Eight Years of Economical and Ecological Experience with Soil-Conserving Land Use

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Abstract

Future land use has to pursue two gods, to protect natural resourses and to ensure high agricultural productivity. To demonstrate that both demands can be met with an improved farming system type the FAM research alliance started its work in 1990 on a test site in Bavaria. One main task of the research project was to show that a soil-conserving land use can improve the economic and the ecologic situation. Eight years after implementing the soil-conserving strategies, consisting of a landscape redesign, local measures to prevent erosion and specific cropping practices it is possible now to present secured economical and ecological results. On the one hand, a dUSLE prediction and long-term measurements of soil loss provide evidence that soil loss can be reduced by two orders of magnitude. On the other hand the improvement of the economic returns are demonstrated according to the economic effects of landscape redesign and new cropping practices.

Key words: Agriculture, Economy, Erosion, Soil conservation

Introduction

To combine high agricultural productivity with the protection of natural resources is a major task of future land use. Taking both into account, a representative segment of a mainly arable landscape was redesigned and principles of sustainable land use were set into practice by the FAM research alliance. To show that these principles can be used in different managing systems they were applied to organic as well as integrated farming practices.

A central aspect of protecting natural resources in the FAM project was to focus on soil as an integral component of the landscape. For this reason an extensive soil-conservation system was established. The goal of this study was to use the long-term (8 years) measurements to evaluate the effects this system on soil loss and economic returns.

Materials and Methods

The test site

The FAM test site is located about 40 km north of Munich in the „Tertiärhügelland", an important agricultural landscape in Central Europe. Typical for this area, the research site is characterized by pronounced differences in relative relief, heterogeneous soils and intensive land use. The research site covers an area of about 114 ha at an altitude ranging from 455 m to 498 m above sea level. The average annual precipitation is 825 mm, whereof 528 mm fall between May and October. Dominating soils are fine-loamy, fine-silty and coarse-silty Dystric Eutrochrepts, fine-loamy Typic Udifluvents and fine-loamy Mollic Endoaquepts (Auerswald et al., 2001).

Before FAM took over in 1990, most of the study area was managed by the Scheyern Benedictine Abby agricultural administration. At that time cultivation focused on arable farming with cash crops such as wheat, barley and oil seed rape (Auerswald et al., 2000).

Soil-conserving measures

One of the first FAM initiatives was to redesign the landscape (Figure 1). Large fields, which were prone to erosion and to non-site-specific farming, were divided following the contours. The new field borders are mostly parallel and field widths have a multiple width of the used agricultural machinery. The heterogeneity of soils within a field was reduced so that a site-specific scheduling of field operations was possible. Furthermore local measures were taken to reduce soil loss: Hedges were planted or fallow land was established on 3-15 m wide strips between field borders. In some cases small dams were built up at field borders to stop runoff in the Thalweg from upper fields to the fields downslope. Behind these dams small retention ponds, with underground-tile outlets (Weigand et al., 1995) were built. A grassed waterway was established in the Thalweg of the largest watershed of the research site (about 650 m long). Existing ditches were rebuilt and new ones were created to prevent runoff over field borders.

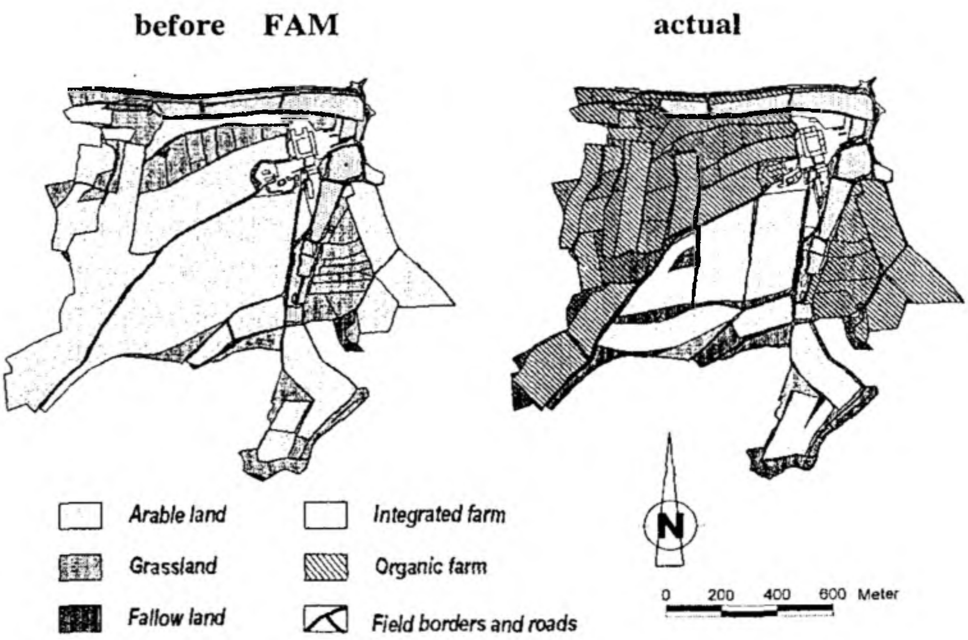

Figure 1: Map of the FAM research.

After redesigning the landscape, two management systems (Figure 1, right) were implemented to show that sustainability was possible under different management systems. One corresponded to the principles of integrated farming, the other followed the rules of organic farming. The main soil-conserving principle of both systems was to keep the soil covered with growing plants or plant residues as long as possible.

The integrated farm has an acreage of 45.6 ha, with 65% arable land, 4% grassland and 19% set aside land. The crop rotation consisted of potatoes, winter wheat with cover crops, maize and winter wheat with cover crops. This rotation allowed planting a cover crop (mustard) before each row crop. Maize was planted directly into the frozen down mustard. Potatoes were planted into dams, which were formed before sowing the cover crop and which thus could be kept covered with frozen-down mustard. Reduced tillage allowed to use the plant residues of maize and winter wheat as mulch cover and to avoid soil compaction. Only ultra-wide tires were used on all machinery to further reduce soil compaction and to avoid surface depressions, which usually support runoff.

The organic farm follows the principles of closed cycles of matter and nutrients as much as possible. It has an acreage of 68.5 ha with 46% arable land, 37% grassland and 6% set aside land. The grassland was grazed in summer. It is located mostly on steeper slopes with a high variability of soils, which are specifically vulnerable to soil erosion. Analogue to the integrated farming the crop rotation was designed to keep soil covered as long as possible. The crop rotation consisted of meadow (grass-clover-alfalfa mixture), potatoes with mustard undercropping, winter wheat with cover crop, sunflowers with undersowing a multi-species mixture for fallow use the following year, green fallow, winter wheat with clover undersowing and winter rye with undersowing of a meadow-mixture. Crop residues were used as mulch as long as tillage could be reduced due to mechanical weed control.

Prediction and measurements of soil loss / delivery

Soil loss was predicted at high spatial resolution by using the dUSLE, a combination of the USLE with a geographic information system (Arc/Info) (Flacke et al., 1990). The factors of the USLE were adapted to this landscape by Schwertmann et al. (1987). For the test site a high resolution DEM was used, which resulted from a detailed geodetic survey. The K factor map was calculated for the research site by a geostatistical interpolation of K values derived from soil analyses data of a 50 * 50 m sample grid (Sinowski, 1995). The C factors were computed from the average R factor distribution and Soil Loss Ratios adjusted to the measured development of plant and mulch cover during the year on all fields.

Runoff and sediment delivery were measured between 1993 and 2000 at 13 (sub-) watersheds, which cover about 42% of the test site. The watersheds range from 0.8 ha to 16.8 ha and small watersheds are partly integrated into larger ones. The runoff is channeled at the downslope end of the fields and is led over a Coshocton-type sampling wheel. This device sampled a constant aliquot of about 1% of the total runoff, which is used to calculate runoff volume and to determine sediment concentration. In the following the sediment load measured in this way is called soil delivery. The term soil loss is used for the measured soil delivery plus the amount of sediment, which was trapped in the ponds and the grassed waterway.

The effectiveness of the retention ponds was evaluated by comparing the amount of the trapped sediments to those in the outflow (Weigand et al., 1995). The effectiveness of the grassed waterway was calculated by comparing neighboring watersheds with and without a grassed waterway.

Evaluation of economic effects

The economic effects of converting arable land into grassland or set aside land were evaluated according to site-specific data of gross margins during the inventory phase and experiences of periodical crop failures in some areas. To demonstrate the effects of reduced field sizes and the improved field layouts, a calculation of working and machinery costs by Wechselberger (2000) was used. The new cropping practices were exemplarily compared to the former for the integrated farm by calculating gross margins for the years before (1990/91 and 1991/92) and after landuse change (1992/93 and 1995/96) (Wechselberger, 2000).

Results and discussion

Effects of land-use change on soil loss / delivery

The dUSLE predicted a reduction of soil loss by about one order of magnitude. Average erosion rates dropped from more than 16 $t \cdot ha^{-1} \cdot a^{-1}$ to 1.7 $t \cdot ha^{-1} \cdot a^{-1}$ for the integrated farm and from 5.1 $t \cdot ha^{-1} \cdot a^{-1}$ to 1.5 $t \cdot ha^{-1} \cdot a^{-1}$ for the organic farm.

Before changing the land use more than 50% of the integrated farm exhibited an erosion rate of 25 $t \cdot ha^{-1} \cdot a^{-1}$ and above, resulting mainly from slopes with highly erodible silt loams, which were part of a single field of 25.4 ha. These values, that exceeded the local soil formation rate of about 1 $t \cdot ha^{-1} \cdot a^{-1}$ (Auerswald et al., 2000) were lowered drastically by dividing fields, setting extremely erodible areas out of arable use and changing cropping practices. A similar situation was found for the organic farm, even though the absolute erosion rates were notably lower than those of the integrated farm. The highest rates of 11 $t \cdot ha^{-1} \cdot a^{-1}$ on steep slopes were drastically reduced by changing arable land into grassland.

The long-term measurements allow us not only to predict soil loss but also to quantify it from measurements. After three years of measurement, the 95% confidence interval allows to estimate average soil delivery within a range of more than three orders of magnitude and after 7 years this range narrows to less than one order of magnitude (example in Fig. 2). After 7 years of measurement the true average soil delivery of the watershed shown in Fig. 3 can be expected between 80 $kg \cdot ha^{-1} \cdot a^{-1}$ and 510 $kg \cdot ha^{-1} \cdot a^{-1}$ for a measured mean value of 200 $kg \cdot ha^{-1} \cdot a^{-1}$.

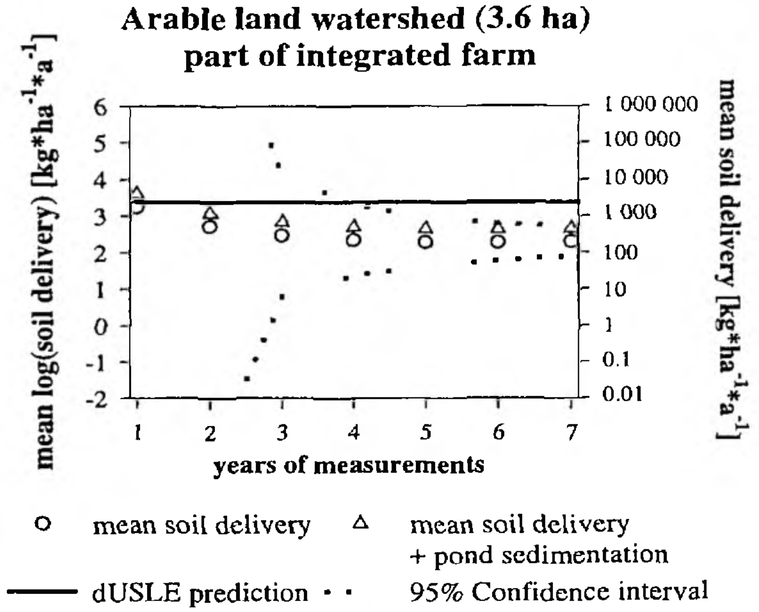

Figure 2: Mean annual soil delivery and soil delivery plus sedimentation in a retention pond.

In all 13 watersheds the sediment delivery was lower than the soil loss predicted by the dUSLE. One main reason for that was the sediment trapping effect of the retention ponds and the grassed waterway. These landscape elements are not accounted for by the dUSLE because they only reduce delivery but not soil erosion itself. Taking into account the specific effect of the grassed waterway and the ponds (Figure 2) reduced the discrepancy between measurements and prediction. But still in 66% of the watersheds of the integrated farm and in all watersheds of the organic farm the predictions were above the 95% confidence interval for the measured soil losses. Comparing the predicted with the measured average soil loss (2.6 $t \cdot ha^{-1} \cdot a^{-1}$ and 2.0 $t \cdot ha^{-1} \cdot a^{-1}$ respectively) of the watersheds of the integrated farm, the predictions were fairly close to the measured values. However, when comparing these values for the watersheds of the organic farm (0.78 $t \cdot ha^{-1} \cdot a^{-1}$ predicted, 0.09 $t \cdot ha^{-1} \cdot a^{-1}$measured) a difference of nearly one order of magnitude was observed. Two main reasons may be responsible for this, which cannot be fully evaluated with the existing data set. The first might be an erroneous prediction associated with an incorrect adaption of the USLE-factors to the organic land use. The second might be related to the fact that organic farming combined with soil-conserving strategies was more effective in stabilizing soil than was actually expected from short-term (one to three years) field experiments, where a complete system change (e.g. recovery from subsoil compaction) was never observed.

Assuming that the soil loss prediction for the conventional farming before FAM represents the true erosion rates in the same manner as the prediction of the actual integrated farming, a comparison of soil loss before FAM with measured soil delivery is possible. For both management systems this comparison shows a reduction of soil delivery by about two orders of magnitude.

Economic effects of land-use change

Effects of landscape redesign: The intention was also to increase economic returns. For this reason unfavorable arable land with gross margins similar to or lower than grassland was taken out of arable use. This can especially be expected at steep slopes, which are difficult and costly to cultivate and provide low yields due to poor soils. For example, one slope that was transferred to grassland had previously caused a net loss of income of 130 €/ha and was subject to enormous tillage and water erosion due to a mean slope of 22% (Schimmack et al., 2001). Similar positive economic effects were obtained for almost all areas where former agricultural use caused environmental problems due to poor sandy soils, wet soils, soils in Thalwegs with frequent ephemeral gullying. The reduction of arable land by 14% in integrated farming and by 28% in organic farming did thus remove "environmental hot-spots" without reducing income.

The second result of landscape redesign were smaller fields (Figure 1). Wechselberger (2000) calculated that the smaller field sizes increased working and machinery cost only by 10.7 €/ha and 6.6 €/ha for integrated and organic farming respectively because of the improved field layout. Moreover

Table 1: Gross margins calculated for the situation before FAM and the actual situation on the bases of crop prizes inclusive subsidies (Wechselberger, 2000).

	before FAM	**actual**
crop rotation:	small grain (represented by winter wheat)	winter wheat, maize, winter wheat and potatoes
winter wheat	conventional	less tillage, no P + K fertilizer
gross margin	596 €/ha	673 €/ha
winter wheat vs. maize		
gross margin	596 €/ha	813 €/ha
winter wheat	conventional	less tillage, no P + K fertilizer
gross margin	596 €/ha	673 €/ha
winter wheat vs. potatoes		
gross margin	596 €/ha	2133 €/ha
gross margin per year in a four year rotation		
	596 €/ha	1073 €/ha

the landscape redesign improved the homogeneity within each field. For example, the mean difference in median grain diameter within single fields was reduced from 0.19 mm to 0.06 mm for the integrated farm and from 0.67 mm to 0.28 mm for the organic farm. Therefore the fields can be used more site-specifically and higher yields can be expected.

Effects of cropping practices: The improved economic situation due to the changed cropping practices is demonstrated exemplarily for the integrated farm (Table 1). Under the assumption that before FAM the most profitable cash crop was wheat, the gross margin of wheat before FAM was compared with the gross margins of the present crop rotation. The new rotation is only possible with the soil conserving cropping practices because the row crops were introduced. It improved the gross margin of the integrated farm by about 470 €/ha.

Conclusions

Implementing soil-conserving strategies reduced soil loss and improved economic returns effective. The avarage soil loss decreased from 10 $t \cdot ha^{-1} \cdot a^{-1}$ to 1.5 $t \cdot ha^{-1} \cdot a^{-1}$. The local measures to prevent erosion reduced soil delivery of single fields by two orders of magnitude. Removing fields with pronounced environmental problems from arable use improved the economical and the ecological situation of the FAM research area. Optimizing the field layout compensated for economic losses due to reduced field sizes. The soil-conserving cropping practices and an improved crop rotation also increased gross margins. In synthesis, eight years of experience in applying the principles of landscape design and alternative farming practices developed by FAM, have proven a definite success in improving the economical situation and reducing soil loss.

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