Field related organisms as possible indicators for evaluation of land use intensity

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Abstract

Most farm activities might cause some hazard for the environment. In this context, the effects on the biotic environment are most complex and require a system approach. In this study, we present results on the relation between different farm activities and some important biotic indicators. Farm activities were monitored to determine the socio-economic and abiotic environmental status of an organic farm system, using a farm modelling system based on the REPRO methodology. The project also included field studies on the same site in order to monitor some important biotic indicators. By doing that, the interrelation between abiotic environmental indicators and selected field related organisms (carabids, weeds, earthworm, microbial soil activity) were demonstrated. A complex assessment of the organic farm compared with a conventional farm illustrates the relation between the different indicator groups. In accordance with the OECD-indicator framework these findings are necessary to establish and implement an indirect way to assess the biotic environmental situation on farm level.

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1. Introduction

The interest to assess the relationship between agricultural practices and the biotic and abiotic environment has increased in recent years. Special impetus came from the climate protection campaign and the reorientation of EU agricultural policy towards more sustainability in agriculture. The implementation of environment-related targets bases on agri-environmental schemes was another major reason for the growing interest in this area of research.

The main objective of those programs was to reduce environmental pollution caused by agricultural activities, as well as the preservation of biodiversity on field, farm or landscape level by means of reduction of inputs, less intensive production systems or organic farming (EC, 1992).

A number of indicator sets have been proposed to measure the sustainability of farm operations with focus on the abiotic environment (soil and water quality, greenhouse gas emission etc.) including the socio-economic situation (farm income, gross margins, etc.) on the farm level (Koepf et al., 1989; Faeth, 1993; Jaeger, 1995; Girardin et al., 1996; Müller and Dittrich, 1996; Fox, 1991; Liebig and Dorn, 1999; Abraham, 2000). A very comprehensive computer-based approach has been developed by Hülsbergen et al. (2000). Additionally a vast scientific literature is dealing with the biotic environment, however, most described indicators have been developed and used for special proposes in landscape ecology or specific scientific questions (Gruschwitz, 1981; Arnd et al., 1987; Nähring, 1990; Steinborn

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From a practical point of view, those indicators have several limitations:

- Data on farm level is scarce.
- Direct measurements (population densities) are extremely expensive and time-consuming.
- Measurements might provide some information about the actual biotic status, but do not allow conclusions about future developments.
- Most measurements do not consider the farm level and therefore separate the results from the socio-economic consequences.
- Cause-effect relations between agricultural production systems and the environment are not determined. As a consequence, farmers or administrators do not have enough information to alter the management system corresponding to environmental needs.

In this paper, we propose a system with pressure indicators to assess the biotic environment on farm level, based on the OECD-indicator framework (pressure-(driving force) state-response model). Most data is readily available on the farm level and allows assessment without direct measurements of the single species or species groups. In order to demonstrate the feasibility of this approach, we present data from some long-term field surveys and accompanied field experiments with special emphasis on the interaction between the abiotic and biotic environmental sector. Carabid beetle (Carabidae) earthworms (Lumbricidae), weed population and microbial soil activity were chosen as organisms and indicators, which show a strong relation to various field cultivation activities. On the other hand, they are regarded as important bioindicators itself providing information about the stability and auto-regulatory processes of agri-ecosystems (Finck, 1952; Chambers et al., 1983; Bryan and Wratten, 1984; Schinner, 1986; Chiverton, 1987; Hance, 1987; Edwards and Bohlen, 1995).

2. Methods

Data were collected during 5-year field studies within the area of a 500 ha farm, situated near the city of Halle (Saale), Saxony-Anhalt (Germany). This area is typical for the loess sites of the Central German Dry Region with a continental climate. During the 5-year period the farm was converted from a conventional intensive to an organic farming system.

Each farm activity was monitored to determine the socio-economic and abiotic environmental status of the farm, using the REPRO-based methodology (p.e. N-balance, humus supply and reproduction) (Hülsbergen et al., 2001). Data on the relevant species were measured at different intervals including the whole field area. Further details on sampling dates and methods are given in Table 1.

Besides the above-mentioned field surveys, experimental plots were established near to the farm area in order to directly measure the impact of plant cover and type of cultivated field plants on the carabid community. These plots allowed special data analysis (Dammer and Heyer, 1997) to estimate the

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<td><strong>Method</strong></td>
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environmental and anthropogenic impact on beetle population.

The combination of survey data and data from experimental plots gave us a sufficient data basis to describe and evaluate relationships between agricultural activities and the selected organisms.


3. Results

3.1. Dependencies between farm operations and selected biotic protectables

3.1.1. Plant coverage and ground beetle activity

The first example demonstrates how the time between sowing and crop harvest or forage cuts affects the occurrence of carabids (Fig. 1). When the ground is kept clear (only short-time growth of a weed cover) a total number of 33 carabid species were registered using pitfall traps.

When the plant cover (winter barley, winter rape, field forage) was allowed to grow without interference, even 56–61 species were recorded within 1 year. A similar result was obtained for the relationship between species and individuals. This is noteworthy since the regulatory benefit of this epigeous arthropod group in the agro-ecosystem ensues mainly via the abundance (biomass) of the beetles. Also from this point of view, extended ground coverage is advantageous for the beetle population. The time period is determined by the indicator “time of ground coverage” as showing by REPRO.

3.1.2. Crop number, crop diversity and ground beetle population

Number and growing period of cultivated crops can be easily surveyed on the farm and entered into REPRO producing the indicator “crop diversity”. It provides information about the structure of a farm and at the same time points out to developments in the biotic sector of the environment. Fig. 2 shows this relationship by demonstrating the relation between the number of cultivated crops and the number of carabid species identified in the fields. It is obvious that the species diversity depends largely on the crop species and the number of cultivated crops. In the cited example, 13 (worst case) or 44 (best case) carabid species were recorded in one single crop within 1 year. When several crops were grown, the difference between favourable and unfavourable crop species (or combinations) decreased.

Regarding the evaluation of the findings, it can be underlined that there is no single “bad” or “good” crop, because the growth period involves major changes and affects the different species (Heyer, 2000), thus the niche conditions for the various beetle species within a single crop changes continuously. When seven crop species were grown, the number of captured carabids could no longer be statistically distinguished (method after Poole, 1974) from the number of carabid species in 10 different crop stands. Further surveys revealed
that the influence of these crops on the variability of carabid population is roughly equivalent to that of the various annual weather conditions (Dammer and Heyer, 1997).

3.1.3. Resource input, land use and earthworm population

The next example focuses on the reduction of inputs during the shift to organic management and the consequences for the earthworm population after previously differentiated land use (Fig. 3).

Earthworms find much better living conditions on grassland than on arable sites (Fig. 3). Old orchards are poor in earthworm populations because of former high pesticide application rates. Despite the marked differences in the basic population density, positive trends of the earthworm numbers due to organic management have been observed on all fields. Although results from one case-study are given here, we can generally conclude that a diverse use of farmland (e.g. ratio between arable land and natural grassland) or a switch to organic farming decreases the pressure of agricultural activities on this indicator group. The respective agronomic and cultural parameters can be successfully analysed by REPRO.

3.1.4. Mineral fertiliser input, N-balance and weed occurrence

Nitrogen is an essential operating resource in agriculture. Yields on the one hand and environmental impacts of a farm on the other depend decisively on the management of the N-cycle. The REPRO model permits to calculate the N-supply by organic fertiliser, crop residues and considers immission from the atmosphere.

Over time, the modified N-supply affected the weed flora, which is given in Fig. 4. The figure shows changes in species number and species composition related to the N-supply to the soil. Declining N-supply slightly increased the species diversity. The number of weed species increased a little, with the percentage of N-seeking species in the total plant cover declining.
This underlines that the weed flora and their composition response rather sensitively to the indicator "total nitrogen input". There is a marked tendency between nitrophyt share and N-cycle in a system, which will be useful for the description of biotic effects (Fig. 4).

3.1.5. Humus supply, humus reproduction and soil organisms

Further examples for relationships between parameters of the abiotic and biotic environment focus on the soil as natural habitat. Table 2 shows the interaction between the microbial biomass (C\text{mik}) and its activity (determined on the basis of enzyme activity) and the earthworm colonisation in relation to the humus content of the soil (C\text{t}). Between the mentioned parameters positive correlations have been measured, which are important for the assessment of changes in the biotic sphere of the soil. This implies that agricultural activities increasing an accumulation of organic matter in the soil present simultaneously a stimulation for soil organisms.

3.1.6. Indicator use in context of the evaluation of farm management systems

The examples given in this paper underline the usefulness of assessing environmental effects of farm management practices in an indirect way. The following evaluation, however, faces also a number of obstacles:

- A system-related assessment requires data aggregation, which itself requires a standardisation and hierarchical integration of the different indicators. This is especially important for the evaluation of biotic data in connection with abiotic and socio-economic indicators.
- When working towards agricultural policy aims, it is less important to harmonise the impact of a special production system with one single target species but to optimise the entire system towards the sustainability of agricultural production. The selection of biotic indicators is to be made with orientation to this aim.
- Antagonistic effects between the different species are very important. Positive effects for one species frequently cause restrictions for other species. Therefore, production systems are to be evaluated by use of different indicator species. The only exceptions are systems, which were solely designed for the protection of a specific species or habitat.
- There is a need of debate about the evaluation of biotic facts. This concerns target values or the definition of thresholds for the population size of indicator species and also the choice of suitable reference situations. It is not useful to compare the biodiversity of natural areas with farmed land.

The need of research and discussion for solving the mentioned problem areas is enormous and can be realised only step by step in pragmatic approaches. First attempts to include those different aspects have been made by the REPRO designers. Fig. 5 shows

**Table 2**

Correlation examples (correlation coefficient $r, n = 64, \alpha = 0.05$) between the abiotic and biotic environment sector (modified according to Hülsergen and Diepenbrock, 2001)

<table>
<thead>
<tr>
<th>Microbial biomass and activity</th>
<th>Earthworm abundance and biomass</th>
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<tr>
<td>$C_{\text{mik}}$</td>
<td>$\beta$-Glucosidase</td>
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<td>$C_{\text{t}}$</td>
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the integration of biotic environmental indicators into the general description of the ecological effects of agriculture using an example of a conventionally managed farm in the German Central Dry Region. As a reference, an organic farm was chosen whose biotic benefits have been documented in long-term concomitant studies. Furthermore, in this example monitoring data about the Skylark (Alauda arvensis) and Grey Bunting (Miliaria calandra) is used.

A juxtaposition of the two farming systems reveals system-related deviations in the application of plant protection agents, which might involve a potential risk for biotic goods. Several indicators range around the value of reference parameters (crop diversity, nitrate losses, ground coverage); others highlight potentially environmental benefits (priority areas for ecological land use, number of brooding pairs). In comparison, more favourable values are reached for the humus supply and the CO₂-fixing capability.

4. Discussion

The Common Agricultural Policy of the European Union (CAP) has set ecological targets for the agriculture sector. These targets can be reached via agri-environmental schemes based on the EC Regulations 2078/92 and 1257/99 (the latter is in force as from the year 2000). At the same time, the research sector is urged to elaborate the methodical tools for checking the expected ecological benefits. Up to now, a large proportion of the discussion focuses on the choice of suitable indicators (Wood, 1998; Jaeger, 1995) and agreement has been achieved about the indicator lists for describing the economic effects of policy decisions and agri-environmental schemes. Similar findings have been recorded for the abiotic environmental benefits (Rennings and Wiggering, 1997). No consensus, however, exists about the relevant indicators for the biotic environment. One reason are fuzzy ideas about the necessary indicators (e.g. biodiversity) (Wood, 1998), and an indiscriminate transfer of indicators to agriculture, which had initially been established for nature conservation areas, (e.g. Red Data Lists, various environmental schemes (Milon and Shogren, 1995)), but also the high cost and time input required for direct indication (Onate et al., 2000).

Those considerations make it necessary to evaluate the cause-effect relations between agriculture and environment and to use them in form of appropriate indicators for describing biotic effects. This principle,
which was stimulated by the pressure (driving force) state response model of the OECD (Münchhausen and Nieberg, 1997; OECD, 1998), has been strictly implemented in the REPRO model. When assessing biological facts in relation to agricultural activities, the latter and their impact on the environment are principally handled in a complex way. This approach, however, implies also restrictions, mainly in cases where exact population data of the selected indicator species are required. If, on the other hand, such data is available, the REPRO model is able to process information of direct monitoring and consider it for the evaluation.

An unsolved problem is the assessment of ecological risks. For certain sectors guide and threshold values are available (e.g. 50 mg/l water in case of nitrate). These values are consensus for policy makers and actually imply legal power.

Applicable knowledge on biotic goods is also available for plant protection agents (Gutsche and Roßberg, 1997). In most cases, however, such values do not exist, particularly since scientifically based studies are largely missing, or because the biotic sector is assessed by region-specific characteristics. Therefore, comparisons between extended regions or with other sites are normally not helpful. For that reason, more realistic are long-term monitoring data with consideration of the initial situation for reference or the comparison among region-specific management systems, which, if required, can be tailored for concrete biotic situations. Examples of species-related demands to agriculture have been described by Wieland (1997) for the Great Bustard (Otis tarda), by Saacke and Fuchs (2001) for the skylark (A. arvensis) and by Stubbe et al. (1998) and Weinhold (1998) for the common hamster (Cricetus cricetus). This approach of screening farming systems for species-related key facts (disturbance frequency, intermediate cuts, plough depth) is especially interesting when effect analyses for defined target species are to be made. They may be accompanied by farm level evaluations (e.g. share of ecological compensation areas), random field checkups and ratings of the intensity of a given management system.

5. Conclusions

This above-mentioned user-oriented point approach led to the following conclusions for intensified investigations of biotic indicators for environmental situations:

- Proposals are made for various indicator species. In general a single indicator approach is not sufficient to describe the environmental pressure of farming systems. On the other hand, a lag of knowledge in the use of “indicator sets” or in the development of entire “evaluation tools” is observed, considering the system character of agricultural production. The integration of biotic findings to REPRO is to make a contribution to the above-mentioned target.

- The different objectives require different biotic indicators. It is necessary to select indicators, closely related to agricultural activities. Such indicators must provide information on the sustainability of agricultural activities by use of an aggregated indicator “Pressure of the farming system on the biotic environment”. For nature conservation, direct indication via target or reference species is recommended.

- The hierarchical order of various farm operations for the populations of potential indicator species in real farm situations is often unclear. Additionally, the population changes from year to year due to the weather conditions. This normally restricts conclusions to specific anthropogenic impact conditions. It is necessary to develop methodical concepts for the rendering of such problems on the basis of the combination of field studies on farmland and exact field plot surveys.

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