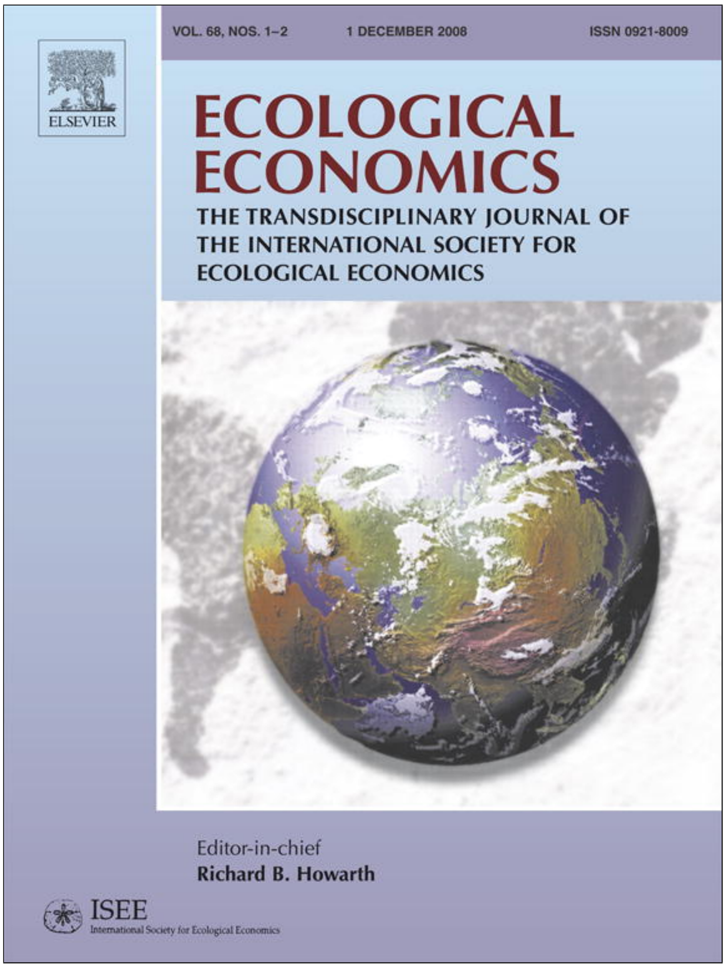
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ANALYSIS

Cost-efficient choice of measures in agriculture to reduce the nitrogen load flowing from the Danube River into the Black Sea
An analysis for Austria, Bulgaria, Hungary and Romania

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ABSTRACT

Selected measures in agricultural production are presented which reduce the national nitrogen soil surface balances and the nitrogen loads in the waters of Austria, Bulgaria, Hungary and Romania entering the Danube River. The measures are appraised empirically by calculating the ratio between their costs to the farmers and their effects on the respective balances and the load of the water entering the Black Sea. The ratios are used to rank the measures accordingly, either separately for each country, or jointly. The measures consist in implementing the best available techniques of agricultural production. The costs of the measures are defined as the net effect of changes of production costs and revenues of the agricultural producers involved. There are even measures characterised by costs being outbalanced by the increase of gross output induced, resulting in negative costs and, hence, negative ratios. This indicates that these measures are profitable to the producers, provided obstacles to their implementation are overcome.

Furthermore, a linear optimisation model is developed which is used to ascertain the measure combinations which accomplish a politically demanded amount of reduction of the nitrogen load at minimum total costs ('cost-efficient solutions'), either at the national or international level. Optimisation at the international level turns out to be superior. Cost savings by an international choice of measures can be induced, and shared, by international compensation payments to be financed from these savings.

1. Introduction

In order to accomplish or maintain ecologically good conditions in the western part of the Black Sea, it is necessary to reduce nutrients flowing into the Black Sea via the Danube River. The most important nutrient sources considered are diffuse sources mainly from agricultural production, and point sources, i.e. basically those within urban areas and industrial facilities (daNUbs, 2005).

Several studies on programmes to reduce, in a cost-optimal way, nutrients in river catchments, such as the Rhine River Catchment and marine waters such as the Baltic Sea, have been published already (Gren et al., 1997a; Schleiniger, 1999; Turner et al., 1999; Gren, 2001; Van der Veeren, Tol, 2001; Ollikainen, Honkatukia, 2001; Schou et al., 2006).

The main objectives of the work presented here are (a) to develop an appropriate method to assess the measures designed to change agricultural production in order to reduce

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the national nitrogen soil surface balances and, finally, the load in the waters flowing into the Black Sea and (b) to formulate an optimisation model to identify cost-efficient combinations of these measures on both the national and international levels. To measure economic, ecological or social benefits of nitrogen load reduction (as, e.g., Gren et al., 1997b; Gren, 2001 for the Baltic Sea) is beyond the scope of this paper.

The Danube River Catchment (DRC) covers an area of 802.890 km^2 and comprises 13 countries: Germany, Austria, Czech Republic, Slovakia, Hungary, Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro, Romania, Bulgaria, Moldavia and the Ukraine, either totally or partially. In the year 2000, the nitrogen load flowing into the Black Sea from its origins in the DRC amounted to 386,816 t N: 81% from anthropogenic sources, 46%-points of which came from agricultural production (daNUbs, 2005). The present paper focuses on Austria as an example for an “old” EU member state and on Hungary, Bulgaria and Romania as new EU member states. Almost the total areas of these four countries are part of the DRC, covering 56% of its area. These four countries account for 47% of the total nitrogen load (considering all of the sources in all 13 countries) flowing into the Black Sea. Their share of the nitrogen load resulting from agriculture is 23% of the total nitrogen load from all sources in all 13 countries (this corresponds to 44% of the nitrogen load from the agriculture of all 13 countries). Non-anthropogenic sources within the four countries contribute only 3% to the nitrogen load from all the sources in all 13 countries.

2. Reference scenario and measures under examination

It is assumed that measures to reduce the contribution from agriculture to the nitrogen load flowing into the Black Sea will be implemented by the year 2015. A general “High Production Scenario (HP 2015)” was defined in which the agricultural production levels of Austria in the year 2000 were assumed to remain constant until 2015. The agricultural production levels of Bulgaria, Hungary and Romania will regain their respective 1990 levels by 2015 because their agriculture is undergoing an intensification of production which will approach western productivity standards. Furthermore, it is assumed that a change in the farming structure, especially in Bulgaria and Romania, will have taken place by 2015. In the year 2000, a characteristic of Romanian agriculture, for instance, was the large proportion of small-scale farms (41% of all holdings cultivate less than 1 ha of land), whose production was mainly to ensure their own subsistence, with only a little to be sold on the market. Based on the assumption that no additional agro-environmental measures are put into effect, in scenario HP 2015 the nitrogen load from agriculture in Austria remains more or less constant. The Bulgarian nitrogen load from agriculture will increase by 95%, that in Hungary by 63% and that in Romania by 60% of the respective levels in the year 2000. Using the HP 2015 scenario as a reference, the impact of implementing four different measures M_1–M_4 was analysed. All of them are aimed at the reduction of nitrogen emissions from agriculture to the environment. Each of the measures consists in an aggregation of several sub-measures found to be the best available techniques with regard to the same objective, such as reduction of nitrogen emissions from manure. In that sense they belong functionally together, being more effective in combination, compared with applying them separately. No single sub-measure is mutually exclusive with any other in this work, much less the measures. These measures are described below (see also Cepuder et al., 2001; De Clercq et al., 2001; Baum et al., 2004, Interwies et al., 2004). An overview is presented in Table 1.

2.1. *M_1: accurate application of fertilisers regarding fertiliser amount and time-related application rates*

(1) If the time-related application rates of fertilisers are in accordance with the nutrient requirements of the crops, it will improve crop production and save fertiliser. The rates of fertiliser application depend on the fertiliser's nutrient value, the nutrients available in the soil, and the expected nutrient

Table 1 – Overview of the measures considered to be realised in Austria (AT), Bulgaria (BG), Hungary (HU) and Romania (RO)

	Objective of measure	Quantitative objective	Best available technique
M_1	Accurate application of fertilisers regarding fertiliser amount and time-related application rates	Reduction of mineral fertiliser use by 10%	(1) Timely application rates (2) Chemical soil analysis (3) Soil surface balance at farm level (4) Ban on application of fertilisers during winter
M_2	Reduction of nitrogen emissions from manure	Reduction of ammonia emissions from manure by 25%	(1) Use of hose spreader (2) Accurate manure storage capacity (3) Accurate straw bedding in animal housing
M_3	Increase of plant productivity by application of capital-intensive production techniques	Increase in plant productivity AT: +10%; BG, HU, RO: +20%	(1) Demand-oriented irrigation (2) Demand-oriented plant protection (3) Improvement of plant nutrition
M_4	Reduction of direct nitrogen emissions into the hydrosphere	Reduction of erosion by 75% and surface run-off by 20%	(1) Minimum soil tillage (2) Zero-tillage (3) Mulch seeding (4) Cover crops and (5) intercropping

Source: IFIP, 2005.

uptake by the crops to be grown (Saskatchewan, 1997; Johnson and Eckert, 1995). (2) Chemical soil analysis, i.e. fertilisation is practised according to the measured nutrient content and predicted crop response (Finck, 1991). Since the degree of nutrient use and nutrient loss varies with each growing season, annual soil testing is recommended. (3) If the determination of the soil surface balance at farm level (Brouwer, 1998) is practised, fertilisation in accordance with the nutrient content of the soil and requirements of the crops becomes feasible. This is to reduce a nutrient surplus or deficit, as the case may be. (4) A ban should be imposed on the application of mineral fertilisers, manure and other organic wastes during the winter months (November/December to February), unless the fertiliser is incorporated in the soil on the same day to a depth of at least 10 cm (BMLF, 1991).

In the calculations, it is assumed that M_1 is implemented in Austria on 30% of the utilised agricultural area (UAA) and in Bulgaria, Hungary and Romania on 10% of the UAA.

2.2. M_2: reduction of nitrogen emissions from manure

(1) The use of a hose spreader to discharge manure just above ground level ensures that the manure is assimilated by the soil in the shortest possible time, and thus prevents its being washed away by rainfall. (2) The construction of an accurate storage capacity for manure, in which the manure is stored in a closed facility until the optimal time for application, is essential to avoid ammonia emissions. Ammonia from manure is the result of a continuous biochemical reaction over the entire storage period. The storage capacity determines the possible storage time before application. The required storage time is anywhere up to 6 months, depending on the climate. Such facilities must be sealed to prevent rain from penetrating the manure, and to protect the atmosphere (BMLF, 1991; Janβen, 2003). (3) The use of exactly the required amount of straw for bedding farm animals facilitates the maximal immobilisation of ammonia emanating from dung and urine.

For the calculations it is assumed that the present rate of implementation of M_2 is expanded to 100% of the utilised agricultural area (UAA) in each of the countries observed.

2.3. M_3: increase of plant productivity by applying capital-intensive production techniques

(1) Demand-oriented irrigation is required because the need for irrigation varies significantly between different zones of a country, according to climate and soil consistency. Adequate irrigation may result in increased yields and reduced nutrient surpluses in the soil, whereas excess water may contribute to surface water run-off and leaching of nutrients and chemicals, which flow into water bodies. Thus, efficient irrigation increases yields and product quality which consequently reduces the demand for fertiliser and other inputs. (2) Demand-oriented plant protection is the management of insects, weeds and diseases that affect agronomic and horticultural crops, hindering their development. (3) Improvements in plant nutrition lead to increased yields and reduce the need for fertiliser.

In the calculations, an implementation of M_3 was assumed in Austria on 15% of the UAA and in Bulgaria, Hungary and Romania on 30% of the UAA.

2.4. M_4: reduction of nitrogen emissions directly into the hydrosphere

(1) Minimal soil tillage implies only minimum soil manipulation for crop production. This minimises the use of conventional tillage equipment, in particular ploughs, and increases the use of, for instance, grubbers which are used to prepare only the top layer of the soil. The major effects of minimal soil tillage, aside from the avoidance of erosion, consist in reduced labour, energy and fertiliser input. (2) At zero-tillage, most of the soil is undisturbed, and seeds are placed in the untilled stubble of a previous crop. All crops, except tuber and root crops, can be grown in this way. Zero-tillage combined with crop rotation results in lower costs than conventional farming, as not only fuel, labour and maintenance costs, but also fertiliser is reduced. Zero-tillage can be practised on all soil types. However, wet and heavy clays are more difficult to manage with zero-tillage (Baker et al., 1996). (3) Mulch seeding is the kind of tillage which retains crop residue or cut weeds and other plants, which are spread onto, or mixed into, the top few centimetres of the soil, thus providing a protective surface cover. The main advantages of this kind of tillage are the reduction of wind erosion and the conservation of water in the soil through reduction of run-off (Baker et al., 1996). Moreover, the need for fertiliser is reduced. (4) The maintenance of a year-round cover crop on arable land is an effective way to reduce erosion and nitrogen leaching (DVGW/LAWA, 1999). A cover crop ensures a continuous uptake of the available soil nutrients, and thereby prevents the leaching of nutrients, as well as wind and water erosion, as water percolates in late autumn and winter (BMLF, 1991). Fertilisers will be partly substituted if the cover crop is incorporated into the soil. (5) Intercropping is the growing of two or more crops in proximity so that some cultural benefit (higher yield, easier pest control, lower fertiliser demand, etc.) is attained. The concept embraces a number of strategies which increase the biodiversity of agricultural ecosystems. Forage legumes, for example, are commonly seeded with grasses to reduce the need for nitrogen fertiliser. Likewise, beans are sometimes intercropped with corn (Kuepper, Dodson, 2001; Sullivan, 2003). Although M_4 includes a variety of labour-saving tillage techniques, it is, on the whole, labour intensive because it requires additional labour for mulch seeding, the maintenance of a year-round cover crop and, especially, intercropping (Klik et al., 2004; Brumfield, Brennan, 2004; Klonsky et al., 2002; Dano, Midmore, 2004; Carr, 2004).

For the calculations, a uniform implementation of minimal soil tillage on 20%, zero-tillage on another 3%, mulch seeding on 10% and maintenance of a year-round cover crop, respectively intercropping on 50% of the UAA is assumed for Austria, Bulgaria, Hungary and Romania.

3. Appraisal of the costs, effects on nitrogen loads and net cost–effect ratios of the measures

Each measure will be assessed empirically by calculating (1) the costs of the measure to all farmers of a certain country per year, (2) its effect on the nutrient load per year ('nutrient load reduction effect') (2.1) in the surface waters and main streams of a country on average, and (2.2) in the Danube water entering the Black Sea, and (3) the ratio between the first variable and one of the other two, called 'net cost–effect ratio', either related to the induced change of the nutrient load in the surface waters and main streams of the country, or to that in the Danube water entering the Black Sea.

3.1. *Calculation method of costs of measures and their effects on nitrogen loads*

The (annual) costs of a measure are defined as the sum (net value) of changes of production costs and sales revenues of the agricultural firms involved, induced by the measure (BMLFUW, 2002; BMLFUW, 2002a; Manea, 2004; Bonazzi et al., 2005; Menzi and Reidy, 2005; Ryan, 2005; Interwies et al., 2004). Both, the change in production costs and the change in sales revenues (roughly equivalent to gross output) may be either positive or negative. If, for example, a measure consists of *reducing* fertiliser use, the corresponding part of production costs will be reduced. However, most measures will increase production costs.

Sales revenue may be decreased or increased. Depending on the different amounts of these components, the (net) cost of a measure may be either positive or negative. The latter would mean that net profits rise.

This kind of definition makes it possible to display uniformly all measures in one kind of figure of the cost–effect-analysis (Figs. 1–3). In cases in which the cost data for Bulgaria, Hungary or Romania were not completely available, the Austrian data were used and adjusted by either the index of general cost level, the index of the cost level for agricultural machinery or the index of the cost level for agricultural wages (see Table 2).

The analysis of costs is based on the price level of 2002/03. In addition, it is assumed that the real price level in Bulgaria, Hungary and Romania will increase by 2% annually up to 2015 as compared to Austria (see also IFIP, 2003; WIIW, 2005). Subsidies (constituting the main part of governmental expenditures) remain out of consideration. The major components of costs accrue from the use of land, buildings and machinery, material and services from other producers as well as labour, paid by the agricultural producers.

To calculate the effects of a measure, first of all their impact on the soil surface must be determined by calculating the national nitrogen soil surface balance both before and after the measure. This calculation is made according to the OECD calculation scheme (OECD, 2001). The nitrogen soil surface balance is calculated as the difference between the total quantity of nitrogen inputs entering the soil (Inputs(N)) and the total quantity of nitrogen outputs leaving the soil annually (Outputs(N)). A positive balance is termed surplus (Surplus (N)). Production data, fertiliser input, nitrogen emission coefficients for livestock and rates of nitrogen fixation by crops are taken from FAOSTAT (2004) databases and national statistics (daNUbs, 2005) and adjusted to the reference scenario HP 2015. Thus, the first calculated effect of carrying out a specific measure is the change in the nitrogen surplus on the soil surface level.

$$\mathrm{Surplus(N)}_i^R = \mathrm{Inputs(N)}_i^R - \mathrm{Outputs(N)}_i^R \quad \text{(Formula 1)}$$

$$\mathrm{Surplus(N)}_i^j = \mathrm{Inputs(N)}_i^j - \mathrm{Outputs(N)}_i^j \quad \text{(Formula 2)}$$

$$\mathrm{Effect}_i^j = \mathrm{Surplus(N)}_i^R - \mathrm{Surplus(N)}_i^j \quad \text{(Formula 3)}$$

Here, i refers to country i (i=1, …,4 respectively, for Austria, Bulgaria, Hungary or Romania), R refers to the reference scenario HP 2015 and j indicates the measure j (j=1,…,4) to be assessed.

A decreasing nitrogen surplus in the soil generally leads to a decrease of the nitrogen load in the surface waters and

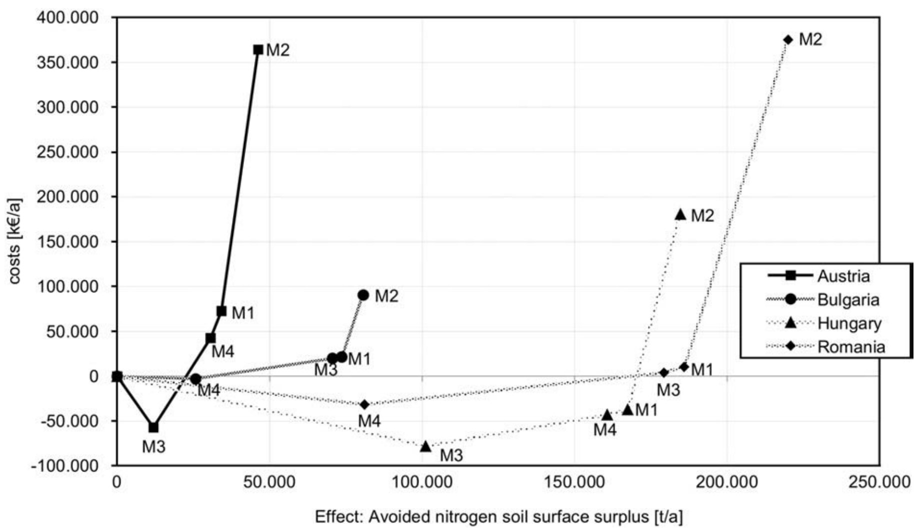

Fig. 1 – Ranking of measures to avoid nitrogen soil surface surplus in Austria, Bulgaria, Hungary and Romania according to their cost–effect ratios. Notes: M_1: Accurate application of fertilisers regarding fertiliser amount and time-related application rates, M_2: Reduction of nitrogen emissions from manure, M_3: Increase of plant productivity by application of capital-intensive production techniques, M_4: Reduction of nitrogen emissions directly into the hydrosphere; k€ = 1000 €. Source: IFIP, 2005.

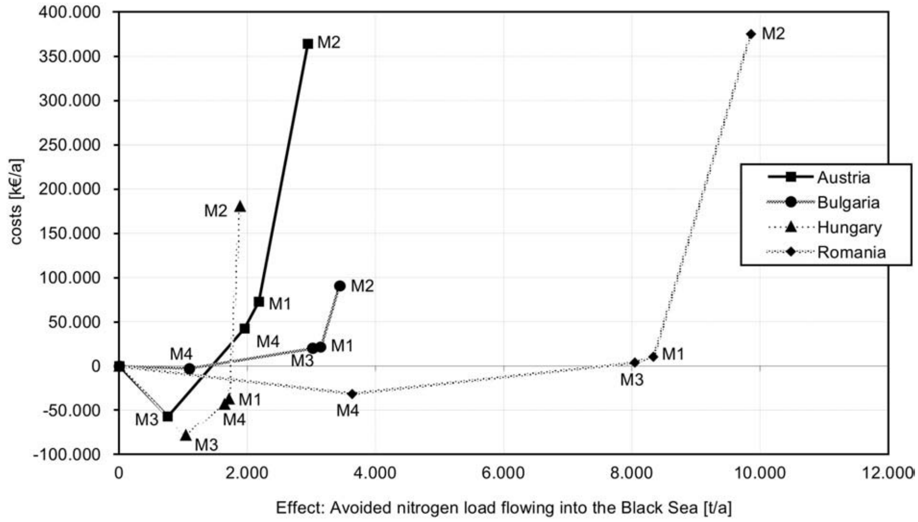

Fig. 2 – Ranking of measures to avoid nitrogen load flowing into the Black Sea in Austria, Bulgaria, Hungary and Romania according to their cost–effect ratios. Notes: M_1: Accurate application of fertilisers regarding fertiliser amount and time-related application rates, M_2: Reduction of nitrogen emissions from manure, M_3: Increase of plant productivity by application of capital-intensive production techniques, M_4: Reduction of nitrogen emissions directly into the hydrosphere; k€ = 1000 €. Source: IFIP, 2005.

mainstreams flowing finally into the Black Sea. In order to obtain the nitrogen load in the surface waters, the calculated nitrogen soil surface surplus is used as an input for the MONERIS-model. The MONERIS-(MOdelling Nutrient Emissions in RIver Systems) model is used for the calculation of nitrogen loads (of both, point and various diffuse sources) in the surface waters and the main streams in the DRC, resulting from the nitrogen leaving the soil. Thus, the MONERIS model shows the transition of nitrogen from the soil into the hydrosphere. The model is based on the data of river flow and water quality, and on a geographical information system (GIS) that includes digital maps and extensive statistical information (Schreiber et al., 2003; Schreiber et al., 2005).

The final effect of a measure is the change of the annual nitrogen load in the water flowing into the Black Sea. This is estimated by using average retention and transport factors for nitrogen in small surface waters and main streams (Table 3).

3.2. *Empirical results of the net cost-effect ratio analysis*

Using the methods described above, the costs of the measures specified and their effects on the nitrogen soil surface surplus

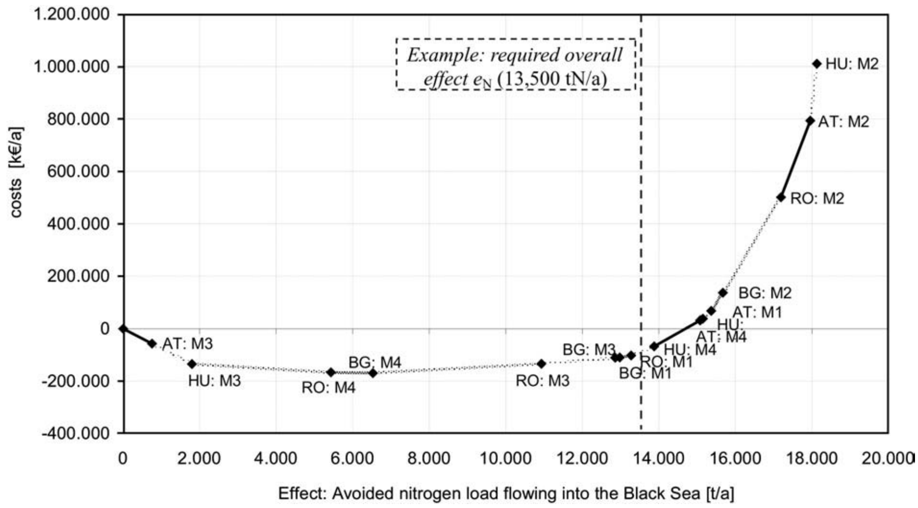

Fig. 3 – Cost-efficient combination of measures to avoid nitrogen load flowing into the Black Sea chosen jointly in Austria, Bulgaria, Hungary and Romania according to their cost–effect ratios. Notes: M_1: Accurate application of fertilisers regarding fertiliser amount and time-related application rates, M_2: Reduction of nitrogen emissions from manure, M_3: Increase of plant productivity by application of capital-intensive production techniques, M_4: Reduction of nitrogen emission directly into the hydrosphere; k€ = 1000 €. Source: IFIP, 2005.

Table 2 – Indices of general cost level, cost level for agricultural machinery and agricultural wages (in 2015) in Austria, Bulgaria, Hungary and Romania used in the cost calculations

	General cost level in 2015	Cost level for agricultural machinery in 2015	Agricultural wages in 2015
		Index AT=100	
Austria	100	100	100
Bulgaria	42	80	7
Hungary	66	89	22
Romania	41	80	4

Source: IFIP, 2005; WIIW, 2005.

(see Table 4) and the nitrogen load in the water flowing into the Black Sea (see Table 5) were calculated. Subsequently, the net cost–effect ratios for each of the measures, with regard to the nitrogen soil surface surplus and the nitrogen load flowing into the Black Sea (see Tables 4 or 5), were calculated.

3.3. *Costs of the measures*

The costs accruing to the agricultural producer when carrying out a measure differ widely, depending on the area to which it is applied, on the structure of production regarding the kinds of agricultural products, and on the cost levels in the countries examined. Both, measures imposing additional costs on the agricultural producers and measures with negative net costs, were found in the analysis.

For instance, the measure to increase plant productivity by applying capital-intensive production techniques (M_3) is commercially profitable in Austria and Hungary. In Bulgaria and Romania this measure imposes costs, and thus decreases profits because the cost-level for the machinery involved in applying the measure is high in comparison to the general cost-level. In particular, irrigation is a major capital investment (Buchanan, Cross, 2004), hardly affordable for many agricultural producers in the eastern countries of the DRC. The measure reduction of direct nitrogen emissions into the hydrosphere (M_4) includes a variety of labour-saving techniques (minimum soil tillage, zero-tillage). However, the measure M_4 is, on the whole, labour intensive, because of the additional labour requirements linked with mulch seeding, cover crops and intercropping. Hence, this measure imposes costs on the agricultural producers in Austria and Hungary, while it is profitable in Bulgaria and Romania, where labour costs are low. In the search for other measures with additional favourable effects on the national nitrogen soil surface balance and the nitrogen loads in the waters, only those measures have been found which cause losses to the farmers in these countries.

Negative net costs of measures raise the question why they should not already be implemented in the form of changes without policy intervention. Presumably, such changes have not been made to the greatest extent possible for the following reasons: To change a certain mode of production instead of continuing the accustomed one requires not only that the net effect of changes in revenue and costs should be higher in absolute terms, but that the *ratio* of this surplus to the capital invested should be higher than at all other occasions available to the producer. In addition, there exists a great variety of market and/or institutional imperfections that impede the adoption of cost-effective technologies in agriculture and, of course, other sectors. The literature on energy efficiency describes a broad range of such imperfections. A comprehensive taxonomy of possible sources of imperfections (and of opportunities, if they are overcome) shown by the literature on energy efficiency comprises missing markets or distorted prices, trade-related barriers, financial market imperfections, weaknesses of the market structure and functioning, shortcomings of the institutional framework, inadequate provision of information (public goods nature if information) as well as specific characteristics of social, cultural and behavioural norms and aspirations (IPCC, 2001, Chapter 5, Table 5.1).

Barriers specifically important in agriculture may be lack of adequate capacity for research and provision of extension services, farms too small for the adaption of new technologies, credit constraints, risk aversion, lack of access to information and training opportunities, inadequate rural infrastructure and tenure arrangements, unreliable supply of complimentary inputs, and, last but not least, subsidies for critical inputs, such as fertiliser, water supply, electricity and fuels, and for outputs (IPCC, 2001, Technical Summary, p. 48). Most likely, they are also relevant in impeding potentially profitable measures which would decrease nitrogen surplus in the soil surface arising from agricultural production.

3.4. *Effects on the nitrogen load*

If all measures are employed, the nitrogen soil surface surpluses will be cut by roughly a third in each of the countries compared with scenario HP 2015. The total reductions achieved in Hungary and Romania, respectively, would be more than twice as high as in Bulgaria and even 4 to 5 times higher than in Austria (Table 4), mainly because of the vast size of their agricultural areas within the Danube River Basin.

Because of the nitrogen retention capability of soil and surface waters the absolute effects on the load entering the Black Sea are, for all these countries, far below those on the soil surface (Tables 4 and 5). The nitrogen load entering the Black Sea is reduced by around 20% (AT: 17%, BG: 19%, HU: 18%, RO: 24%) compared to HP 2015. The retention capability of soil and surface waters differs considerably in the countries examined, the highest being in Hungary. Hence, the absolute effect on the nitrogen load flowing into the Black Sea as a result of the measures taken in Hungary is small, although the agricultural area of Hungary within the Danube River Basin is vast.

Table 3 – Average factors for the retention of nitrogen in small rivers and main streams in Austria, Bulgaria, Hungary and Romania used in the cost calculations

	Share of nitrogen retained in small rivers and main streams [%]	Share of nitrogen transported into the Black Sea [%]
Austria	30.6	69.4
Bulgaria	41.2	58.8
Hungary	61.4	38.6
Romania	40.7	59.3

Source: IFIP, 2005, based on daNUBs, 2005.

Table 4 – Costs (C), effects (E) and cost–effect ratio (CER) of measures in Austria, Bulgaria, Hungary and Romania regarding the nitrogen soil surface surplus in €/kg in 2015

	M_1		M_2		M_3		M_4		Bundle (M_1–M_4)	
	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]
Austria	8.43	30,118 3575	24.21	291,569 12,041	−4.78	−56,950 11,915	5.32	99,543 18,726	7.88	364,280 46,256
Bulgaria	0.56	1.668 2.992	9.69	68.912 7.115	0.51	22.850 44.882	−0.11	−2.906 25.721	1.12	90.524 80.710
Hungary	0.87	5892 6744	12.57	217,681 17,321	−0.77	−78,018 101,158	0.59	35,030 59,452	0.98	180,585 184,674
Romania	1.01	6616 6546	10.68	364,686 34,155	0.36	35,522 98,190	−0.39	−31,635 81,073	1.71	375,189 219,964

M_1: Accurate application of fertilisers with regard to fertiliser amount and time-related application rates, M_2: Reduction of nitrogen emissions from manure, M_3: Increase of plant productivity by application of capital-intensive production techniques, M_4: Reduction of nitrogen emissions directly into the hydrosphere; k€= 1000 €.
Source: IFIP, 2005.

3.5. *Net cost–effect ratios: empirical results*

From these results, the net cost–effect ratios (both with regard to the nitrogen soil surface surplus and the nitrogen load flowing into the Black Sea) were calculated. These ratios could also be termed as 'costs per ton of nitrogen load reduced' or 'nitrogen unit costs'. As a consequence of the retention capability of soil and surface waters, the net cost–effect ratios of measures to reduce the nitrogen load flowing into the Black Sea are up to 100 times higher than those with regard to the soil surface surplus.

On average, the net cost–effect ratios in Austria are higher than in Bulgaria, Hungary and Romania because of the higher cost level in Austria. The most satisfactory measures are those which are commercially profitable, which is expressed by negative costs. Such measures increase plant productivity by applying capital-intensive production techniques (M_3) in Austria and Hungary, and reducing direct nitrogen emissions into the hydrosphere (M_4) in Bulgaria and Romania. The highest costs per ton of nitrogen reduced were found for the reduction of nitrogen emission from manure (M_2) in all of the countries examined, because of the high investment necessary. If all measures M_1–M_4 were carried out simultaneously, the overall net cost–effect ratio would be positive in each of the countries. This means that the bundle of all measures, as a whole, is economically a burden for the agricultural producers.

With regard to the nitrogen soil surface surplus (see Table 4), the lowest overall net cost per ton of nitrogen reduced was found for Hungary. However, the costs per ton reduced found for the nitrogen load flowing into the Black Sea (see Table 5) of the total of measures in Hungary are approximately as high as for Austria. This is because the soil and surface waters in Hungary retain nitrogen to a far higher degree than in Austria (or any other country examined). The least costs per unit to reduce the nitrogen load flowing into the Black Sea were found for Bulgaria.

4. Optimising the choice of measures based on net cost–effect ratios: cost-efficiency analysis

4.1. *Optimisation for each country separately*

If a bundle of measures was to be assembled for each country examined, a cost-efficient choice of measures would be possible. First of all, the measures have to be ranked within the

Table 5 – Costs (C), effects (E) and cost–effect ratio (CER) of measures in Austria, Bulgaria, Hungary and Romania regarding the nitrogen load flowing into the Black Sea in €/kg in 2015

	M_1		M_2		M_3		M_4		Bundle (M_1–M_4)	
	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]	CER [€/kg]	C [k€/a] E [t/a]
Austria	136	30,118 222	382	291,569 764	−75	−56,950 757	83	99,543 1201	124	364,280 2944
Bulgaria	14	1.668 124	230	68.912 300	12	22.850 1.924	−3	−2.906 1.094	26	90.524 3.442
Hungary	85	5892 69	1253	217,681 174	−75	−78,018 1038	58	35,030 606	96	180,585 1887
Romania	23	6616 291	239	364,686 1524	8	35,522 4411	−9	−31,635 3635	38	375,189 9861

M_1: Accurate application of fertilisers regarding fertiliser amount and time-related application rates, M_2: Reduction of nitrogen emissions from manure, M_3: Increase of plant productivity by application of capital-intensive production techniques, M_4: Reduction of nitrogen emissions directly into the hydrosphere; k€= 1000 €.
Source: IFIP, 2005; IGB, 2005.

countries according to their net cost–effect ratios. This ranking can be based either on their ratios for the nitrogen soil surface surplus (Fig. 1) or for the nitrogen load flowing into the Black Sea (Fig. 2). Regardless of which kind of ratio is used, the rankings of the measures within the countries remain the same.

Secondly, it must be decided which kind of objective is to be achieved: If a certain degree of nitrogen soil surface surplus reduction (or reduction of the nitrogen load flowing into the Black Sea) is stipulated as a political goal, the question will be: Which measures are to be chosen to meet the quantitative objective ("nitrogen load limit") at minimum costs? Alternatively, if a certain amount of money is provided by political decision (and transferred as subsidies) for reducing the nitrogen soil surface surplus (or the nitrogen load flowing into the Black Sea), the question will be: Which measures are to be selected in order to maximise the reduction of the load without violating the budget constraint?

In both cases, first of all the measure with the lowest ratio is to be chosen separately for each country, i.e., M_3 for Austria and Hungary, and M_4 for Bulgaria and Romania. By carrying out these measures, the nitrogen soil surface surplus or nitrogen load flowing into the Black Sea would be reduced at negative costs per ton, and thus be profitable for the farmers concerned (provided the barriers mentioned in chapt. 3.3 are removed at zero costs for them). The second measure to be chosen is that with the lowest ratio of the remaining measures, i.e. M_4 in Austria and Hungary, and M_3 in Bulgaria and Romania, all inducing positive costs. In accordance with this procedure, one measure after the other is chosen to be carried out, (a) as long as the internal costs of carrying out all the measures selected do not violate a specified budget constraint and (b) until the required effect is achieved. Figs. 1 and 2 show the result of the cost-efficient choice.

Fig. 2 reveals that the effect of reducing the nitrogen load flowing into the Black Sea is least in Hungary. The reason for this is the significantly higher retention of nitrogen in the soil and surface waters in Hungary, as mentioned above. However, the effect regarding the soil surface surplus in Hungary is almost as high as that for Romania (Fig. 1). Despite this, the effect of the measures in Hungary with regard to the soil surface surplus is of minor importance considering the ecological status of the Black Sea, but it might be important for the quality of the Hungarian soil (e.g. salination of soil) and surface waters (e.g. drinking water quality).

From Fig. 2 it can also be calculated easily that the total amount of avoidable nitrogen load flowing from Austria, Bulgaria, Hungary and Romania, on account of their agriculture, into the Black Sea is over 18,000 t p. a. This would give rise to total costs of 1010 m€ per year. However, the greater proportion of the reduction, namely 54%, is achieved by employing the measures in Romania that incur only 37% of the total costs.

4.2. *Joint optimisation for all countries considered*

Considering this unequal distribution of costs and effects, it is reasonable to optimise the choice of measures jointly, so a linear optimisation model was designed. This can mean either minimising the costs to reduce the nitrogen load by a required amount or, alternatively, maximising the reduction of the nitrogen load without exceeding a given budget constraint. Below, such an optimisation model is developed and applied for the first case mentioned above.

In the optimisation process it must be decided to what degree a measure should be implemented. A measure can be carried out either at the assumed or at a lower degree of implementation. The objective function (Formula 4) is to minimise the total costs (C_{tot}) of implementing measures (j=1,…,n) in the countries examined (i=1,…,m) by selecting measures and their degrees of implementation.

Minimise (with regard to δ):

$$C_{tot} = \sum_{i=1}^{m} \sum_{j=1}^{n} \delta_{ij} \cdot C(i,j) \qquad \text{(Formula 4)}$$

subject to:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \delta_{ij} \cdot E_N(i,j) \geq e_N \qquad \text{(Formula 5)}$$

$$\sum_{j=1}^{n} \delta_{ij} \cdot E_N(i,j) \geq e_{Ni} \quad \forall i \qquad \text{(Formula 6)}$$

$$\delta_{ij} \in [0,1] \quad \forall i,j \qquad \text{(Formula 7)}$$

$C(i,j)$ refers to the costs incurred by carrying out measure j in country i, $E_N(i,j)$ is the corresponding effect on the nitrogen load flowing into the Black Sea, which is based on the effect on the nitrogen surplus and transport coefficients. The degree of implementation of a measure δ_{ij} is non-negative and 1 at most.

The first constraint (Formula 5) provides that an overall reduction (e_N) of the nitrogen load flowing into the Black Sea be achieved. The value for e_N is the result of a political decision aimed at improving the ecological status of the Black Sea.

The polluter-pays-principle can be considered either partially or fully in two different ways:

- First, if transfer payments between the countries involved are possible, measures will be implemented in those countries where reduction is cheapest. The costs for these measures will be shared between these countries.
- Second, if transfer payments are not possible, the constraint represented by (Formula 6) will become effective. Each country i has to carry out those measures which bring about at least a politically decided required effect (e_{Ni}). The country's share of the required effect achieved in agriculture shall not exceed the country's share of the nitrogen load flowing into the Black Sea originating from its agriculture (l_i), i.e. $e_{Ni}/e_N \leq l_i / \sum_k l_k$.

For example, it is assumed that the polluter-pays-principle is implemented by an international transfer payment system (ignoring the constraint represented by (Formula 6)) and furthermore, that a required effect e_N amounts to, for instance, 13.500 t/a. The required reduction will be achieved at minimum costs if (a) measure M_3 is put into effect to the full extent assumed in each of the countries, (b) measure M_1 is put into effect also entirely in Bulgaria and Romania and (c) measure M_4 is put into effect entirely in Bulgaria and Romania, and only partially in Hungary (37% of the assumed degree of implementation).

The total costs C_{tot} for all the countries together are negative (−90 m€), however, the costs accruing to Romania where the greatest effect is achieved, and those in Bulgaria are positive (RO: +11 m€, BG: +21 m€) and should be compensated by the other countries involved. Fig. 3 illustrates this result.

Alternatively, if international transfer payments are not possible (i.e. only national policy action occurs), the polluter-pays-principle will be taken into account by using the constraint represented by (Formula 6). As an example, the share of the required reduction of a country is assumed to be proportional to its share of nitrogen load flowing into the Black Sea ($e_{Ni}/e_N = l_i/\sum_k l_k$). Hence, the polluter-pays-principle is applied at its maximum. In this case, the total costs are positive (+137 m€). In Austria all the measures have to be carried out, M_2 only for 45% of the assumed extent of implementation, thus incurring costs of 203 m€. In Bulgaria the beneficial measure M_4 and measure M_3 (M_3 for 44% of the assumed extent of implementation) have to be implemented, incurring internal costs of 7 m€. In Hungary the beneficial measure M_3 needs to be implemented along with M4 to a very small extent of implementation (5% of the assumed extent), thus resulting in negative costs of 76 m€ for Hungary. Finally, in Romania, the measures M_4 and M_3 must be put into effect, incurring negative internal costs of 8 m€ for Romania.

In addition, budget constraints c_i (Formula 8) could be introduced to the optimisation model to avoid over-extending the countries' financial capabilities.

$$\sum_{j=1}^{n} \delta_{ij} \cdot C(i,j) \le c_i \quad \forall i \qquad \text{(Formula 8)}$$

However, in the work presented here, no budget constraints were considered.

5. Conclusions

The total effect, in terms of achievable reduction of nitrogen load flowing into the Black Sea, is by far the highest in Romania which also has, in general, the lowest net cost–effect ratios. In each of the countries, it is possible to decrease the nitrogen load by implementing measures which are profitable to the agricultural producer. However, in many cases obstacles, such as lack of information and risks to finance high investments, may impede implementation. On average, approximately one third of the possible reduction is found to be achieved in a profitable way for the agricultural producers. A second third would cause only a minor amount of costs and both would approximately outbalance each other. Only the last third would be achieved by measures causing comparatively high internal costs per unit of nitrogen avoided.

Using the optimisation model, it is shown that the joint optimisation for all the countries considered, i.e. international policy actions, is more cost-efficient than merely national policy action. Similar results were found for the Baltic Sea (e.g. Gren et al., 1997a).

The focus in the work presented here is on the effects of the measures with respect to the Black Sea. Quality of surface and ground waters with regard to drinking water quality was not included.

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