, imply an excessive amount of information to be collected. Monitoring costs would also be high. From the viewpoint of a single firm, a fertilizer quota standard need not be less effective than the other economic instruments, but for the whole society they are not likely to be very efficient. The environmental taxes are effective when they can be directed toward the externality, which means that the decision makers need perfect information. N-fertilizer taxes do not fulfill this requirement, since taxes are not based on the N-load, not even on N-leakages. An advantage of N-taxes is that they do not need to be monitored. Since N-leakages and N-loads vary according to biological and physiological factors, the lack of information on the firm level makes N-taxes less attractive. The incentives to change technology provided by the N-taxes is an advantage. Product price taxes do not need to be monitored. Environmental subsidies imply paying support for the use of abating inputs, such as buffer strips, or for the use of less polluting technology. The optimal level of subsidy is, however, impossible to establish on an a priori basis. Tradable permits have not been designed for nonpoint sources pollution because of the measurement difficulties. A policy mix of the different instruments is possible, but needs to be designed carefully, since the effects of different actions may be counteracting. Evidently the superiority of different instruments need to be evaluated from case to case.

In the study four optimal economic instruments for reducing agricultural nonpoint pollution of nitrogen were studied:

1. N-fertilizer price increase of 100 % (equivalent to a 112 % N-tax).
2. Output tax of 50 % (i.e. a producer price decrease of 50 %).
3. Both a fertilizer price increase of 100 % and a producer price decrease of 50 %.
4. N-fertilizer quota of 50 kg N/ha.

The conclusions are:

1. The *MAC* itself is primarily dependent on other than economic factors (such as soil characteristics, slope and precipitation). Since the *MAC* is the lowest on high initial leakage levels irrespective of the functional form or instrument the most cost efficient measures are likely to be measures or instruments designed to reduce leakages from highly leaching land. If the initial leakage level is 40 kg N/ha, 13 times more N-leakages can be abated, as compared with an initial leakage level of only 3 kg N/ha for the same cost (profit loss) to the farmer. A natural recommendation is therefore to develop economic instruments or measures which are directed toward reducing leakages on high initial leakage levels. Such measures are likely to be site-specific, crop-specific, and fertilizer intensity specific. Of the instruments investigated, only the quota system fulfills this requirement. Taxation of growth regulators might be an option. Agricultural practices directed towards abating N-leakages are likely to fulfill this requirement.

2. When biological-physical factors were taken as given and the *MAC* for the four instruments was simulated, assuming a Mitscherlich specification of the nitrogen response curve, the N-fertilizer taxes of 112 % proved to be the most cost efficient, i.e. had the lowest *MAC*. N-quotas of 50 kg N/ha had almost as low *MAC* as N-taxes (no monitoring or administrative costs were taken into account). Since the monitoring costs are likely to be high in a N-quota system, nitrogen fertilizer taxes seem more appealing than a quota system. The third most efficient instrument proved to be a combination of nitrogen and product taxes. Product taxes had the highest *MAC*. The specification of N-response altered the relative order of the *MAC* of the different economic instruments only to a minor degree(i.e. quotas were somewhat superior to N-taxes - had slightly lower *MAC*s - if a quadratic specification was assumed, instead of the Mitscherlich specification). The order of the economic instruments with regard to *MAC* is in other respects the same for the three different specifications for the nitrogen response and for both barley and wheat, which shows that the order of the cost-efficiency of the different instruments is quite stabile with regard to specification. At the initial leakage level of 15 kg N/ha, which might be near the average N-leakage level in Finnish agriculture, the *MAC*s for 100 % N-fertilizer price increases were FIM 103/abated kg N, for N-quotas FIM 121/abated kg N, for a combination of 100 % N-fertilizer increases and 50 % producer price taxes FIM 376/abated kg N, and for only 50 % producer price taxes FIM 573/abated kg N. N-fertilizer price increases of 100 % (corresponding to 112 % N-taxes) were the most cost efficient of the four options investigated here. This conclusion is, however, subject to the constraint that profit maximizing N-fertilization application doses estimated here were far higher than those used by farmers in practice.

3. It must be concluded that the cost of wrong specification of the nitrogen response curve may be substantial. A quadratic form of the nitrogen response curves produced several times higher *MAC*-estimates than if the theoretically (and here statistically) more correct Mitscherlich specification (also called a Spillman function) was used. A square root specification of the nitrogen response, on the other hand, underestimated the *MAC*. A careful specification is therefore obviously a precondition for correct estimates of the *MAC*.

4. Fertilizer price increases or product price decreases do not seem to affect the yield level very much. Enforcing a fertilizer quota of 50 kg N/ha would lower barley and wheat yields the most, i.e. approximately between 19 % and 34 %. Increasing N-fertilizer price by 100 % or reducing producer prices by 50 % only decreases wheat and barley yields between 3.1 % and 3.5 %. Applying both measures would result in between 9.4 % and 10.5 % lower yields. Possibilities to substitute N through manure or legumes has not been taken into account.

5. As such, the reduction of nitrogen leakages by 50 % from the level of 1985 by the year 1994 stipulated by the plan made by the Nordic Council of Ministers (NORDISK HANDLINGSPLAN 1990) is only possible with instruments 3 or 4. The profit losses to farmers of instrument 3 are, however, very high (62.5 %). In the case of a quota system the profit loss is lower (28.8 %), but administration costs have not been taken into account. If the quotas are fixed, like has been assumed here, the administration costs are likely to be high. The current N-fertilizer tax is probably the best alternative of the instruments analyzed. It should, however, be noted that no effort to estimate the cost-effeciency of various changes in agricultural practices (best management practices) was made here. Taking into account the conclusions in point 1, changes in those agricultural practices may well be more important than any of the economic instruments discussed in this study.

A few words of caution are also in place. The analysis has only dealt with the input-output effects within a production line, grain production. If price relations between inputs and output change, the mix of products is also likely to change. This means that different prices of products and nitrogen is likely to affect the relative cultivated areas of grain, oil seeds, grass ley, legumes and root crops. A change in relative cropping areas may have a bigger effect on leakages than the change in fertilizer intensity within grain production.

7. Future research

1. It was found out in this study that the marginal abatement costs, *MACs*, for reducing N-leakages are much lower when initial leakages are high. This led to a recommendation to develop economic instruments or measures which are directed toward reducing leakages on high initial leakage levels, where *MACs* tend to be low. Such instruments or measures are likely to be site-specific, crop-specific, and fertilizer intensity specific. Specific issues in this context are:

    1. How to target instruments toward leakage-prone areas with initially low *MAC*.
    2. Effect of taxation of the use of growth regulators in order to reduce fertilization on high intensity levels.

2. The cost efficiency measure estimated here was based on marginal abatement costs on the farm level. A different measure of the cost efficiency from the point of view of the whole society should be based on *economic surplus changes* of implementing economic instruments. Surplus changes which should be taken into account in such an analysis would include changes in consumer and producer surpluses, changes in export fees for overproduction, and, finally, the value of improved water quality and environmental quality from the viepoint of both consumers and producers.

3. A further topic to study would be the possibilities for implementation of *ambient pollution taxes* designed to tax indicators of environmental quality directly, instead of taxes on inputs or leakages.

4. N-fertilization quotas proved to have the second lowest *MAC*. In any case, the administrative burden with general fixed quotas are not appealing from viewpoint of practical policy. A study on marketable or in other ways easily transferable fertilizer quotas or licenses and their impact on leakages is needed.

5. The effects of economic instruments on cultivated areas of different crops, both on regional and the national level, is likely to have a substantial impact on N-leakages. *A sectoral study* of changes in relative cropping areas and the combined effects on leakages is of great relevance from the viewpoint of practical policy. Existing research on leakages of different crops could partly be used in such a sector study. A precondition for estimation of crop-specific N-leakage functions is, however, that detailed crop-specific leaching experiments with regard to biological factors, soil characteristics, and several nitrogen fertilizer levels are carried out. Especially more detailed research on N-leakages of different crops and different fertilizer levels needs to be done before a sector model of Finnish

agriculture, determining changes of aggregate N-leakages as a consequence of changing cropping areas or changing price relations, can be constructed. A sectoral model could be combined with agronomic and erosion models, in order to simulate the combined effect of changes in biological, physical and economic parameter values.

6. A study aiming at estimating *the cost of adopting good agricultural practices* seems motivated. Good agricultural husbandry or best management practices may be more cost efficient than any of the measures discussed. In order to be reliable, such a study would involve the following components:

    1. A model of crop growth and its relation to biological and physical factors.
    2. A nutrient leakage model
    3. A farm level model

A precondition for the connection of such models would be the collaboration between persons familiar with all three kinds of models, possibly a crop scientist, an agricultural economist, and a leakage scientist.

References

ADAR, Z. and GRIFFIN, J. M. 1976. Uncertainty and the Choice of Pollution Control Instruments. J. Environmental Management 3: 178-188.

AGRICULTURAL CENSUS IN FINLAND 1991.

AGRICULTURE AND WATER QUALITY. INTERNATIONAL PERSPECTIVES 1990. Ed. BRADEN, J. B. and LOVEJOY, S. B. Lynne Rienner Publishers. USA.

ANON 1992. Council regulation No. 2078/92. On agricultural production methods compatible with the requirement of the protection of the environment and the maintenance of the countryside.

BABCOCK, B. and BLACKMER, A. 1992. The Value of Reducing Temporal Input Nonuniformities. Unpublished Journal paper No. J-14947, Project 3408 of the Iowa Agriculture and Home Economics Station, Ames, Iowa. 27 p.

BAUMOL, W. J. and OATES, W. E. 1988. The theory of environmental policy. Second edition. Published by Cambridge University press. Printed in USA. 296 p.

BERGSTRÖM, L. 1987. Leaching of 15-N-Labeled Nitrate Fertilizer Applied to barley and a Grass Ley. Acta Agric. Scand. 37: 199-206.

CHAMBERS, R. G. 1988. Applied production analysis. A dual approach. 317 p. Cambridge University press. USA.

CROPPER, M. L. and OATES, E. O. 1992. Environmental Economics: A Survey. J. Econ. Literature XXX: 675-740.

ELONEN, P. 1991. Plant nutrients as an environmental problem. (In Swedish: Växtnäringen som miljöproblem). LOA 12: 464.

ESALA, M. and LARPES, G. 1984. Placement fertilization of spring grain on clay soils (In Finnish: Kevätviljojen sijoituslannoitus savimailla). Agr. Res. Centre. MTTK-tiedote 2/84. Jokioinen. 31 p.

FARMING AND THE COUNTRYSIDE: An Economic Analysis of External Costs and Benefits, Ed. HANLEY, 321 p. UK.

GRIFFIN, R. L. and BROMLEY, D. W. 1982. Agricultural Runoff as a Nonpoint Externality: A Theoretical Development. Amer. J. Agr. Econ. 64(3): 547-552.

HANLEY, N. 1990. The economics of nitrate pollution. Eur. Rev. Agric. Econ 17 (2): 129-151

HELFAND, G. 1991. Standards versus Standards: The Effects of Different Pollution Restrictions. Amer. Econ. Rev. 81(3): 622-634.

KAUPPI, L. 1993. Contribution of agriculture to nutrient loading of surface waters in Nordic countries. Abstract in Nordisk Jordbruksforskning Nr. 3, Scandinavian Association of Agricultural Scientists (NJF).

KEMIRA. The sales of fertilizers according to rural centers in 1992/1993(In Finnish: Lannoitteiden myynnin jakautuminen maaseutukeskusalueittain lannoitusvuonna 1992/1993). 14 p.

LIBBY, W. L. and BOGGES, W. G. 1990. Agriculture and water Quality: Where Are

We and Why? pp. 9-39 in Agriculture and Water Quality, Ed. BRADEN, J.B. and BOGGES, W.G.

MAATALOUS JA VESIEN KUORMITUS 1992. Yhteistutkimusprojektien tutkimusraportit. The series of the Board of Water and Environment, no. 359. Finland. Helsinki.

MARKKULA, M., TIITTANEN, K. and VASARAINEN, A. 1990. Pesticides in agriculture and forestry (In Finnish: Torjunta-aineet maa- ja metsätaloudessa. Agricultural Research Centre, Res. Rep. 2/90. 58 p. Jokioinen.

MINISTRY OF ENVIRONMENT 1992. COMMITTEE REPORT 68/1992. (In Finnish: Ehdotus maaseudun ympäristöohjelmaksi. Maaseudun ympäristöohjelmatyöryhmän muistio). 47 p.

MONTGOMERY, W. D. 1972. Markets in Licenses and Efficient Pollution Control Programs. J. Econ. Theory 5: 395-418.

MONTHLY REVIEW OF AGRICULTURAL STATISTICS no. 12, 1957

MYLLYS, M. 1992. Drainage of peat and the leakage of nutrients (In Finnish: Turvemaiden salaojitus ja ravinteiden huuhtoutuminen). Pp. 193-196 in the series of the Board of Water and Environment, no. 359 (Maatalous ja vesien kuormitus, yhteistutkimusprojektien tutkimusraportit). Finland. Helsinki.

NETHERLAND SCIENTIFIC COUNCIL FOR GOVERNMENT POLICY. 1992. Ground for choices. Four perspectives for the rural areas in European Community. Reports to the Government 42. 132 p. The Hague.

NORDIC COUNCIL OF MINISTERS. 1993. An evaluation of the instruments to reduce the leakages of nutrients from agriculture in the Nordic countries (In Danish: Mod strømmen - en vurdering af styrningsmidler overfor afstrømningen af næringsalte fra landbruget i de nordiske land). Nordiske Seminar- och Arbejdsrapporter 1993: 565. 165 p. Copenhagen.

PEARCE, D. W. and TURNER, R. K. 1991. Economics of Natural Resources and the Environment. John Hopkins University Press. 378 p. Great Britain.

REKOLAINEN, S. 1991. The Phosphorus and Nitrogen Loading of Waterways Caused by Agriculture (In Finnish: Maatalouden aiheuttama fosfori- ja typpikuorma). pp 9-12. in the series of the Board of Water and Environment, no. 359 (Maatalous ja vesien kuormitus, yhteistutkimusprojektien tutkimusraportit). Finland. Helsinki.

REKOLAINEN, S., KAUPPI, L. and TURTOLA, E. 1992. Agriculture and the loading of waters. (In Finnish: Maatalous ja vesien tila). English summary. 61 p. Helsinki.

ROBERTS, M. J. and SPENCE, M. 1976. Effluent charges and licenses under uncertainty. J. Publ. Econ. (5): 193-208.

RUDE, S. 1991. Nitrogen Fertilizers in Danish Agriculture - present and future application and leaching (In Danish: Kvælstofgødning i landbruget - behov og udvaskning nu og i fremtiden). English summary. Institute of Agricultural Economics. Report 62. 117 p. Copenhagen.

SAARELA, I. 1991. The most profitable phosphorus- dose for grain is 20 kg/ha (In Finnish: Edullisin fosforimäärä 20 kiloa viljahehtaarille.). Newspaper article.

Maaseudun tulevaisuus 14.11.1991.

SEGERSON, K. 1988. Uncertainty and Incentives for Nonpoint Pollution Control. J. Environmental Econ. Management 15: 87-98.

SEGERSON, K. 1990. Incentive Policies for Control of Agricultural Water Pollution. pp. 39-61 in Agriculture and Water Quality, Ed. BRADEN, J.B. and BOGGES, W.G.

SHORTLE, J. S. and DUNN, J. W. 1986. The Relative Efficiency of Agricultural Source Water Pollution Control Policies. Amer. J. Agric. Econ. 68(3): 668-677.

SHORTLE, J. S. and DUNN, J. W. 1991. The Economics of Control of Non-point Pollution from Agriculture. Pp. 29-47 in Farming and the Countryside: An Economic Analysis of External Costs and Benefits.

SIMMELSGAARD, S. E. 1991. Estimation of nitrogen leakage functions. Nitrogen leakage as a funktion of nitrogen applications for different crops on sand and clay soils (In Danish: Estimering af funktioner for kvælstofudvaskning. Kvælstofudvaskning som funktion af kvælstoftilførsel for forskellige afgrøder dyrket på sandjord og lerjord). Annex 2 in Rude (1991), pp.135-150.

SKOP, E. 1993. Calculation of Nitrogen leaching on a regional scale (In Danish: Beregning af kvælstofudvaskning på regionalt niveau). English summary. Ministry of Environment, Danmarks miljøundersøgelser. Rep. 65.

SPULBER, D. F. 1985. Effluent Regulation and Long-Run Optimality. J. Environ. Econ. and Manag. 12: 103-116.

STATISTICAL YEARBOOK OF FINLAND.

STEVENS, B. K. 1988. Fiscal Implications of Effluent Charges and Input Taxes. J. Environ. Econ. and Manag. 15: 285-296.

SUMELIUS, J. 1993a. A survey of the literature on extensification - the arguments and critique. Agr. Econ. Res. Inst. Res. rep. 190, pp. 5-30.

SUMELIUS, J. 1993b. A Response Analysis of Wheat and Barley to Nitrogen in Finland. Agric. Sci. Finl. 2(6): 465-479.

SUMELIUS, J. 1994. Fertilizer expenditure and profitability on grain producing bookkeeping farms in southern Finland 1988-1990. Agr. Econ. Res. Inst. res. rep. 195: 5-12, Finland.

TIETENBERG, T. 1992. Environmental and Natural Resource Economics. Harper & Collins Publishers. Printed in USA. 678 p.

TURTOLA, E. and JAAKKOLA, A. 1985. Effects of crop on the leaching of nitrogen and phosphorus from clay soil (In Finnish: Viljelykasvin ja lannoitustason vaikutus typen ja fosforin huuhtoutumiseen savimaasta). Agricultural Research Centre report 6/85, (MTTK tiedote 6/85). 43 p. Jokioinen.

TURTOLA, E. and JAAKKOLA, A. 1987. Effects of crop on the leaching of nutrients from clay soil at Jokioinen 1983-1986 (In Finnish: Viljelykasvin vaikutus ravinteiden huuhtoutumiseen savimaasta Jokioisten huuhtoutumiskentällä v. 1983-1986). Agricultural Research Centre report 22/87 (MTTK tiedote 22/87). 32 p. Jokioinen.

VAKKILAINEN and PAASONEN-KIVEKÄS. 1992. The effects of fertilization and drainage on the quality of groundwater (In Finnish: Lannoituksen ja kuivatustoimenpiteiden vaikutus maa- ja pohjaveden laatuun). pp. 197-201 in the series of the Board of Water and Environment, no. 359 (Maatalous ja vesien kuormitus, yhteistutkimusprojektien tutkimusraportit). Finland. Helsinki.

WEINBERG, M. 1991. Economic incentives for the control of agricultural non-point source water pollution. Unpublished dissertation, Dep. Agric. Econ., U.C., Davis. 259 p.

WEITZMAN, M. L. 1974. Prices vs. Quantities. Rev. Econ. Studies 61 XLI(4) No. 128: 477-491.

YEARBOOK OF FARM STATISTICS 1990.

YEARBOOK OF NORDIC STATISTICS 1992.

YLÄRANTA, T., UUSI-KÄMPPÄ, J. and JAAKKOLA, A. 1992. Leaching of nitrogen and its use in lysimeter experiments (In Finnish: Typen huuhtoutuminen ja hyväksikäyttö lysimetrikokeessa). Pp. 17-25 in the series of the Board of Water and Environment, no. 359 Finland. Helsinki.

YLÄRANTA, T., UUSI-KÄMPPÄ, J. and JAAKKOLA, A. 1993. Leaching of nitrogen in barley, grass ley and fallow lysimeters. Agric. Sci. Finl. 2, 4: 281-291.

Appendix 1.

Table 14. Estimation results for spring wheat on fine sand clay soils. Standard errors in parenthesis[1)].

	Quadratic	Square root	Mitscherlich
m			36.189***
			(1.598)
k			0.551***
			(0.018)
β_1	16.633***	15.292***	0.181***
	(1.863)	(1.994)	(0.023)
β_2	2.490***	7.329***	
	(0.234)	(1.032)	
β_3	-0.077***	-0.566***	
	(0.010)	(0.206)	
δ_1	-6.200***	-6.200***	-0.198
	(1.959)	(1.986)	(0.887)
δ_2	-1.022	-1.022	-0.002
	(1.959)	(1.986)	(0.930)
δ_3	10.233***	10.233***	0.293
	(1.959)	(1.986)	(0.788)
δ_4	-16.533***	-16.533***	-0.701
	(1.959)	(1.986)	(0.689)
δ_5	19.667***	19.667***	0.486
	(1.959)	(1.986)	(0.674)
δ_6	-10.400***	-10.400***	-0.374
	(1.959)	(1.986)	(0.823)
δ_7	9.311***	9.311***	0.269
	(1.959)	(1.986)	(0.736)
δ_8	5.033**	5.033**	0.142
	(1.959)	(1.986)	(0.786)
δ_9	-1.889	-1.889	-0.090
	(1.959)	(1.986)	(0.841)
δ_{10}	-5.800***	-5.800***	-0.194
	(1.959)	(1.986)	(0.753)
δ_{11}	2.344	2.344	0.052
	(1.959)	(1.986)	(0.840)
δ_t	0.636	0.904	0.027
	(0.837)	(0.858)	(0.024)
df	93	93	93
$\hat{\alpha}^2$	17.275	17.748	1.192
$\hat{\alpha}$	4.156	4.213	1.092
$logL$	-299.030	-300.490	-155.227
$R^2adj.$	0.8802	0.8770	0.9917

1) ***: Null hypothesis rejected at 0.5 % level ($t_{.005} = 2.58$)
** : Null hypothesis rejected at 1 % level ($t_{.01} = 2.33$)
* : Null hypothesis rejected at 5 % level ($t_{.05} = 1.64$)

Appendix 2.

Table 15. Estimation results for barley on loam clay soils. Standard errors in parenthesis[1)].

	Quadratic	Square root	Mitscherlich
m			47.149***
			(3.442)
k			0.770***
			(0.016)
β_1	14.112***	11.684***	0.154***
	(2.073)	(2.133)	(0.020)
β_2	3.669***	10.725***	
	(0.260)	(1.104)	
β_3	-0.107***	-0.683***	
	(0.012)	(0.220)	
δ_1	-13.004***	-13.044***	-0.375
	(2.181)	(2.124)	(0.293)
δ_2	-1.167	-1.167	-0.051
	(2.181)	(2.124)	(0.401)
δ_3	6.978***	6.978***	0.177
	(2.181)	(2.124)	(0.363)
δ_4	-27.944***	-27.944***	-1.437***
	(2.181)	(2.124)	(0.105)
δ_5	10.878***	10.878***	0.301
	(2.181)	(2.124)	(0.466)
δ_6	-14.389***	-14.389***	-0.473
	(2.181)	(2.124)	(0.329)
δ_7	20.011***	20.011***	0.460
	(2.181)	(2.124)	(0.596)
δ_8	6.022***	6.022*+*	0.121
	(2.181)	(2.124)	(0.570)
δ_9	1.300	1.300	0.010
	(2.181)	(2.124)	(0.291)
δ_{10}	-2.578	-2.578	-0.114
	(2.181)	(2.124)	(0.610)
δ_{11}	-3.000	-3.000	-0.099
	(2.181)	(2.124)	(0.474)
δ_t	2.539***	3.026***	0.109*
	(0.932)	(0.919)	(0.039)
df	93	93	93
$\hat{\alpha}^2$	21.396	20.303	1.238
$\hat{\alpha}$	4.626	4.506	1.113
$logL$	-310.584	-307.753	-157.263
$R^2adj.$	0.9186	0.9228	0.9953

1) ***: Null hypothesis rejected at 0.5 % level ($t_{.005} = 2.58$)
** : Null hypothesis rejected at 1 % level ($t_{.01} = 2.33$)
* : Null hypothesis rejected at 5 % level ($t_{.05} = 1.64$)

Appendix 3.

Table 16. The nitrogen and phosphorus added to the soil in fertilizer form in the experiments in 1983-1986 and leakages in the drainage water, kg/ha (Compiled from TURTOLA and JAAKKOLA 1987).

Period	Year Crop	Fertilizer nutrients N	Fertilizer nutrients P	Nutrients in drain. water N	Nutrients in drain. water P
1.5.1983-	*1982 1983*				
30.4.1984	grass grass	206	112	4.8	0.08
	grass barley	106	68	9.3	0.22
	grass fallow	6	24	20.0	0.14
	barley barley	106	68	4.3	0.08
	barley fallow	6	24	16.0	0.07
1.5.1984-	*1984*				
31.8.1984	barley	100	22	7.5[1]	
1.9.1984-	*1985*				
31.8.1985	winter wheat	112	48	2.1	0.17
	spring wheat	100	44	2.4	0.15
1.9.1985-	*1986*				
31.12.1986	winter wheat	148	21	2.5	0.48
	spring wheat	100	22	4.1	0.33

[1] Approximated by J. SUMELIUS on the basis of figure.

Appendix 4.

Table 17. Estimated N-leakages from barley at different levels of N-fertilization when b = 0.7, kg N/ha.

N	y_n 1	3	5	10	15	20	25	30	35	40
50	0.70	2.11	3.52	7.04	10.57	14.09	17.62	21.14	24.66	28.19
60	0.75	2.27	3.78	7.56	11.34	15.12	18.89	22.67	26.45	30.23
70	0.81	2.43	4.05	8.10	12.16	16.21	20.26	24.32	28.37	32.42
80	0.87	2.61	4.35	8.69	13.04	17.39	21.72	26.08	30.43	34.77
90	0.93	2.80	4.66	9.32	13.99	18.65	23.31	27.97	32.63	37.30
100	1.00	3.00	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00
110	1.07	3.22	5.36	10.73	16.08	21.45	26.81	32.17	37.54	42.90
120	1.15	3.45	5.75	11.50	17.25	23.01	28.76	34.51	40.26	46.01
130	1.23	3.70	6.16	12.34	18.51	24.67	30.84	37.01	43.18	49.35
140	1.32	3.97	6.62	13.23	19.84	26.46	33.08	39.69	46.31	52.93
150	1.42	4.26	7.10	14.19	21.29	28.38	35.48	42.57	49.67	56.76

N = Relative nitrogen fertilization in relation to normal fertilizer intensity for the crop.
y_n = Leakage at normal fertilizer intensity level.

Maatalouden taloudellisen tutkimuslaitoksen julkaisuja
Publications of the Agricultural Economics Research Institute

No 60 KETTUNEN, L. Suomen maatalous vuonna 1989. 52 s. Helsinki 1990.
No 60a KETTUNEN, L. Finnish agriculture in 1989. 52 p. Helsinki 1990.
No 60b KETTUNEN, L. Finlands lantbruk 1989. 52 s. Helsinki 1990.
No 61 FAMILY FARMING POSSIBILITIES. Finnish-Baltic Common Seminar, Helsinki, Finland 1990. 121 p. Helsinki 1990.
No 62 PUURUNEN, M. A comparative study on farmers' income. 114 p. Helsinki 1990.
No 63 KETTUNEN, L. Suomen maatalous vuonna 1990. 56 s. Helsinki 1991.
No 63a KETTUNEN, L. Finnish agriculture in 1990. 56 p. Helsinki 1991.
No 64 KOLA, J. Production control in Finnish agriculture. 134 p. Helsinki 1991.
No 65 KETTUNEN, L. Suomen maatalous vuonna 1991. 59 s. Helsinki 1992.
No 65a KETTUNEN, L. Finnish agriculture in 1991. 59 p. Helsinki 1992.
No 66 STRATEGIES AND TACTICS FOR FAMILY FARMING. Finnish-Baltic joint seminar Riga Latvia 1991. 91 p. Helsinki 1992.
No 67 TUTKIMUKSIA SUOMEN MAATALOUDEN KANNATTAVUUDESTA. Tilivuodet 1988-1990. Summary: Investigations of the profitability of agriculture in Finland in business years 1988-1990. 154 s. Helsinki 1992.
No 68 STATE REGULATION OF AGRICULTURAL PRODUCTION. Finnish-Baltic joint seminar Vilnius Lithuania 1992. 104 p. Helsinki 1992.
No 69 TORVELA, M. Maatalousekonomian tutkimukseen liittyviä ajatuksia. Some thougts on the Research of Agricultural Economics in Finland. 36 p. Helsinki 1992.
No 70 KETTUNEN, L. Suomen maatalous vuonna 1992. 59 s. Helsinki 1993.
No 70a KETTUNEN, L. Finnish agriculture in 1992. 59 p. Helsinki 1993.
No 71 KETTUNEN, L. (ed.). Finnish Agriculture and European Integration. 119 s. Helsinki 1993.

KETTUNEN, L. General conditions of agriculture and problems of integration. s. 7-20.

KOLA, J. Principles of agricultural policy in Finland in relation to the CAP of the EC. s. 21-36.

AALTONEN, S. Agriculture and food industries in the Finnish national and regional economy. s. 37-52.

MARTTILA, J. Grain production and the CAP - The competitive consequences of the CAP reform. s. 53-68.

NIEMI, J. Challenges facing the Finnish livestock sector as regards to the integrated European market. s. 69-88.

KUHMONEN, T. The LFA-scheme in Finland - poor criteria or good regions? s. 89-100.

VESANTO, T. & LEHTIMÄKI, S. Horticulture in Finland. s. 101-117.

No 72 AGRICULTURAL DEVELOPMENT PROBLEMS AND POSSIBILITIES IN BALTIC COUNTRIES IN THE FUTURE. Finnish-Baltic Joint Seminar, Saku, Estonia 1993. 87 s. Helsinki 1993.
No 73 KETTUNEN, L. Suomen maatalous vuonna 1993. 61 s. Helsinki 1994.
No 73a KETTUNEN, L. Finnish agriculture in 1993. 62 p. Helsinki 1994.
No 73b KETTUNEN, L. Finlands lantbruk 1993. 63 s. Helsinki 1994.

ISBN 952-9538-45-6
ISSN 0788-5393
Helsinki 1994