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Quantifying Impacts of Different Agri-environmental Policies on the Environment Using the Regional Agri-environmental Information System RAUMIS

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Abstract

RAUMIS has been developed in consequence of an increased demand for model-based decision support regarding agricultural and environmental policies. The area-wide and regionally differentiated model comprehensively and consistently reflects the German agricultural sector with various environmental relationships. The paper describes the nitrogen balance in RAUMIS in more detail. This provides the methodological background for the impact analysis of a tax on mineral nitrogen. The results show that the tax does not mitigate the hot-spot problems with nitrogen surplus in Germany.

1 Introduction

In Germany agriculture plays a major role regarding its impacts on the environment since agriculture uses almost half of the total German area. Driven by an increased overall environmental awareness agricultural research has increasingly focused on environmental topics in the last two decades e.g. on diffuse pollution, biodiversity, and cultural landscape. Government and administration ascertained a need for an agricultural and environmental information system. This need initiated the development of the area-wide Regional Agricultural and Environmental Information System RAUMIS for Germany (Henrichsmeyer et. al. 1996).

RAUMIS is designed for a continuous usage in the scope of long-term agricultural and environmental policy impact analyses. During the last years it has been extensively used for the German Federal Ministry of Consumer Protection, Food and Agriculture (BMVEL) in order to support policy-makers in policy decision processes. Especially the impacts on input use (e.g. fertilizer, chemicals etc.), land use, agricultural income, and agri-environmental-relationships can be evaluated on the basis of implemented indicators.

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This paper presents the decision support system RAUMIS. Following a survey of the general model structure emphasis is put on the implemented environmental indicator *"nitrogen surplus"* and an improvement towards its application in the field of groundwater contamination which is an important topic with respect to the EU-Water Framework Directive. Effects of a tax on the price of mineral nitrogen on the amount of nitrogen potentially leaching into groundwater are chosen in order to demonstrate RAUMIS capabilities in the field of policy impact analyses.

2 Methodological approach of RAUMIS

2.1 General description of the model

Figure 1 gives an overview of RAUMIS' modular design. 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[2] and various other calculation data. The model comprises more than 50 agricultural products and inputs with exogenously determined prices. RAUMIS reflects the whole

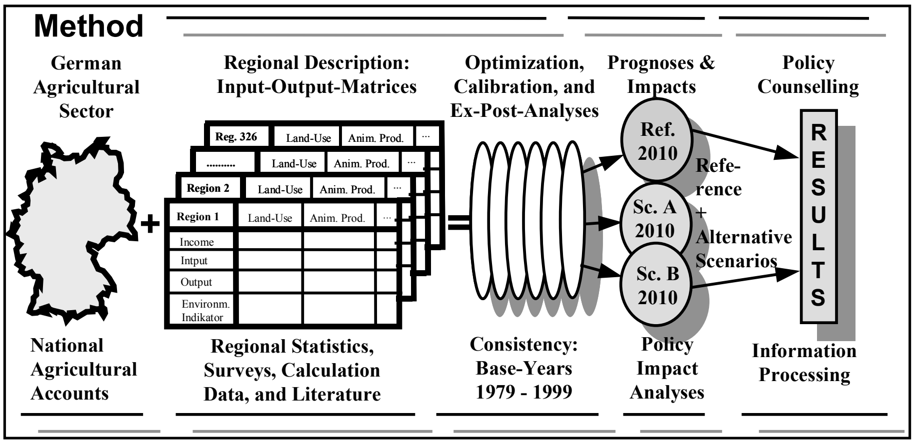

Fig. 1: System of the modular design of RAUMIS
Source: FAA-Description & Layout.

[2] Farm Accountancy Data Network (**FADN**) is an instrument for evaluating the income of agricultural holdings.

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 presently bases on administrative criteria. A 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. Hence, adjustments of production on 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 uses an algorithm to model 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). This 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 partially base on trend and yield dependent regression analyses as well as on estimations of experts particularly regarding prices and the development of farm structures.

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

2.2 Environmental indicator "Nitrogen Balance"

RAUMIS contains a set of agri-environmental indicators that is permanently extended and improved. Currently, the model comprises indicators such as fertilizer surplus (nitrogen, phosphorus and potassium), pesticides expenditures, a biodiversity index, and corrosive gas emissions. On the basis of these indicators the direct and indirect environmental impacts of the agricultural production and changes of agricultural and environmental policies are evaluated at the regional level. The indicator *"nitrogen surplus"* is of particular importance regarding diffuse water pollution. In the following the methodological principles applied in RAUMIS to calculate a nitrogen balances are illustrated.

Figure 2 displays the RAUMIS concept of balancing nitrogen. It follows the PARCOM-guidelines (PARCOM, 1993) where the soil surface represents the system border. In order to satisfy the nutritional demand of plants nitrogen is supplied by mineral fertilizer. Further sources - external to agriculture - are symbiotic and asymbiotic nitrogen-fixation, as well as atmospheric deposition. An internal source of fertilizer is the nitrogen content in manure applied in plant production.

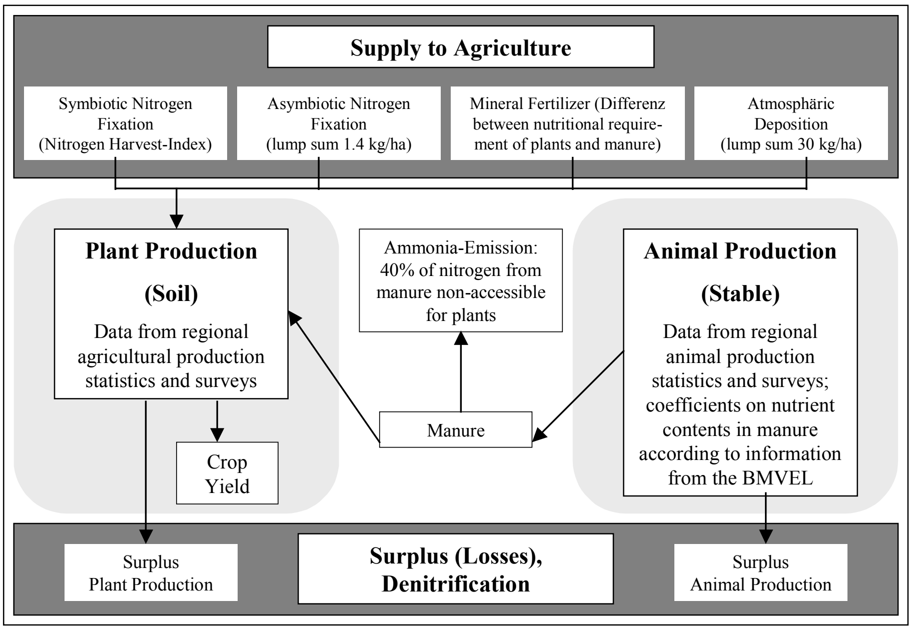

Fig. 2: Structure and elements of the Nitrogen Balance in RAUMIS
Source: Modified according to Bach, M., Frede, H.-G. and G. Lang (1997).

The primary demand for nitrogen bases on the nutrient uptake of plants that are removed from the soil during the harvest. A further reduction of nitrogen occur as a loss of ammonia (NH_3) during storage and application.

The listed positions of the nitrogen balance are calculated by the activity-based framework 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. 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 four kg of nitrogen from dung substitute one 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.

A nitrogen surplus results by the comparison of demand and supply and is calculated in kg per hectare on the regional level (see. **Fig. 3**). This spill-over is regarded as a risk indicator since this amount is potentially available for de-nitrification and leaching into water bodies. The indicator is relevant regarding the absolute nitrogen charges into water bodies and finally into the North Sea. The regions with the highest nitrogen surplus in Germany - partially exceeding 200 kg per ha arable area (AA) - coincide with the regions of intensive livestock farming e.g. in the North West. This coincidence is due to the low utilization rate of manure-nitrogen by plants opposed to utilization rate of mineral nitrogen. The problems with high nitrogen surplus are less prominent in Eastern Germany.

However, nitrogen surplus is less significant concerning the problem of nitrogen concentration in groundwater. In this respect the indicator *"potential nitrogen concentration in regenerate groundwater*" (leachate water) is one step closer to the problem since the groundwater regeneration rate (see. **Fig. 3**) and the de-nitrification rate are taken into account as well. Substituting the current lack of information in RAUMIS about the regional de-nitrification rates by the assumption that 50% of nitrogen surplus are de-nitrificated the potential nitrogen concentration in leachate water is calculated according to the following equation (Weingarten, 1996, 195):

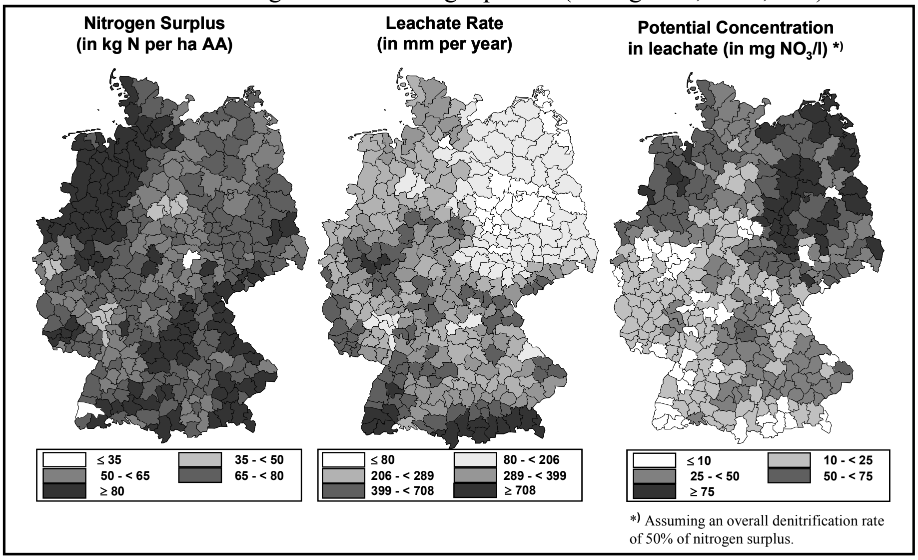

Fig. 3: Regional nitrogen surplus, leachate rate and potential nitrogen concentration in leachate water in Germany under Agenda 2000 in 2010

Source: RAUMIS calculations 7/2002. - German Federal Statistical Office. - Research Centre Jülich, Systems Analysis and Technology Evaluation (STE).

$$\text{NO3Conc} = 4{,}42857 * \frac{\text{Nsp} * \text{SAA} * \text{CA} * \text{DR}}{\text{GRR} * \text{CA}}$$

with: NO3Conc: potential nitrogen concentration in leachate water in mg NO3/l
4,42857: conversion factor nitrogen to nitrate
Nsp: nitrogen surplus in kg N/hectare arable area (AA)
CA: county ("Landkreis") area in hectare
DR: denitrification rate = 50%
GRR: groundwater regeneration rate in mm

The "hot-spot" areas in Germany indicated as such by the potential nitrogen concentration in leachate water are different from those indicated by *"nitrogen surplus"* (see **Fig. 3**). As a result of lower precipitation groundwater regeneration rates are lower in Eastern Germany compared to Western Germany so that the problem of groundwater pollution appears to be more severe in Eastern Germany. However, the calculated nitrogen concentration in leachate water may deviate substantially from measured data. This is primarily due to regionally different de-nitrification rates. Information about de-nitrification is typically included and processed in hydrological models[3]. Hence, a coupling of RAUMIS to hydrological models would unleash synergies since it allows for a consistent modeling from agriculture to the water bodies.

3 Results of a policy impact analysis: tax on mineral nitrogen

RAUMIS capabilities in the field of policy impact analyses are demonstrated by calculating the effects of a tax of 200% on the price of mineral fertilizer on *"nitrogen surplus"* and on the *"potential nitrogen concentration in leachate water"* (see **Fig. 4**). The implementation of a nitrogen tax has been repeatedly discussed since the mid-eighties.

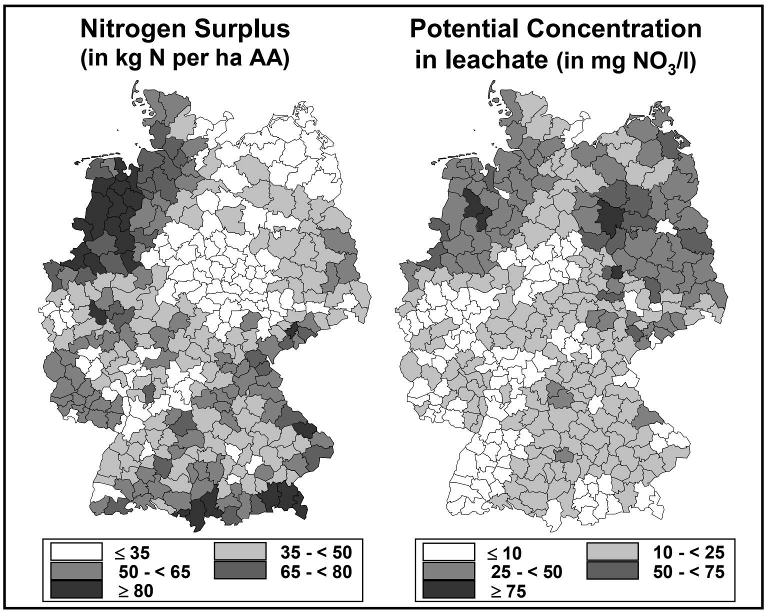

Fig. 4: Regional nitrogen surplus and nitrogen concentration in leachate water in Germany after introducing a tax of 200% on the price of mineral nitrogen in 2010.
Source: RAUMIS calculations 7/2002.

Comparing the effects of a nitrogen tax to the situation under the conditions of the Agenda 2000 the following aspects are important: a) The level of nitrogen surplus and the potential nitrogen concentration in leachate water is reduced in general. However, the tax on mineral nitrogen does not mitigate the hot-spot problems since

[3] Hydrological models such as WEKU (Kunkel/Wendland, 1997), GROWA98 (Kunkel/Wendland, 2002), MONERIS (Behrendt, 1999) and SWIM (Krysanova/Wechsung 2000)

the manure supply in livestock intensive regions is not affected. b) Due to the crop production functions an almost prohibitive tax of 200% on the price of mineral nitrogen is required to obtain a noticeable adjustment towards a reduction of nitrogen input in agriculture. The economic consequences of this tax are enormous for farmers. Topics such as effects on agricultural production, structural change, and agricultural income that are important in the policy decision process and are a particular strength of RAUMIS cannot be discussed within the scope of this paper.

4 Conclusions

RAUMIS is a capable policy decision support system providing a comprehensive set of indicators regarding effects of agricultural and environmental policies. Problems of diffuse water pollution with nitrogen are currently assessed on the basis of the indicators *"nitrogen surplus"* and *"potential nitrogen concentration in the regenerate groundwater"* serving as a risk potentials. The effects of introducing a tax on mineral nitrogen reveal that the mitigation of the diffuse water pollution problems require regionally tailored measures in Germany. However, the specification of the regionally most appropriate strategies necessitates a coupling of RAUMIS to hydrological models in order to get closer to the diffuse pollution problem.

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