Integrated assessment of groundwater protection using Agricultural Best Management Practices – a nitrogen case study

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Gesamtheitliche Bewertung von Agrar-Umweltmaßnahmen hinsichtlich Grundwasserschutz – ein Fallbeispiel für Stickstoff

1 Introduction

Increasing awareness of the problems that polluted water may cause to society has led to the development of measures to reduce pollution. In the case of the pollution of water bodies by nutrients, pesticides or sediments, there is a growing focus on the prevention of diffuse pollution sources, which are mainly, but not exclusively, related to agricultural practices. A variety of technical measures to reduce non-point pollution are recognised, and these can be termed Best Management Practices (BMP).

The environmental effectiveness of BMPs in reducing water pollution has been determined not only in field trials (Stites et al., 2000; Ottman et al., 2000; Power et al., 2001), but also by means of modelling (Hopstaken et al., 1994; Wu et al., 1999; Frede et al., 2002) or the use of indicators (Osinski et al., 2003). On the other hand, many studies have focused on economic issues and the costs associated with the implementation of BMPs (Yuan et al., 2002; Wossink et al., 2002; Forster et al., 2002). Studies have also been carried out on the implementation of BMPs at the farm level, showing the complexity of farmers' environmental decision-making framework (e.g. Wilson et al., 2001; Clark et al., 1997). The European Common Agricultural Policy (CAP) gives increasing importance to environmental considerations and there are efforts to establish BMPs by means of economic incentives and voluntary contracts introduced by the agri-environmental programmes; in spite of this, BMPs are not yet being utilised in a way that guarantees sustainable protection of water bodies (Buller et al., 2000). Measures that are promising from the environmental point of view often fail due to implementation

Zusammenfassung

Für ein Kleineinzugsgebiet in Österreich wurde die Umsetzung einiger im österreichischen Umweltprogramm ÖPUL geförderten Maßnahmen zur Reduktion des Stickstoffaustrags hinsichtlich ökologischer und ökonomischer Effekte sowie deren Akzeptanz bei den Akteuren integral untersucht. Die Bewertung der ökologischen Wirksamkeit verschiedener im österreichischen Programm für die Entwicklung des ländlichen Raums (ÖPUL) geförderten Maßnahmen wurde über Anwendung eines hydrologischen Modells ermittelt, mit dem Sickerwasserraten und Nitratkonzentrationen berechnet wurden. Die Implementierungskosten der Maßnahmen wurden mit Hilfe ökonomischer Modelle ermittelt. Die Akzeptanzanalyse basierte auf spezifischen Befragungen.

Es konnte eine klare Reihung der untersuchten Umweltmaßnahmen betreffend die ökologische Effizienz und die Kosten, welche die Umsetzung der Agrar-Umweltmaßnahmen begleiten, festgestellt werden. Für den Fall des untersuchten Testeinzugsgebietes konnten die betrachteten Maßnahmen keine ausreichende Reduktion der Nitratkonzentration unter die gesetzlichen Grenzwerte bewirken. Um die Nitratkonzentration signifikant zu beeinflussen, war eine großflächige Implementierung der untersuchten BMPs notwendig. Damit zeigt sich, dass ein Ansatz zur Ermittlung kritischer Flächen für den Fall der Nitratverlagerung nur begrenzt sinnvoll ist. Dies steht im Gegensatz zu Ergebnissen, die für andere Elemente wie z.B. Phosphor erzielt wurden. Die Akzeptanzanalyse verdeutlichte hohe Erwartungen an die finanzielle Unterstützung einer Implementierung von Agrar-Umweltmaßnahmen.

Schlagworte: Nitrat, Grundwasserbefrachtung, Agrar-Umweltmaßnahmen, Kosten, optimiertes Management, Umweltwirksamkeit, Akzeptanz.

Summary

An integrated study was carried out in a small Austrian watershed to assess the environmental, economic and acceptability aspects of implementing certain Best Management Practices (BMPs) for nitrogen management. The environmental impact on groundwater pollution by nitrogen was assessed for various BMPs funded by the Austrian programme for environmentally sustainable agriculture (ÖPUL), by calculating both the amount of leakage and its nitrate concentration using hydrological modelling. Costs associated with the implementation of the different BMPs were assessed using economic modelling. The assessment of the levels of acceptance for each BMP was based on a survey methodology.

The study identified a clear hierarchy of BMPs in terms of their environmental effectiveness and associated costs. For the case area studied, the chosen BMPs currently financed by agri-environmental schemes were not able to reduce pollution below the legal standards. Relatively large areas of BMP application were necessary to influence nitrate pollution significantly. This calls into question the necessity of critical area identification for the prevention of nitrogen pollution, which is in contrast to results obtained for other pollutants such as phosphorus. The acceptability assessment revealed that farmers expect a rather high level of compensation for the expenses incurred by the agri-environmental practices.

Key words: Nitrate, groundwater pollution, agri-environmental policy, best management practice, environmental effectiveness, costs, social acceptability.

problems, economic reasons and institutional factors, or because of non-acceptance by farmers.

Furthermore, there is a need for an integrative assessment of the BMPs and for analysis of their cost-effectiveness, and information must be available both at the farm and watershed level. It is, however, the level of participation by farmers that will determine the effectiveness of any changes in practice, and there is a risk that limited adherence by farmers will lead only to marginal changes that will not ultimately address the expected effects on the environment.

Our aim in this paper is to compare different BMPs in terms of their environmental efficiency, economic cost and potential acceptance by farmers. We used as an example a small hydrologically closed unit (= watershed) in Austria and the environmental problem of nitrate loading to groundwater. The chosen BMPs are mainly part of ÖPUL 2000 (BMLFUW, 2000), the Austrian agri-environmental programme, which itself is based on EC-regulation N° 1257/99. The BMPs were selected to try to reflect different degrees of change in management intensity: from application of catch crops (BMP A); application of catch crops plus reduction in fertilisation levels (BMP B); to a complete change in land use from cropland to grassland (BMP C). We tried to combine the different factors to identify the barriers to successful adoption of best management practices to reduce nitrate loading to groundwater. The aim of this paper is therefore to describe the specific work that had to be done in order to evaluate the present and future technical, economical and social situation, and to discuss problems that arise from integration of the different scientific approaches.

2 Methodology

2.1 Description of the case study area

Data from two experimental sites were used. Data from the long-term experimental field site at Petzenkirchen were used to calibrate a nitrogen loading model. The calibrated model was then applied to the Grub experimental watershed to calculate the environmental effectiveness of various BMPs.

Petzenkirchen experimental plot

The experimental plot is located in the pre-Alpine region of the Federal Province of Lower Austria (Figure 1). It is characterised by a humid climate with a mean annual precipitation of about 700 mm and a mean annual air temperature of 9.8 °C (HYDROGRAPHISCHES ZENTRALBÜRO, 1994). The soil is a calcic cambisol with 60–100 cm fine sediments above gravel (FAO, 1998). Agricultural land use is characterised by arable farming in the river basins (mainly cereals and maize) and grassland in the hilly areas. Groundwater is about 4.5–5 m below the surface and is mainly controlled by the adjacent river Erlauf. The plots are located on the youngest terrace of this river.

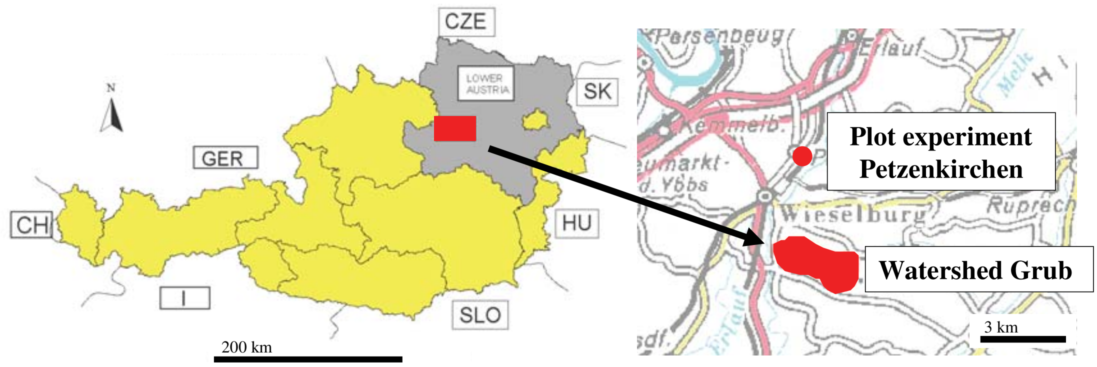


Figure 1: Location of the Petzenkirchen experimental field site and the Grub watershed, Austria
Abbildung 1: Lage der Feldmessstelle 'Petzenkirchen' und des Wassereinzugsgebietes 'Grub', Österreich

Investigations on these field plots started in 1989 and are still ongoing. After a five-year period with a local crop rotation, green fallow was practised, a BMP which was linked to the Austrian environmental programme ÖPUL 95, a forerunner of ÖPUL 2000.

The soil-water regime is recorded continuously by an automatic data acquisition system using gypsum blocks, tensiometers and TDR-probes in different depths of the soil profile. Soil temperatures are measured at the same depths. Leakage is measured at 110 cm below soil surface by means of a field lysimeter and a tipping bucket gauge at the outlet of the lysimeter. After passing the tipping bucket gauge the water is stored in a tank for analysis. A more comprehensive description of the equipment used and results obtained can be found in FEICHTINGER (1999). Annual rainfall, the different agricultural management practices and basic soil properties are outlined in Table 1.

Grub watershed

The Grub experimental watershed is located about 3 km south of the experimental plot site (Figure 1). It covers an area of about 2.89 km^2 and is drained by the Grubbach brook. Geologically it can be divided into tertiary sediments, which form the hilly area of the watershed, and the youngest terrace of the river Erlauf, which covers the plains (Figure 2). This geological background means that the soils of the terrace are potentially highly vulnerable to nitrate leaching, whereas the area covered by tertiary sediments is not. In the modelling section we therefore only included this critical area (47.5 ha) of the terrace in our investigations.

Table 1: Annual rainfall, agricultural management and soil properties for the Petzenkirchen calibration plots
Tabelle 1: Jahresniederschlag, Landwirtschaftliche Bewirtschaftung und Bodeneigenschaften am Versuchsfeld Petzenkirchen

Precipitation		Local crop rotation				
Year	Annual amount mm	Crop	Date: Seeding	Date: Harvest	Fertilizer amount (kg N): Org. N	Fertilizer amount (kg N): Inorg. N
1990	658	Bare fallow	01.01.1990	01.05.1990	155	
1991	669	Maize	02.05.1990	15.10.1990		125
1992	730	Winter wheat	18.10.1990	12.08.1991	70	70
1993	724	Bare fallow	13.08.1990	15.04.1992	230	
1994	686	Field bean	16.04.1992	10.08.1992		
1995	837	Bare fallow	11.08.1992	22.09.1992		
1996	895	Winter barley	23.09.1992	02.07.1993		120
1997	788	Bare fallow	03.07.1993	02.05.1994	95	
1998	787	Maize	03.05.1994	18.08.1994	510	50
1999	923	Green fallow	19.08.1994	31.12.1999		

Horizon Depth	Soil Properties: Particle-size distribution %				Water content (Vol%) at matric potential			
cm	Clay	Silt	Sand	> 2 mm	10 hPa	60 hPa	300 hPa	15000 hPa
0–35	31	47	21	1	31.6	27.0	24.2	15.2
35–75	22	41	36	1	33.6	29.3	25.8	18.4
> 75	3	3	23	71	20.3	16.6	13.9	7.7

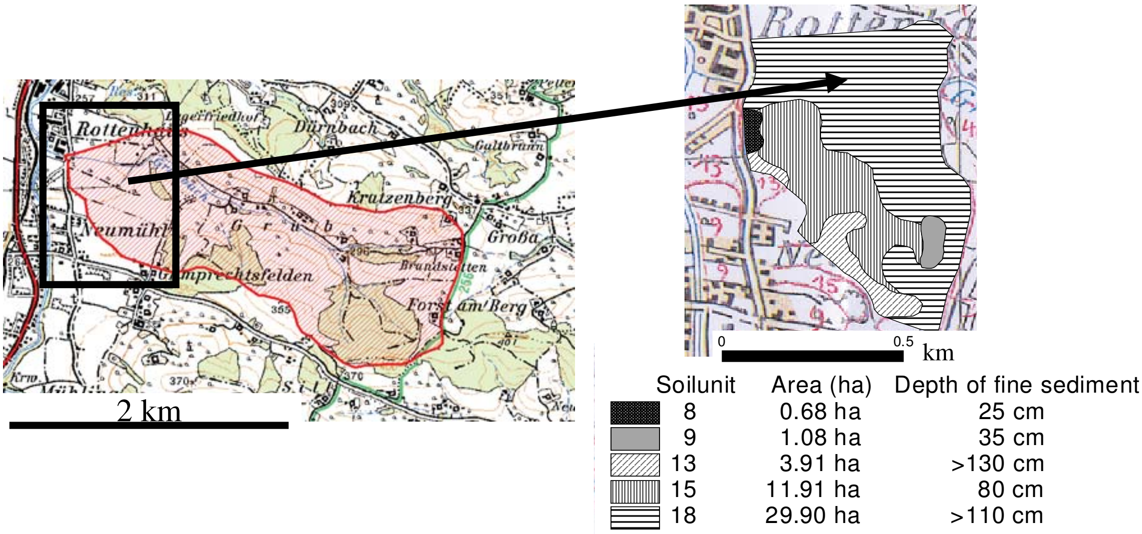


Figure 2: Spatial extension and soil types of the youngest terrace of the Grub watershed
Abbildung 2: Niederterrasse und Bodentypen im Einzugsgebiet Grub

For the critical area, five soil units (Figure 2) were identified according to the Federal Soil Survey Service (ÖBK, 1982). All soils units can be classified as cambisols (FAO, 1998) and the main difference between them is their depth to the underlying gravel. The Federal Soil Survey Service also provides basic information on soil texture, organic carbon content, $CaCO_3$ content and pH of these soils, as well as a brief description of soil structure and density. Based on this information, soil physical characteristics were obtained using pedo transfer functions proposed in MURER (1998). Basic soil properties and derived soil physical properties are given in Table 2. Climatic information was obtained from Petzenkirchen.

2.2 Assessment of environmental effectiveness

The impact of the implementation of BMPs on groundwater pollution by nitrate has been assessed by modelling. The STOTRASIM model (FEICHTINGER, 1996) was calibrated with data from the plot experiment, using the amount of seepage water and nitrate-nitrogen leaching in the period 1 January 1990–31 December 1998. The model was then applied to the critical area (47.5 ha) within the watershed to evaluate the environmental effectiveness of the implementation of different BMPs.

The STOTRASIM model describes one-dimensional vertical flow of water and nitrate-nitrogen within a soil pro-

Table 2: Characteristics of the five soil units at the Grub watershed
Tabelle 2: Eigenschaften der fünf Bodenformen im Wassereinzugsgebiet Grub

Soil unit	Horizon Depth cm	Humus %	Particle-size distribution % Clay	Silt	Sand	> 2 mm	Water content (Vol%) at matric potential 10 hPa	60 hPa	300 hPa	15000 hPa
8	0–25	2.2	20	26	19	35	50.9	49.3	46.3	25.0
	25–		1	1	25	73	23.5	9.5	6.0	2.8
9	0–25	3.2	21	53	17	9	47.4	40.3	32.0	13.0
	25–35	2.6	20	45	35	0	43.9	38.3	30.9	12.3
	35–		1	1	25	73	23.5	9.5	6.0	2.8
13	0–25	2.2	21	72	7	0	51.7	48.0	41.7	11.6
	25–		11	53	27	9	42.5	36.5	29.2	11.2
15	0–25	2.7	21	53	17	9	47.4	40.3	32.0	13.0
	25–80		27	37	27	9	39.0	36.7	33.7	16.0
	80–		1	1	25	73	23.5	9.5	6.0	2.8
18	0–30	2.4	9	64	18	9	49.9	47.0	41.6	12.0
	30–80		21	72	7	0	47.6	41.9	33.6	9.4
	80–		24	57	19	0	47.4	42.7	36.5	18.0

file, neglecting interflow and preferential flow. Soil water fluxes and plant growth are calculated with the SIMWASER deterministic model (STENITZER, 1988), which is part of STOTRASIM. A limitation of potential plant growth is given by a deficiency of water and/or nitrogen. The response of plant growth to the supply of other nutrients and to pests is not taken into account.

SIMWASER simulates the water balance and the crop yield of any number of crop rotations and years on a daily basis. The water balance and the plant growth are interrelated through the physiological interaction of assimilation and transpiration. At the soil surface, precipitation and irrigation act as input, while evaporation and transpiration act as output. Interception is also taken into account. Water fluxes in the soil are calculated according to Darcy's law, resulting in either capillary rise or seepage.

STOTRASIM calculates a daily nitrate-nitrogen balance for a soil profile, taking into account nitrogen inputs (fertilisation, precipitation, irrigation, assimilation from the air by legumes, capillary rise) and losses (volatilisation, denitrification, leaching); nitrogen uptake of the vegetation; nitrogen turnover (mineralisation, immobilisation); and nitrate-nitrogen transport in the soil. Evaporation causes a decreasing amount of the solvent and therefore an increasing nitrate concentration in the upper soil layer. As a result, the nitrate fluxes at the lower end of the soil profile are calculated, identifying nitrate leaching to the groundwater.

To evaluate nitrate leaching at the Grub watershed, the calibrated STOTRASIM model was applied to the soils of the risk area. Management practices were assumed to be identical to those of the experimental plot (Table 1). In addition, different BMPs were tested:

a) mustard as a catch crop during 21 August 1991–5 November 1991 and 10 August 1993–15 December 1993
b) BMP A plus reduction of N-fertiliser input by 30 %
c) permanent green fallow without fertilisation and harvest (mulching one to three times a year)

BMPs A and B are already part of the Austrian agri-environmental programme (ÖPUL 2000). Within this programme, Austrian farmers may contract to BMPs on a voluntary basis. The support for BMP A is 51–109 €/ha/year; for BMP B in addition to BMP A it is 73–98 €/ha/year. BMP C is not part of the ÖPUL 2000 programme, but was a continuation of the ÖPUL 95 programme. The subsidy for BMP C was about 600 €/ha/year in 1996.

The environmental impact on groundwater pollution was assessed for each BMP by calculating the amount of leakage and its nitrate concentration at 150 cm below soil surface for the period 1 January 1991–31 December 1994.

2.3 Assessment of costs

To assess the economic impact of BMPs at the farm and watershed level we need to calculate extra costs arising from the implementation of the BMPs. Furthermore, these costs may help in assessing the level of incentive needed to encourage farmers to modify their practices. To calculate direct extra costs we first constructed an on-farm model representative of the population of the farms within the watershed using linear programming.

The methodology of economic optimisation appeared to be the most relevant for cost analysis of environment-friendly practices because of its facility to allow decision makers to substitute alternative strategies into the decision-making framework. Many practices that appear profitable from a single analysis may in fact prove less attractive when analysed as part of the whole-farm system (FEUZ et al., 1991). Information on farms can be achieved either from regional data (representative farms in an average concept) or by developing sets of typical farms (in a modal concept). These modal farms may be thought of as case farms and can either be real or synthetic. We decided to model a single representative dairy farm devised from regional data and local expert knowledge to reflect the population of the farms within the watershed. For construction of the technical coefficients matrix, technical data consisting of input and output flows were provided by experts on the farming systems in the area (a panel of local farmers and teachers at an agricultural high school). Ratios between output and input for standard and alternative production processes have been assumed to be constant (deterministic farm model). Basic data for running the model are summarised in Table 3.

Direct cost calculation at the farm scale

The linear programming (LP) paradigm (HAZELL, 1986) used for farm modelling is a method of determining a profit combination of farm enterprises that is feasible with respect to a set of fixed farm constraints (Appendix A).

BMPs are represented as alternative farming practices at the farm scale. The maximisation of gross margin as an objective function implies that each individual farmer is considered as a profit maximiser – that is they maximise total revenue plus any net appreciation in livestock capital less

Table 3: Basic values for economic modelling
Tabelle 3: Basisdaten zur ökonomischen Modellrechnung

farm area		30 ha	animal activities	
arable land		21 ha	dairy cows	18
permanent grassland		9 ha	offsprings	17
cash crops	wheat	2.5 ha	calves sold after birth	8
	rape	1 ha	calves fattening	9
fodder crops	permanent grassland	9 ha	heifer fattening	4
	grazing crop	3 ha	fist calving	27 months
	grass-sillage	6 ha	replacement rate	3.6
	corn sillage	5.5 ha	culled cow sold each year	5
	clover	4.5 ha	milk quota	110,000 kg
	wheat	2.5 ha	range of annual yield mild/cow	6,000 kg
	barley	3 ha	suckling cows	6

Appendix A

Farm Model

The model proposed for the representative farm can be written in the following form: a linear programming matrix that is feasible with respect to a set of fixed farm constraints

$$\text{Maximize } z = \sum_{js} c_{js} X_{js} + \left(\sum_{jb} (c_{jb} + I) X_{jb} \right)$$

$$\text{subject to } \sum_{j} \sum_{p} a_{ijp} X_{jp} \le b_i$$

$$\text{and } X_{jp} \ge 0$$

Z: total gross margin of the farm
X_{js}, X_{jb}: level of the *j* th activity with standard and Best Management Practices
c_{js}, c_{jb}: forecasted gross margin of a unit of the *j* th activity with standard *(s)* and Best Management Practices *(p)*
a_{ijp}: technical coefficients describing the production processes (quantity of the *i* th resource required to produce one unit of the *j* th activity) and practices (standard and environment friendly)
b_i: amount of the *i* th resource available
i: incentive

Optimal solutions provide activities combination allowing to maximise the total gross margin. Activities with BMP are not chosen in optimal solutions (that squares with the real world where farmers do not usually apply such farming practices) as BMPs generally imply reduced profits compared with more polluting standard practices. Farmers need then to be compensated for their adoption that is in the model, incentive is progressively added to activities with BMP so that these activities are chosen gradually or entirely in optimal activities combination. These levels of incentives are considered to represent direct costs for BMP implementation that is the loss in the objective function that the farmer would have suffered in adopting such practices.

labour and capital costs. Prices of inputs and outputs have been supposed to be constant and it is their mean value for the current year that has been used. Because of some variables relating to heads of stock, the model devised is a mixed integer programming model. The mathematical specification of a mixed integer programming model is the same as for linear programming with one exception: in addition to requiring the levels of all activities in a solution to be greater than or equal to zero, some activities – here the number of heads in the herd – are required to take only zero or integer values. This model has been developed using GAMS (General Algebraic Modelling System), a high-level modelling system for mathematical programming problems (Brooke et al., 1992). It consists of a language compiler and a set of integrated solvers.

Upscaling to watershed scale

One solution to assessing costs at the watershed level is to model farms in some aggregate manner (representative farms and typical farms) and then to multiply results according to the frequency of each farm type within the watershed. Available data on the joint size and type distribution of farms are not sufficient to ensure exact aggregation or to identify aggregation bias (Day, 1963). An alternative form of aggregation that overcomes these problems is to model farms together as if they were a single mega farm.

Appendix B

1. **Costs for the watershed**
   The costs for the watershed (K_w) are calculated with individual farms as follows:

   $$K_w = \sum_i s_i K_i$$

   Where K_i represents the costs per ha for farm i, s_i the area of BMP which is implemented on the farm i.

2. Costs are calculated assuming that the watershed may be represented as a single large farm. If the linear programming model of the i farm is written in matrix notation:

   $$\text{Max. } Z = f(X_i) = C_i \; X_i$$

   subject to $A_i \; X_i \leq B_i$

   and $Xi \geq 0$

   And the aggregate farm model is denoted in the same way but with w subscripts, we make the assumption that:

   $A_w = A_i$

   $B_w = B_i$

   and $C_w = C_i$

If no aggregation bias exists, the optimal solution for the watershed would be equal to the sum of the optimal solution of the i^{th} farms within the watershed and the costs for the watershed K_w be equal to the sum of the costs for the farms.

Doing so may overstate flexibility and co-ordination of agricultural production. It is, however, a widely accepted means of modelling large areas (O'CALLAGHAN, 1996) and may also be appropriate for small catchments, in particular when farms straddle different watersheds (Appendix B).

Calculation of farm direct costs has been made by assuming first that all farms will apply BMPs to a constant share of their acreage (same area implemented on each farm and cost per ha constant or not depending on the BMP); secondly that the watershed could be considered as a single large farm (140 ha in arable land and 12 farms). For BMP C (permanent green fallow) and for a similar area dedicated to BMP at the watershed level, we made a comparison of costs when the acreage with BMP varies between the farms according to their location in the watershed.

2.4 Assessment of social acceptability

The acceptability study elaborates the social factors contributing to the "willingness to contract". The focus is on farm-level decision-making and farmers' perceptions about the implementation of agri-environmental policy.

The assessment is based on a survey methodology. The survey focused on elaborating the issues that may contribute to the willingness to make a contract for a particular BMP. The farmers were first asked some general questions relating to agri-environmental issues and policy. We asked the farmers to estimate

1. changes in their farming and environmental management practices,
2. acceptability of the policy model,
3. their information channels in environmental issues and
4. agriculture's share of water pollution.

Secondly we asked more focused questions about the chosen BMPs. Farmers were asked to estimate the BMP's impact on farm management and the environment, as well as the level of compensation offered by the ÖPUL programme. The survey was built on the basis of closed questions, i.e. farmers were not able to add free text.

The questionnaire was sent to 100 farms in the region surrounding the Grub watershed and the Petzenkirchen field site; 91 answers were received. The political districts of Melk and Scheibbs were the main target of the survey. Although the watershed is located within the district of Scheibbs, it is

Table 4: Respondents according to the production sector, farm size and share of agricultural income
Tabelle 4: Struktur der landwirtschaftlichen Betriebe hinsichtlich Produktionszweig, Betriebsgröße und Verdienstquelle

Production sector	Respondents total	Farm size	Respondents total	Share of agricultural income	Respondents total
Crop production	2 %	< 10 ha	12 %	All from agriculture	20 %
Milk production	64 %	10–20 ha	29 %	More than 50% from agriculture	17 %
Meet production	12 %	20–30 ha	30 %		
Pig husbandry	14 %	30–50 ha	20 %	Less than 50% from agriculture	63 %
Other production	8 %	> 50 ha	9 %		
Total	100 %	Total	100 %	Total	100 %

obvious that the area covered by the survey is much bigger than the watershed area under study. Answers were collected during spring 2002 with the assistance of students from the Agricultural Technical High School Francisc Josephinum. Although the survey sample is rather small, careful planning of the survey and collection of answers has ensured a relatively representative sample. The 1999 agricultural survey (Agrarstrukturerhebung) for the districts of Melk and Scheibbs gives about 60 % of farmers with a farm size of 10–50 ha and a more or less equal share of farmers with milk production, meat production and pig husbandry. When comparing the respondents of the survey (Table 4), a bias towards a greater number of answers from milk producing farmers can be observed, but the general characteristics of farm sizes and mixed farm types for this region are met. However, the small sample size must be kept in mind when interpreting the results, and far-reaching conclusions cannot be made.

3 Results and discussions

3.1 Environmental effectiveness

As a result of the model calibration, Figure 3 gives a comparison of measured and modelled amounts of accumulated seepage and nitrate leaching at 110 cm below soil surface at the Petzenkirchen experimental plot.

The results of the amount of seepage and nitrate-nitrogen leaching for the Grub watershed are summarised for the five soil units in Table 5.

These results were ranked according to their decreasing impact on the reduction of nitrate leaching. Based on this ranking of the soil units, an area-weighted nitrate concentration of deep percolation was calculated for an increasing participation ratio of a BMP within the critical area. Figure 4 gives the relation of the mean nitrate concentration of the leakage to the extension ratio of the BMPs. For this particular situation a target value of 50 mg NO_3 l^{-1} (Guideline 98/83/EC) cannot be met by the BMPs A (catch crop) and B (BMP A + reduction of N fertilisation) alone. Only a combination with BMP C (permanent green fallow) enables this goal to be achieved.

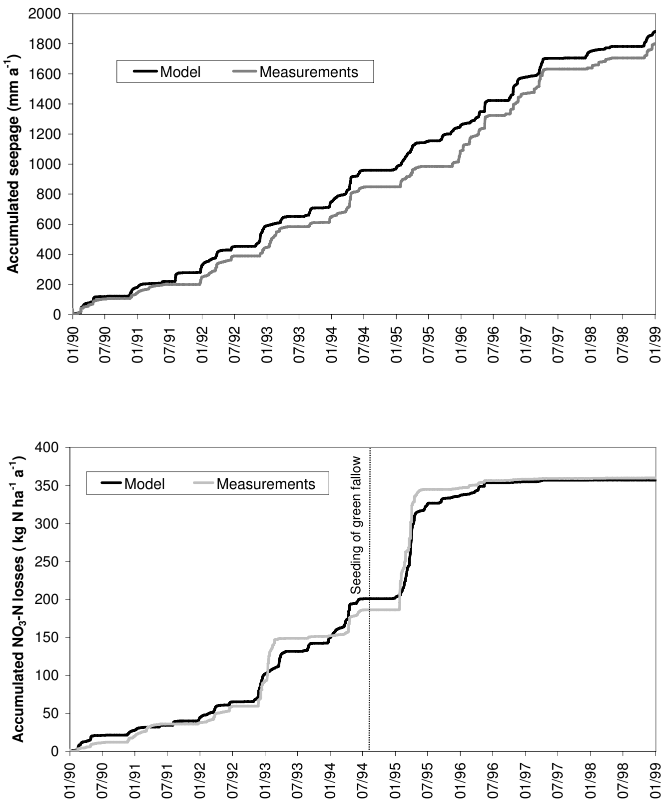


Figure 3: Comparison of the accumulated amount of seepage and nitrate leaching from measurements and modelling for the period 1 January 1990–31 December 1998 and 110 cm below soil surface

Abbildung 3: Gegenüberstellung der Ergebnisse akkumulierter Grundwasserneubildung und Nitratversickerung in 110 cm unter Gelände aus Messung und Modellrechnung für den Zeitraum 1 January 1990–31 December 1998

Table 5: Leaching, nitrate concentrations and nitrogen losses for five soil units and the different BMPs tested
Tabelle 5: Versickerung, Nitratkonzentration und Stickstoffaustrag der fünf Bodenformen bei Implementierung der untersuchten BMPs

		Deep percolation at 150 cm below soil surface											
		Amount of water, mm a^{-1}				N-loss, kg N ha^{-1} a^{-1}				Nitrate concentration, mg $NO_3^{-}l^{-1}$			
Soil Unit	Area ha	Local crop rotation	BMP A	BMP B	BMP C	Local crop rotation	BMP A	BMP B	BMP C	Local crop rotation	BMP A	BMP B	BMP C
8	0.7	259	247	244	161	63	57	39	8	107.8	102.2	70.8	22.0
9	1.1	195	171	171	128	65	38	32	8	147.7	98.4	82.9	27.7
13	3.9	168	142	144	66	21	14	14	7	55.4	43.7	43.1	47.0
15	11.9	159	134	134	78	38	23	20	4	105.9	76.0	66.1	22.7
18	29.9	145	119	119	49	24	16	16	5	73.3	59.6	59.6	45.2

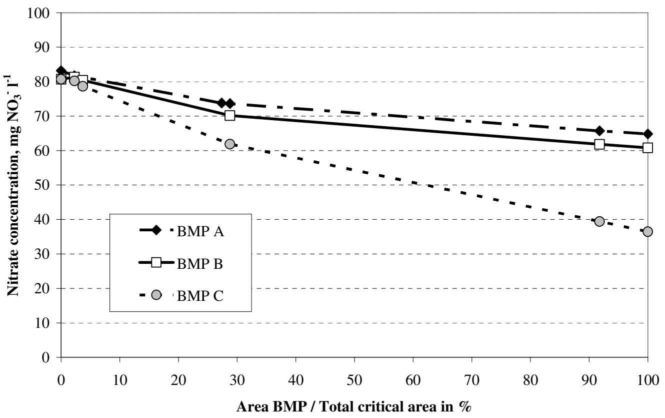


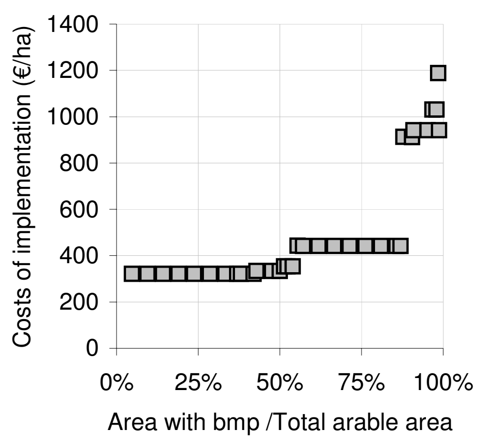
Figure 4: Change of nitrate concentration of deep percolation with increasing share of different BMPs
Abbildung 4: Veränderung der Nitratkonzentration im Sickerwasser in Relation zum Flächenanteil der verschiedenen BMPs

3.2 Costs

Costs at the farm level

Analysis of model results shows that when environment-friendly practices involve changes in activities (BMP C – permanent green fallow), the levels of compensation per hectare needed to make changes profitable are not linear (Figure 5). Implementation of BMP C results in marginal opportunity costs for the farm; but when it is put in place over larger areas, opportunity costs rise exponentially because of broad changes in crops and herd. Direct costs per hectare calculated from incentives can be presented in a step-wise function, showing that non-marginal changes cost much more than marginal ones (Figure 5).

In the case of the permanent green fallow, choosing extensive practices on one part of the farm may actually lead to a shift to more intensive practices on other parts in order to keep the farm economically viable. Indeed, model results



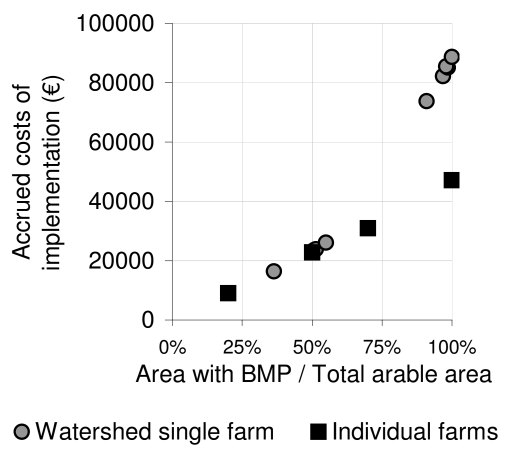


Figure 5: Costs of BMP C (permanent green fallow) implementation at the farm level
Abbildung 5: Kosten für die Umsetzung von BMP C (Dauergrünbrache) auf Betriebsebene

Figure 6: Costs of BMP C (permanent green fallow) implementation at the watershed level
Abbildung 6: Kosten für die Umsetzung von BMP C (Dauergrünbrache) im Wassereinzugsgebiet

show that adoption of BMP C leads in the first instance to potentially more polluting farm management practices, because milk production becomes more intensive to make up for the reduction of heads following the increase in green fallow, and because corn acreage increases to account for the reduction of fodder crops. Costs for the watershed are calculated assuming that every farm will implement the same level of green fallow (Figure 6).

When Best Management Practices refer to changes of practice in the strict sense of the word – catch crop (BMP A) and reduction of N fertilisation (BMP B) – the model outcomes reveal the existence of a threshold value for incentives and thus for cost to make these changes in practice profitable for farmers. Model outcomes show that beyond this threshold value, the margin obtained from crops with BMPs applied becomes higher than for crops on which BMPs are not applied. Thus, increasing incentives cause a larger acreage of crops with BMP's applied.

For implementation of BMP A (catch crops) at the farm level, threshold values for compensation are 108 €/ha for 76 % of the arable land which is used for cereals before and after corn and 111 €/ha for the total arable land. Costs for the watershed are calculated assuming that every farm will implement the same level of BMP (Figure 7).

For BMP B (reduction of N-fertilisation), assessment of the costs has been achieved by assuming that the reduction of fertilisation will lead to a yield decrease of 10 %, 20 % or no decrease. Outcomes show that costs per hectare differ between crops (Table 6). Figure 8 represents the costs for the watershed calculated with a single large farm.

Table 6: Threshold values (€/ha) for the compensation of costs arising from the implementation of BMP B depending on crop and yield decrease

Tabelle 6: Erforderliche, finanzielle Abgeltung (?/ha) für die Implementierung von BMP B in Abhängigkeit von Fruchtart und Ertragsreduktion

Crop	Yield decrease no decrease	10 %	20 %
Rape	30	38	75
Fodder cereals	–129	40	81
Wheat for cash	16	136	201
Corn sillage	–202	84	201

Costs at the watershed level

From the comparison of costs calculated for individual farms and for a single mega-farm, it emerges that similar results can be obtained from both approaches when BMPs are implemented over only a small portion of the watershed. On the other hand, calculated costs may differ considerably between the two methods when they are implemented on a large part of the arable area (Figure 5–8). This difference may be explained either by the non-linearity of direct costs of BMP implementation or by the bias from overstatement of the degree of resource flexibility in the aggregate-level LP model. Furthermore, costs may differ considerably when BMPs are implemented on every farm within the watershed or are targeted only on few farms.

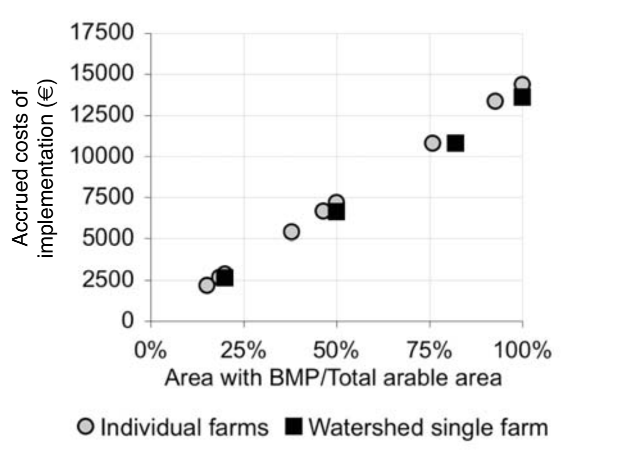


Figure 7: Costs of BMP A (catch crops) implementation at the watershed level

Abbildung 7: Kosten für die Umsetzung von BMP A (Zwischenbegrünung) im Wassereinzugsgebiet

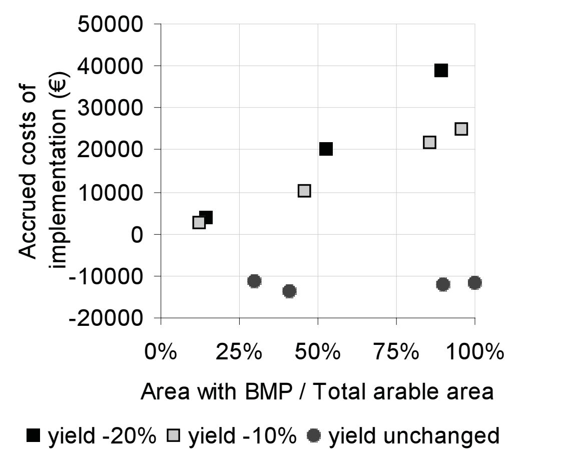


Figure 8: Costs of BMP B (reduced N-fertilisation) implementation at the watershed level

Abbildung 8: Kosten für die Umsetzung von BMP B (reduzierte Stickstoffdüngung) im Wassereinzugsgebiet

3.3 Social acceptability

According to the farmer survey, 62 % of the farmers have an ÖPUL contract for the catch crops (BMP A) and 10 % have considered contracting in the future (Table 7). In line with the cost assessment presented above, nearly half of the farmers estimated that the current compensation (51–109 €/ha/year) covers the costs, 28 % argued for a slight increase in the amount of compensation and only 10 % for a major increase (Figure 9).

Compared to the catch crops, the contract for reduced N fertilisation has not been as successful. According to the survey, 27 % of the farms have a contract for BMP B and 14 % have considered contracting in the future (Table 7). Of those who had made or have considered making a contract, only 25 % estimated the level of compensation as good and nearly half of them argued for higher compensation (Figure 10). The farm-level costs seem to vary a great deal depending, for example, on the crop cultivated, as the assessment of costs also showed.

Although in the current ÖPUL 2000 there is no opportunity to contract for BMP C (permanent green fallow), we did ask the farmers if they would be willing to change their cropland into permanent green fallow and at what cost. According to the survey results, 20 % of the farmers have increased the acreage of permanent green fallow and 11 % are considering doing so in the future. As the proportion of farmers who have considered changing cropland to permanent grassland is rather low, most of the farmers (more than 70 %) did not want to comment on the level of compensation. The estimates of those few who commented varied from 20 to 2000 €.

When we examine the willingness to contract, we can detect some differences between the BMPs depending upon the management requirements and the effects of the BMP, for example on yield. The results also reveal that farmers who do not have a BMP contract know very little about the possibilities offered by the agri-environmental policies, or do not want to comment on them. The survey results also indicate that larger, full-time farms were more interested and capable of making the contract than the smaller, part-time farms. However, the small sample size of the survey must be borne in mind, and makes it difficult to really assess this question.

Farmers expect a rather high level of compensation for the costs incurred as a result of implementing the BMPs and

Table 7: Willingness to contract according to the farmer survey
Tabelle 7: Bereitschaft der Landwirte zu einem Vertrag

Willingness to contract	BMP A Catch crops	BMP B Reduction of N fertilisation	Willingness to contract	BMP C Permanent green fallow
Yes, we have a contract	62 %	27 %	Yes we have changed	20 %
No, but we've considered contracting in the future	10 %	14 %	No, but we've considered to change	11 %
No, we backed down	5 %	8 %	No, we've not considered to change	63 %
No, we've not considered	15 %	40 %	No, we've increased cropland	6 %
I don't know	8 %	12 %		
Total	100 %	100 %	Total	100 %

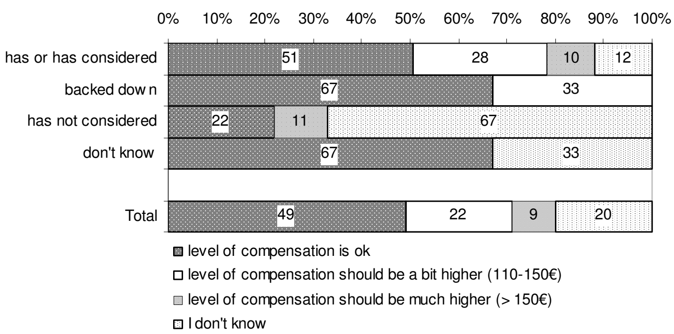


Figure 9: Farmers' perceptions of the level of compensation – ÖPUL2000 contract for BMP A
Abbildung 9: Vorstellungen der Bauern zur finanziellen Abgeltung einer Implementierung von BMP A

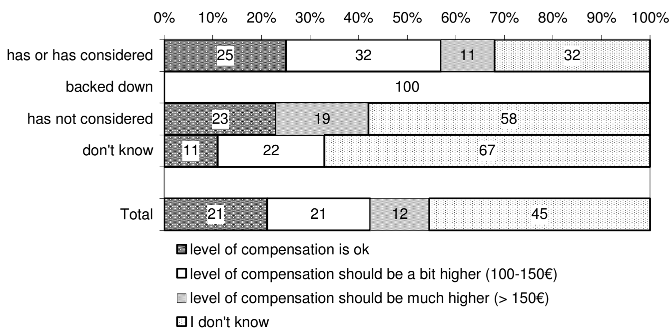


Figure 10: Farmers' perceptions of the level of the compensation – ÖPUL2000 contract for BMP B
Abbildung 10: Vorstellungen der Bauern zur finanziellen Abgeltung einer Implementierung von BMP B

agri-environmental management. Other results from the survey support this observation. For example, we asked farmers what were the most important aspects that should be taken into account when developing agri-environmental policy (Figure 11). There is a consensus about the importance of agri-environmental policy, as well as about the voluntary nature of agri-environmental schemes and financial compensation for the costs. No one is really arguing for revoking of all environmental norms (30 % see it "quite important"). Farmers also call for better monitoring and control of the agri-environmental subsidies.

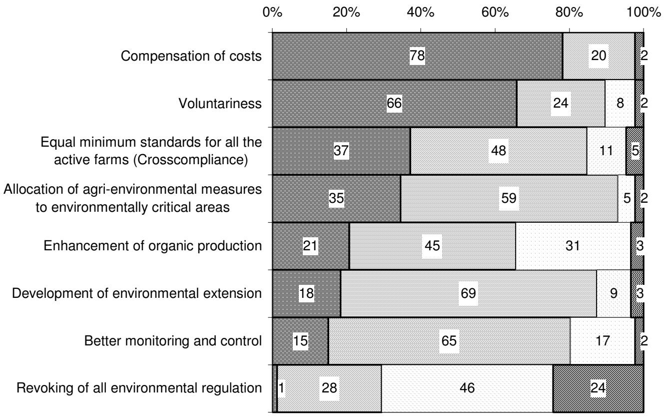


Figure 11: The most important aspects that should be taken into account when developing agri-environmental policy according to the farmer survey
Abbildung 11: Erfordernisse und Schwerpunkte in Agrar–Umweltprogrammen aus Sicht der Landwirte

Although agri-environmental schemes are voluntary, there is an element of control or compulsion. The ÖPUL schemes are partly income support and therefore contain economic incentives. On the one hand this means that the farm's economy is reliant on the support distributed through the agri-environmental schemes. On the other, it means that the farm's activities must be able to be monitored and inspected, which in turn requires the farmer to invest a significant amount of working time to the paperwork. These elements of control and bureaucracy are crucial social factors contributing to the acceptability of the BMPs and agri-environmental policy in general. According to the survey results, farmers believe that agri-environmental regulation will increase in the future; however, nearly 70 % of the respondents say it should not (Figure 12).

3.4 Integrative assessment

To understand the decision making for a BMP contract both at the farm and policy implementation level, an integrative assessment of the environmental impacts, economic costs and social acceptability of BMPs is necessary. One approach is to relate the environmental effectiveness of BMPs and the associated costs to a common scale (Figure 13) and to apply to this graph the results of the acceptability study in a descriptive, qualitative manner. The common axis of Figure 13 is the percentage of the total arable area of the watershed on which the BMPs are applied. The ordinate axis represents the decrease of pollution (according to Figure 4) for the left axis, and the associated costs (according to Table 6, individual farm) for the right axis. The decrease of pollution is assessed following Figure 4, with the difference that the BMP implementation area relates not to the total critical area (47.5 ha) but to the total arable land (140 ha).

According to Figure 13, the lowest environmental impact on groundwater pollution results from BMP A (catch crops), but this is the contract that is the most accepted by the farmers (see section 3.3 and Table 7). In addition, nearly half of the farmers agree with the current subsidy level (51–109 €/ha/year) offered by the ÖPUL schemes. BMP B, i.e. reduced N-fertilisation in combination with BMP A, is environmentally slightly more successful, and 27 % of the farmers have a contract. Of those who had made or have considered making a contract for BMP B, only 25 % estimated the level of compensation as good and nearly half of them argued for higher compensation. For the most efficient BMP, BMP C (permanent green fallow), which is not part of the ÖPUL schemes at the moment, only 11 % are considering increasing the permanent green fallow area in the future and the expectations of subsidy level varied greatly.

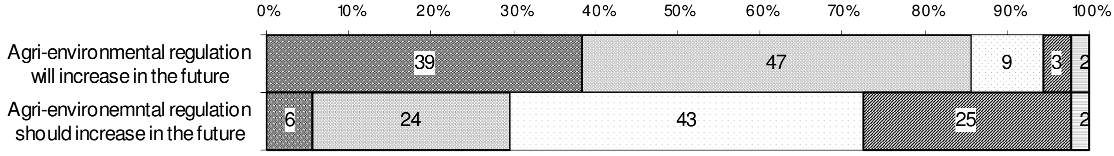


Figure 12: Perceptions of the direction of agri-environmental regulation in the future according to the farmer survey
Abbildung 12: Sicht der Landwirte zur Ausrichtung künftiger Agrar-Umweltregulative

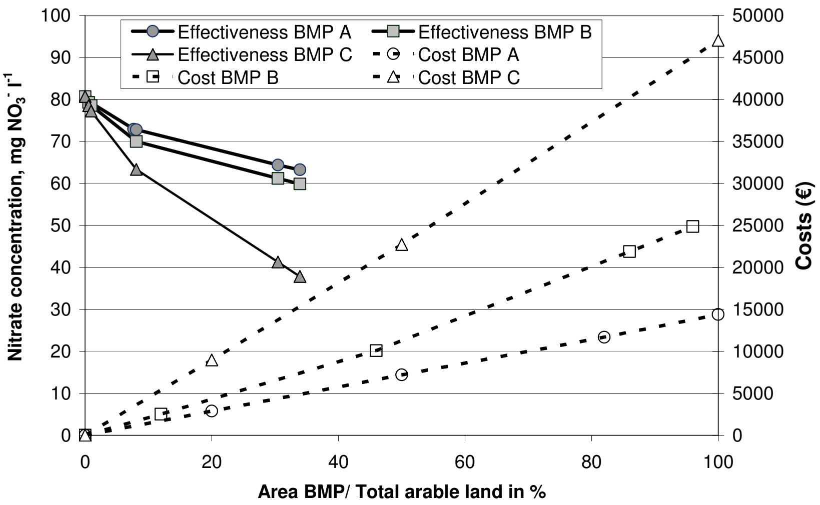


Figure 13: Quantitative assessment of environmental effectiveness and the associated costs of the implementation of BMPs related to a common scale

Abbildung 13: Bewertung der ökologischen Effizienz von BMPs und der Implementierungskosten bezogene auf ein gemeinsames Maß

The farmers' willingness to contract according to the survey agrees well with the actual ÖPUL contracts in the study region. In the district where our investigations were conducted, about 45 % of the farmers in 1999 had a contract for BMP A, and 23 % had a contract for BMP B.

Results of Painter et al. (1994) suggested that more flexible agriculture policies could increase both groundwater quality and farm returns. Implementation of BMPs and other adjustments of current cropping practices usually result in marginal improvements in groundwater quality with little (or no) change in farm income. In some cases this may be sufficient to satisfy public demands for safety; in other cases it may not. Direct costs of environment-friendly practices rise exponentially with more widespread implementation. The research questions raised are then to define if large improvements in groundwater quality can be achieved through farm management strategies that are also economically viable for the individual farm.

From the point of view of farm management and economy, the BMPs vary significantly. Some BMPs (catch crops and reduction of N fertilisation) have no effect on the design of individual management activities or their combination in the management of the farm. Only crop management techniques are modified by BMP A (catch crop), and this change in technology has no consequence on the output. This could be one reason for its wide acceptance. Similarly, for BMP B (catch crop combined with reduction of N fertilisation) the choice of management activities is not modified, but the level of output may decrease and varies between activities. For these BMPs the existence of a threshold value for costs allows constant compensation rates per hectare and crop, independent of the area implemented at the farm level. Furthermore, the costs of BMP B are very dependent on whether or not there is a yield decrease following the reduction of fertiliser application.

BMPs that directly modify the activities (such as permanent green fallow, for example) may lead to broad changes in farm management, in particular if they are implemented over a large area. For such BMPs, compensation level/area cannot be constant and should increase cumulatively according to the area implemented. This could be one explanation of the wide range of expectations with regard to compensation shown in our questionnaire results.

Environmental effectiveness concerning the nitrate concentration of deep percolation was assessed in isolation for each of the three BMPs considered, but not for combinations of them. Based on these results, only permanent green fallow (BMP C) enables the value of 50 mg NO_3 l^{-1} as a target of the quality of the leakage within the critical area of the watershed to be reached; but at the same time it is the most expensive measure.

Cost calculation has helped to identify reasonable incentives for realising a sustainable agriculture. High levels of implementation of BMPs such as land retirement could lead to large costs at the farm level, but should also simultaneously generate enough water quality benefits. The higher the effectiveness of such a BMP, the more effective it is to appropriately target the measure. Based on such assessment tools, the decision whether the benefits of the BMP offset the costs of its implementation has to be made in each individual case.

4 Conclusions

In a study of diffuse groundwater pollution by nitrate in an Austrian watershed, different tools have been employed to assess the environmental effectiveness, the economic costs and the social acceptability of the implementation of BMPs into local agricultural practice. The tools have been calibrated with locally available data. This type of methodological approach can be applied everywhere, but calibration and validation have to be done on a case-by-case basis.

A clear hierarchy of the BMPs investigated was identified in relation to their environmental effectiveness and associated costs. For the case area studied the results indicate that current measures to prevent nitrogen pollution may not be sufficient to reach legal targets. The results gained from the integrative analysis show that for particular BMPs a large number of farms need to contract in order to reach any improvement in the environmental conditions. This calls into question the necessity of critical area identification for preventing nitrogen pollution. This is in contrast to findings for other pollutants such as phosphorus (STRAUSS et al., 2007) where critical area identification may lead to effective allocation of control measures. However, allocation of funds within the current agri-environmental policy does not, in any case, provide for critical area identification. The acceptability assessment also revealed that farmers expect a relatively high level of compensation for the costs incurred by agri-environmental practices. Voluntary environmental policies have a long tradition within the agricultural sector (e.g. GLAASBERGEN 1992). These can still be seen in the debates on the multifunctional role of agriculture within the CAP reforms. The close linkages between the environmental and agricultural policy within the European Union give particular challenges for the control of the non-point source pollution within the local context.

After the period from 2007 to 2013 (the present ÖPUL funding scheme), it is likely that total funds for agri-environmental policy measures will decrease. With this in mind, we need to know which pollutants may be controlled using area-focused approaches and which may not. In this context, the present study of assessment of cost-effectiveness of different BMPs at a watershed scale can be seen as a contribution towards a more targeted and effective agri-environmental policy.

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References

BMLFUW – Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (2000): Öpul 2000 – Sonderrichtlinie für das Österreichische Programm zur Förderung einer umweltgerechten, extensiven und den natürlichen Lebensraum schützenden Landwirtschaft. Zl. 25.014/37-II/B8/00. (German).

BROOKE A., D. KENDRICK and A. MEERAUS (1992): GAMS: A User's Guide, Release 2.25. The Scientific Press.

BULLER, H., G.A. WILSON and A. HÖLL (eds.) (2000): Agri-environmental policy in the European Union Countries. Ashgate Publishing Limited, Aldershot.

CLARK, J. and J. MURDOCH (1997): Local Knowledge and the precarious extension of scientific networks: a reflection on three case studies. Sociologia Ruralis Vol. 37, 38–60.

DAY, R.H. (1963): On aggregating linear programming models of production. Journal of Farm Economics 45: 797–813.

FAO (1998): World Reference Base for Soil Resources. World Soil Resources Reports, FAO 84, Rome.

FEICHTINGER, F. (1999): Reduzierte Grundwasserbefrachtung durch veränderte landwirtschaftliche Bodennutzung im NÖ. Alpenvorland. Bericht über die 8. Gumpensteiner Lysimetertagung, BAL Gumpenstein 13–14. April 1999, 121–123.

FEICHTINGER, F. (1996): Simulation of the Soil Water Balance and Nitrogen Dynamic by STOTRASIM for irrigated maize. In: ICID-CIID – Workshop on Crop-Water-Environment Models, Cairo, Egypt, September 15–17, 1996, 150–162.

FEUZ, D.M. and M.D. SKOLD (1991): Typical farm Theory in Agricultural Research. Journal of sustainable agriculture 2: 43–58.

FORSTER, D.L. and J.N. RAUSCH (2002): Evaluating Agricultural Nonpoint – Source Pollution Programs in Two Lake Erie Tributaries. Journal of Environmental Quality 31: 24–31.

FREDE, H.G., M. BACH, N. FOHRER and L. BREUER (2002): Interdisciplinary modelling and the significance of soil functions. Journal of Plant Nutrition and Soil Science 165, 460–467.

GLASBERGEN, P. (1992): Agro-environmental Policy: Trapped in an Iron Law? A Comparative Analysis of Agricultural Pollution Control in the Netherlands, the United Kingdom and France. Sociologia Ruralis Vol. 32, 11–29.

HAZELL, P. B. and R.D. NORTON (1986): Mathematical Programming for Economic Analysis in Agriculture, Mac Millan Publishing Company – New York.

HOPSTAKEN, C.F. and E.F.W. RUIJGH (1994): Modelling N and P loads on surface and groundwater due to land-use. In: ADRIANO et al. (ed.), Contamination of Groundwater: Advances in Environmental Sciences, 161–188. ISBN 0-905927-44-3.

HYDROGRAPHISCHES ZENTRALBÜRO (Bundesministerium für Land- und Forstwirtschaft) (1994): Jahrbücher. Beiträge zur Hydrographie Österreichs, Heft 52. Die Niederschläge, Schneeverhältnisse und Lufttemperaturen in Österreich im Zeitraum 1981–1990 (German).

MURER, E. (1998): Die Ableitung der Parameter eines Bodenwasserhaushalts- und Stofftransportmodelles aus den Ergebnissen der Bodenkartierung. Modelle für die gesättigte und ungesättigte Bodenzone. Schriftenreihe BAW, Band 7, 89–103 (German).

ÖBK (1982): Österreichische Bodenkartierung 1:25.000, Kartierungsbereich 173, Ybbs. Bundesministerium für Land- und Forstwirtschaft, Bundesamt und Forschungszentrum für Landwirtschaft, Wien. (German).

O'CALLAGHAN, J.R. (1996): Land Use, the interaction of economics, ecology and hydrology, Chapman and Hall, London.

OSINSKI E., U. MEIER, W. BÜCHS, J. WEICKEL and B. MATZDORFET (2003): Application of biotic indicators for evaluation of sustainable land use – current procedures and future developments. Agriculture, Ecosystems and Environment 98 407–421.

OTTMAN, M.J., B.R. TICKES and S.H. HUSMAN (2000): Nitrogen-15 and Bromide Tracers of Nitrogen Movement in Irrigated wheat Production. Journal of Environmental Quality 29: 1500–1509.

PAINTER, K.M. and D.L. YOUNG (1994): Environmental and Economic Impacts of Agricultural Policy Reform: An Interregional Comparison J. Agr. and Appl. Econ. 26 (December 1994): 451–462.

POWER, J.F., R. WIESE and D. FLOWERDAY (2001): Manging Farming Systems for Nitrate Control: A Research Review from Management Systems Evaluation Areas. Journal of Environmental Quality 30: 1866–1880.

STENITZER, E. (1988): SIMWASER – Ein numerisches Modell zur Simulation des Bodenwasserhaushaltes und des Pflanzenertrages eines Standortes. Mitteilung Nr. 31, Bundesanstalt für Kulturtechnik und Bodenwasserhaushalt, A-3252 Petzenkirchen, 203 S. (German).

STRAUSS P., A. LEONE, M.N. RIPA, N. TURPIN, J.M. LESCOT and R. LAPLANA (2007): Cost-Effectiveness of various Best Management Practices to mitigate phosphorus and sediment transfer at the watershed scale. Soil Use and Management, 23 (Suppl. 1), 144–153.

STITES, W. and G.J. KRAFT (2000): Groundwater Quality beneath Irrigated Vegetable Fields in a North-Central U.S. Sand Plain. Journal of Environmental Quality 29: 1509–1517.

WILSON, G. and K. HART (2001): Farmer participation in agri-environmental schemes: towards conservation-orientated thinking? Sociologia Ruralis Vol. 41, No. 2, 254–274.

WOSSINK, G.A.A. and D.L. OSMOND (2002): Farm economics to support the design of cost-effective Best Management Practice (BMP) programs to improve water quality: Nitrogen control in the Neuse River Basin, North Carolina. Journal of Soil and Water Conservation 57: 213–220.

WU, J. and B.A. BABCOCK (1999): Metamodeling Potential Nitrate Pollution in the Central united States. Journal of Environmental Quality 28: 1916–1928.

YUAN, Y., S.M. DABNEY and R.L. BINGER (2002): Cost effectiveness of agricultural BMPs for sediment reduction in the Mississippi Delta. Journal of Soil and Water Conservation 57: 259–267.

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