MARGINAL ABATEMENT COSTS FOR REDUCING LEACHING OF NITRATES IN CROATIAN FARMING SYSTEMS

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ABSTRACT

The aim of this paper is to identify optional ways of preventing NO_3-levels from rising within Croatian farming systems, and the 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 its possible influence on NO_3-N-levels. 2) To estimate the marginal abatement cost (MAC), at the farm level, of reducing NO_3-N leaching through the following instruments: a tax on optimal N-doses, a product tax and an N-fertiliser quota and a requirement for all instruments to correspond to the same abatement level. Based on. N-response experiment from feld trial for maize N-response curves were estimated. A sample of 20 family farms was used for calculating 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 the use of nutrients on farms. An effluent production function was estimated based on experiments with NO_3-N contents in lysimeter water for the same treatment levels as those in the N-response experiments. The results indicate that farmers use higher than optimal levels of N-fertilisers, if the manure is fully accounted for. In this case the estimated NO_3-N/l level in groundwater is 162-192 % higher than the critical level stipulated by the Nitrate Directive. Neglecting the N-content in manure shows close to profit maximising nutrient levels . At this fertlising level the estimated NO_3/l is approximately 62 mg NO_3/l or clearly higher that the critical level stipulated by the nitrate directive (50 mg NO_3/l). Through any of the three instruments a 76% NO_3-leaching reduction could be obtained. It was concluded, however, that the quota has the lowest MAC (0.92 euro/mg NO_3/l), followed by the N-fertiliser tax (3.65 euro/mg NO_3/l), and the product tax comes in third place (9.32 euro/mg NO_3/l). Management practices that may increase yield levels, and correspondingly NO_3-leaching in the short and long run, were also identified. One way to achieve a quick improvement might be a system of cross compliance, stipulating a code of good agricultural practices.

JEL classification codes*:* Q12, Q25
Keywords: Marginal abatement cost, N-response, Nitrate Directive, Taxes, Effluent production function, Croatia.

INTRODUCTION

Non-point source pollution of nitrogen (N) from agriculture is widely known as a major cause of water quality problems. Excessive levels of N-fertilisation may increase 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 the possible death of fish and other aquatic life. Another principal side effect, or externality is rising NO_3-levels in drinking water. N, in the form of NO_3, is easily soluble and is transported in runoff, in tile drainage and with leakage.

In many places within 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 that there is surface water and ground water pollution, as well as water quality impairment in the USA (Yadav et al. 1996, Ribaudo 2001, Shortle 1996). In Europe as well, clear evidence exists that increased fertiliser use may contribute to the pollution of both surface and groundwaters (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 significant problem led to the Nitrate Directive, which was addressed to the EU member states in 1991. The main objective of the Nitrate Directive is to reduce water pollution caused or induced by the nitrates that come 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). The two primary conomic instruments for preventing NO_3-leaching are taxes and quotas. A review of experiences with fertiliser taxes in Europe has recently also been published by Rougoor et al. (2001). Evidence of high nitrate levels in Croatia and other Central and Eastern European Countries exists as well (Tomic et al., 1997, Romic et al., 1997, Klacic et al. 1998, Zellei, 2001, Zellei et al. 2002).

One general aim of this article is to find possible ways of preventing NO_3-levels from rising in Croatian farming systems, and considering their implications from the viewpoints 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 fertiliser intensity in order to increase profitability, or find the other critical factors or management practices in the farming system that are limiting their yield levels. Such an adjustment of agricultural practices in maize production would result in a better utilisation of N and, consequently, in reduced amounts of NO_3-levels in groundwater. On the other hand, if farmers optimise their N-fertiliser use there will be real, farm level cost of reducing intensity. A second specific objective of this research is to estimate the marginal abatement cost, on the farm level, of reducing NO_3-leaching through following the use of economic instruments: a tax on optimal N-doses, the use of a product tax or through enacting a fertiliser quota.

This paper is organised in the following way. The paper begins with the determination of economically optimal N-doses on the basis of field experiments (56 observations) with maize and are based on first and second order conditions for profit maximisation. This profit maximising N-dose is compared with actual N-fertiliser use on a sample of 20 farms surveyed to see whether profir maximising levels are exceeded or not. Second, the effects of a change in fertiliser intensity on the leaching of NO_3 must be established. In order to establish this relation, a leakage function is estimated based upon Croatian lysimeter experiments in 1996-1999. The effects on NO_3-leaching through a change in optimal fertiliser intensity are thereby approximated through this leakage function. Third, the cost for farmers of implementing a 50 % fertiliser tax, a 100 % product tax and a quota that corresponds 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-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.

MODEL

Doses of crop nutrients, especially the pure N-dose, will have a great effect on both production and economic results as they impact wheat and maize production. In case a farmer uses excessive levels of N-fertilisers, this excessive use will result in an additional economic cost for him. In addition, the likelihood of N-leaching will increase. Hence, we assume that the experimental conditions can be considered as a "suggested way of production ".

The profit function of the farmer can be written as a restricted profit function (Varian 1992, p. 26):

$$\pi(p,w) = \underset{X \geq 0}{Max}\, \pi = \{pf(x) - wx | y = f(x)\}, \qquad (1)$$

where π = profit

p = price of y

$f(x)$ = production function

x_n = quantity of N – fertilisers applied

w = price of 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 vary when *w* changes, we must differentiate the indirect profit function (Silberberg 1990).

Differentiating (1) with respect to *w* according to Hotelling's lemma gives

$$\frac{\partial \pi\,*}{\partial w} = p\left(f\,\frac{\partial x_n\,*}{\partial w}\right) - w\left(\frac{\partial x_n\,*}{\partial w}\right) - x\,* \qquad (2)$$

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

$$\frac{\partial \pi\,*}{\partial w} = -\,x_n\,* = \frac{\partial \pi}{\partial w} \qquad (3).$$

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

$$\pi(p,w) = pf(x_n) - w(1+k)x_n \qquad (4)$$

and correspondingly, if *k* is a product tax, as

$$\pi(p,w) = p(1-k)f(x_n) - wx_n \qquad (5)$$

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

$$\pi(p,w) = pf(\overline{x_n}) - w\overline{x_n} \qquad (6)$$

Differentiating (4) with respect to input x_n and taking the first order conditions for profit maximisation will give

$$\partial\pi/\partial x_n = pf'(x) - w(1+k) = 0, \qquad (7)$$

or

$$f'(x_n) = \frac{w(1+k)}{p} \qquad (8)$$

Correspondingly, if the incentive is a product tax, differentiating (5) with respect to input x_n and taking the first order conditions will give

$$\partial\pi/\partial x_n = p(1-k)f'(x_n) - w = 0, \qquad (9)$$

or

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

In the case of an 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

$$L = pf(x_n) - wx + \lambda(\overline{x} - x_n) \qquad (11)$$

subject to

$$\partial L/\partial x_n = pf'(x) - w - \lambda = 0 \qquad (12)$$

$$\text{or } f'(x_n) = \frac{w+\lambda}{p} \qquad (13)$$

In other words, comparing instruments (1), (2), and (3) is equal to comparing (8, (10, and (13) 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

$$z = g\left(x_n\left(p, w, w_1^k\right), s, r\right) \qquad (14)$$

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

$$\partial z/\partial k = \partial g\left(x_n\left(p, w, w_1^k\right)\right)/\partial k \qquad (15)$$

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

$$\partial z/\partial k = \partial g\left(x_n\left(p, p_1^k, w\right)\right)/\partial k \qquad (16)$$

The Marginal Abatement Cost *MAC* for the fertiliser taxes will be

$$MAC = \frac{\partial\left(pf(x_n) - w_1^k x_n\right)/\partial k}{\partial g\left(x_n\left(p, w, w_1^k\right)\right)/\partial k}. \qquad (17)$$

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

$$MAC = \frac{\partial\left(p_1^k f(x_n) - wx_n\right)/\partial k}{\partial g\left(x_n\left(p, p_1^k, w\right)\right)/\partial k} \qquad (18)$$

and for the fertiliser quota

$$MAC = \frac{\partial\left(pf(x_n) - wx_n + \lambda\left(\overline{x_n} - x_n\right)\right)/\partial x_n}{\partial g\left(\overline{x_n} - x_n\right)/\partial x_n} \qquad (19)$$

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 (17), (18) and (19) takes the costs of change in the 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 (17, (18) and (19), 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; Laurila, 1992**;** Bakken and Romstad, 1992). Some authors, however, have questioned the use of polynomial functions (Anderson and Nelson, 1975; Lanzer and Paris, 1981). Paris (1992) have indicated that the quadratic function may lead to an excess estimate of the profit maximising N-use level. Lanzer and Paris (1981) as well as Frank et al. (1990) have advocated using the Mitscherlich function instead of polynomial functions. The main argument in favor of the Mitscherlich function is that this functional form is logically in accordance with von Liebig´s "law of the minimum". According to this law, a crop yield is a proportional function of the scarcest input available. In case there are several inputs, a von Liebig function with Mitscherlich regimes would typially be advocated. Such inputs are characterised by right angle isoquants (for a test of the von Liebig hypothesis, see Berck et al., 2000). 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 the production 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	$y = m(1 - ke^{-\beta x_n})$	$x_n^* = \dfrac{ln\left(\frac{pmk\beta}{w}\right)}{\beta}$

The effluent production function (14) will influence the *MAC* in (17), (18) and (19). How can an appropriate form of the effluent production function (i.e. a NO_3-N-leakage function) be chosen? One might 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 substantially to rise with increasing N-levels, with a positive second derivative. This is a starting point for choosing the 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 instead of an effluent production function?

In an article developing an empirical model for estimating NO_3-leaching, Simmelsgaard and Djurhuus (1998) provide a good argument for using leaching functions based on more simple models that rely on the use of regression analysis. They argue that the more complex models in many cases are of limited use because of the high input requirements concerning climate, as well as the chemical and physical properties of the soil. Such models are best used for research purposes and specific areas where these data requirements can be fulfilled. In situations where actual empirical data on NO_3-leaching exists, it may be enough for estimation purposes to assume a simple form of effluent production function and then to estimate it. Simmelsgaard and Djurhuus propose a simple empirical model based on relatively few data on NO_3-leaching incorporating only the short-term effects of an N-fertiliser rate. The model proposed by Simmelsgaard and Djurhuus 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 are based on a logarithmic regression, where NO_3-leaching is the dependent variable:

$$ln(z) = \alpha_0 + crop + year(crop) + location + \alpha_1 N_r + \varepsilon \qquad (20)$$

or

$$ln(z) = \beta_0 + crop + year(crop) + \beta_1 N_r + \beta_2 ln\left(\frac{D_a}{D_{norm}}\right) + \varepsilon \qquad (21)$$

$z = NO_3$ - leaching, kg 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

α_0, β_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 (22)

$$z = \alpha_0 + \beta_1\sqrt{x} + \beta_2 x + \delta_1 D_1 +_2 D_2 + \delta_3 D_3 + \varepsilon \tag{22}$$

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. One noteworthy fact is that the leaching is estimated in terms of NO_3, not in terms of NO_3-N. The NO_3-leaching and the N-response functions will be substituted back to (17), (18) and (19) in order to find the MAC. The annual dummies were included to take into account the yearly variation. If the δ_i-coefficients equal zero, the correct model will be the restricted model (23):

$$z = \alpha_0 + \beta_1\sqrt{x} + \beta_2 x + \varepsilon \tag{23}$$

It is possible to test the null hypothesis that $\delta_1 = \delta_2 = \delta_3 = 0$ in the unrestricted model (22) through a F-test or through a likelihood ratio test (e.g. Pindyck and Rubinfeld 1998, p. 128-130 and 275-276).

STUDY AREA AND DATA

The area in Croatia were the sample farms are located is situated close to a protected nature park, Lonja field, which covers about 50 600 hectares 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 hectares of agricultural land. Approximately 1,600 family farms that are an average size of 3.3 hectares of agricultural land are engaged in agricultural production in this area. Only 10 percent of the farmers own more than 7.5 hectares of land. The farms are currently receiving subsidies based on their cultivated area. No cross-compliance between agronomic practices and areas subsidies exist. There is a high level of technology on only a few of these farms (Grgić and Mesić, 2001).

The most important crops in the area are maize, winter wheat, red clover, and, in some cases alfalfa. Average yields of crops are low, despite the relatively high doses of N-fertilisation, in particularly regarding winter wheat and maize crops. Because of the very complex conditions in Croatian agriculture today, farmers want to have higher yields, but their knowledge concerning many important issues related to soil tillage, mineral and organic fertilisation, and, in general, the improvement of soil fertility, can at best be described as "problematic". In most cases, it is possible to speak about a markedly narrow crop rotation, because maize and winter wheat are the 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 purposes of this study, we selected 20 family farms as the targets for a survey concerning their capacities. These farms are typical as regards the agricultural production in the region. Farms which have 3-10 hectares of maize and wheat production, and more than 5 dairy cows were selected. The total sown area of self-owned and rented land was on average 16 hectares. As regards the surveyed farms, the calculation of nutrient balances on a 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 by some of us. All prices are expressed in values from October 2000, using the exchange rate of 1 euro = 7.60 kuna (kn). The average price obtained for maize was 0.75 kn/kg (0.0987 euro/kg), and 1.05 kn/kg (0.138 euro/kg) for wheat. In addition to the sales revenue, the producers obtained an area-based subsidy equal to 700 kn/ha in maize production and 1,050 kn/ha in wheat production.

Maize yields on the 20 surveyed farms ran from 4,332 kg/ha to 5,130 kg/ha, and ragards maize the yields ran 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 Mesić (2001), who 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 carried out in 1996 and 1999, and for wheat in 1997 and 2000. Each year included four replications, which implies 56 observations per crop. Values of the NO_3-N-concentration in lysimeter water for the same treatment levels as those in the N-response experiments, 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. The highest in the treatment with 300 kg/ha of mineral N per year, in which 257 N kg/ha of NO_3-N was leached (in a four years time period). The quantity of NO_3-N leached in the black fallow treatment during the four trial years (90 kg/ha) was higher than in the check treatment, as well as in the treatments fertilised with phosphorus and potassium, combined with 0, 100 and 150 kg/ha of mineral nitrogen. Even higher NO_3-N leaching levels than that determined in the treatment with black fallow in the four-year trial period were recorded only in treatments with 200, 250 and 300 kg/ha of mineral N (Mesić et al., 2000).

RESULTS AND DISCUSSION

N-response

Based on those experiments, the production function (N-response) of maize under the experimental conditions with different doses of N was estimated with Ordinary Least Squares (OLS) (quadratic and square root forms) and Non-linear Least Squares (Mitscherlich form) 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 percent level measured by the *t*-test. The goodness of fit is modest, showing an adjusted coefficient of determination corresponding to 0.62. The White test demonstrates 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 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 is at a 5 percent significance level.

All three functional forms seem to do well in 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 the 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 a theoretical point of view, this type 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

$\hat{\sigma} = 13.074$

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

Estimating polynomial response functions for wheat provided somewhat different results. Heteroscedasticity was found to be 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 wheat crop 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 our analysis.

Table 3. Profit maximising fertiliser 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, EURO/KG/HA	PROFIT MAXI-MISING FERTILI-SER 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

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

Second order conditions for a maximum were satisfied in all cases. According to the Mitscherlich function the profit maximising dose in maize production is 171.7 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 was 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 an N-input close to an optimal level. Could farmers possibly increase profits by lowering the intensity level of N? This is not necessarily the case.

One possible explanation for the higher than optimal N-input is that the technology used by farmers for spreading manure do not allow them to use the N-input of manure in an efficient way. Instead only a part of the N-content in manure will be used by the plant by the time the farmers need it the most. If this is true, a rational farmer will base his fertlising decision based on the N-input artificial fertlizers. 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 in adequate yields. It seems as if factors other than nutrient input are therefore constraining the yields.

From this, it follows that farmers could choose one of two options to increase profits:
- try to influence growth factors constraining yields, and thereby utlize the N-input of both artificial fertilizers and manure more efficiently,
- Reduce the nutrient intensity. Both actions would be sensible from an environmental point of view. Changing the functional form to a quadratic or a square root form changes the optimal N-fertiliser doses and corresponding yields somewhat, but the conclusions remain the same.

Enforcing an N-fertiliser tax of 100 percent, or a product tax of 50 percent would decrease the profit maximising dose about 100 kg N/ha. The profit maximising doses in the case of a 100 percent N-tax is on a 98 kg N/ha lower level. The yield level would decrease by 1,434 kg/ha, and the gross margin by 43 euro/ha, in case such a tax was to be implemented.

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

Effluent production function

The effluent production function (leakage function) was estimated in both its unrestricted (22) and restricted form (23). The restrictions of the model (23) were tested. It was found that the null hypothesis of the dummies being zero ($H_0 = \delta_1 = \delta_2 = \delta_3 = 0$) could not be rejected, according to either 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 (23) 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 percent or better). Goodness of fit of the leakage function was rather good, given that the data was pooled, 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.

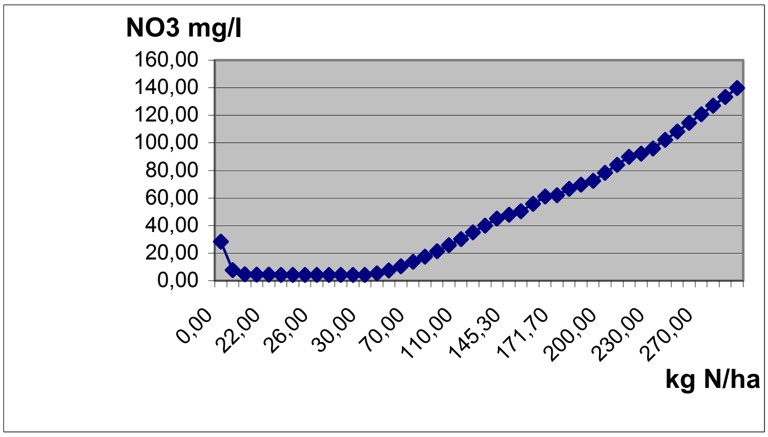

Figure 1. The estimated restricted leakage function, leached NO_3 mg/l.

The NO_3-leaching is initially decreasing, and becomes its lowest at a fertiliser input of 26 kg N/ha. At the profit maximising level of fertilisers (171.7 kg N/ha) the amount of leached NO_3-N is estimated to be 62.11 mg/l NO_3. This is a level above the critical level stipulated by the Nitrate Directive, 50 mg/l NO_3. The claim that NO_3-levels in groundwater are critically high in some areas in Croatia is confirmed by this estimate.

Altering the functional form of the N-response function of maize changes the values of leached NO_3 slightly. The profit maximising doses stipulated by the square root form changed the nitrate leaching to 47.8 kg NO_3-N/ha, and the corresponding doses for the quadratic form resulted in NO_3-leakage of 69.6 kg NO_3/ha.

Marginal abatement costs

Estimating the marginal abatement cost according to Equation (17)-(19) will show us what the marginal abatement cost on the farm level is for implementing economic instruments. The estimated different MACs 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 percent N-fertiliser tax or a 50 percent product tax will lead to reduced NO_3-leaching of 47.16 mg NO_3/l. The MAC for the N-fertiliser tax would be 3.65 euro/mg NO_3/l. For the product tax, the MAC would be 9.32 euro/mg NO_3/l. Corresponding MAC for a quota of 47.16 mg NO_3/l is stipulated by (19). The costs for this reduction will only be 0.92 euro/mg NO_3/l. Of the economic instruments analysed, the quota therefore has the lowest MAC, followed by an N-fertiliser tax, with a product tax in third place. The descending order of these instruments is hardly surprising. The magnitude of the difference is, however, quite significant. The relative order of the instruments is not dependent upon specification of the N-response function.

Another noteworthy fact is that the calculated MAC only takes into account the farm level cost of reduced NO_3-leaching. No monitoring costs for authorities have been taken into account. No efforts to estimate the net social benefits from a reduction of NO_3-leaching have been done, either.

CONCLUSIONS

Profit maximising levels of fertilisation in maize production were estimated to be in the 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 superior functional form lead to profit maximising N-doses of approximately 171.7 kg N/ha. Corresponding NO_3-levels in waters at this intensity level were estimated to 62.11 mg NO_3/l . This is an NO_3level above the critical level stipulated by the Nitrate Directive (50 mg NO_3/l). The average N applied as mineral fertilisers by farmers in the sample, 160.56 kg N/ha, was close to the estimated profit maximising N-dose. Corresponding NO_3-N levels in the water is estimated to 56.00 mg NO_3/l or slightly above the what, according to the Nitrate Directive, is defined as a critical maximum level

If one still takes into account the N-content in the manure, which farmers apply on the fields the total N-dose increases to between 206 and 230 kg N/ha depending upon farm. The corresponding estimated NO_3/l level in groundwater is between 81.71 mg NO_3/l and 96.02 mg NO_3/l, or about 1.6-1.9 times higher than the critical maximum level mentioned in the Nitrate Directive.

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 currently seem to lead to adequate yields. The excess of the nutrients is susceptible to leaching, and unnecessarily burdens the surface and underground waters of the area, which 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.

One way to try to influence nitrate leaching is by applying economic instruments, which reduce NO_3-leaching. In this 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 of these taxes. A 100 percent N-tax or a 50 percent product tax would reduce profit maximising N-doses to around 74 kg N/ha (i.e. a reduction of 98 kg/ha), and would reduce nitrate levels from 62.11 mg NO_3/l to 14.96 mg NO_3/l). This is a reduction of 47.16 mg NO_3/l (a 76 percent leaching reduction). It was found that a quota corresponding to that reduction level of NO_3/l has the lowest farm level MAC, 0.92 euro/mg NO_3/l. The fertiliser tax had the second lowest MAC (3.65 euro/mg NO_3/l) and the product tax the highest MAC (9.32 euro/mg NO_3/l). The order was insensitive to changes in the functional form of the N-response function.

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-leaching would be correspondingly decreased. It is likely that the technology used by farmers is not as efficient as the technology used in field trials, and in spite of using profit maximising N-fertiliser doses, farmers will not reach an adequate level of yields in maize production. What 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 a in relatively short time period. Such measures encompass a large range of factors; rational technical equipment and the current production incentives for their use, fertilisation and liming based on soil analysis, improvement in the soil tillage system, changes in crop rotation with a higher proportion of leguminous plants, proper drainage, change in the system of support for producers and applying adequate technological procedures in harmony with appropriate soil management. Other measures will take a longer time. Long-term changes would need to focus on the determination of basic indicators of soil sustainability in the area, as well as the 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 utilised in a more rational way.

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

Finally, there is no special responsibility for the support users to maintain a consistent fulfilment of technological procedures, according to the 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 the vital importance of fertilisation based on adequate soil analysis. Research activities should be oriented toward a detailed determination of the basic indicators of soil sustainability in this area, and determination of the real production capacities should be harmonised with the requirements of sustainable soil management. The results of detailed extended period research suggest that there is a need to create a computer model, based on contemporary science, professional practice, and methodology, in order to determine the impact of agricultural production on surface and ground waters. This model should also produce a favourable allocation of production for utilisation of the area due to soil sustainability principles, as well as maintaining the population of this rural area.

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