The effectiveness and feasibility of economic incentives of input control in the mitigation of agricultural water pollution

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Agricultural water pollution in Finland is mainly caused by nutrient losses from fields. Nutrient losses can be mitigated, e.g., by changing management practices and by plant rotation. Adoption of the necessary measures may be voluntary, but economic incentives can also be used. Nutrient losses can be regulated, e.g., by incentives to decrease the use of fertilizers. Economic incentives include a change in product prices, an input tax or an input quota. So far an input tax has been applied in Finnish agriculture. The effectiveness and feasibility of these policy measures on the farm can be assessed by calculating the change in farm profit and nutrient losses. The input quota was found to be the least-cost measure at the farm level when the marginal abatement costs of measures were compared on a grain farm growing barley. Alternative policy measures caused bigger losses in profit on the farm and the reduction in nitrogen leakage was smaller.

Key words: non-point source pollution, nitrogen, policy measure, assessment, farm profit

Introduction

The environmental impacts of agriculture in Finland mainly concern surface waters and take the form of soil erosion and nutrient losses which cause eutrophication and oxygen deficit. High nitrate concentrations also reduce the quality of groundwater. However, the nitrate concentration in groundwater in Finland is generally low and concentrations of over 25 mg/l (National Board of Waters and the Environment 1988) are met only rarely in rural wells.

In Finland the total phosphorus load from field cultivation varies between 2,000 and 4,000 tonnes per year, and the total nitrogen load between 20,000 and 40,000 tonnes per year (Rekolainen 1989). The nutrient loads from manure storage are about 400 tonnes per year for phosphorus and 1,100 tonnes per year for nitrogen. The present phosphorus fertilization rate clearly exceeds the uptake of phosphorus by crops (26 kg P/ha vs. 12 kg P/ha). Moreover, the phosphorus content in the soil has increased by 36% since the early twenties (Rekolainen et al. 1992).

According to a decision made by the Finnish government in 1988 (Ministry of the Environment 1988), the phosphorus load from agriculture should be reduced by 30% by the year 1995, combined with a significant reduction in nitrogen loading. Reduction of the phosphorus load was given priority, since phosphorus is usually the limiting factor for algal growth in fresh waters in Finland. Since then a new program has been preparead for environmental protection in agriculture (Ministry of the Environment 1992), in which the target for the reduction of nutrient losses is set at 50%.

Agricultural pollution can be mitigated by changing the management practices on farms. The load of total phosphorus can most effectively be controlled by decreasing the rate of erosion through reduced tillage methods (REKOLAINEN et al. 1992). Nitrogen leaching cannot be prevented through reduced tillage methods, so it is more important to reduce the use of nitrogen. This can be affected through economic incentives, e.g. taxes. Nutrient taxes have, in fact, already been used in Finland, but there is no broader experience of the effect of economic incentives.

In the OECD the agricultural policy measures which address environmental issue are divided into three groups: 1) direct regulations, 2) information policy, and 3) economic instruments (OECD 1992). Direct regulation is an administrative means of achieving a particular environmental objective. The opposite of direct regulation is information policy, which is usually aimed at informing farmers of research results and technical innovations, as well as of new management practices which can be applied to obtain environmental benefits. Economic instruments are based on market incentives to apply methods which mitigate pollution. These instruments can be divided into different categories such as taxes and charges, tradeable discharge quotas and permits, or subsidies. The effectiveness of economic instruments on agriculture depends on the impact on farm income and profitability. Decisions about which mitigation method is to be used are left to the farmer.

To achieve improved water quality it is important to find a measure whose cost to the farmer is as low as possible (e.g. ANDRÉASSON 1990). This paper evaluates the effectiveness and feasibility of various policy measures in reducing the use of nitrogen by comparing the changes in farm profit and nitrogen loss resulting from different measures. The results are especially important for the authorities in deciding which measures to apply, and they also benefit the farmers if error-trial decision making can be avoided.

Environmental policy measures in agriculture

The theory of point-source pollution regulation includes means such as effluent taxes, tradeable emission permits and emission quotas. The topic has been discussed widely in literature, e.g. BAUMOL and OATES (1971, 1990), TIETENBERG (1978), SESKIN et al. (1983), O'NEIL et al. (1983), STRASSMANN (1984), BRAULKE and ENDERS (1985), CROWDER et al. (1985), MCGARTLAND and OATES (1985), MALUEG (1989, 1990). In the case of nonpoint source pollution it is not feasible to use standard pollution control measures such as direct restrictions or effluent taxes because of the physical uncertainty and monitoring difficulties involved. Although losses could be estimated, it is difficult to determine the connection between a discharge level and the damage caused by the pollutant (SEGERSON 1988).

When assessing different measures it has to be kept in mind that the main target is to reduce the damage resulting from nutrient leaching. There are three alternative ways of creating an incentive to reduce non-point source pollution: 1) to change farm management practices, 2) to regulate the input of nutrients, and 3) to regulate the ambient level of nutrients in the environment. The second alternative will be discussed in more detail since i has been applied in Finland. So far, the regulation of inputs has been mainly used to collect funds via nutrient taxes for marketing excess production of Finnish agriculture (Council of State of Finland 1992).

Some measures for regulating the use of input are presented in the following. The efficiency of input taxes and input restrictions in reducing agricultural pollution have been discussed on many occasions, e.g. TAYLOR and FROHBERG (1977), de HAEN (1982), GRIFFIN and BROMLEY (1982), ENGLAND (1986), SHORTLE and DUNN (1986), BRADEN et al. (1989), ANDRÉASSON (1990), HANLEY (1990), CONWAY (1991), JOHNSON et al. (1991) and FUCHS and MUERSCHEL-RAASCH (1992).

While estimation of the socially optimal pollution level is inaccurate due to incompleteness of information about consumers' preferences, a target level can be set for input use which should be

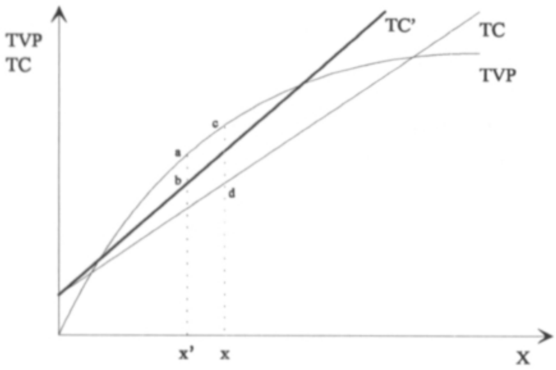

Fig. 1. Input tax increases total production costs TC (total cost) to TC' and the economically optimal use of input decreases according to the TVP-curve (total value of product) from x to x'. The farm profit declines from [c, d] to [a, b].

reached in order to reduce damage to the environment. The level of input use can be changed by, e.g., taxing the products (HUANG and URI 1992). Taxation of a product reduces its total value and thereby decreasing the optimal use of the input which also reduces nutrient losses.

Input taxation can also be used to reduce nutrient losses. A target level can be achieved by setting a tax e.g. on the total use of input. In setting an input tax, production costs should be taken into account. In Figure 1 the total cost of production is TC, and TVP is the total value of the product. The horizontal axis shows x_i use of input X. If there are no restrictions, input use is x. The profit from selling the production is [c,d]. The input tax increases the total costs such that the curve TC changes to TC'. The new optimum of input use is x'. Profit has been reduced to the difference between a and b.

Assuming that the relationship between the amount of input and nutrient losses can be estimated, a direct restriction can also be set. This so-called input quota is equal to the amount of input after tax has been introduced. The farmers' choice is to maximize their profit when the use of one input is restricted. An attempt can be made to compensate for this by using other inputs. In the case of fertilizer this could mean growing leguminous plants or increasing the use of manure. Although a part of the restricted input use can be compensated by other inputs, the marginal productivity of these decreases at a faster rate than in the case where no restrictions exist.

Policy measures in Finland

In Finland environmental measures in agriculture are mainly enacted through direct regulation. There is no general and consistent environmental legislation, but a number of laws have been introduced to protect nature. Legislation concerning agriculture comprises, e.g., the Water Act, the Chemicals Act, the Air Protection Act and the Fertilizer Act (VAINIO-MATTILA 1990).

Market-based incentives in Finland have so far been established for fertilizers. In 1979 a fertilizer tax of FIM 0.20/kg was imposed, mainly as a means of collecting funds for marketing excess agricultural production (Council of State of Finland 1978). The effect of this tax remained modest with respect to environmental benefits. In 1990 the first nutrient tax was introduced for phosphorus (FIM 0.50/kg P). It was raised after six months to FIM 1.00/kg P and one year later to FIM 1.50/kg P. At the beginning of 1992 the fertilizer tax and the phosphorus tax were combined, and a nitrogen tax was introduced. The tax for nitrogen was FIM 2.90/kg P and for phosphorus FIM 1.70/kg N. The tax for phosphorus has remained the same since September 1992, but the nitrogen tax has been reduced to FIM 2.60/kg N due to general fall in agricultural profitability (KETTUNEN 1993).

Methods

Background to the assessment

When comparing environmental policy alternatives for reducing non-point source pollution, the main interest is on optimality, efficiency and feasibility (WEINBERG 1991). Optimality means social optimality, which should be achieved by a policy measure. Efficiency means cost-efficiency, i.e. which measures are most profitably applied to achieve goals for nonpoint source pollution. Feasibility means the possibility of achieving those goals.

If all three conditions are fulfilled, the so-called first-best measure has been found. The socially optimal level of pollution is difficult to define owing to the huge amount of information needed. The costs incurred in obtaining this information could be so high that they would be override benefits gained. If the first-best conditions cannot be reached, we can try to find a situation with a potential improvement in welfare. This so-called second-best situation is different from the Pareto improvement, since it is possible for an individual to be worse off, although total welfare is increased. Still, there is a problem in evaluating the effects on the environment and on society. Let us denote the change in total utility by ΔU, which should be positive for a measure to be carried out.

$$(1)\quad \Delta U = \Delta u_c + \Delta u_p + \Delta u_s > 0$$

where Δu_c is the change in consumer's utility, Δu_p is the change in producer's utility and Δu_s is the change in the utility of society caused by a reduction in costs for water purification and health services. The change in consumer's and society's utility is positive, and in producer's utility mainly negative although positive changes are possible.

To solve the problem of pollution we should determine those conditions by which the social optimum is reached, and the means by which profit-maximizing firms and welfare-maximizing citizens meet these conditions. Different factors of economic action may be determined inefficiently due to externalities and improperly defined property rights (see e.g. TIETENBERG 1992). Inefficient determination can also result in incomplete market information about resource use and differences in social valuation.

Another way of assessing policy measures, instead of social and private utility, is to consider the cost-effectiveness of the different measures. To assess cost-effectiveness we should be able to evaluate the costs of pollution abatement. The most profitable measure can be found by comparing abatement costs. At the farm level, pollution abatement costs are related to changes in total yield, use of technical and chemical inputs, and work. These costs vary depending on the set production target. On a farm specialized in cereal crop production, losses from the whole field area are possible, whereas on a dairy farm the share of grassland of the total cultivated area is much larger and nutrient losses consequently lower.

Pollution abatement costs of a farm

In the following we consider a cereal farm with production input x with unit price w , producing product Y with unit price p. The farmer's objective is to maximize farms profit π by the optimal use of inputs, i.e.

$$(2)\quad \max \pi_1 = p\,Y_1 - w\,x_1$$

where $Y_1 = f(x_1)$ is the yield without control measures and x_1 is the use of input. An optimal solution can be found by differentiating π_1 with respect to x (first order condition):

$$(3)\quad \frac{\partial \pi_1}{\partial x} = 0 \Leftrightarrow p\frac{\partial f(x_1)}{\partial x} - w = 0 \Leftrightarrow \frac{\partial f(x_1)}{\partial x} = \frac{w}{p}$$

which shows us that, in order to maximize profit, marginal product (MR) with respect to input use should equal the price relation between input price and product price. The optimal level of input use x_1^* can be solved as a function of input price and product price $x_1^* = x(w,p)$. To make sure that the maximum exists at that point also a second order condition must be fullfilled:

$$(4)\quad \frac{\partial^2 \pi}{\partial N^2} = \frac{\partial^2 f(N)}{\partial N^2} < 0$$

When measures for the mitigation of environmental problems are considered, the costs of the measures are included in profitmaximizing equation such that product tax T_Y decreases the unit price of product p, input tax T_x raises the unit price of the input and effluent tax T_L sets a value on the emitted discharge L i.e.

$$(5)\quad \max \pi_2 = (p-T_Y)\,Y_2-(w + T_x)x_2-LT_L$$

where Y_2 and x_2 are the yield and the use of input when control measures are introduced. The marginal loss in profits ($\Delta\pi$) on a farm are obtained by subtracting π_2 from π_1 :

$$(6)\quad \Delta\pi = p\Delta Y + T_Y Y_2 + LT_L + w\Delta x + T_x x_2$$

When comparing different measures it is important to know their cost-effectiveness. Cost-effectiveness can be compared using the marginal abatement cost, MAC, for a given measure which can be calculated by dividing the change in profit $\Delta\pi$ by the change in loss ΔL:

$$(7)\quad MAC = \frac{\Delta\pi}{\Delta L}$$

The MAC is affected by losses, and it varies depending on the crop and soil type. In this analysis the idea is to assess the relative effectiveness of different measures. The loss function parameters are kept constant in all calculations.

Farm costs of controlling the use of input

Structure of the model

Control of the use of inputs by economic means can be performed by raising prices administratively or through taxation. When the price of an input rises, the economically optimal level of the input decreases. Another factor affecting the use of input is total yield. Therefore the following costs have to be considered when calculating the cost-effectiveness of various measures: input price and loss of total revenue. The effect of a nitrogen tax depends on the response of the yield to nitrogen fertilization, the relation of the price of nitrogen fertilizer and the price of product, and the rate of nitrogen tax. If the yield function of a plant is Y=f(N), the optimal level of (nitrogen) input use can be obtained by setting marginal revenue MR equal to the marginal cost of input MC (see Eq. 3).

Barley is the most common crop in southern and western Finland (National Board of Agriculture 1992f) where environmental problems are most severe (REKOLAINEN et al. 1992). A quadratic nitrogen yield function was estimated for barley (see Appendix 1) assuming no nitrogen carryover. This function is used in comparing the effects of different policy measures on farm profit. The optimal level of input use depends on the shape of the yield function. PARIS (1992) has criticized the use of the quadratic function because it overestimates the optimal nitrogen level. The non-linear von Liebig - function would be more feasible (PARIS 1992), but the Finnish data required for that are incompatible (SUMELIUS 1993).

A condition for the farmer's production decision can be formulated on the basis of Equation 3. The production costs of barley (Association of Rural Advisory Centres 1991) are divided into harvest costs which include harvesting, drying and work, and other production costs which include other variable costs and fixed costs. The maximization problem is:

$$(8)\quad \max \pi = (p-HC-T_Y)Y-PC-(w_N + T_N)N^*$$

where π is profit, p is the unit price of barley, $Y=f(N^*)$ is the yield function of barley, HC the harvest cost per kg of barley yield, PC other production costs, T_Y product tax, w_N price of nitrogen, T_N nitrogen tax, and N^* the optimal level of nitrogen fertilizing. Other production costs include costs that depend on the fertilization level, but their effects on profit calculation are negligible.

Agricultural water pollution in the model is considered as nitrogen leaching. A Danish nitrogen loss function presented by SIMMELSGAARD (1991) is a function of nitrogen application as a fraction of the average nitrogen use:

$$(9)\quad \ln\frac{y}{y_n} = b_0 + bN \Leftrightarrow y = y_n e^{b_0 + bN}$$

where y = nitrogen leaching, kg/ha
y_n = nitrogen leaching at average nitroge use
N = applied nitrogen as a fraction of average nitrogen use

There are not enough results for Finland to estimate an accurate loss function for nitrogen. In this paper the Danish function form was adopted and parameters fitted for Finnish conditions according to present expert information (TURTOLA and JAAKKOLA 1985, REKOLAINEN 1989). This hypotetic function is:

$$(10) \quad L = u + ve^{z(N-1)}$$

where L is total loss of nitrogen (kg/ha), N is applied nitrogen as a fraction of average nitrogen use, and u, v and z are parameters. The values of these parameters are u = 10, v = 10 and z = 1.8. Average nitrogen use is set at 100 kg N/ha annually, according to latest data on the use of fertilizers in Finland (Kemira 1992). The loss function presented here is not the only possible function. The parameters of the loss function could be adjusted and an analysis of different loss functions could be made, but the type of function used here gives a good example and a possibility to assess relative changes in profits and losses.

The profit maximizing equation can, in theory, be used to assess the effects of changes in producer prices, fertilizer taxes, fertilizer quotas and effluent taxes on the profit of a farm. This evaluation is static and gives the outlines for the effects of policy measures on input regulation.

Results

Effects of changes in product prices

As an environmental policy measure, a reduction in product price can be considered as taxing environmentally harmful production. In an open economy, the tax would be transferred to consumer prices and the demand for environmentally harmful products would subsequently decline. In a closed economy, the taxing of prices would lead to diminished returns for farmers, but no change in the prices of products would take place because prices are defined administratively. By differentiating product prices on the basis of the environmental effects of production, it might be possible to change to less polluting production. However, the differentiation of prices requires a political decision and could, therefore, be difficult to carry out.

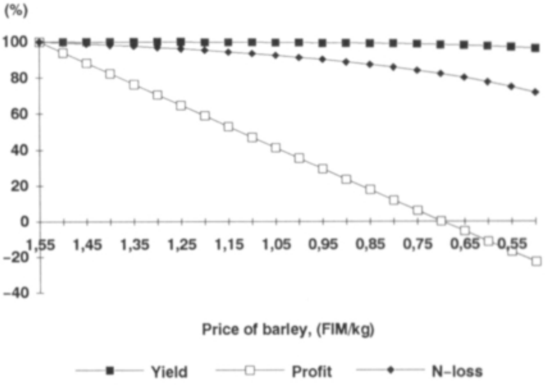

Fig. 2. Estimated relative yield of barley, nitrogen loss and profit at optimum as a function of the price of barley.

A static assessment of the effects of a change in product price was made for barley. The effects of price change on production costs were not taken into account because of the dynamic nature of cost adaptation to price changes. The producer price of barley was decreased until it finally reaches the so-called world market level. Figure 2 shows barley yield, farm profit and nitrogen loss as percentages of situation when no policy measures are implemented. The horizontal axis shows the farm price of barley.

In order to obtain a significant reduction in nutrient losses, the price of barley should be lowered very dramatically, and the reduction in nutrient loss would be very expensive for farmers. When the price of barley goes down to FIM 0.70/kg, the calculated farm profit becomes negative and it is not possible to continue production. Neither are there any more negative environmental effects from agricultural production.

The low efficiency of a price change as an environmental measure can be explained partly by the shape of the yield function Y(N). The economically optimal level of fertilization remains relatively high, despite the reduction in profitability. The other reason is the relationship between fertilizer and product price. Fertilizer can be seen as a

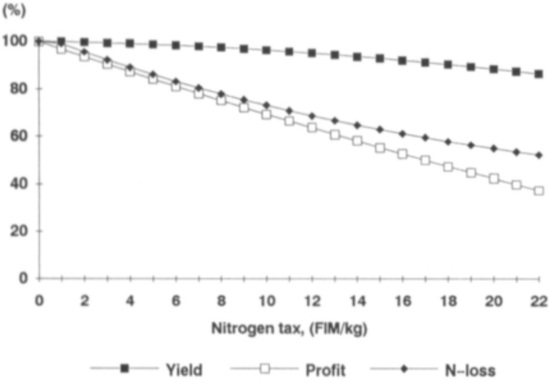

Fig. 3. Estimated relative yield of barley, profit and nitrogen loss at optimum as a function of the nitrogen tax.

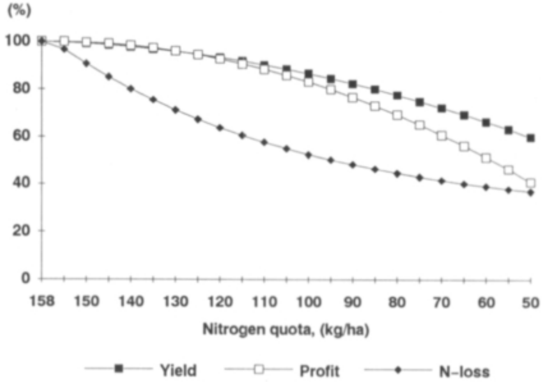

Fig. 4. Estimated relative yield of barley, profit and nitrogen loss at optimum as a function of the nitrogen quota.

relatively low-cost production input and, therefore, there is no incentive to compensate it with other inputs as long as the given conditions apply.

Effects of an input tax

The input tax in agriculture is an application of the effluent tax in industry. The difficulty is how to measure the amount of discharge from agriculture. A nitrogen tax increases the price of all units of nitrogen applied. In Figure 3 the amount of nitrogen tax varies from 0 to 22 FIM per kg of nitrogen. The increase in fertilizer price reduces its economically optimal use. The farm profit does not decrease as rapidly as in the case of a change in price.

In the simulation the nitrogen tax has to be relatively high in order to bring about a significant reduction in nutrient losses. Here, as well as in the previous case, the estimated response of barley to nitrogen shows such a small marginal productivity for nitrogen at the optimal input level that the effect of the input tax remains weak.

This analysis does not take into account the possibility of compensation of nitrogen fertilizer with other inputs such as growing of leguminous crops or increased manure use, because there is no data available in Finland about the costs of compensating inputs in cereal crop production.

Effects of an input quota

The input quota can be defined by the desired quality level of the environment. It is determined by the biological tolerance of the environment for nutrient loading. This same limit can also be used for other measures such as the input tax. The setting of an input quota is an administrative measure only, and can be implemented by legislation which fixes these limits. There is no market incentive in this case, and an administrative control system is, therefore, needed to successfully introduce this abatement measure. Figure 4 shows the input quota on the horizontal axis and the respective relative changes of yield, farm profit and nitrogen loss are presented by curves.

When the quota is set, the farmers reduce their use of input so that the quota is fullfilled. A input quota does not affect farm profit as drastically as a change in product price, but the nutrient loss decreases quite rapidly. The input quota could lead to inefficiency in production if no compensating inputs exist. Some ways of compensating the limited input use have already been presented. An additional possibility would be to increase the field area of a farm by renting fields or by clearing new ones.

Table 1. Marginal abatement cost of reducing leaching by 30%.

	change in profit FIM/ha	MAC FIM/kg N
Product tax	5728	572.8
Nitrogen quota	147	14.7
Nitrogen tax	1441	144.1

Marginal abatement costs of the measures

In order to compare the cost-effectiveness of the different measures, marginal abatement costs (MAC) were calculated for each abatement measure considered in this study. MAC was calculated for a 30% reduction in nitrogen loss. The marginal abatement cost is the relationship between the total change in profit and the change in nitrogen loss. The abatement measures not only affected the use of nitrogen but also the use of phosphorus due to the fact that fertilizers used in Finnish agriculture are mainly compound fertilizers. Table 1 shows the change in farm profit and the marginal abatement cost for each of the simulated measures.

If only farm costs were considered, the input quota would be the most profitable alternative at the farm level. A similar conclusion has been drawn, e.g., by Johnson et al. (1991). However, it should be kept in mind that the adoption of an input quota would also cause administrative costs. These costs cannot be easily verified, and they do not affect the decision making of farmers. Changing the product price cannot be a feasible measure because of its high expenses for farmers (see also Huang and Uri 1992).

Conclusions

Agricultural non-point source water pollution is mainly caused by nutrient losses from fields. Several mitigation methods and techniques have been proposed for reducing runoff and erosion. One of the most effective measures to get farmers to adopt these methods is the use of economic incentives. Product tax, input tax and input quota for controlling input use were evaluated in this study.

When introducing control measures, the target is to achieve a pollution level which reduces the detrimental effects of discharges. It is not possible to determine the social optimum because economists are incapable of knowing all the preferences of individuals concerning the environment. However, a socially desirable pollution level can be determined administratively. To be able to do this, information is required about the state of the environment and its tolerance for discharges. In order to reach the desired pollution level, environmentally beneficial production methods can be used that can be promoted either voluntarily or through economic instruments (legislation, charges, taxes).

Economic incentives can be aimed at, e.g., an ambient pollutant level, a discharge level, production techniques or input use. In this paper, economic incentives for the regulation of the use of fertilizers were considered. Of the studied alternatives, the input quota was the most efficient measure at the farm level. In reality, a variable input like fertilizer, which can be easily transported, cannot be controlled and the possibility of a "black market" does exist.

The input tax on nitrogen has to be considerably high in order to bring about the desired reduction in the use of input, and the respective abatement costs would greatly reduce the farm profit. Nitrogen was used as an example here, but a similar tax could be set on phosphorus. A change in product price was also examined. This measure is not feasible due to the severe reduction it causes in farm profit. Furthermore, the decrease in input use was quite fractional.

Incentives to regulate input use can be set in several ways, but the heterogeneity of different geographical areas - e.g. southwestern and eastern Finland - may cause problems in the application of measures. Most of the nutrient losses in Finland are discharged from cereal farms (Rekolainen et al. 1992). On dairy farms, storaging and spreading of manure is a major environmental problem. If a nitrogen tax is imposed, it will lead to certain imbalances; production costs would rise also on farms with less discharge, and a reduction in input use would not guarantee any improvement in water quality even if losses might be reduced. Dairy farms basically use more nitrogen per unit of field area, but the losses of nutrients from grass fields are lower than from, e.g., cereal crop fields.

More research is needed to validate the assessment of different environmental policy measures. According to the results of this study show that for environmental measures to be both feasible and effective at the farm level, new solutions or combinations of measures will have to be introduced. The assessment of measures can be developed by calculating more accurate yield responses and loss responses for both nitrogen and phosphorus. Moreover, soils and different management practices, e.g. reduced tillage and buffer stripes, have to be considered.

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SELOSTUS

Taloudellisten ohjauskeinojen tehokkuus maatalouden vesiensuojelussa

ASKO MIETTINEN

Vesien ja ympäristöntutkimuslaitos

Maatalouden aiheuttamaa vesistökuormitusta pyritään rajoittamaan mm. vähentämällä lannoitusta. Lannoitteiden käyttömääriin voidaan vaikuttaa kiintiöinnillä, lannoitteiden hintamuutoksilla tai maataloustuotteiden hintamuutoksilla. Näitä vaihtoehtoja tarkasteltiin tutkimuksessa. Päätös lannoitteiden käyttömäärästä jää siis viljelijän ratkaistavaksi riippuen panosten ja tuotteiden hinnoista ts. tuotannon kannattavuudesta. Mikäli lannoitteille asetetaan kiitiö, voi viljelijä valita enintään kiintiön edellyttämän määrän lannoitteita.

Lannoitteiden käytön vähentämiseen tähtäävien taloudellisten ohjauskeinojen vaikutuksia simuloitiin mahdollisimman yksinkertaisella mallilla, jossa tilalla oletettiin tuotettavan vain yhtä tuotetta, rehuohraa. Mallissa kuvattiin viljelijän päätöksentekotilanne, jossa annettujen rajoitusten puitteissa oli löydettävä taloudellinen optimi. Vertailukohteeksi otettiin tilan voitto, joka muodostui kokonaistuotosta vähennettynä tuotantokustannuksilla. Muuttuvina kustannuksina otettiin lannoituskustannus typen osalta sekä puintikustannukset, muut kustannukset laskettiin kiinteisiin kustannuksiin. Tuotantopanosten käytön taloudellinen optimi saatiin selvitettyä asettamalla tuotannon rajatuotto ja rajakustannus yhtäsuuriksi.

Huuhtoutuminen arvioitiin pohjautuen Tanskassa estimoituihin huuhtoutumafunktioon, jota muokattiin vastaamaan suomalaisia olosuhteita. Toistaiseksi ei vielä pystytä nykyisten kenttäkoetulosten perusteella estimoimaan varsinaisesti suomalaisiin olosuhteisiin soveltuvaa huuhtoutumafunktiota. Vertailtaessa toimenpiteiden keskinäistä edullisuutta, ei huuhtoutumafunktion muodolla ole kuitenkaan niin ratkaisevaa merkitystä kuin tuotantoa kuvaavalla funktiolla.

Ohjauskeinojen arvioinnissa vertailtavana suureena käytettiin huuhtoutumisen vähentämisen rajakustannusta, joka on se kustannus, mikä viljelijälle aiheutuu tuotannosta saatavan voiton pienentymisenä, kun pellolta huuhtoutuvaa ravinnekuormitusta pyritään vähentämään. Vertailun edullisimmaksi toimenpiteeksi osoittautui lannoitekiintiö, joka ei varsinaisesti ole taloudellinen ohjauskeino. Lannoitekiintiö edullisuus perustui siihen, että kiintiöinnistä ei aiheudu muita kustannuksia kuin sadon aleneminen. Lannoiteveron vaikutuksen voimakkuuteen vaikuttavat lannoitteen hinnan ja tuotteen hinnan välinen hintasuhde, lannoitteelle asetettavan veron suuruus sekä lannoitteen tuotantovaikutus ts. lannoitteella saatava sadonlisä. Tuottajahinnan muutos aiheutti hyvin voimakkaan pudotuksen viljelijän tuottoihin, eikä saavutettu huuhtoutumisen vähentyminen ollut kovin voimakasta.

APPENDIX 1.

Estimation of a yield function for barley

Nitrogen yield functions for barley were estimated on the basis of the empirical results of ESALA and LARPES (1984). The nitrogen response of barley and wheat was tested at five different levels (0, 50, 100, 150, 200 kg N/ha) on different soils in 1969-1980. Other factors affecting production (weather, soil, tillage, pests, etc.) were considered as constant.

Average yields of barley on siltclay soil with injection fertilization have been used in estimating the yield functions (linear, squareroot, quadratic). The coefficients in all functions are linear and the ordinary least squares method is used in all estimations. In practice the estimates of coefficients were calculated by SHAZAM computer program.

	Coefficients	Estimate	t-value	
Linear,	a	1898.0 (676.6)	2.8052*	$F = 16.38; p < 0.05$
$Y=a+bN$	b	22.360 (5.524)	4.0475*	$R^2 = 0.8452$
				$d = 1.4869$
				$MS_{resid.} = 762960$
Squareroot,	a	1137.2 (207.2)	5.4883**	$F = 169.3; p < 0.001$
$Y=a+bN^{1/2}$	b	344.77 (20.70)	16.656***	$R^2 = 0.9826$
				$d = 1.4416$
				$MS_{resid.} = 85834$
Quadratic,	a	1103.7 (119.6)	9.2266**	$F = 182.1; p < 0.01$
$Y=a+bN+cN^2$	b	54.131 (3.793)	14.273***	$R^2 = 0.9945$
	c	-0.1589 (0.2846)	-5.5815**	$d = 2.6187$

* significant at 0.05
** significant at 0.01
*** significant at 0.001.

F test showed significance for linear function at 5% risk level, for quadratic function at 1% risk level and for squareroot function even at 0.1% risk level. A quadratic function was selected because of its highest significance (R^2) compared to the linear and squareroot functions, and because the mean square of residual was smallest in the quadratic function. The t-values of the estmated coefficients also showed the highest statistical significance for the quadratic function. The Durbin-Watson test was indecisive for all the functions estimated.