Farm level cost of reducing nitrate leaching by economic instruments in Croatian farming systems.

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Abstract

Croatian farming systems have become more intensive in recent years. There is some evidence of rising NO_3-N-levels in ground water. The aim of the paper is to find possible ways of preventing NO_3-levels to rise in Croatian farming systems and their implications from the viewpoint of the manager. More specifically the purpose is to 1. Determine whether Croatian farmers exceed profit maximising levels of N-fertiliser use in maize cultivation and possible influence on NO_3-N-levels. 2. To estimate the marginal abatement cost (MAC) at farm level of reducing NO_3-N leaching through following economic instruments: a tax on optimal N-doses, a product tax and a N-fertiliser quota, all instruments corresponding to the same abatement level. Based on N-response experiments from field trials for maize N-response curves were derived. A sample of 20 family farms was used to calculate intensity, nutrient content in manure and the prices paid for N and obtained for maize. Profit maximising doses from the field trials were compared with nutrient use on farms. An effluent production function was estimated based on experiments with NO_3-N contents in lysimeter water for the same treatments as in the N-response experiments. The results indicate that farmers use higher than optimal levels of N-fertilisers, if the technology and conditions of experimental fields could be applied on the farms and if manure is accounted for. Neglecting the N-content of the manure shows close to optimal nutrient levels. At profit maximising levels the NO_3-N level is approximately 14 mg NO_3-N/l (62 mg NO_3/l) or clearly higher that the critical level stipulated by the nitrate directive (11.3 mg NO_3-N/l or 50 mg NO_3/l). If the N-content in the manure is taken into account the estimated NO_3-N/l level in groundwater is about twice higher than the critical level stipulated by the Nitrate Directive. Through any of the three instruments a 76% NO_3-leaching reduction could be obtained. However, it was concluded the quota has the lowest MAC (4.08 €/mg NO_3-N/l or 0.92 €/mg NO_3/l), followed by the N-fertiliser tax (16.16 €/mg NO_3-N/l or 3.65 €/mg NO_3/l) and the product tax in third place (41.25 €/mg NO_3-N/l or 9.32 €/mg NO_3/l). Management practices that may increase yield level and correspondingly NO_3-leaching in the short and long run were identified. One way to achieve a quick improvement would be a system of cross compliance stipulating a code of good agricultural practices.

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CONTENTS

1. INTRODUCTION

Non-point source pollution of nitrogen (N) from agriculture is a major cause of water quality problems. Excessive levels of N-fertilisation may increase of nitrate (NO_3)-leaching. The negative effects of excessive N-leakage are well documented: N is a plant nutrient which causes eutrophication and, consequently, algal bloom and possible death of fish and other aquatic life. Rising NO_3-levels in drinking water is another principal side effect, or externality. N in the form of NO_3 is easily soluble and is transported in runoff, in tile drainage and with leakage. In many places of Europe and North America excessive N-application may cause water problems (Griffin and Bromley 1982, Andréasson 1990, Hanley 1990, Sumelius 1994, Vatn et al. 1996, Vatn et al. 1997, Blekken and Bakken 1997, Jansson 1997, van der Bijl and van Zeijts 1999, Granstedt 2000, Shortle et al. 2001).

Intensification of farming systems through increased nutrient use is one reason to surface water and ground water pollution and water quality impairment in USA (Yadav et al. 1996, Ribaudo 2001, Shortle 1996). Also in Europe clear evidence exists that increased fertiliser use may contribute to water pollution of both surface and groundwater (Gren et al. 1997, Hanley 2001, Brouwer and Hellegers 1997, Goodschild 1998, De Clerc et al. 2001). Increased concern that NO_3-leaching was becoming a big problem led to the Nitrate Directive addressed to the EU member states in 1991. The main objective of the Nitrate Directive is to reduce water pollution caused or induced by nitrates from agricultural sources and to prevent further such pollution. The Nitrate Directive recognises groundwater containing more than 50 NO_3/l as being situated in vulnerable zones (Directive 91/676/EEC). This corresponds to 50 mg/l * 0.226 = 11.3 mg/l NO_3-N (pure N). The conversion factor 0.226 is based upon the atomic weights of N and oxygen (O). In some European countries a stipulation of a maximum amount corresponding to 170 kg N/ha to be spread in manure has been adopted (De Clerck, et al. 2001). Economic instruments for preventing NO_3-leaching are taxes and quotas. A review on experiences with fertiliser taxes in Europe has recently been published (Rougoor et al. 2001). Evidence of high nitrate levels also in the Central and Eastern European Countries exist (Zellei, 2001).

Although Croatian farming systems are as intensive as in some Western European countries, rising NO_3-levels is becoming a concern. There is an increasing hazard of surpassing the critical level of NO_3- in drinking water in some areas. This concerns especially areas with shallow aquifers. In such cases a strong correlation between amount of applied N-fertilisers and NO_3-levels in ground water can be expected. There are recent data that indicate on contamination of wells in family farms, while the majority of households in this rural area don't use the public waterworks for drinking.

A general aim of the article is to discuss possible ways of preventing NO_3-levels to rise in Croatian farming systems and their implications from the viewpoint of the manager. The first specific objective of this study is to determine whether Croatian farmers exceed profit maximising levels of N-fertiliser use in maize (*Zea mays*) cultivation. If this is the case, farmers may either reduce intensity in order to increase profitability, or find the other critical factors or management practices of the farming system that limits the yield level. Such adjustment of agricultural practices in, maize production would result in a better utilisation of N and, consequently, reduced amounts of NO_3-levels in groundwater. On the other hand, if farmers optimise the N-fertiliser use there will be real, farm level cost of reducing intensity. A second specific objective is to estimate the marginal abatement cost at farm level of reducing through following economic instruments: a tax on optimal N-doses, through a product tax or through a fertiliser quota.

The paper starts with determination of economically optimal N-doses on the basis of field experiments (56 observations) with maize based on first and second order conditions for profit maximisation. Actual N-fertiliser use on the farms are compared with the calculated optimal N-doses on actual farm level (a sample of 20 farms surveyed). Profit maximising N-doses are then calculated based on first-order-conditions for profit maximisation. Second, the effects of a change in fertiliser intensity on leaching of NO_3 have to be established. In order to establish this relation a leakage function is estimated based upon Croatian lysimeter experiments 1996-1999. The effects on NO_3-N-leaching through a change in optimal fertiliser intensity are approximated through this leakage function. Third, the cost for farmers of implementing a 50 % fertiliser tax, a 100 % product tax and a quota corresponding to these taxes are calculated. The farm level cost of implementing such economic instruments is called an abatement cost. The marginal reduction in NO_3-N-leaching and the marginal change in gross margins are calculated in order to estimate the marginal abatement cost (the marginal net profit change of reducing one kg of nitrate). Finally, conclusions are drawn and recommendations made for Croatian agriculture in order to reduce the threat of rising NO_3-levels in groundwater.

Intensive application of mineral fertilisers is one reason for excessive leakage. A rational application of mineral fertilisers from ecological and economic point of view requires experiments on fertilisers, yield increase and leakage to be implemented and used as a basis for educating farmers about an ecologically acceptable way of applying fertilisers. According to some Croatian experimental studies involving lysimeters (Tomic et al. 1997, Romic et al. 1997), NO_3-N-concentrations in the percolate vary considerably, with total N-losses up to 157.6 kg N/ha. Differences in N-losses are influenced by soil properties, N-rates applied, crop type, precipitation, and in some cases by mulch type. According to the results of Vidacek et al. (1996), NO_3-concentration in lysimeter water may vary from 1 to 261 mg/l of NO_3 if common mineral N-rates are applied. In Croatia, Simunic et al. (1997) studied the NO_3- and NH_4-concentrations in drainage water. The lowest values of leached NO_3 were recorded just before the seeding and fertilisation, viz. 11.7 to 27 mg/l of drainage water. The highest values were recorded in September primarily owing to extremely high precipitation in that month. Concentrations of leached NO_3 were much above the tolerated 50 mg/l (57 to 107.8 mg/l NO_3). Klacic et al. (1998) studied the effect of different pipe drainage distances upon the concentration and quantity of N leached in winter wheat production on hydromorphic soils of Sava River valley. Depending on the pipe drainage distance leached N ranged from 11.0 to 21.7 kg N/ha. About 56 % of total leached N originated from fertilisers added in basic and pre-seeding soil preparation. Results of these investigations substantiate the importance of investigating the influence of different N-rates upon its leaching in the agro-ecological conditions of Croatia, notably in regions where intensive agricultural production is practised.

2. MODEL

Crop nutrients doses, especially the pure N-dose, will have a great impact on production and economic results in wheat and maize production. In case a farmer use excessive levels of N-fertilisers this will result in an additional economic cost for him. In addition, the likelihood of N-leaching will increase. Here we assume that the experimental conditions can be considered as "suggested production way". Starting from the assumption of profit maximisation, the profit function can simply be written as.

$$\pi = p_i f\left(x_n, x_1 \ldots x_z, s, r\right) - w x_1 \qquad (1)$$

where y = production, x_i = production inputs except N-input *(i = 1, 2,. .., z-1,z)*, x_n = N-input (N from both artificial fertilisers and manure) s = soil, r = precipitation and w= price of input i. Based on experimental conditions we calculate the profit-maximising levels of N-fertilisers as following: We assume the farmer knows his production function with full certainty. Keeping soil and precipitation as well as all other inputs (x_i) except the N input (x_n) constant, the profit maximising level of the input x_n is given by the first-order conditions (FOC)

$$\partial\pi / \partial x_n = \partial pf\left(x_1 \ldots x_n, s, r\right) / \partial x_1 - \partial w_1 x_1 / \partial x_1 = 0 \qquad (2)$$

$$\partial\pi / \partial x_n = p\, \partial f\left(x_n\right) / \partial x_n - w_1 = 0$$

$$\partial f\left(x_n\right) / \partial x_n = w_1 / p$$

which is a standard result from economic textbooks. Based on this simple model it possible to determine whether farmers use excessive levels of fertilisers. According to data on areas sown by wheat and maize on farms of similar size and production as in the survey from the Lonja field area, it is possible to calculate the yield N- surplus.

We also assume the production function y is concave and homothetic. It is argued that this case represents the most typical production function. We then denote the production function of the effluent (i.e. the NO_3-leakage function or the non-point production function) as $z = g(x, s, r)$, where z = NO_3-leakage kg/ha and x = N- fertilisation kg/ha. The effluent production function is assumed to be convex, i.e. exhibits increasing returns to scale at medium or high intensity levels. This implies that the leakage is low at initial input levels, but increase proportionally more than the input increase. According to the definition of non-point pollution, the leakage function is not known. However, an effluent production assumed to be representative of the leakage can be estimated (Griffin and Bromley 1982, Stevens 1988, Ribaudo and Shortle 2001). If s and r are kept constant in this effluent production function, the effects of increasing or decreasing x can be estimated. From the effluent production function $z = g(x, s, r)$, we can eventually calculate the reduction of NO_3-leakages.

Comparing profit maximising levels of N-fertilisation from field experiments with the fertiliser levels actually used by farmers in Croatian wheat and maize production gives us an idea about possible surpluses of N. By estimating the effluent production function we can also approximate the potential N-leaching through application of profit maximising N-doses. If farmers are profit maximisers they optimise the N-input. Since we also are interested in how to decrease these surpluses through economic instruments we need to deepen the analysis. This is possible through an examination on the one hand of the production function, which describes the relation between N-fertiliser input and yield, and on the other hand the effluent production function which described the relation between N- fertiliser input and NO_3-leakage.

We assume the farmer knows his production function with full certainty; $y = f(x_1 ... x_n, s, r)$.

The profit function can also be written as a restricted profit function (Varian 1992, p. 26)

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

where $\pi =$ profit

$p =$ price of y

$f(x) =$ production function

$x_n =$ quantity of $\mathrm{N}-$fertilisers applied

$w =$ price of $\mathrm{N}-$fertiliser input

The profit function $\pi(p,w)$ is the indirect objective function of the farmer. Its value is always the maximum value of profits given w and p when the profit maximising levels of input x_n* have been substituted back into the profit function. If we want to evaluate how maximum profits varies when w changes we must differentiate the indirect profit function (Silberberg 1990).

Differentiating (3) with respect to w according to Hotelling's lemma gives

$$\frac{\partial \pi *}{\partial w} = p\left(f \frac{\partial x_n *}{\partial w}\right) - w\left(\frac{\partial x_n *}{\partial w}\right) - x * \qquad (4)$$

However, the term $\left(\frac{\partial x*}{\partial w}\right)$ is zero. Therefore

$$\frac{\partial \pi *}{\partial w} = - x_n * = \frac{\partial \pi}{\partial w} \qquad (5).$$

Assume a financial incentive or economic instrument, denoted k, corresponding to a 1. N-fertiliser tax 2. a product tax 3. a non-uniform fertiliser quota.

If k is a fertiliser tax, (1) can be written as

$$\pi(p, w) = pf(x_n) - w(1 + k)x_n, \qquad (6)$$

and correspondingly, if k is a product tax, as

$$\pi(p,w) = p(1 - k)f(x_n) - wx_n. \qquad (7)$$

Finally, if *k* is a quota, (1) should be written as

$$\pi(p,w) = pf\left(\overline{x_n}\right) - w\overline{x_n}. \qquad (8)$$

Differentiating (6) with respect to input x_n and taking the first order conditions for profit maximisation will give

$$\partial\pi/\partial x_n = pf'(x) - w(1+k) = 0, \qquad (9)$$

or

$$f'(x_n) = \frac{w(1+k)}{p} \qquad (10)$$

Correspondingly, if the incentive is a product tax, differentiating (7) with respect to input *x* and taking the first order conditions will give

$$\partial\pi/\partial x_n = p(1-k)f'(x_n) - w = 0, \qquad (11)$$

or

$$f'(x_n) = \frac{w}{p(1-k)} \qquad (12)$$

In the case of a N-fertiliser quota per hectare of land, $\overline{x_n}$, the optimisation problem of the farmer can be written as a constrained maximisation problem, i.e. maximise the Lagrangian

$$L = pf(x_n) - wx + \lambda\left(\overline{x} - x_n\right) \qquad (13)$$

subject to

$$\partial L/\partial x_n = pf'(x) - w - \lambda = 0 \qquad (14)$$

or

$$f'(x_n) = \frac{w+\lambda}{p} \qquad (15)$$

In other words, comparing instruments (1), (2), and (3) is equal to comparing (10), (12), and (15) in a situation where $wk = pk = \lambda$.

Profit maximising input levels will adjust to a new level $x_n^f{*} = x(p, w, (w+k))$ in the case of fertiliser taxes, and to $x_n^p{*} = x(p, (p-k), w)$ in the case of product taxes. We denote $w_1^k = (w+k)$ and $p_1^k = (p-k)$. In the case of fertiliser taxes, the effluent production function can now be written as

$$z = g\left(x_n\left(p,\, w,\, w_1^k\right), s,\, r\right) \qquad (16)$$

and the effects of the fertiliser taxes on the leakage will be

$$\partial z / \partial k = \partial g\left(x_n\left(p, w, w_1^k\right)\right) / \partial k \qquad (17)$$

Correspondingly, the effects of the product taxes on the leakage will be

$$\partial z / \partial k = \partial g\left(x_n\left(p, p_1^k, w\right)\right) / \partial k\ . \qquad (18)$$

The marginal abatement cost *MAC* for the fertiliser taxes will be

$$MAC = \frac{\partial\left(pf\left(x_n\right) - w_1^k x_n\right) / \partial k}{\partial g\left(x_n\left(p,\, w,\, w_1^k\right)\right) / \partial k} \qquad (19)$$

In a similar way, the *MAC* for the product taxes will be

$$MAC = \frac{\partial\left(p_1^k f\left(x_n\right) - w x_n\right) / \partial k}{\partial g\left(x_n\left(p, p_1^k, w\right)\right) / \partial k} \qquad (20)$$

and for the fertiliser quota

$$MAC = \frac{\partial\left(pf\left(x_n\right) - w x_n + \lambda\left(\overline{x_n} - x_n\right)\right) / \partial x_n}{\partial g\left(\overline{x_n} - x_n\right) / \partial x_n} \qquad (21)$$

To put it more simply, the *MAC* for reducing leaching by applying financial incentives is equal to the relation between marginal profits lost and the marginal amount of reduced NO_3-N-leakage. The *MAC* in (19), (20), and (21) takes the costs of change in intensity level of the firm as the criteria for measuring the cost efficiency of reduced NO_3-N-leakages. It is different from a social efficiency measurement.

In order to estimate (19), (20) and (21) assumptions concerning the forms of the production functions and the effluent production function need to be made. Polynomial forms of the production functions (quadratic and square root) have often been assumed for describing the N-response e.g. by Heady and Dillon (1961), Heikkilä (1980), Laurila, (1992**),** Bakken and Romstad (1992). However, some authors have questioned the use of polynomial functions Anderson and Nelson 1975, Lanzer and Paris (1981) and Paris (1992) have indicated that the quadratic function may lead to excess estimate of the profit maximising N-use level. Lanzer and Paris (1981 as well as Frank et al. (1990) have advocated the use of the Mitscherlich function instead of polynomial functions. The main argument is that this functional form is logically in accordance with the von Liebig´s “law of the minimum”. According to this law, a crop yield is a proportional function of the scarcest input available.[1] A comparison between the polynomial and the Mitscherlich form of the N-response has also been carried out in a number of other studies (Sumelius 1993, Bäckman 1997). In this study quadratic, square root and Mitscherlich functions were all initially assumed. The different forms of this function and corresponding FOCs are presented in Table 1.

Table 1: Alternative functional forms of the N response curve

Functional form		FOC
Quadratic function	$y = \beta_0 + \beta_1 x_n + \beta_2 x_n^2$	$x_n^* = \dfrac{\frac{w}{p} - \beta_1}{2\beta_2}$
Square root function	$y = \beta_0 + \beta_1 x_n^{\frac{1}{2}} + \beta_2 x_n$	$x_n^* = \left[\dfrac{\frac{w}{p} - \beta_2}{\frac{\beta_1}{2}}\right]^{-2}$
Mitscherlich function	$y = m(1 - ke^{-\beta x_n})$	$x_n^* = \dfrac{ln\left(\frac{pmk\beta}{w}\right)}{\beta}$

How can an appropriate effluent production function (NO_3-N-leakage function) be chosen? One could think that NO_3-leaching is an increasing function of increasing N-input levels in grain production. As pointed out by Vatn et al. (1996) the NO_3-leaching function is initially decreasing for very low levels of N (below 3 g N/m^2). The explanation is that if yield growth is low because of low N-input it will prevent nutrient uptake. As pointed out by the same authors this decline may be of academic interest only, since grain cropping without fertilisers is relatively rare. At levels above 6 g N/m^2, the NO_3-leaching is seen to substantially rise with increasing N-levels, with a positive second derivative. This is a starting point for choosing functional form of the effluent production function.

It is well known that several sophisticated simulation models for describing NO_3-leaching exist. Why not use a simulation model used instead of an effluent production function? In an article developing an empirical model for estimating NO_3-leaching Simmelsgaard and Djurhuus (1998) give a good argument for using leaching functions based on more simple models based on regression analysis. They argue that the more complex models in many cases are of limited use because of the high input requirements concerning climate, and chemical and physical properties of the soil. Such models are best used for research purposes and specific areas where these data re-

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[1] In case there are several inputs a von-Liebig function with Mitscherlich regimes would be advocated. Such inputs are characterised by right angle isoquants. For a test of the von Liebig hypothesis see Berck et al. 2000.

quirements can be fulfilled. In situation where actual empirical data on NO_3-leaching exist it may be enough for estimation purposes to assume a simple form of the effluent production function and estimate it. They propose a simple empirical model based on relatively few data on NO_3-leaching incorporating only short-term effects of N-fertiliser rate. The model proposed by Simmelsgaard and Djurhuus (1998) is used in a situation where existing data on NO_3-leaching is lacking, and in situations when expected values of NO_3-leaching cannot be calculated from other models. The two basic models is a based on a logarithmic regression where NO_3-leaching is the dependent variable:

$$ln(z) = \alpha_0 + crop + year(crop) + location + \alpha_1 N_r + \varepsilon \qquad (22)$$

or

$$ln(z) = \beta_0 + crop + year(crop) + \beta_1 N_r + \beta_2 ln\left(\frac{D_a}{D_{norm}}\right) + \varepsilon \qquad (23)$$

$z = \mathrm{NO_3}$ - leaching, kg $\mathrm{NO_3}$/ha per year

$N_r =$ actual N - fertilisation divided by economically optimal N - fertililisation (*1N)*

$D_a =$ drainage from the root zone, mm/year

$D_{norm} =$ average normal drainage from the root zone, mm/year

$\alpha_0, \beta_\mathrm{i} =$ the coefficients to be estimated

According to the authors the logarithmic transformation was used in order to obtain constant variance.

In this study the logarithmic transformation was dropped since no problems with a nonconstant variance could be observed. Furthermore, no data on drainage was available. However, one may argue like Vatn et al. that the NO_3-leaching is decreasing for very low levels of N. Consequently, a square root functional form would better be able to capture this fact. Therefore a model according to (24)

$$z = \alpha_0 + \beta_1 \sqrt{x} + \beta_2 x + \delta_1 D_1 +_2 D_2 + \delta_3 D_3 + \varepsilon \qquad (24)$$

where

$z = \mathrm{NO_3}$ - N, mg/l

$x =$ N - fertlisation, kg/ha

$D_1 - D_3 =$ dummies for year (4 years)

$\beta_i, \delta_i =$ coefficients to be estimated

was assumed. To be noted is that leaching is estimated in terms of NO_3-N, not in terms of NO_3. The NO_3-N-leaching and the N-response functions will be substituted back to (19), (20) and (21) in order to find the MAC. The annual dummies were included to take into account the annual variation. If the δ_i-coefficients equal zero the correct model will be the restricted model (25):

$$z = \alpha_0 + \beta_1 \sqrt{x} + \beta_2 x + \varepsilon \qquad (25)$$

The restrictions can be tested through a F-test or through a likelihood ratio test (e.g. Pindyck and Rubinfeld 1998, p. 128-130 and 275-276).

3. STUDY AREA AND DATA

The area in Croatia to be investigated is situated close to a protected nature park, Lonja field, which covers about 50,600 ha of forest, pastures and meadows. There are some signs that rising levels of NO_3 may become a problem for the nature park. The agricultural area itself consists of approximately 6,000 ha of agricultural land, About 1,600 family farms with an average size of 3.3 ha of agricultural land are engaged in agricultural production in this area. Only 10 % of farmers own more than 7.5 ha of land. The farms are receiving subsidies based on cultivated area. No cross-compliance between agronomic practices and areas subsidies exist. The level of technology is good only on a small number of farms. Farmers do not systematically monitor the quantities of nutrients in the soil, nor applying soil analysis. For primary crop, considerable deviations have been registered between actual use of nutrients on farms and experimental yields for similar quantities of applied mineral fertilisers and manure. It seems that the farms are using excessive levels of nutrients in wheat and maize production when comparing with experimental yields (Grgic and Mesic, 2001).

The most important crops in the area are maize, winter wheat, red clover, and, in some cases alfa alfa. Average yields of crops are low, despite the relative high doses of N-fertilisation, especially for winter wheat, and for maize. Because of very complex conditions in Croatian agriculture today, farmers want to have higher yields, but their knowledge about many important issues related to soil tillage, mineral and organic fertilisation, and, in general, about improvement of soil fertility, can be described as “problematic”. In most cases it is possible to speak about too narrow crop rotation, because maize and winter wheat are most important crops. According to the relation between fields under these two crops it is obvious that maize is often grown in short term monoculture.

For the purpose of this study, 20 family farms were selected on which a survey about their capacities and production was carried out. These farms are typical for production in the region. Farms which have 3-10 ha of maize and wheat production and more than 5 dairy cows were selected. The total sown area of own and rented land was on average 16 ha. For the surveyed farms the calculation of nutrient balances on farm level were calculated for all 20 farms based upon the production results in the years 1999 and 2000. The N-input in the form of artificial fertilisers was calculated and the prices paid for fertilisers were collected. All prices are expressed in values from October 2000 using the exchange rate 1 EUR (€)=7.60 kn. The average price obtained for maize was 0.75 kn/kg (0.0987 euro/kg) and 1.05 kn/kg (0.138 €/kg) wheat. In addition to the sales revenue the producers obtained an area-based subsidy equal to 700 kn/ha in maize production and 1050 kn/ha in wheat production. Maize yields in the 20 surveyed farms are from 4,332 kg/ha to 5,130 kg/ha and of maize they are from 5,130 kg/ha to 6,270 kg/ha. In wheat production the 20 farms have used from 234 to 236 kg/ha of pure N including manure, and in maize production from 206 to 230 kg/ha.

N-response experiments from field trials were used as input in determining the N-response on the farm sample. The basic N-response data from field trials with maize and winter wheat are based upon the studies of Mesic (2001). He carried out N-response experiments with maize and wheat with six different levels of fertilisation (0-300 kg/ha) and, in addition, a control treatment (zero N kg/ha) in 1996-2000. The experiments for maize were done in 1996 and 1999, for wheat 1997 ands 2000. Each year included four replications which implies 56 observation per crop.

Values of the NO_3-N-concentration in lysimeter water, and the quantity of water in lysimeters, were used to calculate the total NO_3-N loss. The lowest NO_3-N leaching in the four-year trial period was recorded in the check treatment (36 kg/ha), where crops were grown without fertilisation, and the highest in the treatment with 300 kg/ha of mineral N per year, in which 257 kg/ha of NO_3-N was leached (in four years). The quantity of NO_3-N leached in the black fallow treatment in the four trial years (90 kg/ha) was higher than in the check treatment, and in the treatments fertilised with phosphorus and potassium, combined with 0, 100 and 150 kg/ha of mineral nitrogen. Higher NO_3-N leaching than that determined in the treatment with black fallow in the four-year trial period was recorded only in treatments with 200, 250 and 300 kg/ha of mineral N (Mesic et al. 2000).

4. RESULTS AND DISCUSSION

4.1 N-response

Based on those experiments the production function of maize under the experimental conditions with different doses of N was estimated with Ordinary Least Squares (OLS) and Non-linear Least Squares using the Eview version 3.1 program. The results for the various specifications are presented as response functions N-fertiliser-yield shown in Table 2. The results for the quadratic form of the production functions show that all coefficients are significant at 1 % level measures by the *t*-test. The goodness of fit is modest showing an adjusted coefficient of determination corresponding to 0.62. The White test shows that the assumption of homoskedastic errors cannot be rejected. The Durbin-Watson test showed no evidence of correlated errors. There is no evidence that the central assumptions behind OLS would not be in accordance with estimated results.

The square root function also fits the data well. The main exception compared with the quadratic form is that the third coefficient β_2 is not significant. The goodness of fit is similar to the quadratic form. According to the White test there is no reason to believe in the existence of heteroskedasticity. The Durbin-Watson test does not indicate first order autocorrelation. In total, the polynomial forms for estimating the N-response for maize do seem to work out well.

The goodness of fit for the Mitscherlich function is similar to the quadratic form. According to the White test there is no reason to believe in the existence of heteroskedasticity. The Durbin-Watson test does not indicate first order autocorrelation. The coefficients are all significant, however the coefficient describing the N-response at 5 % significance level.

In sum, all three functional forms seem to do well with describing the N-response for maize. The goodness of fit is almost identical. The response functions estimated by OLS for maize seem to be satisfying. Estimating Mitscherlich functions with non-linear least squares gave satisfactory results with respect to heteroscedasticity and autocorrelation as well. Since the Mitscherlich functional form seems to be best justified from theoretical point of view this form of functional form was given first priority.

Table 2: OLS and Non-linear Least Squares estimation results for maize[1]

Quadratic function $$y = 54.9450 + 0.2914x_n - 0.0005x_n^2$$
$$(17.153) \quad (5.411) \quad (-2.775)$$

$\text{Sample size} = 40$

$\text{Adjusted } R^2 = 0.6247$

$\text{logL}: -221.617$

White heteroskedasticity test : F - statistic 0.3474

$\hat{\sigma} = 13.014$

Square root function $$y = 55.0666 + 2.6256x_n^{\frac{1}{2}} - 0.0073x_n$$
$$(16.722) \quad (2.472) \quad (-0.112)$$

$\text{Adjusted } R^2 = 0.6146$

$\text{logL}: -222.370$

White heteroskedasticity test : F - statistic 0.2622

$\hat{\sigma} = 13.188$

Mitscherlich function $$y = 103.3900(1 - 0.4680\exp(-0.0071))$$
$$(10.4370) \quad (8.3891) \quad (-2.1000)$$

$\text{Adjusted } R^2 = 0.6213$

$\text{logL}: -221.875$

White heteroskedasticity test : F - statistic 0.4953

$\hat{\sigma} = 13.074$

1) Figures in parenthesis are the *t*-values of corresponding estimates

Estimating polynomial response functions for wheat gave somewhat different results. Heteroscedasticity was found a problem when using OLS. In order to find a remedy against heteroscedasticity response functions for winter wheat Weighted Least Squares (WLS) were applied, using yields as a weighting series. According to the White test heteroscedasticity remained a problem for estimating response functions for winter wheat in the WLS-model. Nonlinear least squares applied to the wheat data did not solve the heteroscedasticity problem. Therefore it was decided to drop the winter wheat response function from the analysis.

The optimal fertiliser levels for profit maximisation stipulated by the first order conditions of profit according to (2) for different the functional forms are summarised in Table 3. The prices used in the calculation, kn/kg maize 1.02 (€/kg maize 0.134) and kn/kg N 7.62 (€/kg N 1.00) were the prices the producers received in October 2000 according to the farm survey.

Table 3: Profit maximising fertliser doses for maize, corresponding yield level and impact on doses of a 100 % fertiliser tax or 50% product tax

Functional form	Profit-maximising fertiliser doses, kg/ha according to prices of October 2000	Yield, kg/ha	Return-fertiliser cost, €/kg/ha	Profit maximising fertiliser doses, kg/ha when 100% N-fertiliser tax or 50% product price tax
Quadratic	185.0	9,130	715	86
Square root	145.3	8,565	700	39
Mitscherlich	171.7	8,904	707	74

Second order conditions for a maximum were satisfied in all cases. Since the Mitscherlich function is the one best motivated on theoretical grounds one might believe that the profit maximising dose in maize production is around 172 kg N/ha in maize production and the corresponding yield level would be 8,904 kg maize/ha. The farmers in the surveyed sample used N-fertiliser doses in the interval between 206 kg N/ha and 230 kg/N ha when the manure is taken into account. In other words, the Croatian farmers in this sample seem to use higher levels of N than optimal if the N in manure is taken into account. If only N in artificial fertilisers would be taken into account (161 kg N/ha) farmers used a N-input close to optimal level. However, the yield level achievable at profit the maximising intensity level in experimental conditions is about 3,100-3,800 kg/ha higher than the maize yields in sample (5,130-5,814 kg/ha). One can therefore conclude that the use of N- fertilisers and manure on the farms studied does not result with adequate yields. It seems like other factors than nutrient input are constraining the yields. Therefore, farmers could try to influence these critical factors. Alternatively, reducing the nutrient intensity may be sensible from environmental point of view.

Changing the functional form changes the optimal N-fertiliser doses and corresponding yields somewhat, but the conclusions are the same. Enforcing a N-fertiliser tax of 100 % or a product tax of 50 % would decrease the profit maximising dose with about 100 kg N/ha. The profit maximising doses in the case of a 100 % N-tax is on a 98 kg N/ha lower level. The yield level would decrease by 1,434 kg/ha and gross margin by 43 €/ha in case such a tax was to be implemented.

One might add that efforts to estimate reliable N-response curves for winter heat were abandoned due to problems with heteroscedasticity in the data. No N-response functions have therefore been reported here. However, the N-response functions for wheat indicated same trends as those for maize.

4.2 *Effluent production function*

The leakage function was estimated in its unrestricted (24) and restricted form (25). The restrictions of the model (25) were tested. It was found the H_0 of the dummies being zero could not be rejected according to the F-test or the log likelihood ratio. The estimated leakage function therefore should not include dummies. The estimation result of the NO_3-N-leakage function according to (25) is presented in Table 4.

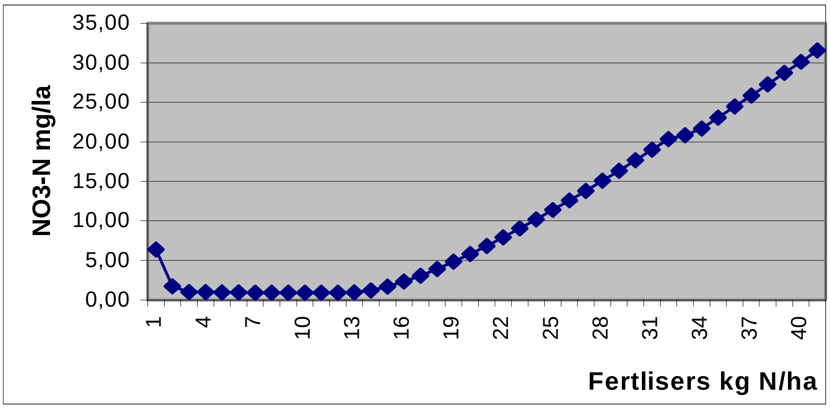
Table 4: Estimation results for the NO_3-N-leaching function

$$z = \alpha_0 + \beta_1 \sqrt{x} + \beta_2 x$$

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
α_0	6.396	1.835	3.486	0.0013
β_1	-2.124	0.692	-3.071	0.0040
β_2	0.207	0.043	4.834	0.0000
R-squared	0.697			
Adjusted R-squared	0.68			
Standard error of regression	6.360			
Log likelihood	-129.201			
Durbin-Watson statistic	1.628			
F-statistic	1.4307			0.2509
Log likelihood ratio	4.755247			0.1906
White Heteroskedasticity Test:				
F-statistic	2.060			0.107
Obs*R-squared	7.823			
	0.106			

All estimated coefficients are highly significant (significance level of 1 % or better). Goodness of fit in the pooled data was rather good as indicated by the adjusted coefficient of determination 0.68. The assumption of homoscedastic errors could not be rejected on the basis of the White test. First-order autocorrelation was not detected based on the Durbin-Watson test. The estimated restricted leakage function is presented in Figure 1.

Figure 1: The estimated restricted leakage function, leached NO_3-N mg/l



Altering the functional form of the N-response function of maize changes the values of leached NO_3-N a little. The profit maximising doses stipulated by the square root form changed nitrate leaching to 10.3 kg NO_3-N/ha and the corresponding doses for the quadratic form resulted in NO_3-N leakage of 15.7 kg NO_3-N/ha.

4.3 *Marginal abatement costs*

Estimating the marginal abatement cost according to equation (19)-(21) will show us what the marginal abatement cost on farm level is for implementing economic instruments. The estimated different MACs for NO_3-N and for NO_3 are shown in Table 5. Conversion of NO_3-N to NO_3 is obtained by multiplying the former with a conversion factor of 4.427. The N-response curve for yields is based on the Mitscherlich specification.

Table 5: Marginal abatement cost of economic instruments, Euro/mg NO_3-N/l and Euro/mg NO_3/l

	N-fertiliser tax	**Product tax**	**Quota**
Reduction in gross margin	172.11	439.39	43,43
Reduction in leaching NO_3-N/l	10.65	10.65	10.65
Reduction in leaching NO_3/l	47.16	47.16	47.16
MAC = Reduction in gross margin/reduced mg NO_3-N/l	16.16	41.25	4.08
MAC = Reduction in gross margin/reduced mg NO_3/l	3.65	9.32	0.92

A 100 % N-fertiliser tax or a 50% product tax will lead to reduced NO_3-N-leaching of 10.65 mg NO_3-N/l or 47.16 mg NO_3/l. The MAC for the N-fertiliser tax would be 16.16 €/mg NO_3-N/l (3.65 €/mg NO_3/l). For the product tax the MAC would be 41.25 €/mg NO_3-N/l (9.32 €/mg NO_3/l). Corresponding MAC for a quota of 10.65 mg NO_3-N/l is stipulated by (21). The costs for this reduction will be only 4.08 €/mg NO_3-N/l (0.92 €/mg NO_3/l). Of the economic instruments analysed, the quota therefore has the lowest MAC, followed by a N-fertiliser tax and a product tax in third place. The order of the instruments is hardly surprising. The magnitude of the difference is, however, big. The relative order of the instruments is not dependent upon specification of the N-response function.

To observe is that the MAC calculated only takes into account the farm level cost of reduced NO_3-leaching. No monitoring costs for authorities in order to administer such economic instruments have been taken into account. No efforts to estimate the net social benefits from a reduction of NO_3-leaching have either been done.

5. CONCLUSIONS

1. Profit maximising levels of fertilisation in maize production were estimated to be in the range of 145-185 kg N/ha depending upon specification of the crop response when the prices for maize and N in the sample were used. Using the theoretically and empirically best function lead to profit maximising N-fertiliser dose of approximately 172 kg N/ha. NO_3-N levels in waters at this intensity level were estimated to 14.03 mg NO_3-N/l or 62.11 mg NO_3/l. This is a level above the critical level stipulated by the nitrate directive (11.3 NO_3-N/l or 50 mg NO_3/l). The average N applied by farmers as artificial fertilisers, 160.56 kg N/ha, were close to this level. If the N included in the manure is taken into account total N-fertilisers are higher, or 206 to 230 kg N/ha. The corresponding estimated NO_3-N/l level in groundwater is 18.46 mg NO_3-N/l - 21.69 mg NO_3-N/l (81.71 mg NO_3/l - 96.02 mg NO_3/l) or about twice higher than the critical level mentioned in the Nitrate Directive. It can be concluded that farmers use higher N-doses than optimal if the N-content of manure is taken into account. If N-content of manure is not observed, farmers use close to profit maximising levels of N-fertilisers. The amount N-content in only manure is well below the 170 kg N/ha.

2. The possible yield level obtained in experimental conditions at profit maximising N-intensity level is 8,904 kg maize/ha or 3,100-3,800 kg/ha higher than on the sample farms. The use of mineral fertilisers and manure on the sample farms does not seem to lead to adequate yields. The excess of the nutrients is susceptible for leaching and unnecessarily burdens surface and underground waters of the area, what can cause considerable long-term effects. If the Nitrate Directive is taken as the norm, measures to decrease the NO_3/l level are needed.

3. One way to try to influence the nitrate teaching is through applying economic instruments, which reduce NO_3-N-leaching. In the study three economic instruments for reducing NO_3-N-leaching were analysed: a fertiliser tax, a product tax and a fertiliser quota corresponding to both these taxes. A 100% N-tax or a 50% product tax would reduce profit maximising N-doses to around 74 kg N/ha (i.e. a reduction of 98 kg/ha) and nitrate levels from 14.03 mg NO_3-N/l to 3.38 mg NO_3-N/l (approximately from 62.11 mg NO_3/l 14.95 mg NO_3-/l). This is a reduction of 10.65 mg NO_3-N/l or 47.16 mg NO_3-/l (76% leaching reduction). It was found that a quota corresponding to that reduction level of NO_3-N/l has the lowest farm level marginal abatement cost, 4.08 €/mg NO_3-N/l or 0.92 €/mg NO_3/l. The fertiliser tax had the second lowest MAC (16.16 €/mg NO_3-N/l) and the product tax the

highest MAC (41.25 €/mg NO_3-N/l). The order was insensitive to changes in functional form of the N-response function.

4. Since yields in Croatia are relatively modest other crop husbandry practices than N-fertilisation may be the constraining factors for yield increase. If these factors could be identified an economical optimal yield level corresponding to the actual use of N might be accomplished and NO_3-N-leaching correspondingly decreased. It is likely that the technology used by farmers is not as efficient as the technology used in field trials and that, in spite of using profit maximising N-fertiliser doses, farmers will not reach the adequate level of yields in maize production. Which are the limiting factors then? They should be sought in elements relating to soil cultivation, crop protection and crop rotation. It is probably easy to identify some measures, which can be reached in relatively short period. Such measures encompasses a large range of factors; rational technical equipment and current production incentives for their use, fertilisation and liming based on soil analysis, improvement in the soil tillage system, changes in crop rotation with higher proportion of leguminous plants, proper drainage, change in the system of support for producers and applying adequate technological procedures harmonised with soil management. Other measures will take longer time. Longer term changes would need to focus on determination of basic indicators of soil sustainability in the area, as well as determination of real production capacities and a favourable production allocation according to principles of soil sustainability. If these agronomic principles would be applied in practice the current N-level would be used is a more rational way.

5. In order to achieve quick results a system of cross compliance stipulating a set of crop management practices in order to obtain the current area based subsidy might be quick way to achieve environmental and agronomic improvement. A code of good agricultural practices would include reduced tillage, crop rotation, choice of proper varieties for maize and wheat, observation of nutrient content in manure and proper plant protection. The current institutional structure is well suited for such a system.

6. Finally, there is no special responsibility of the support users for consistent fulfilment of technological procedures according to instructions of the advisers from the Extension Service, which considerably diminishes the efficiency of the state support service. From the agronomic point of view it is necessary to educate farmers about importance of fertilisation based on soil analysis. Scientific and research activities should be oriented toward detailed determination of the basic indicators of soil sustainability in this area, and determination of the real production capacities harmonised with requirements of the sustainable soil management. Results of detailed long period research suggest there is a need of creating a computer model, based on contemporary scientific and professional practice and methodology to determine the impact of agricultural production on surface and ground waters. The model should also produce a favourable allocation of production for utilisation of the area due to soil sustainability principles and of keeping the population in this rural area.

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