Environmental and economic assessment of agricultural production practices at a regional level based on uncertain knowledge

Claudia Sattler and Peter Zander*

Abstract

The concept of sustainability and international trade relations require changes in the current agri-environmental policy of the European Community. Therefore, in the future, the EU funded agricultural subsidies will increasingly be linked to the environmental performance of agricultural practices. To develop an effective agro-environmental policy, tools are needed that allow detailed economic and environmental analysis of different policy options. At the same time there is often only limited knowledge about the complex interdependencies between the different forms of agricultural land use and the related effects on the environment and landscape functions.

The aim of this paper is to introduce a fuzzy-logic-based approach, which is tolerant of uncertain knowledge, to evaluate agricultural production practices regarding their effects on different abiotic and biotic environmental indicators on a regional scale refering to a modeled region of 200 km² in the northeast of Germany.

Keywords: *impact assessment, bioeconomic models, agricultural production practices, uncertain knowledge, fuzzy logic*

1 Introduction

Currently the agro-political EU framework is undergoing substantial changes. On the one hand, the globalisation of the agricultural markets forces farmers to produce more efficiently and on the other hand, in the context of the European Model of Agriculture, transfer payments will increasingly be linked to the environmentally friendly performance of agricultural production practices to promote sustainable development (BUCKWELL et al. 1997). Sustainable development[1] has become a major item on the political agenda and efforts have to be undertaken to figure out the guidelines and aims for future development and to determine meaningful indicators to measure the progress towards reaching them which can only be done in a process of societal discourse.

Changes in agricultural land use may thereby influence essential ecological functions of agricultural ecosystems like groundwater recharge or habitats for wild flora and fauna species. Accordingly landscapes are no longer seen as mono-functional, i.e. serving only for food production, but rather multifunctional (EUROPEAN COMMISSION 2000).

---

* Centre for Agricultural Landscape and Land Use Research – Institute of Socioeconomics, Eberswalder Str. 84, D- 15374 Müncheberg, e-mail: csattler@zalf.de; pzander@zalf.de

[1] There are a multitude of different definitions for sustainable development. For example the Food and Agriculture Organization of the United Nations (FAO 1989) gives the following: „Sustainable development is the management and conservation of the natural resource base, and the orientation of technological and institutional change, in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agricultural, fisheries and forestry sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable“.

The concept of multifunctionality of agriculture can be a powerful political tool to organize financial transfers in favour of a sustainable development and in accordance with international trade relations. But it requires knowledge about the complex interdependencies between changes in agricultural production and the effect that these changes might have on the environment and the different landscape functions. This knowledge is often incomplete and insufficient. Although there are many detailed process models concerning specific issues (e.g. nitrate leaching, water erosion), comprehensive and integrated approaches to assess both positive and negative effects of agricultural management systems still need to be developed (CHRISTEN 1999). It is particularly challenging to integrate sources of uncertain knowledge into the development of such approaches due to the lack of meaningful data and often insufficient data quality.

The aim of this paper is to introduce a fuzzy-logic-based Environmental Impact Assessment-Tool (EIA-Tool) to evaluate[2] a multitude of agricultural production practices regarding their effects on different abiotic and biotic environmental indicators on a regional scale. The assessment is integrated into an economic modelling system MODAM (Multi Objective Decision Support Tool for Agroecosystem Management; ZANDER 2003, ZANDER & KÄCHELE 1999) to allow the simultaneous assessment of ecological and economic effects.

The approach is based on the hypothesis that there is always more than one alternative in cultivating a specific agricultural crop depending on the means of production or machinery, which differ in their contribution to environmentally friendly crop production.

2.1 Methods

2.1 Modeled region

The modeled region 'Prenzlau-West' is situated in northeastern Germany (Brandenburg) and encompasses about 200 km². The annual average precipitation amounts to 554 mm. The temperature is 7,8°C on average. The main portion of the region (about 70%) is dominated by agriculture but there is also a significant amount of natural areas (7,3%) which are protected in accordance with the nature protection act (§32, BbgNatSchG). Approximately 3% of the area is covered with water. Sixteen percent is woodland and forest and 11% is allotted to settlements and infrastructure.

2.2 Project

In this region a large interdisciplinary project (GRANO[3]) was implemented which aimed to enhance regional sustainable development of agriculture (MÜLLER et al. 2002). During the project a variaty of data were collected constituting a very valuable source of information for this work. One important achievement of GRANO was the elaboration of a list of meaningful environmental core indicators for the region.

---

[2] Every kind of evaluation inherently is subjective or at least contains subjective elements. After GIEGRICH (1997) evaluation is the linkage between the accessible information concerning a certain situation with a personal system of normative values, which leads to a decision about this situation.

[3] GRANO research-program (1998-2002): 'Approaches for Sustainable Agricultural Land Use in the Northern-East of Germany', sponsored by the German Federal Ministry for Education and Research – BMBF .

2.3 Environmental indicators

In the context of the GRANO-project, this list of environmental indictors was produced through an iterative and participatory process. At first a situation-analysis was conducted, which allowed local stakeholders to identify regional problems. For that purpose more than 100 face to face interviews with farm managers, administrators, politicians, NGO[4] representatives, extension workers as well as researchers from numerous disciplines were carried out. Based upon this survey a synopsis was elaborated to delineate all problems related to social, economic or ecological issues stated in the interviews. Subsequently the synopsis served as a guideline for so-called ‘regional planning workshops’. In these workshops up to 25 representatives and key actors from all stakeholder groups took part and after three days of discussion agreed on a list of aims with the highest priorities for the region (MÜLLER et al. 2002). To deepen information according the ecological objectives, additional in-depth interviews were conducted to develop a catalogue of environmental quality targets[5] for the region (ARZT et al. 2000). Based on the findings, the following indicators[6] and environmental sub-targets have been chosen for the ecological evaluation of the agricultural production practices for this study (Table 1).

Table 1: Overview of selected indicators

	Environmental media	**Environmental quality main targets***	**Indicators**	**Derived environmental quality sub-target**
abiotic	Water	‘Conservation and protections of ground and surface water** and improvement of the water quality’	• Nitrate (NO^{3-}) entry into groundwater • Nutrient entry (N, P) into ground and surface water • Pesticide entry into ground and surface water • Ground water recharge	• Protection of ground water from nitrate entries • Protection of ground and surface water from nutrient (N, P) entries • Protection of ground and surface waters from pesticide entries • Conservation of ground water recharge
	Soil	‘Conservation and Protectio of the soil fertility’	• Water erosion	• Protection of the soil from water erosion
biotic	Habitat & Biodiversity	‘Conservation and protection of habitats within agricultural landscapes and improvement of the habitat quality for wild flora and fauna species’	• Habitat quality for skylarks • Habitat quality for field hares • Habitat quality for red belly toads • Habitat quality for hover flies • Habitat quality for fall germinating plant communities	• Protection of skylarks from the decrease of habitat quality • Protection of field hares from the decrease of habitat quality • Protection of red belly toads from the decrease of habitat quality • Protection of hover flies from the decrease of habitat quality • Protection of fall germinating plant communities from the decrease of habitat quality

*after Arzt et al. (2000)
**especially potholes which are very typical for the region

Biotic indicators may be single species (e.g. skylarks) or species communities (e.g. fall germinating plant communities, hover flies). The selected biotic indicators can be seen in some degree as flagship species (e.g., skylarks for field breeding birds or the red belly toad for amphibians, which have to cross

[4] NGOs = non-governmental organisations, like nature protection groups, tourism agencies or other interest groups and associations

[5] Environmental quality targets are defined as “… a legally, politically or scientifically defined quality of the environment. Environmental quality targets serve as yardsticks (points of reference) for any evaluation steps. Apart from the objectively recorded modifications of the environmental situation it is the target, on which it depends, how a project or a plan is evaluated environmentally. Environmental quality targets can be related to the following strategies: a) retention of the status quo of the environmental quality, b) definition of protection purposes or quality of the environment orientated to the targets for certain spaces or environmental media (e.g. a certain water quality), c) compliance with laws and regulations (critical values), d) political target predicates and assertions of a general and non-committal character, e) environmental precaution (in consideration of the most sensitive areas) or f) orientating on consequences for other environmental areas)”; Springer Environmental Dictionary (HÜBLER & OTTO-ZIMMERMANN 1989).

[6] Indicators in general are data, witch can give significant information about the specific state or condition of a system (WALZ et al. 1997)

agricultural fields twice a year when migrating between summer and reproduction habitats and their wintering habitat).

In general it is important to check the selection of indicators very carefully whenever the regional reference changes because addition or replacement of indicators could be necessary. For example in another region, wind erosion may be a problem of serious interest instead of water erosion. Furthermore the priorities of the social community for certain environmental objectives may change over time.

2.4 Modelling system MODAM

MODAM consists of hierarchically linked moduls on three levels (ZANDER 2003). Level one encompasses the databases to descripe the practices of crop, fodder and lifestock production. On the second level the economic and ecological evaluation of the single production practices is conducted. Costs for the economic evaluation are calculated depending on farm machinery, prices, energy consumption, required labour etc. All necessary data are derived from standard data tables. The ecological evaluation benefits from the very detailed description of the single measures per production practice. Level two is where the fuzzy-based environmental impact assessment-tool is embedded into the modelling system. On level three finally the linear programming (LP) farm models are generated for integrated analysis. ‘Farms’ in this context can be real farms or whole regions (‘regional farms’). On the ‘farms’ any kind of crops or type of lifestock can be produced described in the databases of level one. Thereby every production activity refers to a certain site (either a real ‘field’ or a specific ‘field type’, classified by it’s soil quality and sensitivity concerning the environmental issues). To generate the results on farm level the outcomes per field or field type are aggregated in relation to their extent. The basic assumption of the linear programming modul is that the farmers’ decision is always based on economic rationality. Although farmers have obviously other motivations than only profit maximation, these are neglected for reasons of simplicity (SCHULER & KÄCHELE 2003). The modelling system is used to generate two kinds of results: (i) goal driven scenarios, that use the ecological evaluation to impose restrictions on the farm organisation and that result in trade-off functions between the level of ecological achievements and the total gross margin of the farm and (ii) policy driven scenarios that evaluate the impact of certain policy instruments on ecological indicators, based on the ecological evaluation results. In this total gross margin is only one economic indicator, which in critical cases has to be complemented by full costing.

So far MODAM has been used for a number of studies conducted in Germany. The modelling system was also applied to a river catchment area in Ontario, Canada. Before the model can be transfered to a new region the databases concerning grown crops, yields, production practices, machinery etc. as well as the environmental evaluation have to be adapted to the changed conditions. For a complete list of applications see ZANDER (2003).

2.4.1 Agricultural production practices

Agricultural production practices of conventional, integrated and organic farming are described in detail in the modelling system MODAM. At present the database contains more than 1200 different production practices for about 30 agricultural crops valid under the climatic conditions of northeastern Germany. Yield expectations are estimated for four different soil qualities. Per crop there is always defined a ‘standard’ cropping practice and additionally several derivatives differing from the standard in kind and amount of means of production, production techniques and machinery. Every production practice is divided into single operations in sequence of application: tillage, sawing, application of fertilizers, application of plant protection agents, mechanical weeding and harvesting.

2.5 Uncertain knowledge and data quality

As mentioned there is often only limited knowledge[7] about the complex interdependencies between agricultural practices and their effects on the environment that can be elicited from literature or experts[8]. HERZOG (2002) distinguishes three different types of uncertainty: informal (epistemic), linguistic (lexical) and stochastic uncertainty. Informal uncertainty is due to missing, incomplete or inconsistent information. Dealing with linguistic uncertainty the difficulty lies in interpreting linguistic expressions, like “this measure has got a ‘large’ effect”. Regarding stochastic uncertainty, one has to estimate how calculated probabilities can be used to make predictions on future real situations. The kind of uncertainty affects data quality and model development. Data can be available on a quantitative (cardinal) or qualitative (nominal, ordinal) scale.

2.5.1 Fuzzy logic

Fuzzy logic is a concept, which allows to process uncertain knowledge in modelling. The concept is derived from classical set theory and two-valued or binary logic (ZADEH 1994). Two-valued logic always requires a well-defined unambiguous meaning of information. Hence, when such information can not be provided, two-valued logic delivers unsatisfactory conclusions. (CORNELISSEN 2003). In contrast fuzzy or multi-valued logic enables intermediate assessment between the extremes ‘true’ and ‘false’ or ‘yes’ and ‘no’.

<u>Example:</u> The total amount of nitrogen fertilizer is one criterion that influences the habitat quality of agricultural sites for some endangered plant species, which can no longer compete for light, water and nutrients within the crop stand when large amounts of fertilizer are applied. If an assessment has to be generated to classify between those amounts which only have a ‘low’ and those which have a ‘large’ negative impact on the habitat quality for endangered plant species there will be differences in applying binary and fuzzy logic (Figure 1).

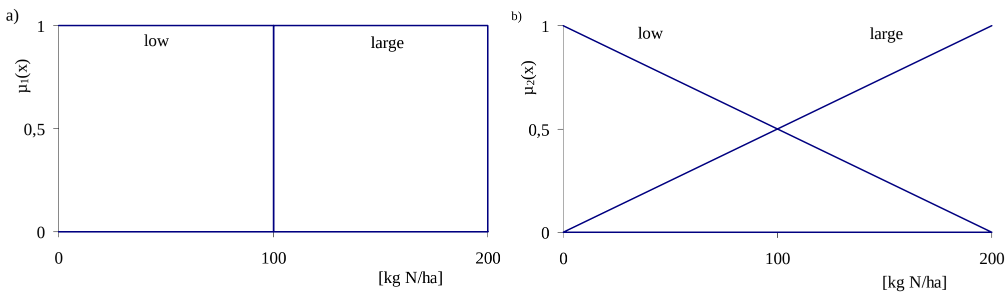


Figure 1: Differences between binary and fuzzy logic – basic definitions. The Figure shows the membership functions $\mu(x)$ of the two subsets represented through the linguistic expressions ‘low’ and ‘large’ (standing for a ‘low’ or ‘large’ potential for reducing the habitat quality) for the criterion ‘nitrogen fertilizer’. Thereby x is the amount of applied fertilizer in kg N/ha within the universe X and $\mu_{1/2}(x)$ is the degree of membership to the defined subset within the interval [0, 1]. A membership degree of 1 indicates a full membership, a memberschip degree of 0 a non-membership. a) In binary logic only hard thresholds can be defined: $\mu_1(x)$ is either 1 or 0. Though all production practices with less or more than 100 kg N/ha are classified as those with a low potential in reducing the habitat quality for certain plant species or as those with a large potential, respectively. b) In contrast fuzzy logic allows soft thresholds. Consequently the transition between both subsets is gradual.

---

7 HERZOG (2002) differs between *data, information* and *knowledge*: *Data* simply are numerical values. Data within a logical and classified structure result in *information.* Aggregated and reliable information which is acquired by intelligence, experience and learning yields in *knowledge*. *Knowledge* is the base for evaluation, decision-making and action.

8 Experts have vast knowledge in a specific domain obtained through a long period of working and experience. This includes the ability to handle uncertain information as well. This specific knowledge generally can’t be found in literature because expert knowledge often is intuitive knowledge (REIF 2000).

The hard threshold in Figure 1a) - binary logic- seems inadequate and unrealistic because there is nearly no difference in applying 99 or 101 kg fertilizer per ha although one is depicted to have a low and the other one to have a large influence on habitat quality. By contrast gradual transition in case of fuzzy logic in Figure 1b) seems more suitable to display the real correlation, that the statement "effect is low" slowly decreases while the statement "effect is large" steadily increases.

Membership functions[9] as shown in Figure 1 are generated for all evaluation criteria that should be considered per indicator. Subsequently single criteria are connected by operators (AND-, OR-, compensatory operator, LUTZ & WENDT 1998). Doing this, one crucial question is, whether better partial results can compensate poorer ones or not. For example many crossovers of agricultural machinery lead to an increase in soil compaction within wheel tracks, which can be a promotional factor for soil erosion, but this process can be partly reversed through tillage (OR-operator). In the case of irreversible effects, e.g. amphibians are very sensitive to the application of mineral fertilizer (particularly ammonium nitrate), which can eliminate considerable parts of the population (OLDHAM et al. 1993) an AND-operator must be chosen because subsequent measures can not mitigate the harm done no matter how good they are assessed.

2.6 Environmental evaluation scheme

The assessment of environmental impact of agricultural production follows a scheme of three steps:

(i) Environmental evaluation of all agricultural production practices in MODAM

(ii) Assessment of the site-specific potential (e.g. for providing habitats for flora and fauna species, contributing to ground water proliferation) or risk potential (e.g. for water erosion, nitrate leaching etc.)

(iii) Evaluation of all possible combinations of sites and management practices.

The result of the evaluation procedure in general is a non-dimensional index of goal achievement (IGA), a value between 0 and 1. An index of 0 indicates a minimum and an index of 1 a maximum suitability to attain a certain environmental target. In some cases, as later shown for the example of water erosion, also quantitative statements can be made.

2.6.1 Expert knowledge

The selection of evaluation criteria is based on literature review and expert questioning (unstructured and semi-structured interviews[10]). The elicited knowledge then has to be structured and formalised to be entered into a rule base for the model development. The procedure follows the method of rapid prototyping - also called incremental development - (GOTTLOB et al. 1990), meaning that a model

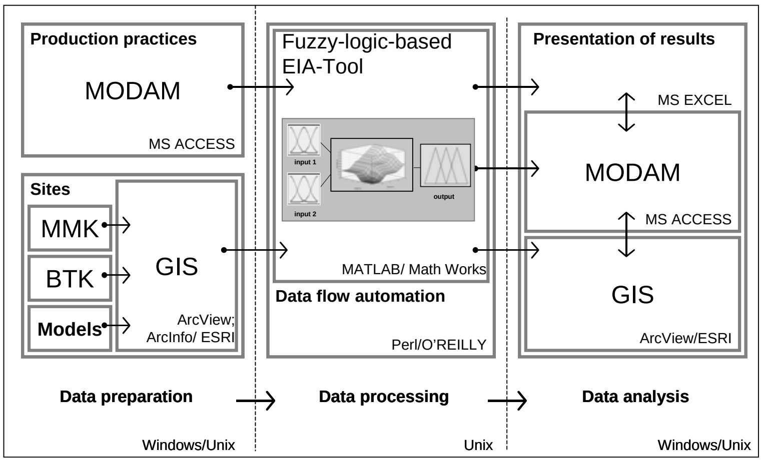
9 In this study only linear membership functions are used because the processing time is considerably lower compared with quadratic or e-functions (LUTZ & WENDT 1998).

10 In those cases where already prototypes could be developed on the base of information gathered from literature sources, a structured interview was conducted. The expert answered on questions or filled in prepared schemes to close gaps in the knowledge base and gave comments on the hitherto proceeding. Only when no prototype could be elaborated unstructured interviews were chosen. In that case only a short introduction was given according intension and aims of the work and the expert stated his opinion which criteria should be selected and what the model structure should look like ('thinking-loud-model' alternatively 'introspection', PUPPE 1988). With the help of this information the prototyping was done and in a second meeting the expert was requested to give feedback on model structure and preliminary results.

prototype is elaborated as quickly as possible. Subsequently the prototype has to be improved through feedback from the experts on preliminary results (REIF 2000).

2.6.2 Model structure

The whole Environmental Impact Assessment-Tool (EIA-Tool) consists of diverse modules: one for each indicator divided again in sub-modules to support transparency. The EIA-Tool is linked with MODAM to enable integrated ecological and economic multi-criteria-analysis.



Fuzzy-logic-modelling is done with fuzzy-supporting software MATLAB (MATH WORKS 1998), automation of data flow is programmed with Perl (O'REILLY) and site potential assessment is done with the help of GIS (ArcView and ArcInfo; ESRI) under operating system UNIX. The modelling system MODAM itself runs under ACCESS, Windows (MICROSOFT).

Figure 2: Structure of the Environmental Impact Assessment-Tool (EIA-Tool). MMK = Meso-scale soil characterisation map (1:25.000), only available for East Germany, BTK = Map of biotope types for Germany, colour infrared air photography (1:10.000); GIS = Geographical Information System.

3 Results

3.1 Environmental evaluation of agricultural production practices – all indicators

For each of the 10 selected indicators, an index was calculated to indicate its suitability to attain the corresponding environmental quality targets (Table 1). Figure 3 shows the results for the standard cropping practices for the region's most important crops. Refering to the evaluation results set aside is determinded to be highly beneficial for the majority of objectives but especially for the biotic indicators. This is due to the very few operations and hence low disturbance potential. Only ground water recharge is an exception because of the vegetation coverage of the soil throughout the whole year. To prevent nitrate leaching into groundwater the most suitable crops are set aside and cereals while the least suitable crop is winter rape with the highest level of nitrogen fertilizer application.

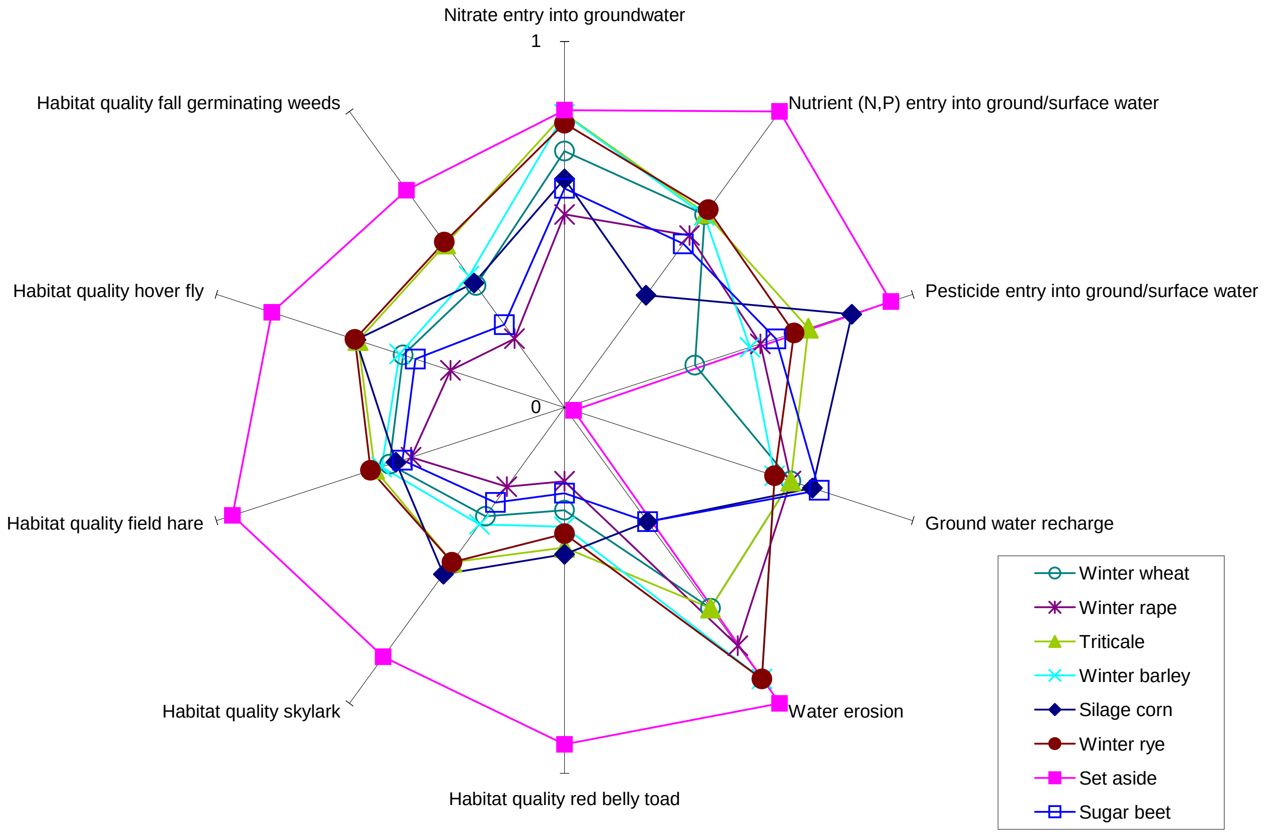


Figure 3: IGA (Index of goal achievement) for the most important crops of the modeled region. Only standard cropping practices are displayed (integrated farming, tillage by plough, no intercrops or companion crops). IGA = 0 is equal to a low contribution of the production practice to attain a defined environmental quality target, IGA = 1 means high contribution, respectively.

Silage corn reaches the lowest IGA to avoid nutrient transfer into water bodies, which is due to the high amounts of nitrogen and phosphorus fertilizers alloted for this production practice. With altogether 4 pesticide applications wheat is the least matching crop concerning pesticide loadings in opposite to silage corn with one and set aside with none application. To support groundwater recharge row crops (sugar beet, silage corn) attain the highest IGAs because there is no vegetation cover in between rows that hinders infiltration of rain water into the ground. Besides set aside, rye and barley score well to prevent water erosion. Both crops are conceded a sufficient soil coverage throughout the year conversely to the two row crops. To diminish the hazard potential for amphibians, rape and sugar beets are at least favourable. This is due to their high disturbance potential within sensitive periods. The best appropriateness for skylarks shows set aside followed by silage corn. Compared to other crops silage corn has a lower disturbance potential and there is no insecticide application (insects are the main diet of the birds during summer). For the protection of field hares in first place again set aside followed by rye, triticale and barley seem most promising as a matter of the disturbance potential through operations. For the same reason the best results concerning hover flys are obtained by set aside and furthermore rye, silage corn and triticale. Rape and sugar beet are by far the least preferable crops for the conservation of fall germinating plant communities because of the number of herbicide applications. Overall, winter rape in six out of 10 cases is the least suitable crop with respect to the defined environmental targets.

As crop production varies considerably depending on the site, the specific farm organisation and farmers objectives, we evaluated not only standard but also several alternative cropping practices. Thus, the result for a specific crop is a range of values (as shown for winter wheat in Figure 4).

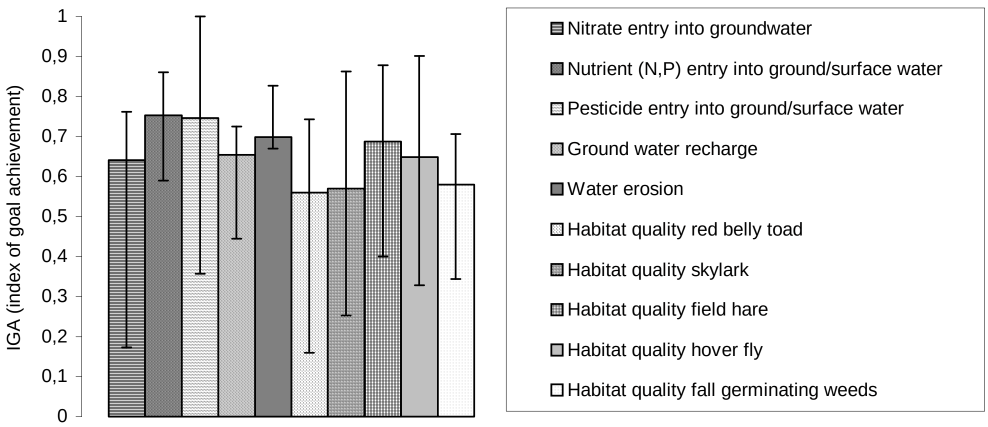


Figure 4: Mean, maximum and minimum value of IGA for winter wheat concerning all indicators. In dependency on the performance (e.g. integration of catchcrops, reduction of fertilizer application, etc.) the IGA per crop can vary significantly.

3.2 Environmental evaluation of site-specific potentials - example water erosion

The site-specific risk potential for water erosion[11] as an example is estimated with the universal soil loss equation (USLE), developed by WISCHMAIER & SMITH (1978), which is designed to predict the long-term average annual soil loss caused by water erosion. The equation is: $A = R * K * LS * C * P$, where A is the average annual soil loss in t/ha (tons per hectare), R is the rainfall erosivity index, K is the soil erodibility factor, LS is the topographic factor (L is for slope length and S is for slope inclination), C is the cropping factor and P is the conservation practice factor.

Factors were adjusted to the climatic conditions of the modeled region. The site-specific risk for water erosion was calculated under the application of a digital elevation model (DGM 25) by DEUMLICH et al. (2001). For each site the multitude of potential soil losses under different crops can be calculated when different C-factors are inserted into the USLE. For example a C-factor of 1 for dark fallow causes the highest soil losses while winter rye with a relatively low C-factor of 0,036 reduces the potential risk. Grassland is awarded a C-factor close to zero and nullifies the potential risk for soil losses.

3.2.1 Combining the evaluation of sites and production practices

To evaluate every cropping practice for each site, all possible combinations of sites and management practices are composed. Thereby in the fuzzy-model the assessed potential soil losses for different C-factors are related to the standard production practices on every site to calibrate the model. With the calibrated model, the deviations within the scope of alternative performances for each crop can be calculated.

[11] The site-specific potential risk for water erosion (after the USLE) estimates the average soil loss when weather conditions are like the average of the last twenty years. Actual soil loss may vary due to deviant weather conditions. For instance heavy precipitation can effectuate enormous soil losses within a very short time period. Hence the USLE is unsuitable to predict actual soil losses.

3.3 Combining environmental and economic assessment

The economic effects of the enforcement of higher goal achievements for environmental objectives are analysed on the basis of the farm linear programming model of MODAM. By introduction of environmental restrictions, the farm model is forced to choose production activities, which accomplish these restrictions. The farm level is chosen, because total micro-economic effects can only be calculated by taking compensatory possibilities at the farm level into account. For instance light restrictions on one site can have no effect on the total farm rentability if there are other sites available to cultivate the required crops.

The combined environmental and economic assessment considers the modeled region as a regional farm model. Production factors like manpower or machinery are based on the region's average data. The LP-matrix for MODAM can be formulated for any number of sites and production practices (ZANDER & KÄCHELE 1999). The objective function is the maximisation of the total gross margin while environmental targets can be formulated as additional constraints (goal driven scenarios for different goal attainment levels, SCHULER & KÄCHELE 2003). During the optimisation process, the model has the choice to substitute either the production practices defined for a certain crop or allow a replacement of crop types. Below, we present results related to the indicator 'water erosion'.

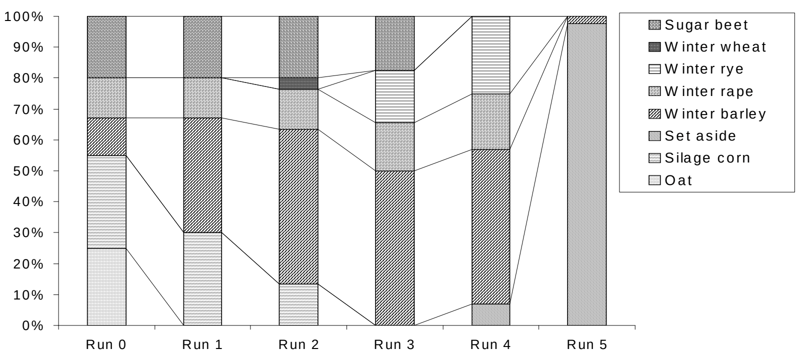
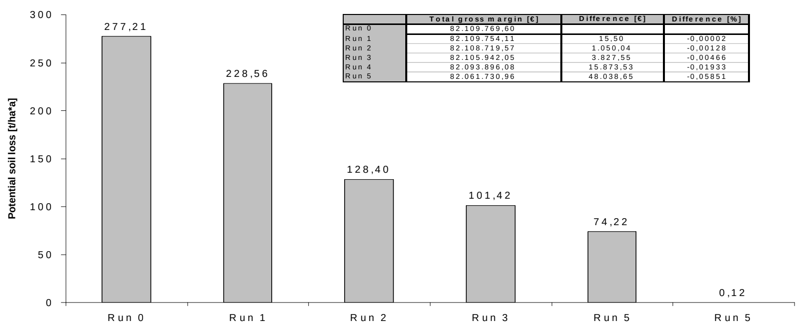


Figure 5: Stepwise reduction of potential soil losses through water erosion on sites assigned to the highest risk class. Run 0 represents the situation when no environmental restriction is defined and the model optimises only the economic output. From step 1 to 5 the environmental restrictions are strengthened constantly.

Figure 5 shows the model results after 5 steps, during which the potential soil loss should be diminished close to zero only on those sites with the highest potential risk for water erosion assumed under dark fallow (soil losses > 8t/ha). Run 0 represents the situation when no additional restrictions are formulated. From run 0 to 4 those cultures with a lesser IGA concerning water erosion prevention like sugar beets and silage corn (both crops with a large row distance and slow growth in vegetation during the year) are stepwise decreased while those with lower likelihood of water erosion are increased (like winter rye and winter barley). To push water erosion risk close to zero (last step from run 4 to 5) the only suitable crop (based on the assessment) is set aside. From run 0 to 5 the annual potential soil loss on sites with the highest risk class decreases from about 277 t/ha to nearly zero (0,12 t/ha). At the same time the total gross margin of the whole farm decreases only slightly about 0,06% (Figure 6).



	Total gross margin [€]	Difference [€]	Difference [%]
Run 0	82.109.769,60		
Run 1	82.109.754,11	15,50	-0,00002
Run 2	82.108.719,57	1.050,04	-0,00128
Run 3	82.105.942,05	3.827,55	-0,00466
Run 4	82.093.896,08	15.873,53	-0,01933
Run 5	82.061.730,96	48.038,65	-0,05851

This can be explained by the replacement of production practices with plough tillage through production practices with reduced tillage. This helps in reducing costs because of the saved expenditures for fuel, machinery and manpower.

Figure 6: Stepwise decrease in the potential soil losses of sites assigned to the highest risk class for water erosion and effect of the environmental optimisation process on the total gross margin. Losings in total gross margin are little, because production practices are substituted by variants with lower costs (reduced tillage).

The example shows that the improvement of the ecological performance must not be combined with high economic losses. As the environmental restrictions are only related to those sites with the highest risk potential for water erosion, the modelling system has enough leeway to put production practices that go potentially with a high level of erosion and a high economic revenue on sites insensitive for water erosion.

For other indicators, particularly the biotic ones, the restraint of high gross margin losses is not always possible. Here mostly production practices with low inputs of fertilizers and pesticides are evaluated as highly suitable which is linked in general with reduced yields. In these cases compensation payment to improve the ecological performance has to be considered.

4 Discussion

4.1 Pros and cons of the approach

The main advantages of this fuzzy-logic-based approach to assess environmental effects of agricultural production practices are the possibilities to access uncertain knowledge and to translate ambiguous linguistic expressions into computational language, which is highly beneficial when precise information is not available. Overall the approach is relatively uncomplicated and can be quickly elaborated for numerous indicators given that enough knowledge is available about how an indicator is affected by agricultural measures.

The most time-consuming part of the model development is the elicitation of knowledge. For example one reason for incomplete knowledge elicitation from experts may be that some information is seen as self-evident and not announced by the experts, pictorial knowledge often is not easily expressed verbally, parts of knowledge can be unconscious and experts may not want to surrender all their knowledge to maintain their 'information headstart' (WIELINGA 1984, cited in PUPPE 1988).

In general the model output is a dimensionless index, but as shown for the example of water erosion also quantitative statements can be derived. Before the approach can be transfered to other regions the definition of regional environmental targets must be reviewed with the participation of local stakeholders. Eventually the elaboration of new assessment procedures is nessecary. Both can be as well a time-consuming process.

A disadvantage of the approach is that validation is extremely difficult. The model development undergoes several cycles of feedback and is assumed to be finished when model outputs satisfy the expectations of experts and are comparable to observed real situations. Although quantitative results are possible in cases where the site potential is assessed quantitatively, they are difficult to provide for every indicator. Especially for biotic indicators quantitative assessments are extremely difficult.

Finally the approach is a static one as combinations of production practices and sites are considered as certain points in time and space. Neither time related changes and interactions nor spatial interdependencies between agricultural fields and neighbouring habitats are considered.

4.2 Other comparable studies

Static approaches to evaluate the performance of agricultural production practices for environmental indicators were also used by Meyer-Aurich (MEYER-AURICH 2001; MEYER-AURICH ET AL. 1998) and STACHOW ET AL. (2003). In the first study all in all seven ecological indicators were evaluated for integrated farming systems. In the latter work only biotic indicators were objekt of the evaluation for both integrated and organic farming. The result of this study was an assessment of the habitat quality of agricultural fields in 5 classes from ‘very low’ to ‘very high’. Both studies were not designed to handle uncertain information but delivered very valuable links for this work.

Fuzzy-logic has been applied in a broad number of studies to assess single indicators in the field of sustainable development; e.g. to assess animal walfare in agricultural production systems (CORNELISSEN 2003), to calculate nitrate leaching (MERTENS & HUWE 2002), to model soil erosion (MITRA et al. 1998) or to conduct an environmental impact assessment of pesticide use (WERF & ZIMMER 1998). Furthermore an overview about 12 different indicator-based evaluation methods (some of them using fuzzy techniques) to address the question of environmental impacts of agriculture is given by WERF & PETIT (2002).

5 Conclusion

The integration of the fuzzy-logic-based Environmental Impact Assessment-Tool (EIA-Tool) for 10 different ecological indicators into the modelling system MODAM enables the evaluation between different alternatives of agricultural land use practices. All in all, the results can provide useful information in the ongoing debate of sustainable development in agriculture. The findings indicate that certain environmental restrictions are not compelled to result in economic losses for the farmer, especially if they are linked only to those sites, which are particularly sensitive regarding the chosen indicator (as shown for water erosion). Other restrictions may cause substantial economic losses, which should be compensated to promote sustainable development of agriculture. In this case the model can give an idea about the appropriate hight of financial incentives.

6 Literature Cited

ARZT, K., E. BARANEK, J. EGGERS, U. FISCHER-ZUJKOW, J. GEWALTER, K. HAGEDORN, K. P. MÜLLER, U. PETERS, R. SCHMIDT, J. SCHULER, S. TEIGELER, AND H.-P. WEIKARD. 2000. Projektbereich 1: Dezentrale Bewertungs- und Koordinationsmechanismen. Pages 21-45 *in* K. Müller, H.-R. Bork, A. Dosch, K. Hagedorn, J. Kern, J. Peters, H.-G. Petersen, U. J. Nagel, T. Schatz, R. Schmidt, V. Toussaint, T. Weith, A. Werner, and A. Wotke, eds. Nachhaltige Landnutzung im Konsens - Ansätze für eine dauerhaft-umweltgerechte Nutzung der Agrarlandschaften in Nordostdeutschland. Gießen: Focus Verlag.

BUCKWELL, A., J. BLOOM, P. COMMINS, M. HOFREITHER, H. V. MEYER, E. RABINOWICZ, F. SOTTE, AND J. M. SUSPI VINAS. 1997. Towards a Common Agricultural Policy for Europe.

CHRISTEN, O. 1999. Nachhaltige Landwirtschaft. Von der Ideengeschichte zur praktischen Umsetzung. Heft 1 ed. Bonn: Institut für Landwirtschaft und Umwelt (ilu).

CORNELISSEN, A. M. G. 2003. Two Faces of Sustainability. Fuzzy Evaluation of Sustainable Development. 1-184. Thesis, Wageningen University, the Netherlands.

DEUMLICH, D., J. THIERE, H.-I. REUTER, AND L. VÖLKER. 2001. Einzugsgebietsbezogene Standortanalyse für Boden- und Gewässerschutz (Uecker). Mitteilungen der Deutschen Bodenkundlichen Gesellschaft Band 96: 481-482.

EUROPEAN COMMISSION. 2000. Agriculture’s contribution to environmentally and culturally related non-trade concerns. International Conference on Non-Trade Concerns in Agriculture. Session 4. http://europa.eu.int/comm/agriculture/external/wto/document/nor2_en.pdf

ESRI – Webpages. http://www.esri.com

FAO. 1989. http://www.fao.org/wssd/SARD/index-en.htm

GIEGRICH, J. 1997. Gegenüberstellung der Bewertungskonzepte für Agrar-Umweltindikatoren und bei Ökobilanzen. Pages 291-312 *in* W. Diepenbrock, M. Kaltschmitt, H. Nieberg, and G. Reinhardt, eds. Umweltverträgliche Pflanzenproduktion - Indikatoren, Bilanzierungsansätze und ihre Einbindung in Ökobilanzen. Osnabrück: Zeller.

GOTTLOB, G., T. FRÜHWIRT, AND W. HORN. 1990. Expertensysteme. Wien: Springer.

HERZOG, C. 2002. Das Methodenpaket IeMAX mit dem Fuzzy-Simulationsmodell FLUCS. Entwicklung und Anwendung eines Entscheidungsunterstützungssystems für die integrative Raumplanung. Dissertation, Mathematisch-Naturwissenschaftliche Fakultät der Christian-Albrechts-Universität zu Kiel.

HÜBLER, K. H. AND OTTO-ZIMMERMANN. 1989. Bewertung der Umweltverträglichkeit: Bewertungsmaßstäbe und Bewertungsverfahren für die Umweltverträglichkeitsprüfung. in M. Bahadir, H. Parlar, and M. Spiteller, eds. Springer Umweltlexikon.

LUTZ, H. AND W. WENDT. 1998. Taschenbuch der Regelungstechnik. 2. überarbeitete und erweiterte Ausgabe ed. Frankfurt am Main: Verlag Harri Deutsch. 954 p.

MATH WORKS. 1998. Fuzzy Logic Toolbox - For Use with MATLAB. User's Guide. http://mathworks.com.

MERTENS, M. & B. HUWE. 2002. FuN-Balance: a fuzzy balance approach for the calculation of nitrate leaching with incorporation of data imprecision. Geoderma 109: 269-287.

MEYER-AURICH, A. 2001. Entwicklung von umwelt- und naturschutzgerechten Verfahren der landwirtschaftlichen Landnutzung für das Biosphärenreservat Schorfheide-Chorin. Agrarökologie ed. Bern, Hannover; zugl.: Universität Potsdam, Dissertation 1999: vaö-Verlag. 1-137 p.

MEYER-AURICH, A., P. ZANDER, A. WERNER & R. ROTH. 1998. Agricultural land use strategies appropriate to nature conservation goals and environmental protection. Landscape and Urban Planning 41: 119-127.

MICROSOFT-Webpages. http://www.microsoft.com.

MITRA, B., H. D. SCOTT, J. C. DIXON & J. M. MCKIMMEY. 1998. Applications of fuzzy logic to the prediction of soil erosion in a large watershed. Geoderma 86: 183-209.

MÜLLER, K., V. TOUSSAINT, H.-R. BORK, K. HAGEDORN, J. KERN, U. J. NAGEL, J. PETERS, R. SCHMIDT, T. WEITH, A. WERNER, A. DOSCH, AND A. PIORR. 2002. Nachhaltigkeit und Landschaftsnutzung. Neue Wege kooperativen Handelns. Weikersheim: Margraf Verlag.

OECD. 1997. Environmental Indicators for Agriculture. Paris.

OLDHAM, R. S., D. M. LATHAM, D. HILTON-BROWN, AND J. G. BROOKS. 1993. The Effect of Agricultural Fertilizers on Amphibians. The Toxicity of ammonium nitrate, the persistance of fertilizer granules, the effect of organic manure, the wider implication of fertilizer impact. De Montfort University.

O'REILLY - Webpages. http://www.oreilly.com.

PUPPE, F. 1988. Einführung in Expertensysteme. Studienreihe Informatik ed. Berlin, Heidelberg, New York, London, Paris, Tokyo: Springer.

REIF, G. 2000. Moderne Aspekte der Wissensverarbeitung. Ein interaktiver Lernbehelf für das Web Based Training. Diplomarbeit an der Technischen Universität Graz, Institut für Informationsverarbeitung und Computergestützte neue Medien (IICM) ed.

Schuler, J. & H. Kächele. 2003. Modelling on-farm costs of soil conservation policies with MODAM. Environmental Science & Policy 6: 51-55.

STACHOW, U., J. HUFNAGEL, M. GLEMNITZ, G. BERGER, J. BACHINGER, P. ZANDER, AND C. SATTLER. 2003. Indicators of Landscape Functions Related to Modifications and Patterns of Agricultural Systems. Pages 209-221 *in* Agricultural impacts on landscapes; developing indicators for policy analysis. Proceedings from the NIJOS/OECD Expert meeting on Agricultural Landscape Indicators, 7th - 9th October 2002, Olso, Norway.

WALZ, R., N. BLOCK, W. EICHHAMMER, H. HIESSEL, C. NATHANI, N. OSTERTAG, M. SCHÖN, M. HERRCHEN, D. KELLER, D. KÖWENER, K. RENNINGS, AND ROSEMANN. 1997. Grundlagen für ein nationales Umweltindikatorensystem - Weiterentwicklung von Indikatorensystemen für die Umweltberichterstattung. Forschungsbericht 101 05 016 des Umweltbundesamtes ed. Berlin.

WERF, H. V. D. & C. ZIMMER. 1998. An indicator of pesticide environmental impact based on a fuzzy expert system. Chemosphere 36: 2225-2249.

WERF, H. V. D. & J. PETIT. 2002. Evaluation of the environmentalimpact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agriculture Ecosystems & Environment 93: 131-145.

WISCHMEIER, W. H. AND D. D. SMITH,. 1978. Predicting rainfall erosion losses: A guide to conservation planning. Agriculture handbook No. 537, U.S. Department of Agriculture, Washington DC.

ZADEH, L. A. 1994. The Role of Fuzzy-Logic in Modeling, Identification and Control. Modeling Identification and Control 15 (3): 191-203.

ZANDER, P. AND H. KÄCHELE. 1999. Modelling multiple objectives of land use for sustainable development. Agricultural Systems 59: 311-325.

ZANDER, P. 2003. Agricultural Land Use and Conservation Options - a Modelling Approach. Dissertation University of Wageningen.