Agricultural Impacts on Soil Erosion and Soil Biodiversity:
Developing Indicators for Policy Analysis

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# Agricultural Impacts on Soil Erosion and Soil Biodiversity: Developing Indicators for Policy Analysis

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# CURRENT APPROACHES AND METHODS TO MEASURE, MONITOR AND MODEL AGRICULTURAL SOIL EROSION IN SWITZERLAND

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### *Abstract*

Since 1993 several legal regulations regarding soil and water conservation have been introduced in Switzerland. Among other things threshold values for soil loss of 2 t/ha and year and 4 t/ha and year respectively have been introduced. Regarding their potential to reduce soil losses, these measures are evaluated in a test region. For that purpose two different methods are used simultaneously: On the one hand model calculations on the basis of an adapted USLE, on the other hand mapping of erosion damages in the field. Model calculations showed that the mean C-factor of all fields diminished from 1989 to 1998 by 29%, mainly due to changed crop rotations and the introduction of conservation tillage systems. According to the mapping of erosion damages the field mean soil losses during the period 1998-2001 decreased by 6% compared to the period 1987-1989; this comparison was strongly influenced by the weather conditions. Mean soil losses estimated by mapping of erosion damages in the field were 0.7 t/ha and year. Dominating effects were linear erosion and erosion during the winter half-year. Mapping of erosion damages in the field will be continued, because only repeated estimations allow for reliable results.

## Erosion in Switzerland



### *State of erosion research in Switzerland*

In Switzerland research on soil erosion by water on arable land started in the beginning of the seventies, mostly done by universities within the scope of basic and process research in test plots, sprinkling experiments, etc. A small soil erosion research group was established at the Geographical Institute of the University of Basle, which published up to now a series of scientific papers (mostly dissertations) related to soil erosion with grants of the Swiss National Science Foundation (*e.g.* Prasuhn and Schaub 1991, Prasuhn 1992, Schaub and Prasuhn 1993, Rüttimann *et al.* 1995, Leser *et al.* 2002). Schaub and Prasuhn (1998) established a simplified map of the risk of soil erosion by water on arable land in Switzerland in order to get a general idea at national level.

During the Swiss National Research Programme "Soil use in Switzerland" 1987-1990 a comprehensive assessment of the state of soil erosion damages and risks on Swiss arable fields was done for the first time. This comprised the measurement of soil losses in the field, mapping of erosion damages in the field, interviews with farmers and modelling of erosion (Mosimann *et al.* 1990, 1991). Although the results of this study were not spectacular, soil erosion became for the first time an issue for the general public in Switzerland and was covered extensively by media.

Afterwards the results of these studies slipped into national legislation (*e.g.* Ordinance on Soil Protection, Ordinance on Direct Payments) and into agricultural advisory services. For example Mosimann and Rüttimann (1995 and 1999) developed a key to the assessment of the erosion risk, which – based on a simplified USLE – allowed farmers and advisors a simple assessment of the erosion risk on single arable fields. In the course of a re-orientation of the Swiss agricultural policy 1993 direct payments were introduced to compensate for ecological achievements of farmers.

**Keywords**: Soil erosion, soil loss, USLE, modelling, mapping of erosion damage, off-site effects

These ecologically motivated subsidies were based on the fulfillment of ecological requirements by the farmers and call among other things for a regular crop rotation and adapted measures for soil protection. In order to evaluate the efficiency of these ecologically motivated direct payments investigations related to soil erosion are done, too (Prasuhn and Grünig 2001). Based on the above mentioned work, mapping of erosion damages, interviews with farmers and modelling of erosion is done in a test-region which has been investigated in 1987-1990 yet. The methodology and first results of these study will be presented in this paper.

Although in Switzerland natural erosion processes (geological erosion, mass movement, bank erosion, etc.) are clearly dominating, especially in the Alps, the following remarks will concentrate on soil erosion in arable fields caused by agricultural soil use. The main factors determining the risk of erosion, in particular slope steepness and length, erodibility of soils and erosivity of precipitations, are changing often in small scales. Because soil erosion by wind is a minor problem in Switzerland, all of the following statements are related to soil erosion by water and concentrate on rill and interrill erosion. There are no results available concerning effects of tillage erosion.

At the moment there is neither a national monitoring network nor a national database on soil erosion available in Switzerland. Presently soil monitoring in Switzerland is confined to pollutants.

A national soil database is in initial stages. A soil map covering the whole aerea of Switzerland is only available at a 1:200.000 scale.

Up to now no estimation of the costs of erosion damages on arable land is available for Switzerland. Investigations into offsite damages of soil erosion are mostly assessing the pollution of rivers and lakes by transported phosphorous (Prasuhn and Grünig 2000). Within the scope of a national set of agri-environmental indicators two indicators related to soil erosion are developed (soil erosion“ and soil cover“).



## *Legal basis in Switzerland*

Since 1993 there are several legal regulations in Switzerland dealing with the protection of soil, rivers and lakes, hopefully leading to a reduction of soil erosion. The most important laws are listed in the following.

- In the Law on Agriculture (German abbreviation: LwG) the so called ecological subsidies are described (LwG, Art. 76): “With ecological subsidies the Federation encourages natural agricultural production forms, which are respecting the environmental and animal welfare, as well as their expansion.” The supported agricultural practices are described in the Ordinance on Direct Payments. For example a regulated crop rotation is prescribed (Art. 8): “The share of crops and the crop rotation have to be chosen in a way to avoid erosion, soil compaction and soil decline as well as leaching and losses of fertilizers and pesticides due to surface runoff as much as possible.” In Art. 9 soil protection is regulated: “The avoidance of erosion and of chemical soil pollution is an integral part of soil protection. Soil protection is promoted by an optimal soil coverage, measures against thalweg erosion and by using soil friendly fertilizers and pesticides.” These measures are specified in the technical annex of this Ordinance: “Farms with more than 3 ha arable land must have on its arable acreage an average area-weighed soil protection index of at least 50 points for arable crops and 30 points for vegetables respectively.” The calculation of this soil protection index is explained in detail in the technical annex. Moreover is valid: “No noticeable soil losses are allowed on areas where suitable measures to control erosion are missing. Suitable measures are considered to be in particular grass strips at least 3 m wide along ways on inclined arable fields or surface measures to drain off or to pass by water in order to avoid thalweg erosion.”

- In the Law on the Protection of Rivers and Lakes there is an article concerning soil management, as well (Art. 27): “Soils have to be managed according to the state of art in agricultural techniques, in order to avoid adverse effects on rivers and lakes, in particular by losses due to surface runoff and leaching of fertilizers and pesticides.”

- In the Law on the Protection of the Environment measures against soil pollution are regulated in Art. 33: “The soil may be physically affected only to the extent that its fertility is not permanently degraded; such shall not apply to building areas. The Federal Council may issue regulations or recommendations on measures against physical impacts on the soil such as erosion or compaction.” The “Ordinance relating to impacts on the soil” (German abbreviation: VBBo) specifies measures against soil compaction and erosion in Art. 6: “A person who constructs an installation or who exploits the soil shall choose and utilise vehicles, machines and tools such that compaction and other changes in soil structure which may threaten its long-term fertility can be prevented, taking into account the physical characteristics of the soil and its level of humidity. A person who intends to carry out modifications of the terrain or exploits the soil shall ensure that appropriate kinds of building and exploitation are used, in particular through anti-erosion building or cultivation techniques, rotation and adaptation of crop cultivation, so that the fertility of the soil is not threatened in the long term by erosion. If protection of the soil against erosion so requires, the cantons shall order measures to be taken jointly by several enterprises, particularly in the case of erosion caused by concentrated runoff (thalweg erosion).” In the annex to this ordinance the following guide values for soil erosion on arable land are formulated:



Table 1. Guide values for erosion on arable land according to VBBo

| Depth through which roots can penetrate | Total mean erosion1 (in tonnes dm perhectare and year) |
|---|---|
| Up to 70 cm | 2 |
| More than 70 cm | 4 |

dm = dry matter;

1 total mean erosion = sum of soil losses by sheet and linear erosion

These guide values were not only defined regarding onsite effects (soil loss), but also relating to potential offsite effects (ecological side effects).

## Methods and results of a case study

### *Methods*

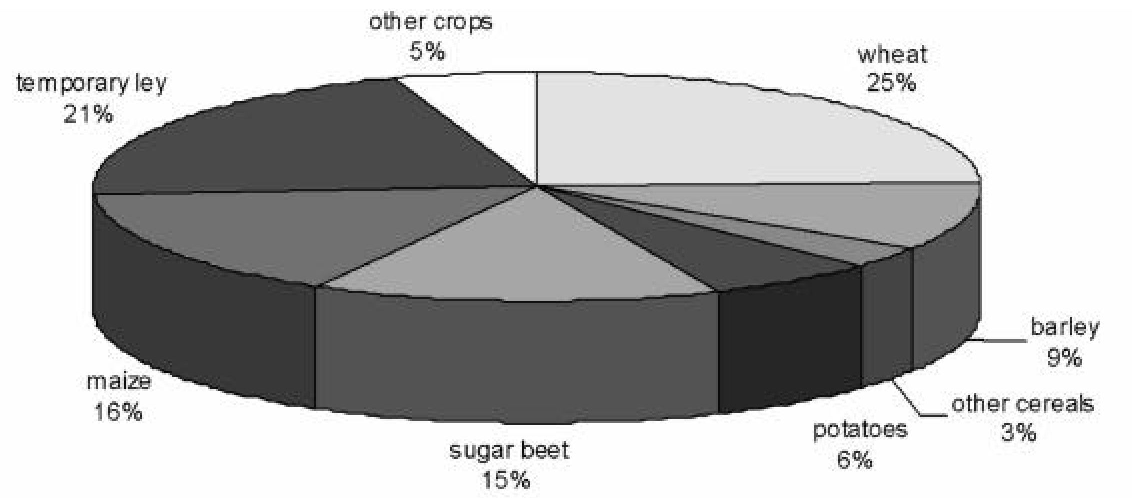
The area of investigations is situated in the central Bernese lowlands, one of the main agricultural regions of Switzerland. A survey of the main characteristics of this region is given in table 2. Compared to international standards farm and field sizes are small, although typical for Swiss circumstances. Annual rainfall and erosivity of precipitations are relatively high; erodibility of soils may be rated as moderate. The slope steepness of the arable fields are relatively high, the length of the slopes rather small, however, because of the normally small field size. The relief in the area changes in small scales, thereby giving rise to frequent slope depressions even in arable fields. The high share of temporary leys (21%) in arable crop rotations is striking, but typical for Swiss arable farming (fig. 1).

The methodological approach of this study is based on two totally different and independent procedures in the same investigated area (fig. 2). On the one hand the mean long-term risk of soil erosion is assessed by model calculations, on the other hand actual soil losses are regularly estimated by mapping erosion damages in the field (Prasuhn and Grünig 2001).

Table 2. Characterisation of the investigated area

| | |
|---|---|
| Altitude | 475 - 720 m above sea level |
| Total size | 360 ha |
| Size of arable area | 270 ha |
| Number of arable fields | 210 |
| Mean size of fields | 1.3 ha |
| Number of farms | 52 |
| Mean size of farms | 16.7 ha |
| Mean annual precipitations | 1035 - 1150 mm |
| Erosivity (R-factor) | 80 - 90 N/h |
| Soil types (arable fields) | cambisols, luvisols |
| Soil textures | sandy loams |
| Mean erodibility (K-factor) | 0.033 kg h / N m2 |
| Range of erodibilities | 0.017 - 0.042 |
| Mean slope steepness (arable fields) | 6.5 % |
| Range of slope steepness | 1 - 25% |
| Mean slope length (arable fields) | 68 m |
| Range of slope lengths | 5 - 210 m |

Figure 1. Shares of different crops in the investigated area in 1998



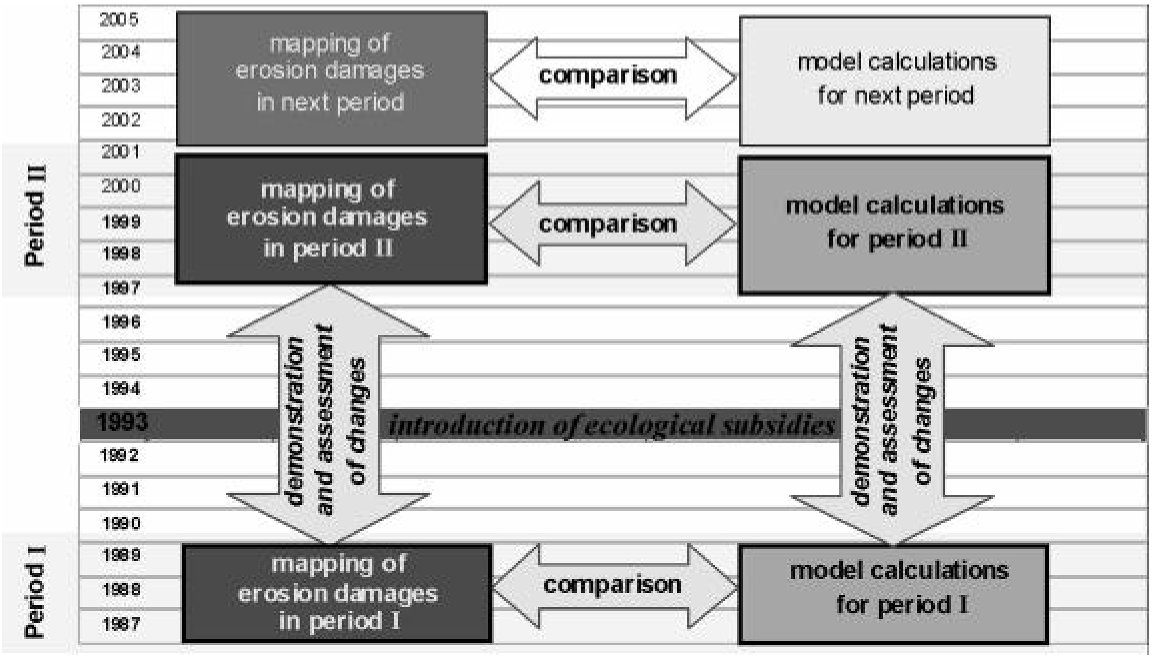



### *Model calculations*

The basis of these calculations is the worldwide probably most widespread erosion model, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). An adaptation of the USLE to Bavarian conditions is the “Allgemeine Bodenabtragsgleichung (ABAG)” (Schwertmann *et al.* 1990); this ABAG was empirically adapted to Swiss conditions in a second step.

Based on field investigations and interviews with farmers, for every field of the survey the USLE-factors (R, K, LS, C and P) were calculated for the years 1988 and 1998 in order to determine possible changes. Of particular interest was the detailed assessment of the C-factor, *i.e.* the soil cover and management factor, because this factor should reflect changes in agricultural practices above all. Interviews with farmers delivered for every field the necessary information to assess crop rotation and soil tillage system (like “ploughing combined with pto-driven tools for seedbed preparation”, “ploughing combined with drawn tools for seedbed preparation”, “ploughless tillage systems with less than 30% mulch cover”, “conservation tillage systems with more than 30% mulch cover”, “zone tillage” or “direct drill”). By using region-specific development stages for crops, the region-specific annual distribution of erosive precipitations and the relative soil loss of every crop combined with every soil tillage system the C-factors were calculated and compared.

Figure 2. Methodological concept of the study




### *Mapping of erosion damages*

Based on a mapping guide of Rohr *et al*. (1990) and DVWK (1996), after every erosive precipitation or snow melting event the erosion damages were mapped in the 210 arable fields; this way about 10 to 20 mappings were done per year. For every erosion rill its length, mean width and mean depth are surveyed and the volume of soil loss determined. In case of interrill erosion the percentage of damaged area per field was assessed and quantified by using results for soil losses from field measurements. Additional information concerning *i.e.* off-site damages, water inflow and wheel tracks was also registered and stored in a data base. Precipitation data of a nearby official weather station was used. The results of the mapping and modelling of erosion damages during the period 1987-1989 were compared to the current findings since 1997, considering the climatic differences.



## *Results*

### *Model calculations*

For R- and K-factors identical values for both of the compared periods have been used, because these factors were assumed to be relatively constant, at least during the time interval of 10 years. The values for the LS- and P-factors hardly changed as well, because sizes and orientations of fields stayed more or less the same. However, the mean value for the C-factor of all fields in 1998 (0.095) was 29% lower than in 1988 (0.133).

Reasons for changes can be found in the crop rotations and the soil tillage systems. Whereas the area of the main crops hardly changed, the share of bare soil during winter was reduced from 22% to 5%; at the same time the percentage of cover crops increased from 11% to 25% (fig. 3). Moreover 5% of arable land have been set aside. While 95% of the acreage was ploughed in 1988, soil tillage systems were more diversified in 1998: 3% direct drill, 4 % zone tillage, 7% mulch seed with more than 30% mulch cover and 19% conservation tillage systems with less than 30% mulch cover (fig. 4).

Figure 3. Soil cover during winter in the test region in 1988 and in 1998

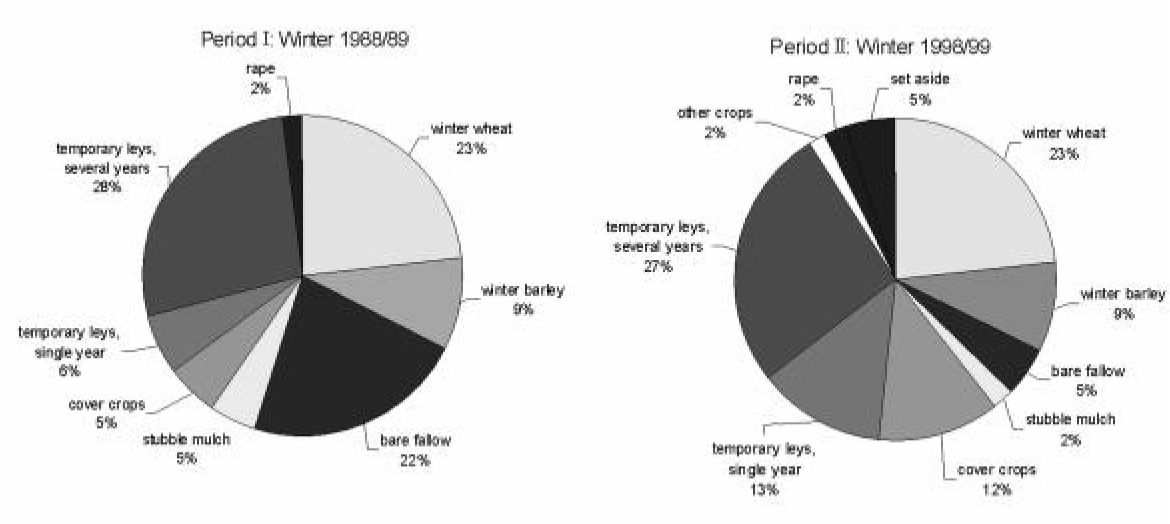
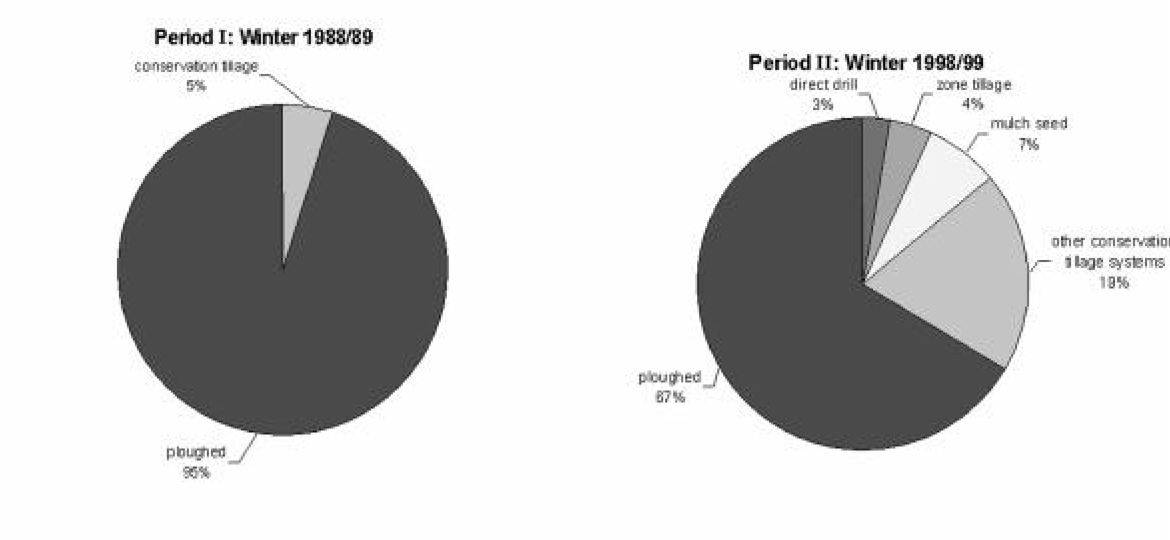



Figure 4. Soil tillage systems in the test region in 1988 and in 1998






Because the values for the rest of the USLE-factors hardly changed or didn’t change at all, the reduction of the values for the C-factor was reflected in the calculated amount of soil loss. Consequently the risk of soil erosion was reduced by 27% from 1988 to 1998.

### *Mapping of erosion damages*

During the period between winter 1997/98 and summer 2001 a total of 770 erosion damages was assessed and analysed. The results so far show that around 20% of the arable land was affected by soil erosion every year. Mean soil loss of all fields during this period was well below 1 t/ha and year (0.67 t/ha and year), with erosion damages in single fields and years totalling even more than 20 t/ha and year. The photographs in figures 5 to 8 are showing typical situations of erosion damages in Switzerland. Fig. 9 shows a detail of an erosion damage map of the test region. While there were significant erosion damages in single fields, especially in winter wheat, other fields (especially with temporary ley, cover crops) were spared of erosion entirely.

Figure 5.
Linear erosion in a winter wheat field in spring (March 1999)

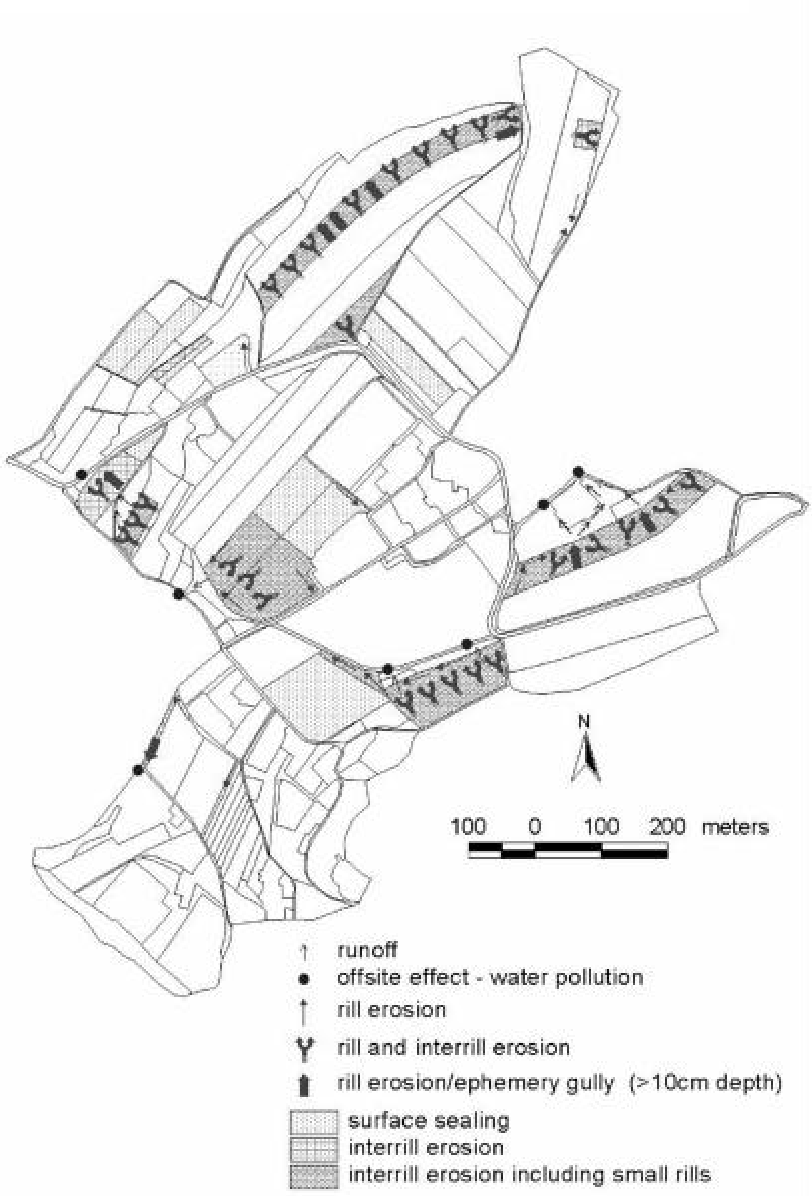
Figure 6.
Erosion and accumulation in autumn (October 1998)



Figure 7.
Network of erosion rills in a winter wheat field (March 1999)

Figure 8.
Sheet and linear erosion in a newly tilled winter wheat field (October 1998)

Figure 9. Detail of an erosion damage map (winter 1998/99)




The share of rill erosion amounts to around two thirds, the share of interrill erosion around one third. Over two thirds of the soil losses arised during the winter half-year (especially during October/November in winter wheat), one third during the summer half-year (mostly in maize, potatoes, sugar beet). The variability of soil losses due to weather is very high, as is shown in fig. 10. Soil losses during the winter half-year 1998/99 were considerably above average due to extremely unfavourable weather conditions in late autumn.

The results of the mapping of soil erosion damages (fig. 11) confirm the protective effects against soil erosion, which have been attributed to soil conservation tillage systems in the model calculations. While there hardly could be noticed any erosion in fields with direct drill and tillage systems with mulch cover, soil losses in ploughed fields occurred most frequently and intensively.

Figure 10. Mapped soil losses during 8 half-years in the test region

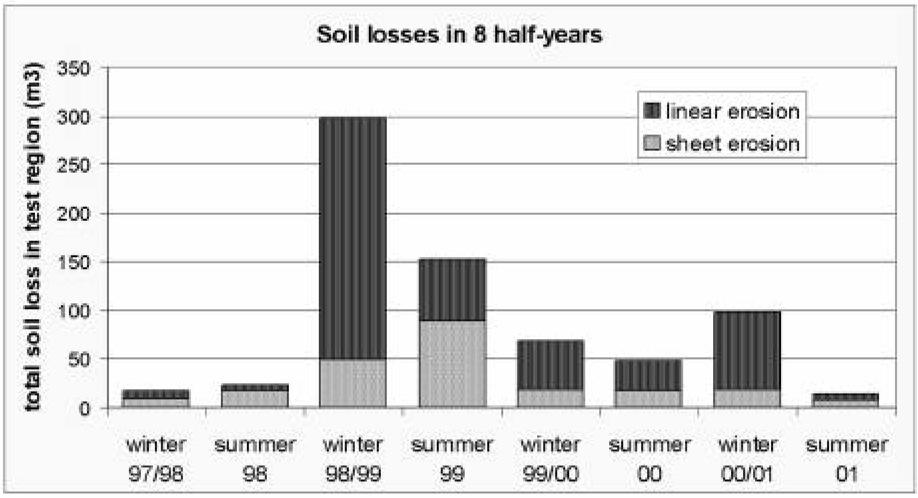



Figure 11. Mapped soil losses dependent on soil tillage system in 1998-2001

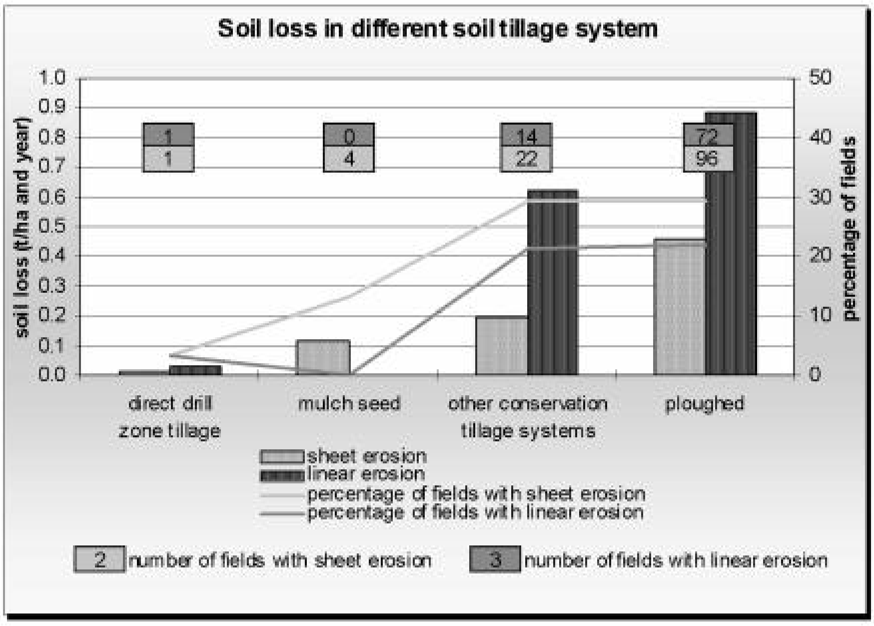





Table 3. Comparison of some results of the mappings 1987-1989 and 1998-2001

| | **1987-1989 Æ 3 years** | **1998-2001 Æ 4 years** |
|---|---|---|
| number of arable fields | 259 | 210 |
| mean field size (ha) | 1.06 | 1.30 |
| number of mapped erosion forms | 108 | 192 |
| number of affected fields | 85 | 147 |
| area with erosion damage (% of total arable area) | 16 | 17 |
| total soil loss on arable fields ($m^3$) | 196 | 180 |
| mean soil loss (t/ha of total arable area) | 0.71 | 0.67 |
| share of linear erosion (%) | 67 | 68 |
| share of sheet erosion (%) | 33 | 32 |
| share summer half-year / summer crops (%) | 65 | 33 |
| share of winter half-year / winter crops (%) | 35 | 67 |
| share of soil loss transported in rivers and lakes (%) | 10-20 | 18 |

According to the mapping on average 20% of the eroded soil material is transported into a river or a lake.

A first comparison of the results of the mappings 1998-2001 and 1987-1989 shows that mean soil loss slightly decreased from 0.71 to 0.67 t/ha and year, corresponding to a reduction of 6%. Whereas the relation between linear and sheet erosion remained constant, the share of soil loss during summer to soil loss during winter was reversed. However, this comparison must be interpreted carefully, because weather conditions during these two periods differed; only long-term investigations will give reliable results.

## *Discussion*

A two step procedure was chosen because both model calculations and mapping of damages have their strengths and weaknesses, and only a combination of both methods makes a comprehensive assessment of soil erosion in Switzerland possible. The used model, an adapted USLE, is especially suited to assess sheet as well as rill and interrill erosion, whereas linear erosion forms like ephemery gully erosion, exfiltrating subsurface flow erosion or erosion caused by water inflow from roads cannot be assessed. However, these linear erosion forms are of great importance in Switzerland. An advantage of the model is that it allows for the calculation of mean long-term soil losses; this way short-term changes in weather conditions do not influence the results. The C-factor makes it possible to assess the influence of agricultural practices on erosion risk and to show trends. This is an important feature for the evaluation of ecologic measures. Drawbacks of the model are that it is not fully validated for Swiss conditions and that it clearly overestimates real soil losses (Nearing 1998, Prasuhn 1991), because soil losses in Switzerland are relatively small and the extremely sensitive LS-factor is often overestimated due to the high slope steepness.



The mapping of erosion damages allows for a relatively reliable assessment of linear erosion, whereas sheet erosion can only be estimated. A big advantage of the mapping is the possibility to analyse causes directly in the field, to assess special cases (inflow from roads, exfiltrating subsurface flows, furrows, small slope depressions, etc.) and to identify offsite damages. A big problem of this method is its strong dependence on weather conditions. Therefore long-term investigations over 10 and more years are necessary in order to make reliable assessments of long-term soil losses which can be compared to the results of model calculations. Therefore the mapping requires a comparatively great deal of time. An experienced mapper surveys the 270 ha arable region after small erosion events in one day, after big events in two days. Thus the 10 to 20 mappings per year require about 10 to 20 working days. The interviews of farmers and the field surveys for model calculations require ca. 20 working days, though not in every year, but only every 4 to 5 years.

The following conclusions for Swiss conditions can be drawn from the mapping of erosion damages, which can be helpful for the development of protective measures against erosion:

- Linear erosion is of greater importance than sheet erosion. Protective measures against erosion like a regulated crop rotation or conservation tillage are relatively established in the surveyed area and work against sheet erosion, whereas the high energy of the soil relief and numerous slope depressions promotes concentrated surface flow and therefore linear erosion. Apart from conservation tillage specific measures are required (*e.g*. grassed waterways) for the prevention of this threat.

- Erosion during the winter half-year is at least as important than erosion during the summer half-year. Conservation tillage is used above all for summer crops (maize, sugar beet), whereas for winter wheat no efficient tillage system exists. In late autumn, long lasting precipitations on already water saturated soil lead to concentrated surface flow in slope depressions.

## Conclusions

With mean soil losses of less than 1 t/ha and year soil erosion on arable fields in Switzerland is generally a less serious problem compared to other countries. However, with regard to sustainable land use including the avoidance of nonpoint-source pollution effects, these rates are still considered too high; consequently it is important to pursue resolutely the implementation of measures to reduce the risk of soil erosion. In Switzerland only 409.000 ha or 10% of the total area or 38% of the agriculturally used area (without alpine areas used for summer pasture) are used as arable land. Natural erosion in unproductive areas of the Alps and bank erosion for example are the causes for a great share of the sediment yield of rivers. Given the site characteristics there is also a rather high disposition for soil erosion in arable areas of Switzerland: Precipitations are high and the relief shows a lot of slopes with convex and concave elements. However, soils are only moderately susceptible to erosion. Soil use and cultivation practices of arable areas are generally well adapted to the given site characteristics. The size of the arable fields is for example relatively small with a mean area of 1 to 2 ha, and the crop rotations are rather well-balanced; monocultures are practically non-existent. In particular the incorporation of temporary leys with durations of several years in the crop rotation has positive effects; accordingly the C-factors are comparatively low.

Since 1993 several legal bases have been introduced which allow for an efficient soil protection. Therefore there exist guide values for soil erosion of 2 t/ha and 4 t/ha and year respectively in Switzerland. The execution of these legal bases yields the first positive consequences by decreasing soil losses which can be shown by model calculations and by mapping of erosion damages. The mean soil loss of all fields in the surveyed region is clearly below these guide values, although exceeding it in single fields. The investigation has to be continued in order to get reliable long-term results. Therefore it is planned to do more interviews with farmers and more model calculations in 2004, and the mapping of erosion damage shall be continued as sort of a monitoring until at least 2007.



The results of this study are also used to assess off-site damages of soil erosion, especially in river and lake pollution by phosphorous (Prasuhn and Grünig 2001). They form also a basis for an estimation of phosphorous and nitrogen losses by diffuse sources into rivers and lakes of different catchment areas in Switzerland, which is done by the MODIFFUS model (Schmidt and Prasuhn 2000, Prasuhn and Mohni 2003).

Finally there is the question whether the results of this study can be extrapolated on the total arable area of Switzerland. The test region is relatively small and certainly doesn't represent the whole spectrum of site characteristics, soil uses and cultivation techniques of arable agriculture in Switzerland. Therefore the extension of this kind of investigation to other regions in Switzerland is actually under consideration. In a first step the erosion risk map of Switzerland should be updated in order to improve the general idea and to choose future test regions. In a second step model calculations and mapping of erosion damage will be carried out in these test regions. Only by the combination of both these methods it is possible to assess erosion in Switzerland adequately. This could be done within the scope of a concept for agri-environmental indicators, which shall be adopted in Switzerland.

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