# INTEGRATING SUSTAINABILITY IN AGRICULTURE – TRADE-OFFS AND ECONOMIC CONSEQUENCES DEMONSTRATED WITH A FARM MODEL IN BAVARIA*

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*Abstract*:

Within the German “Research Alliance on Agroecosystems Munich” (Forschungsverbund Agrarökosysteme München, FAM) optimal land use strategies are investigated since 1990 in terms of minimization of environmental impacts and maximization of profit from agricultural lands (Auerswald et al. 2000). For this purpose a conventional agricultural land use system was converted into two more sustainable forms of land use. One part of the farm was converted into an integrated land use system with reduced tillage, direct seeding methods and catch crops to minimize nutrient losses and to prevent soil erosion hazards. The other part of the farm was converted into a land use system following the principles of organic farming with the omission of mineral fertilizers and pesticides and the enrichment of crop rotation.

In order to evaluate changes in the state of the agroecosystem a goal and indicator system was elaborated which was aimed to represent important issues of sustainable agriculture. With the help of the goal and indicator system the impact of land use on issues of sustainability can be assessed. The indicators are furthermore integrated into a farm model to assess the implications of the realization of environmental issues in agriculture.

For this purpose the model system MODAM (Zander & Kächele 1999) was used to compare different land use options at the farm level. The model system simulates agricultural land use, calculates the economic returns and runs farm optimizations with a linear programming tool. The integration of agro-environmental indicators in the model framework enables a multiple goal optimization and the calculation of trade-offs. Optimization runs show the complex interactions which occur when the farm system is forced to reduce soil erosion on his farm. A slight improvement of soil conservation results in marginal opportunity costs for the farm. With the realization of a higher level of soil protection opportunity costs rise exponentially.

The calculated opportunity costs can give valuable hints on bottlenecks of the realization of sustainable agriculture and help to identify reasonable incentives for a better agriculture. Furthermore conflicts between divergent goals can be identified to find optimal pathways of a sustainable development of agriculture.

Keywords: sustainable agriculture, multiple criteria decision making, linear programming

# 1 Introduction

Integration of sustainability into agriculture is an issue which became very popular since the report of the Brundtland-Commission and the following international agreements and contracts. The first idea of sustainability came up in 1972 on the UN conference on Human Environment in Stockholm by stressing the relevance of the relationship between environment and development. In 1980 followed a nature protection programme, set up by IUCN (World Conservation Union), WWF (World Wild Life Fund) and UNEP (United Nations Environment Programme) named 'Living Resource Conservation for Sustainable Development' before the Brundtland-Commission formulated the sustainability definition.

Sustainable is aimed "…to meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Sustainability is thus an ethical ideal, trying to cover social, economic and ecological aspects. Applying the concept to agriculture, sustainable agriculture can be described as follows: 'A sustainable agriculture is one that, over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable and enhances the quality of life for farmers and the society as a whole' (American Society of Agronomy 1989). However, many definitions can be found for sustainable agriculture and it remains difficult to link the concept to practical actions and decisions (Hansen & Jones 1996). Following Pannel & Schilizzi (1997) the best approach to integrate the different dimensions of sustainability into agriculture is a multiple criteria decision making approach. Therefore, indicators are needed to indicate the sustainability and enable an assessment.

The purpose of this paper is to discuss the economic consequences of integration of sustainability exemplarily with the results of trade off calculations for an experimental farm where the impact of the integration of environmental targets into the farm has been investigated thoroughly. The calculations were done within the framework of the "Research Alliance on Agroecosystems Munich" (Forschungsverbund Agrarökosysteme München, FAM), where optimal land use strategies are investigated since 1990 to reduce environmental impacts and increase profits from agricultural land (Auerswald et al. 2000).

In order to analyze the processes in agricultural ecosystems a conventional agricultural land use system was converted into an integrated and an organic land use system with changes in landscape patterns and cropping practices. Within the integrated system mulch tillage with direct seeding and catch crops was implemented. The agricultural and environmental effects of these measures are studied in detail since 1990 and provide the data base for the present study. The two farming systems are briefly described in table 1.

The experimental farm ´Klostergut Scheyern´, is situated approximately 40 km north of Munich, 450 to 490 m above sea level. The mean annual temperature is 7.5°C, with a mean annual precipitation of 830 mm. The territory of the experimental station can be regarded as typical for the natural habitat of the tertiary hills of Southern Germany. The tertiary sediments consist primarily of sandy loam with a varying content of gravel. Loamy and sandy brown soils with loess clay layer of varying thickness are characteristic. Loess deposits covering the tertiary sediments are often missing at ridge crests and at up-slope positions.

Table 1: Description of the two farm systems at the experimental farm ´Klostergut Scheyern´

| Organic farm system (68 ha) | Integrated farm system (46 ha) |
|---|---|
| FARM SYSTEM | |
| mixed farm system with breeding cows (31) and bull fattening following the principles of organic farming (EU regulation 2092/91) | mixed farming system with bull fattening (barn with 50 bulls) |
| CROP ROTATION (UNDER SOWING AND CATCH CROPS IN BRACKETS) | |
| grass-clover mixture | potatoes(Mustard) |
| winter wheat | winter wheat |
| winter rye (clover) | corn (Mustard) |
| grass-clover mixture | winter wheat |
| Potatoes (mustard) | |
| winter wheat | |
| Sunflowers (grass-clover mixture) | |

Working on the subject of sustainability with scientists means, finding a pathway between scientific methods and implementing evaluation algorithms for an ethical concept. In case of agriculture it is helpful to focus on the factors agriculture is dealing with. In the research project this paper is dealing with, it was attempted to make sustainability more concrete by setting up a goal and indicator system (Meyer-Aurich et al. 2001a). Goals for sustainable agriculture were formulated referring to the protection of main resources that are influenced by agricultural practices: protection of atmosphere, soil, ground and surface water, species and biotopes, saving fossil resources and protect production and recreational functions of agricultural landscapes. By use of a hierarchical goal concept each main goal is described by one to many sub-goals.

## 2 MODAM framework to analyze economic and ecological implications of different land use options

MODAM is a simulation tool which enables to model farm decisions and their economic and environmental effects (Zander & Kächele, 2000). It consists of a set of relational databases and analytical functions which allow to compute the economic returns and environmental impact of land use alternatives. MODAM has already been applied for studies in Northeast Germany (Kächele 1999, Meyer-Aurich 2001). Because of its modular and hierarchical structure MODAM can be applied to various agroecological problems. However, for specific applications adjustments have to be made. In order to apply MODAM on “Klostergut Scheyern” specific production systems were defined and new modules were created to calculate nitrogen balance, energy input, soil erosion and global warming potential of the production process. MODAM consists of a set of relational databases. Figure 1 gives an overview of the structure of the core databases in MODAM. The module “PLANT” stores plant production activities with all operation sequences necessary to obtain the desired product. All activities are characterized by the applied inputs, the implements used and the time span in which the activity is normally carried out. The module “ECOL” calculates the impact of the cropping practices on the environment. From the modules “ECON” and “FARM” gross margins are calculated for each production activity for a given price scenario. A linear programming module “LP” optimizes land use in terms of economic returns and estimated site specific soil erosion for each plant production activity. A predefined level of tolerated soil loss is considered in the optimization run as a restriction. Thus MODAM provides an array of land use scenarios under different frame conditions which can be used for a discussion of appropriate policies to achieve environmental objectives.

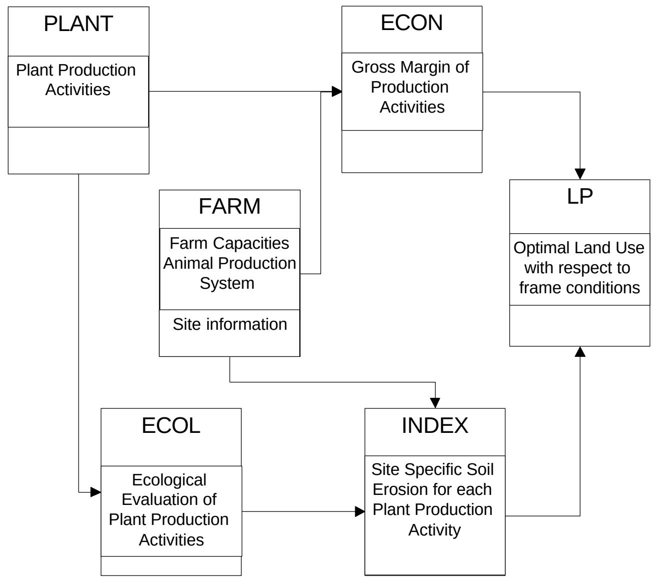


Fig.1: Structure of databases in MODAM (simplified)

## 2.1 Farm model and site specific land use options

The farm model represents the integrated farm system of the experimental farm of the Research Alliance Agroecosystems Munich “Klostergut Scheyern”. The modeled farm has an acreage of 30.5 ha of cultivated land divided into 7 fields.

Table 2: Relative Yield as a function of preceding crop and tillage system based on expert judgement and experiences at the research site

| Crop | Tillage system | Preceding crop | | | |
|---|---|---|---|---|---|
| | | SMA | SKA | WWE | WGE |
| Corn (SMA) | RT | 1 | 1.05 | 1 | 1 |
| | CT | 1 | 1.05 | 1 | 1 |
| Potato (SKA) | NT | 0.95 | 0.9 | 1 | 1 |
| | CT | 1 | 0.9 | 1 | 1 |
| Winter wheat (WWE) | RT | 0.85 | 1 | 0.8 | 1 |
| | CT | 1 | 1 | 0.9 | 1 |
| Winter barley (WGE) | RT | 0.85 | 1 | 1 | 0.9 |
| | CT | 1 | 1 | 1 | 0.9 |

RT: reduced tillage, CT: conventional tillage, NT: no tillage

Animal husbandry is bull fattening with a capacity of 50 bulls. For each cropping practice yield was calculated based on site specific yield potential and information about the tillage system and the preceding crop (table 2). A set of cropping practices was defined for the relevant crops of the integrated farm section (winter wheat, maize, potato). Each cropping practice consists of a set of operation sequences in which timing, inputs, outputs and implements are defined (table 3). For scenario calculations additional cropping practices were defined for barley and set aside. For each crop a site-specific array of different management practices including direct seeding and conventional practice were defined which represent the land-use options for the farmer.

Table 3: Operation Sequence of a specific cropping practice (Silage corn with reduced tillage and catch crop, no slurry; Code: SMAF1030a )

| Code | Operation(Implements) | Input/ Output | Quantities (per ha) | Timing Begin | End |
|---|---|---|---|---|---|
| 1141 | **Tillage and Seed** | | | | |
| 408 | Grubbing with seed spreader | Mustard | 15 kg | AUG 1 | AUG 30 |
| 711 | Herbicide Application | Round up | 1 kg | APR 1 | APR 20 |
| 611 | Drilling (direct seeding machine) | Seed corn | 2 Units | APR 20 | MAY 10 |
| 9999 | | N-P-fertilizer | 200 kg | APR 20 | MAY 10 |
| 212 | **Fertilizing** | | | | |
| 505 | Urea-Spreading | Urea (48% N) | 245 kg | APR 10 | MAY 30 |
| 505 | Fertilizer Spreading | CAN[1] (27% N) | 190 kg | MAY 1 | JUN 10 |
| 301 | **Weed Control** | | | | |
| 711 | Herbicide Application | | 1 Application | APR 1 | MAY 30 |
| 90 | **Harvest** | | | | |
| 1401 | Maize Chopping | | | SEP 5 | OCT 10 |
| 1471 | Maize transport | Silage Corn | 14 t DM | SEP 5 | OCT 10 |
| 1481 | Silage storage | | | SEP 5 | OCT 10 |

[1]CAN: Calcium Ammonium Nitrate

The calculation of gross margin is based on the applied inputs and partial depreciation of implements and machines. For the calculations available mean prices for 2000 and the regulations of the EU Agenda 2000 were considered.

## 2.2 Implementation of Indicators in MODAM to assess the ecological impact of land use options

In order to assess the impact of land use changes on the environment the economic and environmental effects of all cropping practices were assessed with the MODAM framework. Therefore indicators were derived which illustrate the impact of the land use practices on the environment. For this study site specific soil loss potential, Nitrogen balance, energy input and global warming potential of the cropping practices were used to indicate the major impact of land use on the abiotic environment.

Soil loss potential of the cropping practices was assessed with an adapted version of the USLE (Meyer-Aurich et al. 2001b). In order to give a figure of the range of estimates for soil loss two different functions for estimating the soil loss ratio were implemented in the model. The functions differ in the estimated impact of mulch cover on soil erosion. While the generally accepted function of Wischmeier (1975) estimates a moderate protection of mulch, the function of Kainz (1989), which is based on experiments on the Scheyern Research Station, gives a considerably higher estimate of soil protection due to mulch.

The agricultural nitrogen soil surface balance indicator involves calculating the difference between all nitrogen inputs as chemical fertilisers, livestock manure and legume crops and nitrogen removal by agricultural crops or fodder production following OECD (2001). $N_2$-fixations by legumes were calculated following Biermann (1995). The coefficients for energy input and global warming potential were calculated following an adapted version of the life cycle assessment procedure (Haas et al. 2001, Wechselberger 2000). The calculations of energy inputs are based on all direct and indirect inputs of primary energy which are necessary to obtain the desired agricultural product (table 4). Energy for manufacturing the machines was allocated according to common depreciation rules. Global warming potential was calculated from the emission of greenhouse gases due to the production process in $CO_2$ equivalents (Houghton et al. 1996). Besides emissions which were directly associated with the production process of machines and inputs, $N_2O$ emissions from the soil were calculated as 1.25% of Nitrogen input to the soil following Houghton et al. (1996).

Tab. 4: Data for calculating energy input and global warming potential of cropping practices (see Wechselberger 2000)

| | Unit | Energy-Input (MJ Unit$^{-1}$) | Global Warming Potential[1](kg $CO_2$) | References |
|---|---|---|---|---|
| DIRECT ENERGY SOURCES | | | | |
| Diesel fuel | l | 39.6 | 2.9 | Reinhardt (1993) |
| Electricity | kWh | 11.4 | 0.74 | |
| INDIRECT ENERGY SOURCES | | | | |
| Mineral fertilizers | | | | |
| Urea | kg N | 48.3 | 5.97 | Patyk & Reinhardt (1997) |
| Calcium Ammonium Nitrate | kg N | 42.9 | 9.19 | |
| CaO | kg N | 2.4 | 0.3 | |
| Plant protective agents | kg | 260 | 5.4 | Green (1987) |
| Machines incl. repair | kg | 80 | 8 | Scholz & Kaulfuss (1995), Jolliet (1993) |

[1] Global Warming Potential in $CO_2$ - Equivalents following Houghton et al. 1996

There is evidence, that $N_2O$ emissions from agricultural soils are much higher on the Scheyern Resarch Station (Kaiser & Ruser 2000) than 1.25 % of Nitrogen Input. Nevertheless for these calculations the internationally accepted 1.25% were considered. Energy input and global warming potential of seed was calculated as a function of the seed-free energy input and global warming potential of the cropping practice, respectively (Wechselberger 2000).

# 3 Model Calculations for “Klostergut Scheyern” – Opportunity costs of environmental protection

## 3.1 Environmental impact of cropping practices

The impact of the cropping practices on the considered indicators is given in table 5. It can be seen that a high reduction of the susceptibility to soil erosion can be achieved by reduced or zero tillage in combination with catch crops. However these practices are linked with a higher nitrogen input, so that nitrogen balance, energy input and global warming is increased. The model calculations show that erosion potential can be reduced substantially with the integration of catch crops in combination with reduced tillage.

Table 5: Susceptibility to soil erosion (C-factor), nitrogen balance surplus, energy input and global warming potential (GWP) of cropping practices in MODAM, adapted to the model farm in Scheyern

| Cropping practice/ tillage system | Code | C-factor | Nitrogen balance surplus (kg N/ha) | Energy Input (GJ/ha) | GWP (kg $CO_2$ Equ.) |
|---|---|---|---|---|---|
| Potato (SKA) | | | | | |
| CT | SKA1000 | 0.30 - 0.37 | -88.5 - 1.7 | 11.89 | 1323 |
| RT+CC | SKA1024 | 0.13 - 0.17 | -65.2 - 24.9 | 13.99 | 1645 |
| NT+CC | SKA1030 | 0.02 - 0.14 | -65.2 - 24.9 | 13.25 | 1634 |
| Corn (SKA) | | | | | |
| CT | SMA1002 | 0.24 - 0.25 | 52.1 | 12.37 | 3357 |
| RT+CC | SMA1026 | 0.07 - 0.08 | 75.3 | 14.69 | 3674 |
| NT+CC | SMA1032 | 0.01 - 0.07 | 75.3 | 14.27 | 3665 |
| Winter wheat (WWE) | | | | | |
| CT | WWE2100 | 0.05 - 0.09 | -24.6 - 15.1 | 10.42 | 1834 |
| RT | WWE2106 | 0.05 - 0.08 | -24.6 - 15.1 | 9.79 | 1823 |
| Winter barley (WGE) | | | | | |
| CT | WGE2200 | 0.04 - 0.07 | 1.6 - 34.8 | 10.8 | 1841 |
| RT | WGE2206 | 0.04 - 0.07 | 1.6 - 34.8 | 9.8 | 1825 |

CT: conventional tillage, no catch crop, RT: reduced tillage, NT: no tillage, CC: catch crop

## 3.2 Farm optimizations with consideration of environmental targets

Model calculations show that the highest economic return will be achieved with conventional tillage for corn and potato and reduced tillage for winter wheat after potato (table 6). However, a substantial soil loss of almost 10 t/ha over the whole farm would have to be taken into account. On the most susceptible fields soil loss of more than 15t/ha is calculated. If the model is forced to consider soil loss in the optimization of the farm the effect on gross margin can be obtained from figure 2. In the optimization runs the model was forced to reduce soil erosion on the farm in steps by 10% of the initial value, while keeping the animal husbandry system constant. Thus the model considers the cropping practices with reduced or zero tillage or substitutes cash crops with lower erosion susceptibility. It can be seen that especially when forcing the farm model to reduce soil loss to a minimal level the trade off functions based on Wischmeier and Kainz deviate considerably. However, the changes in cropping patterns are the same for both approaches at least at the beginning of soil loss reduction (figure 3). While forcing the farm system to consider soil protection first catch crops and no tillage is implemented in corn, second in potato.

Table 6: LP output activities of the farm model with maximized gross margin

| Activity | Unit | Value |
|---|---|---|
| Total gross margin | Euro | 24336 |
| Gross margin per ha | Euro/ha | 797 |
| Labor | working hours | 488 |
| Plant production activities | | |
| SKA CT | ha | 7.18 |
| SMA CT | ha | 7.84 |
| WWE CT | ha | 7.84 |
| WWE RT | ha | 7.18 |
| Animal husbandry | | |
| bulls (0.5 to 1 year) | number | 35 |
| bulls (1 to 1.5 years) | number | 35 |
| bulls (1.5 to 2 years) | number | 35 |
| Environmental Indicators | | |
| Soil loss (A) | t/ha | 9.6 |
| Soil loss (B) | t/ha | 8.4 |
| Nitrogen balance | kg/ha | + 18.3 |
| Energy input | MJ/ha | 10 665 |
| GWP | $CO_2$/ha | 1 014 |

(Abbreviations see table 2)

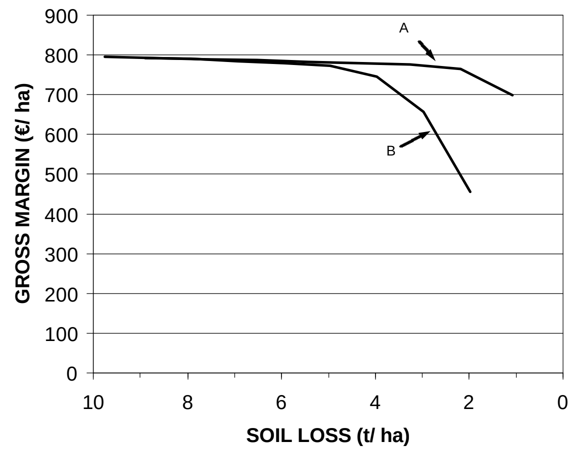


Figure 2: Trade off of soil loss against gross margin following the soil loss estimates based on **A** Kainz (1989) and **B** Wischmeier (1975) respectively

With the integration of catch crops in combination with zero tillage, soil loss can be reduced to 20% and 50% depending on the soil loss estimates based on Kainz (1989) and Wischmeier (1975) respectively. This measure only results in marginal costs for the farm. A further soil protection can only be achieved by substitution of crops. It can be seen that first wheat then also potato is substituted by barley, then by set aside (figure 3). These substitutions result in considerable losses in gross margin (figure 2) which hardly can be covered by environmental programs or the farmer himself.

Besides soil loss nitrogen balance, energy input and global warming potential of the production process has been considered in the optimization runs. Figure 4 illustrates the impact of increasing soil protection on the other indicators. Following these calculations soil protection has a significant impact on nitrogen balance and a moderate impact on energy input and global warming potential. The reason for this can be found in a lower efficiency of nitrogen fertilization in the cropping practices with catch crops and zero tillage. Within this cropping system an additional fertilization of the catch crop is necessary to enable a sufficient soil cover by the catch crop which is not available anymore for the following corn or potato crop. The change in nitrogen balance leads to increased energy input and global warming potential of the cropping practices. This is due to high energy inputs which are necessary for producing fertilizers (table 4). However, at farm level higher nitrogen balance surplus of these crops could be compensated with other crops with lower nitrogen surplus, which lead to further opportunity costs.

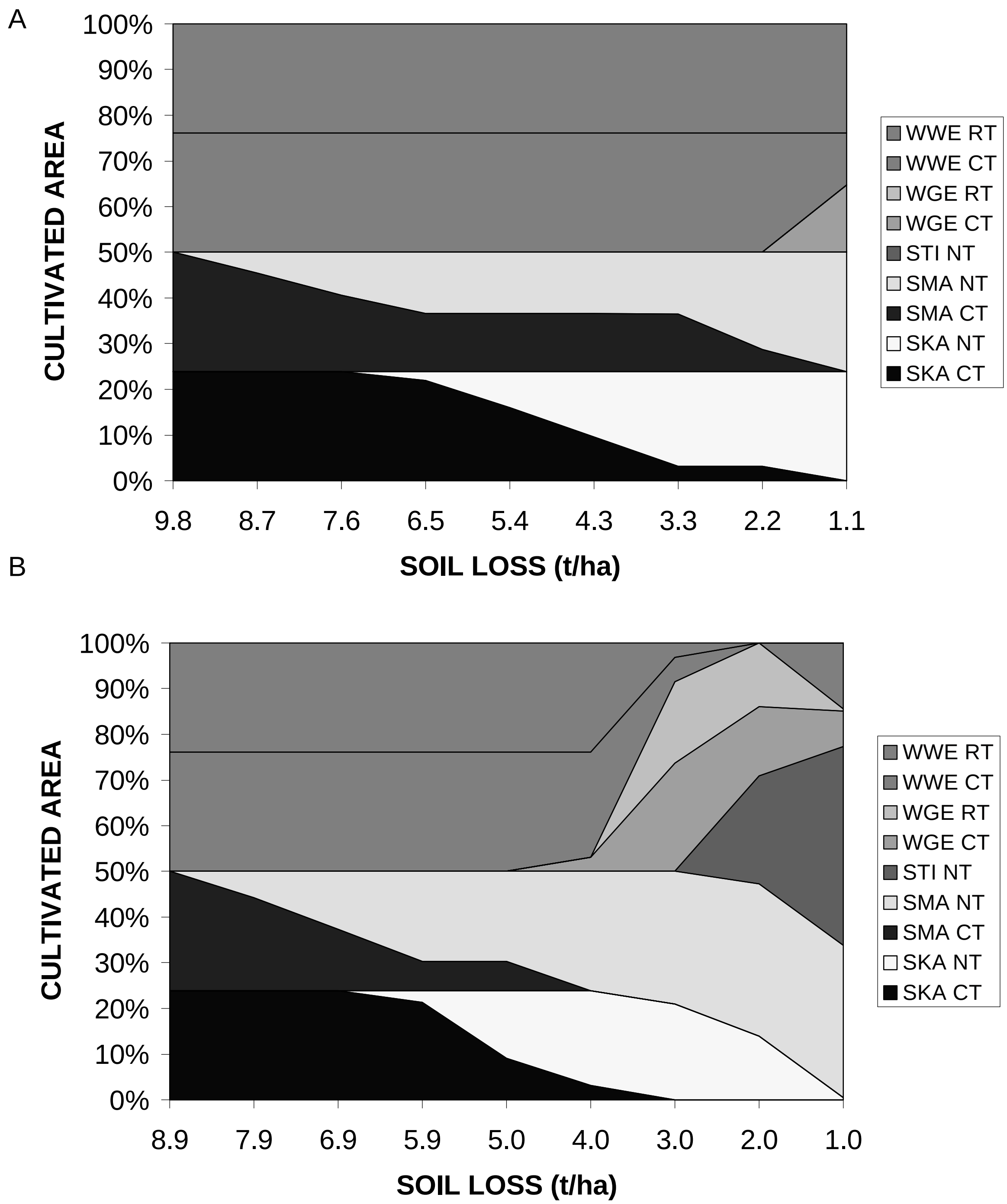


Fig 3: Change in cropping patterns with increased consideration of soil protection in the goal function of the farm following the soil loss estimates based on **A** Kainz (1989) and **B** Wischmeier (1975), abbreviations see table 3

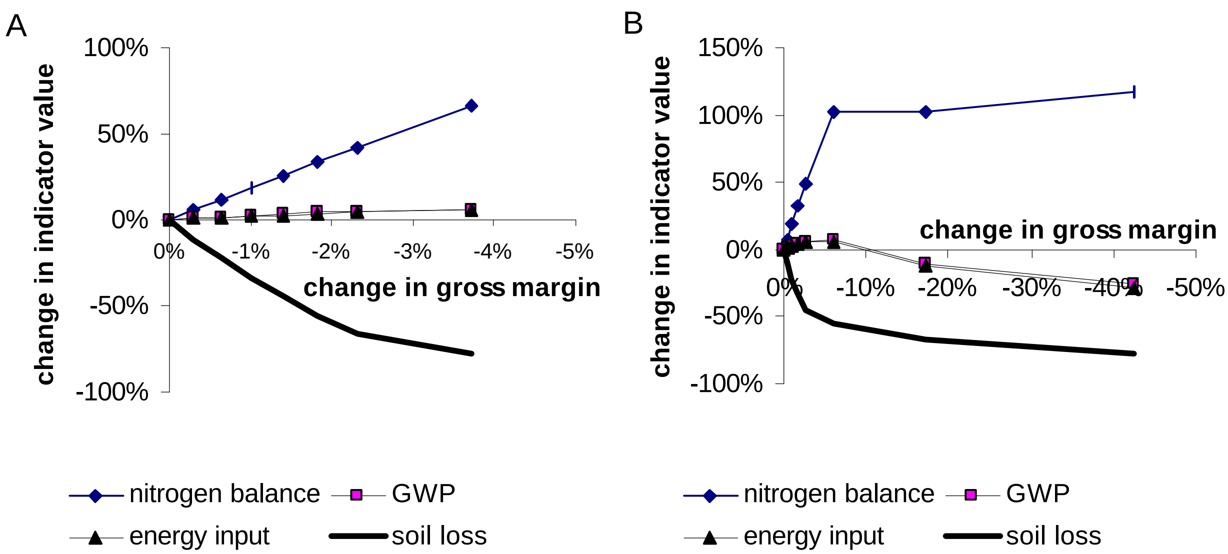


Figure 4: Impact of reducing soil loss on other environmental indicators following the soil loss estimates based on **A** Kainz (1989) and **B** Wischmeier (1975)

# 4 Conclusions

The presented calculations have given some insight into the complex interactions of some considered indicators in agroecosystems. There is substantial knowledge about the impact of land use on environmental indicators which can be used to adapt land use systems appropriately. However, improvements for one indicator might result in worsening for an other indicator and often also for the economic situation. So when improvement of the system is desired the complex effects of changes in the agroecosystems have to be taken into account.
The considered indicators only reflect a proportion of indicators which are necessary to illuminate sustainability. Here only the abiotic environment and the economic return has been taken into account. The choice of indicators has to be made carefully, as they determine the results of evaluations. While global warming potential and soil loss is related near to the environmental problem, nitrogen balance and energy input is more related to the agricultural inputs of the system. There is a high correlation between global warming potential and energy input (figure 4), so for the presented calculations only one of the indicators would have led to the same results. However, it has to be proved if the correlation persists also with other agricultural systems, before one of the indicators could be omitted.
With the help of the MODAM framework it could be shown, that the implemented practices of the experimental farm to prevent soil erosion are effective to prevent soil erosion. The integration of catch crops and zero tillage results in a reduction of soil loss to 20% - 50% of the soil loss with conventional tillage. This can be stated by observations on the Research site before and after the restructuring of the Research site in 1992 (Finer & Auerswald 2001). However there are still uncertainties with the estimation of soil loss due to mulch cover. The differences in the functions considered do not lead to different management recommendations – so for multi criteria calculations the differences rather have an impact on the level of opportunity costs than on the modeled land use patterns. Also it has to be stated, that the differences in the functions only have

an impact after a soil loss reduction beyond 50% of the reference value. The most effective and reasonable soil protection measure remains to be the zero tillage system with catch crops for corn and potato.

It could also be shown, that soil protection may have a negative impact on other environmental indicators. These also could be integrated into the goal function of the farm but would in turn increase opportunity costs. This leads to the question which level of environmental quality should be secured by agriculture. The presented model framework can contribute to this question and help to discuss the consequences of different claims on agriculture.

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