ENHANCING SUSTAINABILITY BY LANDSCAPE-DESIGN AND CONVERSION TO ORGANIC AGRICULTURE

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Abstract

A hilly site with variable soils and facing all the problems of modern agriculture was re-designed and converted to organic agriculture in 1992. After 10 years of measurements and observations it was determined that soil compaction, runoff, and erosion were reduced, quality of groundwater and ponds was gradually enhanced, diversity of wildlife was enriched, and the economic situation of the farmer was improved. Besides landscape design, conversion to organic agriculture is regarded as a key instrument towards sustainable land use in this region.

Introduction

Agricultural systems of the future must protect resources while being productive, economically sound and socially viable. This paper describes the multi-disciplinary, multi-aimed project including landscape-redesign and conversion to organic agriculture performed on a representative segment of an arable landscape in Bavaria, Germany, that faced problems of impaired abiotic and biotic resources. Over the 13 years of the research, changes in the ecosystems and the environment were recorded and assessed. For some key indicators it has been estimated whether those changes result in a higher level of sustainability on the farm level.

Material and methods

The 1.5 km^2 research site is typical of this region, which contains the most important arable land in southern Germany and constitutes about 30% of the arable land of Bavaria. It is located in a rural area 40 km north of Munich in the middle of a prospering area with more than four million inhabitants. This hilly region was confronted with all the problems of modern intensive agriculture, such as deterioration of soil and water quality and species diversity. During a two-year inventory phase (1990-1992), all arable fields (125 ha) were cultivated equally with small grains and according to the intensity of the former owner in a conventional manner. The grassland (25 ha) was used in the same way as previously. Soils, nutrients, water balance parameters, growth properties, flora and fauna were recorded in a 50-m grid at approximately 500 points. Additionally, 3 weather stations, 18 stations for runoff and erosion, 6 shafts for measuring the soil water regime, 14 groundwater shafts and 23 soil pits were established for long-term monitoring. Measurements were performed according to the methods of the different disciplines. Details are published by AUERSWALD ET AL. 2001. In summer 1992 an experiment at the landscape level was started: the landscape was re-designed and the area was divided along a border of a watershed to implement two farming systems: integrated and organic.

Landscape design:
In order to arrange site-specific land use in this landscape with its small-scale variations in soils and slopes, the size of fields was decreased from 4.0 to 2.3 ha on average, but their layout was improved for machinery: the new fields have two parallel sides with a length of 60 to 180 m, and are mainly rectangular. By extending the fields along the contour and decreasing their length along the slope the homogeneity of soils and water conditions within the fields increased (SINOWSKI AND AUERSWALD 1999). This concept is regarded as superior to the so-called precision farming on huge fields, because the timing of soil-dependent farming operations can be optimized. Narrow-angled field corners, areas that did not fit into the new field design ("space left over in planning"), steep slopes (> 0.3 m/m), wet areas, and strips between the fields and along the woodland were set aside or converted to grassland. These areas may give space for species that cannot survive on intensively managed arable fields. Buffer strips along the creeks may reduce direct agricultural influence on water bodies. Pilings of deadwood may provide shelter and nesting places for many animals and will develop into living hedges. The area of unused land was increased to 13.5%. The farm roads are connected to the nearby village and a well-known abbey in order to increase accessibility for people who want to enjoy themselves by walking and visiting a farm.

Farming system:
An area of 96 ha has been converted to organic agriculture according to the EU legislation. The central issues when implementing organic farming were: (1) integration of animal husbandry to use non-arable land as grassland and the ley crops on the arable land, to enrich the diets for humans and to enhance attractiveness for visitors, (2) preventing loss of matter on the farm level by reducing leaching and erosion from fields and by processing of harvests while keeping wastes on farm, (3) high yields of a broad range of marketable products, (4) growing crops that were regarded as difficult to grow organically, and (5) growing crops that are attractive to visitors and wildlife. Besides this farm, an area of 54 ha was made into another farm following the principles of integrated farming. About 38% of the area of the organic farm is grassland, which is used for beef production using Simmental suckling cows with an Angus or Piedmonts bull. 60% of the grassland is used as pasture, where cows and calves graze day and night in the summertime, and 40% is used as meadow that is cut three times a year for hay or silage. The grassland received no fertilizers over 14 years except for the dung pats and the urine left by the animals when grazing and waste potatoes that were partly spread on the pastures in the wintertime.On the plots of arable land a 7-phase rotation was implemented: ley - potatoes - winter wheat with a legume cover crop - sunflowers + ley - ley - winter wheat - winter rye + ley. The grass-red clover-alfalfa mixture (ley) establishes itself under the preceding rye or sunflowers, providing an untilled and perfectly covered soil for 28 or 17 months, respectively.

The soil is ploughed twice in the 7-year rotation with a two-layer on-land mouldboard plough, each time after the purely ley crops in order to control voluntary grasses and alfalfa. In three years out of seven, soil is chiselled and in the two years when ley is established it is not tilled at all. For cultivation of small grains in order to reduce weeds and to aerate the topsoil, tiny springs are used. Potatoes are cultivated two to four times using a spring hoe and a rotating wheel ridger. All work is performed with light-weight tractors. Manure from the cowshed is spread before planting potatoes or rye, and slurry from a sealed pit is applied to growing winter wheat in the spring using tight hoses. Crop varieties were selected from on-farm plot trials. Main items were found to be the most vigorous and competitive varieties with very good quality and acceptable yields. The straw is collected, baled, and used for bedding. Mineral P and K fertilizers are not used because of the large supply from the soils. In order to increase the income of the farm, potatoes and small grains are sold for seed. Wastes are fed to the beef cattle. Oil from sunflowers is extruded and sold, wiith the residues used as feed for fattening bulls. Some new methods are being applied to achieve best management practices: ultra-wide tyres on all farming machinery and use of the lightest tractor for a given task; mouldboard-ploughing with an on-land plough, which allows running both tyres on the unploughed land; and sowing mustard into potato fields when chaffing the potato foliage in order to cover soil, produce biomass, and create an attractive landscape for insects and humans.

Measuring methods:
The Munich Research Alliance on Agro-Ecosystems (FAM) performed research over 13 years to measure pools and to study (1) matter fluxes by farming and natural processes, (2) energy fluxes, (3) information fluxes such as spreading of knowledge and genomes, and (4) money fluxes. Land-use change and conversion to organic agriculture gives the chance to study those fluxes, which are hard to detect under equilibrium conditions. In order to get representative results the cross-sections of a 50 x 50-m grid were used as measuring points for crop yields, soil and nutrient properties, water regime, and variables characterising wildlife. Meteorological conditions, groundwater, and runoff were measured at permanent stations (AUERSWALD et al. 2000, 2001).

Results and discussion

Soil compaction:
All the different measures – setting aside wetlands, reducing headlands, using wide tyres and light-weight machinery, reducing tillage, and long phases of ley with no-tillage - helped to avoid over-compaction and to increase the pore volume and infiltration capacity (Rogasik et al. 1995). The main contribution was from using ultra-wide tyres on combine harvesters. AUERSWALD et al. (1996) found that more than 90% of the arable land deviates by less than 0.2 g cm-3 from the optimum fixed soil density.

Runoff and soil erosion:
Runoff decreased from 43 l m^{-2} yr^{-1} to about 8 l m^{-2} yr^{-1}, resulting in 35 l m^{-2} yr^{-1} more water available for plant growth or seepage. Along with sediment and runoff reduction, P-transport to water bodies

was diminished to one twentieth but remained high enough for eutrophication of water bodies. The P-concentration in runoff correlates well with P-concentration in soil water. Because the amount of P exported from the farm by harvests is only 3 kg ha^{-1} yr^{-1} it will take years before the concentration of P in the soil is reduced to an amount compatible with the demands of water conservation. The rate of water erosion was diminished from 9.1 t ha^{-1} yr^{-1} before 1992 to less than 0.05 t ha^{-1} yr^{-1}. The options of landscape design such setting aside steep land, creating field borders and dams to stop runoff, creating grassed waterways and border strips along water bodies contributed 58% to the total reduction of soil loss, whereas farming practices using almost continuous soil cover contributed about 42% (PFADENHAUER et al. 1997). Due to the reduced depth and frequency of tillage and the setting aside of the steepest slopes, tillage erosion dropped as well, which until 1992 had exceeded water erosion in some areas.

Organic matter and nitrogen:
Organic matter content in the soil has increased by 180 kg ha^{-1} yr^{-1} on average over the 10-year measuring period; therefore, soil gain by accumulation of organic matter after conversion to organic farming is higher than the soil loss by erosion. 56.5 kg ha^{-1} yr^{-1} of N is stored in the topsoil, thereby increasing the richness of the soil. Using mustard as a cover crop in potatoes helped to save about 50 kg ha^{-1} N that otherwise would have been leached. The amount of N fixed by legume-grass-mixtures was 240 kg ha^{-1} yr^{-1} (HEUWINKEL et al. 2003) leading to acceptable yields of 4.8 t ha^{-1} of wheat and 28 t ha^{-1} of potatoes, which are about 30% less than on conventional farms but much above comparable organic farms of the region. The N-concentration in the leachate at a 1.8 m depth decreased to less than 20 mg l^{-1} NO_3 at each measuring point, showing no hazard of nitrogen leaching even after ploughing of the ley crop. A reduction of nitrate in the regional groundwater ten years after conversion also can be detected (HEILMEIER et al. 2002), proving the positive effect of organic farming on groundwater quality.

Biodiversity:
The diversity of plant species on the farm scale remained nearly unchanged, whereas the number of species at the 129 measuring points on the arable fields increased from 17 to 32; on pastures from 26 to 32; on meadows from 28 to 40; and on former arable land that was set-aside from 19 to 40 (AUERSWALD et al. 2000). Endangered plant species increased at 49 and decreased at 18 of the measuring points. This increase is caused by a less efficient and more selective weed control since the land was farmed organically, compared to the former herbicide use. Six years after conversion the number of plant species in arable fields decreased (ALBRECHT 2003) because the crops grew more vigorously and had a higher leaf area index, resulting in a greater competition to weeds. Not all of the rare species respond with an increase in their habitat size due to their inefficient dispersal strategies. The diversity of all investigated animal groups increased from 1991 to 1995. The number of nesting birds and bird species increased rapidly from 1991 to 1993 (AGRICOLA et al. 1996), but remained almost constant afterwards (OSINSKI et al. 2005). Five rare bird species were attracted and are now constantly found on the farm.

Energy:
The energy input from gasoline, oil, machinery, seed and fertilizers of 453 kg ha^{-1} yr^{-1} CO_2-equivalents shows that the farm is run very intensively (KÜSTERMANN AND HÜLSBERGEN, 2005). The input for wheat is 1820 MJ t^{-1} and for potatoes 990 MJ t^{-1}, which results in a global warming potential of 210 and 100 kg CO_2 t^{-1} , respectively (WECHSELBERGER 2000). A typical output/input relation for the whole farm is 16.7. This can be regarded as high and sustainable.

Economic situation:
Economic calculations based on high-resolution yield mapping (AUERNHAMMER et al. 1994) showed that there are areas that caused a negative income in the inventory phase 1990-1992 (AUERSWALD et al. 2000), especially on steep slopes, which caused high inputs and nutrient losses, on wet soils, and on soils with a high sand content. Environmental quality and economic benefits could both be improved by taking these areas out of arable or even completely out of agricultural use (AUERSWALD et al. 2000). The new arrangement of the fields along with smaller field sizes increased the labour demand when using machinery by only 1.2 %, but for the triangles of land that can be weeded only by hand, the labour demand was reduced drastically. Economically most important for the farm are the prices for beef and potatoes and the marketable yields of potatoes. Compared to the former situation, the organic farm is economically prospering now, but is dependent on higher prices for organically grown

products and on payments from the government. In former times the entire farm, with about 150 ha, was run by two individuals who were employed by the owner. Now the organic farm employs 1.5 individuals and works together with about three farmers from the surrounding area partly using their machinery. In particular, the growing, sorting, and packing of potatoes results in a lot of work and gives a chance also to employ people in the wintertime, when work in agriculture is scarce.

The new design of the landscape was rated more attractive by comparing pictures from 1991 and those from 1999 taken from the same site (WECHSELBERGER 2000), and the number of visitors has increased. The public finds the animal husbandry with cows and calves, the diverse cropping situation with nice flowering crops like potatoes and sunflowers, and the wildlife areas to be the most attractive features.

Conclusions

Re-designing the landscape and implementing an improved concept of organic agriculture drastically improved the environmental and economic situation of the farm site studied. The improvements included: reduction of soil compaction and soil erosion, improvement of drinking water quality, and diminished risks for water bodies. Under organic management, the content of soil organic matter has increased as well as the CO_2 sequestration in the soil. Rare and sensitive species are being conserved, but dispersal to new habitats is sparse. Diversity of animal species has increased. The economic situation has stabilized due to comparably high yields and price premiums for potatoes and through payments from the government. Under current conditions the implemented land-use system can be regarded as sustainable.However, despite such positive results from the conversion to organic farming, the adoption of such management practices by farmers, remains limited in this region.

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