Impact of nitrogen reduction measures on nitrogen surplus, income and production of German agriculture

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Abstract Among the numerous non-point sources of diffuse water pollution with nitrogen, agriculture is counted one of the main sources. The agricultural policies of the Agenda 2000 and a decoupling of direct payments for farmers from their production decisions are exemplarily evaluated as nitrogen reduction measures using the Regional Agricultural and Environmental Information System RAUMIS. The results show that until the target year 2010 the risk of diffuse pollution of water bodies with nitrogen is a regional problem in Germany. These problems are neither mitigated by the policies of Agenda 2000 nor by a decoupling of direct payments from production decisions of farmers. While total nitrogen surplus reduces considerably after a decoupling of direct payments due to decreases of land-use the nitrogen surplus on the remaining cultivated area increases resulting from structural changes. Granting the same amount of direct payments to farmers in both policy alternatives the agricultural sector income would be higher after a decoupling of direct payments opposed to the Agenda 2000 resulting from a more efficient allocation of inputs.

Keywords Agriculture; diffuse water pollution; nitrogen surplus; policy impact analyses; sector modeling

Introduction
Considerable progress has been achieved over the past four decades to diminish water pollution from point sources. However, water pollution from non-point sources upon which the political and scientific interest is focusing continues to be of concern. Among the numerous non-point sources agriculture plays an important role. Depending on production intensity and natural conditions, agriculture is counted among the main sources of diffuse water pollution with nitrogen. The negative environmental consequences of nitrogen leaching into water bodies are chiefly an impairment of drinking water and eutrophication of surface water.

Various measures, e.g. agricultural policies and environmental regulations exist that directly or indirectly reduce the nitrogen surplus of agricultural production. Measures can be different in nature (e.g. nitrogen-tax, nitrogen-quotas or technical requirements) and can apply on different levels (e.g. on EU, national, regional or business level). Regarding policy counseling and policy recommendations, the measures have to be assessed with respect to their efficiency in reducing diffuse water pollution. In addition to their impacts on water protection, socio-economic consequences for agriculture such as farm income and structural changes have to be taken into account, too.

The agricultural markets in the EU have a long tradition of agricultural policies and in more recent years of environmental policies, as well. Agricultural markets are still strongly regulated by the Common Agricultural Policy (CAP). The CAP causes substantial problems primarily emerging from considerable expenditures for the agricultural market regulation, the WTO-negotiations and the east-enlargement of the EU. Currently, various alternative policy options are being discussed preparatory to the mid-term review of Agenda 2000. Emphasis is placed on liberalizing the agricultural markets of the EU, in particular a decoupling of direct payments from the production decisions of farmers.

The objective of the paper is to evaluate the impacts of the policy options a)
Agenda 2000 and b) “a Decoupling of Direct Payments” on diffuse water pollution as examples of nitrogen surplus reduction measures. The following aspects are of particular interest:

- changes of agricultural production and its regional distribution,
- reduction of fertilizer surplus in order to comply with water pollution control targets,
- and socio-economic consequences for agriculture.

The evaluation of these alternative measures is carried out using the Regional Agricultural and Environmental Information System RAUMIS (Henrichsmeyer et al., 1996). Beside extensive analyses of ex-post developments as well as competitiveness between regions, RAUMIS’ strengths lie in impact analyses of alternative agricultural and environmental policies. The analyses focus on the consequences of input use (e.g. fertilizer, chemicals, etc.), land use, agricultural income, and agri-environmental relationships.

The paper is structured as follows. A methodological section gives a brief overview about RAUMIS. After a description of its general approach important features that are relevant for diffuse water pollution are explained. Results of the policy impact analyses are presented for the alternative agricultural policy scenarios Agenda 2000 and a decoupling of direct payments for the target year 2010. These scenarios are compared to the status quo of the base year 1999. The paper closes with conclusions about further policy options as well as methodological extensions and improvements of the model RAUMIS.

**Methods**

RAUMIS is designed for continuous usage in the scope of long-term agricultural and environmental policy impact analyses and aims to support policy-makers in policy decision processes. During the last years the model has been extensively used for policy impact analyses carried out for the German Federal Ministry of Consumer Protection, Food and Agriculture (BMVEL). Figure 1 gives an overview over RAUMIS’ modular design. Impacts of alternative policies being analysed are in particular the development of agricultural production, inputs, and the net agricultural value added as well as the resulting changes in environmental risk factors such as nitrogen surplus.

The model consolidates various agricultural data sources and generates base model data with the national agricultural accounts as a framework of consistency. The most relevant information being processed in RAUMIS are activity specific data about production and yields on national and on regional level from the official agricultural statistics, technical input-output coefficients, cost estimates, data from a network of representative farms and

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**Figure 1** System of the modular design of RAUMIS. Source: FAA – description and layout

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1 Farm Accountancy Data Network (FADN) is an instrument for evaluating the income of agricultural holdings
various other calculation data. The model comprises more than 50 agricultural products and used inputs with exogenously determined prices. RAUMIS completely reflects the German agricultural sector with its sector linkages. Due to the four year interval of the official agricultural statistic survey base, model data for six base years are currently available ranging from 1979 to 1999.

According to the data availability the spatial differentiation of RAUMIS is presently based on administrative criteria. The true continuous spatial distribution of agricultural production is approximated by some 326 regions basically on a county level ("Landkreis"). These Regions are treated as single "region enterprises" that autonomously reach their production decisions i.e. adjustments of production on a national level base on the aggregated responses of the "region farms".

Adjustments caused by changes in general conditions such as agricultural policies are determined using a mathematical programming approach with a non-linear objective function. This method is an algorithm that models responses of producers to changes in the relative profitability of production activities subject to technical, political and economic constraints. The calculated optimal production plan generates the maximum feasible farm income which is the basic assumption of this approach. However, the derived optimal production plan does not necessarily match exactly the amounts of production being observed ex-post because of imperfect information about the true coefficients. This problem is overcome by applying the technique of positive mathematical programming (Howitt, 1995). The positive mathematical programming approach provides substantial advantages with respect to the long-term forecasting behavior of the model. In the projection phase a variety of exogenous variables such as implicit costs resulting from positive mathematical programming, input-output coefficients, yields, capacities, and prices are forecast. Updates are partially based on trend and yield dependent regression analyses as well as on estimations of experts, particularly regarding prices and the development of farm structures.

Because various parameters are changing in the long-run in addition to the variations of policy measures being investigated comparative static policy impact analyses for a future target year require a scenario of reference. Deviating from the scenario of reference alternative policy measures and environmental regulations are imposed on the model leaving all other parameters and variables constant. This procedure separates the policy impacts on agricultural production and hence indirectly on the environment e.g. nitrogen surplus as deviations from the scenario of reference.

In RAUMIS a set of agri-environmental indicators is implemented to analyze the direct and indirect environmental impacts of the agricultural production at the regional level. Regarding diffuse water pollution, the indicator “Fertilizer Surplus” is of particular importance. In the following the methodological foundations applied in RAUMIS to calculate a nitrogen balance are illustrated.

The concept of balancing nitrogen as shown in Figure 2 follows the area principle (Bach, 1987) where the soil surface represents the system border. The primary demand for nitrogen is based on the nutrient uptake of plants that are removed from the soil during the harvest. A further reduction of nitrogen occurs as a loss of ammonia (NH₄) during storage and application. Important inputs of nitrogen are organic and mineral fertilizer. Other sources are symbiotic and asymbiotic nitrogen-fixation, as well as atmospheric deposition. A nitrogen surplus results from the comparison of demand and supply and is displayed as quantity unit per acreage (kg per ha) on the regional level. This spill-over is regarded as a risk indicator for this amount is potentially available for de-nitrification and leaching into water bodies.

The listed positions of the nitrogen balance are calculated by the activity-based frame-
work in RAUMIS. In order to obtain regional input and output positions, activity-specific coefficients are multiplied with the level of each activity, e.g. area harvested or livestock.

Nutritional requirements for each crop production activity and region are based on expected crop-specific yields as well as soil and climate conditions. Nitrogen use of individual crop production activities is calculated by linear yield-dependent requirement functions. The loss of ammonia during storage and application is adapted from the assumption that 40% of the nitrogen in manure inaccessible by plants is converted into ammonia during storage and application.

The nitrogen supply from manure is derived from nitrogen contents in the excrements of farm animals. RAUMIS differentiates between four processes of manure and its application i.e. dung and liquid manure from cattle, hogs and poultry. Coefficients about the nutrient content in manure as well as the utilization factors of plants are taken from the literature and are provided also from experts of the BMVEL. Presumably, these coefficients are neither static over time nor identical between regions especially regarding (bio)technological progress and regional differences in feeding practices. However, due to missing information, average sectoral parameters are assumed temporally and spatially constant in RAUMIS except for cows. The regional nitrogen content in cowshed manure is calculated subject to the share of green fodder. Following the concept that nitrogen from manure can replace nitrogen from mineral fertilizer, mineral fertilizer equivalents for manure are calculated based on different nitrogen utilization factors of dung and liquid manure from cattle, hogs and poultry. It is assumed that the mineral fertilizer equivalent for dung is constantly 25% which implies that 4 kg of nitrogen from dung substitute 1 kg of nitrogen from mineral fertilizer. The coefficients for liquid manure regionally vary between 16 to 25% for cattle, 20 to 30% for hogs, and 26 to 39% for poultry.

Because of high transport costs it is assumed that organic fertilizer remains in the region and substitutes mineral fertilizer in crop production, subject to regional rates and thresholds of substitution. A regional excess demand for nitrogen in plant cultivation is equalized by using mineral fertilizer in a way that the derived aggregated mineral fertilizer demand matches the amount of national fertilizer sales from the national agricultural accounts for the base years.

The positions’ asymbiotic nitrogen fixation and nitrogen entry from the atmosphere are included as lump sum amounts, namely 30 kg per hectare for atmospheric entry and 1.4 kg per hectare for asymbiotic nitrogen fixation. Calculations for symbiotic nitrogen fixation are based on expert information and depend on the levels of pulses, clover and alfalfa.
Policy scenarios, results and discussion

In the EU the CAP had a lasting effect on agricultural production. However, during the last decade the measures of the CAP have been partly changed. In particular, high support prices for cereals, oilseeds, pulses and beef (“Grand Cultures”) have been reduced resulting in a lower intensity of production and a decline of nitrogen surplus (Weingarten and Kreins, 2002). High support prices have been replaced by crop and animal specific payments that still strongly channel agricultural production and currently amount to more than €25 billion. In Agenda 2000 this reform is extended to the production of cattle and milk, too, in addition to synchronizing direct payments for the “Grand Cultures”. Hence, within the next decade animal specific payments will be implemented in order to compensate for income losses of farmers resulting from the envisaged reduction of support prices for butter, skim milk powder, cheese, and beef.

The Agenda 2000 does not substantially solve these problems. Against this background the subsequent policy scenarios projected for the target year 2010 are compared to the situation in the base year 1999.

Agenda 2000

Beside the measures that are already in effect such as a reduction of the support price for cereals and a synchronization of direct payments for “Grand Cultures”, policies that will be introduced within the next years especially the reduction of the support price for milk, and the implementation of direct payments are taken into account, too.

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Figure 3  Regional shares of arable land in Germany in 1999 (in % of total AA)
Source: RAUMIS calculation 5/2002

Figure 4  Regional distribution of livestock in Germany in 1999 (in LU per ha AA)
Source: RAUMIS calculation 5/2002

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The results are partially based on policy impact analyses carried out within the project: “Assessment of selected measures to protect water bodies from diffuse pollution.” funded by the Federal Environmental Agency.
Decoupling of direct payments (DDP)

A decoupling of the direct payments for “Grand Cultures” and animals implies granting the money to farmers without obligations of production.

A comparison between the situation in the base year 1999 and the situation of the scenarios in the target year 2010 comprises both the projected autonomous developments over the time period and the policy variations. Since the autonomous developments are identical for both scenarios, differences between Agenda 2000 and DDP are purely policy driven.

In order to understand the effects that underlie observable changes of nitrogen surplus between the base year and the scenarios projected for the target year 2010, some basic information about the regional distribution of agricultural production in Germany is needed. Figure 3 displays the regional specialization of agricultural production on the basis of the shares of arable land of total agricultural area (AA). On the one hand there are regions with preponderant arable farm land where cash crop growing dominates. On the other hand in particular in the mountain and coastal regions land can be used as permanent grassland only so that farming is specialized in cattle and milk production. In between are regions with mixed cropping.

During the last two decades grassland has been turned into arable land. This development took place especially in the north western regions of Germany driven by their comparative advantages over other German areas in livestock farming. Due to the rising concentration of livestock in this region the feed use increased, too. However, agricultural area is limited. Therefore, the cropping of silage maize gained weight since the fodder productivity per hectare is higher compared to grassland.

Regarding the problem of diffuse water pollution, the spatial allocation of livestock is of particular importance since nitrogen surplus emerges especially from animal production. Figure 4 presents the regional concentration of livestock in Germany on the basis of livestock units (LU) per hectare for the base year 1999. The chosen classification refers to an approach being discussed by the Working Group of the Federal States on water problems (LAWA) in stratifying regions according to their risk-potential for diffuse water pollution (Helmer, 2001). The chart clearly reveals that livestock clusters in two regions, i.e. in the

Figure 5 Regional distribution of agricultural nitrogen surplus in Germany in 1999 (in kg per ha non-idled AA) Source: RAUMIS calculation 5/2002
North West of Germany and in Bavaria. While in Bavaria the above average density of animals primarily accrues from cattle and the specialization in milk production, the northwestern regions of Germany are counted among the European regions with the highest concentration of hogs, poultry, and cattle. A couple of counties in North West Germany even exceed 2.5 LU per ha.

Because of the low utilization rate of manure-nitrogen by plants opposed to nitrogen from mineral fertilizer as mentioned above, animal production and nitrogen surplus are closely related. Hence, the regions with the highest nitrogen surplus as displayed in Figure 5 coincide with the regions of intensive livestock farming. In regions with a density of livestock of above 2.5 LU per ha, e.g. in the North West of Germany, the nitrogen surplus partially exceeds 200 kg per ha on non-idled AA. The non-idled AA was chosen as the base since fertilizer is applied to the cultivated area only. In 1999 an average of 5% of total agricultural area was unused with an almost even distribution. This was primarily due to a compulsory set-aside-program within the direct payment program for “Grand Cultures” and other facultative set-aside-programs. A negligible share of AA accounted for fallow land, i.e. land being unused because any production is unprofitable.

Figure 6 shows the expected regional changes of the shares of unused agricultural area after full implementation of Agenda 2000 or a decoupling of direct payments compared to the base year. These variations are relevant for interpreting changes in the nitrogen balance. While the unused agricultural area increases insignificantly with Agenda 2000 except for a few regions, a distinct up-rise of this share can be observed after the DDP. The changes are more distinct in regions that are specialized in the production of “Grand Cultures” such as the new German Federal States, eastern Schleswig-Holstein, and northern Bavaria. In these areas the share of unused AA of total AA exceeds 30%. However, in the very fertile regions e.g. counties around Brunswick or between Aachen and Cologne even less agricultural area is idled in comparison to the base year.

Figures 7 and 8 present the indirect consequences of changes in agricultural production – demonstrated exemplarily by land-use changes – on the nitrogen balances. The average

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**Figure 6** Regional change of the share of unused Agricultural Area in Germany 2010 at Agenda 2000 and Decoupling of Direct Payments compared to the base year 1999 (difference of the percentages of unused AA of total AA) Source: RAUMIS calculation 5/2002
agricultural nitrogen surplus of 84 kg per ha non-idled area remains constant by the policies of Agenda 2000 in comparison to the base year. Regional changes vary between an increase and a decrease of nitrogen surplus by 10 kg per hectare non-idled AA (see Figure 7). However, relating the nitrogen surplus to the total AA an average decline by 2.5 kg per ha arises compared to the base year due to higher share of set-aside area.

After a decoupling of direct payments the nitrogen surplus strongly rises on non-idled land on average by 10 kg per ha compared to the base year resulting in the first place from structural changes of land-use. One factor is that the agricultural area left unused in this scenario is primarily less favored land with lower intensities of production so that the average nitrogen surplus on the remaining cultivated land increases. The same holds true for less profitable crops that generally require lower intensities of production. A strengthened substitution of low by high intensity crops causes the average regional nitrogen surplus on non-idled land to rise, too. A comparison of Figure 6 and Figure 8 clearly reveals that regional impacts are stronger if land is noticeably falling fallow. Of course, the higher the regional density of livestock (see Figure 4) the higher the increase of nitrogen surplus on non-idled land. This effect arises from the fact that an increased amount of manure is applied to the remaining cultivated land since the decline in animal production is lower than in crop production and land-use. However, relating the nitrogen surplus to total AA the spill-over reduces by 10 kg per hectare on average in comparison to the base year due to the considerable reductions of production and land-use.

Assessing the impacts on agricultural income is important as changes reflect implicit costs or gains of nitrogen reduction measures. In Figure 9 the net value added of the German agricultural sector is presented for the base year and the two scenarios being considered in the target year. In 1999 the net value added representing the agricultural sector income amounted to about €10.7 billion. Approximately half of the sector income were subsidies.

Until the target year 2010 the sector income slightly increases up to €11.4 billion under
the conditions of Agenda 2000 with the share of subsidies (including direct payments) rising up to 57%. However, after DDP the agricultural sector income exceeds the net value added of Agenda 2000 by €0.4 billion, arising from a more efficient allocation of production inputs.

**Conclusions**

Based on the analyses of current developments of agricultural policies with respect to nitrogen surplus reduction, the following aspects can be concluded: a) in Germany the risk of diffuse pollution of water bodies with nitrogen is a regional problem. Neither the policies of Agenda 2000 nor a decoupling of direct payments – not explicitly aiming at a reduction of nitrogen surplus – mitigate these “hot spot” problems. This is mainly attributable to the small impact on animal production so that the regional manure supply stays constant and the fact that direct payments do not influence the crop specific intensity whether coupled to or decoupled from production; b) structural changes of land-use cause a limited decline of nitrogen surplus when related to total agricultural area within Agenda 2000 and DDP. However, because of an increased idling, manure is applied to a smaller cultivated area. Hence, in particular in “hot spot” regions with a high density of livestock the problems emerging from a surplus of nitrogen may even aggravate.

From these impacts it follows that neither Agenda 2000 nor a decoupling of direct payments are appropriate instruments to alleviate the regional problems with agricultural nitrogen surplus. Consequently, alternative policy options directly aiming at a reduction of nitrogen spill-over, e.g. nitrogen taxes/quotas, or restrictions on the regional density of livestock have to be assessed. This will be carried out within the project mentioned in Footnote 2.

According to the identification of the diffuse water pollution problem as a regional problem the subsequent conclusions follow from a methodological point of view: a) the current spatial differentiation of RAUMIS needs to be refined in order to appropriately account for natural locations within catchments. Depending on the availability of appropriate data, further improved consideration on a lower municipality level is possible; b) a direct inference from the risk indicator “nitrogen surplus” to actual depositions of nutrients into water bodies is limited since natural conditions and soil properties (e.g., nutrient storage capacities, retention periods, etc.) vary considerably among regions. This could be achieved by an

![Figure 9](German agricultural net value added (sector income) in 1999 in comparison to Agenda 2000 and to a decoupling of direct payments in 2010 (Mill. €))

*Source: RAUMIS calculation 5/2002*
integrated framework of RAUMIS and hydrological/geo-hydrological models, e.g. GROWA98 (Kunkel and Wendland, 2002) or WEKU (Kunkel and Wendland, 1997).

References


