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Working Group on Soil Erosion

Task Group 7

Monitoring Soil Erosion in Europe

Final Report

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

- Monitoring soil erosion should be based on an **indicator based approach**.

- The **area at risk of soil erosion** is proposed as an indicator of **state** of soil erosion. The indicator should be derived from:
  1. An assessment of soil erosion risk derived from an appropriate tool (e.g. an erosion model);
  2. Measurements of actual soil erosion rates (t/ha/y) at a limited number of sites.

- A risk assessment tool/model is needed for the following reasons:
  1. Selection of measurement sites (plots and catchments): selected sites should have a moderate to high erosion risk and be representative for an agro-ecological zone;
  2. Interpolation of results from local measurements to larger areas: to assess the state of soil erosion in areas where no measurements have been done while accounting for local conditions of the factors affecting soil erosion;
  3. Scenario analysis: to predict soil erosion under different land uses and/or climate change.

- At a European level, the use of a unique methodology is recommended in order to get comparable results. The use of national or regional assessments may be useful to verify the result of a European model (and vice versa).

- In order to produce reasonable results, modelling requires:
  1. Input data;
  2. Calibration and validation.

- The **input data** for a soil erosion model consists of static and dynamic data.
  - Static data are to be determined at the start of the monitoring process (no further monitoring is required), and consist of:
    - Soil data;
    - Topographical data.

    The accuracy requirements of these data depend on the type of model and the scale of the modelling (European or national/regional). More details are given in the report.
  - Dynamic data requiring specific monitoring:
    - Land use and land management data;
    - Climatic data.

    The accuracy of these input data will largely determine the quality of the resulting indicator, e.g. its ability to show the effects of local management interventions resulting from policy measures (action driven monitoring). Different data collection methods are discussed in the report. The recommended time interval for the measurement of land use data is once in ten years. For climatic data, long term averages are necessary.

- Calibration and validation requires **measurements of actual soil erosion rates (monitoring sensu stricto)**. We recommend that first use should be made of existing sites and only in cases where existing data are not sufficient should additional sites be selected.

- Measurement should be carried out at the plot scale and at the catchment scale (nested approach). At the catchment scale a combination of methods can be used, as discussed in the report:
  - Mapping visible erosion features;
  - Continuous measurements of sediment transport at the outlet of small catchments;

- Measurements of sediment deposition in ponds and lakes.

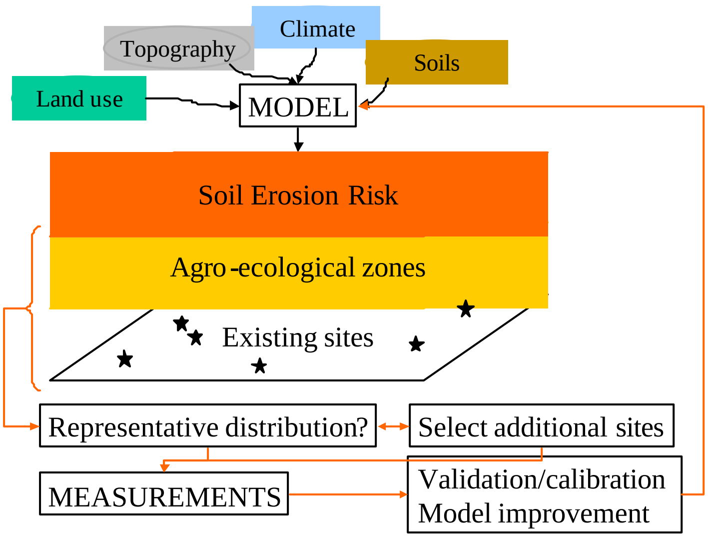
As soil erosion is highly variable in time and space, soil loss measurements should be continuous. From these long term measurements, averages can be determined, e.g. over a period of 10 years.

- **Actions to be taken** to set up a European soil monitoring system are:

1. Use existing measurement data on soil erosion and apply existing risk assessments tools (models) using the best available input data to identify areas at high or moderate risk of soil erosion. These data should provide the **baseline (t_0);**
2. Make an inventory of existing measurement sites;
3. Check whether existing sites are representative with respect to soil erosion risk and within agro-ecological zones;
4. Select additional sites if necessary;
5. Start collecting new data at all sites (e.g. over a period of 10 years);
6. Validate and calibrate the model using the collected data;
7. Improve model concepts;
8. Produce new model output: these data should provide the first trend in soil erosion **(t_1-t_0)** with respect to the baseline (e.g. t_1-t_0 = 10 y);
9. Select additional sites if necessary.
10. …

The process should be seen as an iterative one, which can be visualised as follows:

Practical methodology using modelling and measuring: an iterative process



- In areas susceptible to salinisation and sodication, monitoring of the following parameters is recommended:
  - Electrical conductivity as an indicator of salinisation; and
  - Sodium Adsorption Ratio (SAR) as an indicator of sodication.

- Monitoring on site impacts of soil erosion and salinisation/sodication requires the monitoring of soil quality indicators. A list of potential parameters is given in Table 1. However, these parameters and data are less relevant at a small, e.g. European, scale but are more relevant at large, e.g. regional or local, scales.

Introduction

In this report, emphasis is put on monitoring the state and trends of soil erosion in Europe. However, the proposed methods also allow for monitoring pressures (through land use) and impacts. Provided that measurements are carried out at a sufficiently large scale, the effects of specific land use and management practices, i.e. the responses, can also be monitored (i.e. action driven monitoring).

1. Overall approach

Monitoring trends of soil erosion by measuring actual soil loss requires a relatively high input of financial and human resources compared to soil physical, chemical or biological properties, because soil erosion events are highly variable in space and time. Peaks of soil erosion events differ from place to place and from year to year. Therefore, the monitoring of soil erosion in the field requires:

a) installations which are managed year round and sampled continuously;

AND/OR

b) a strict and frequent sampling scheme of measuring different sites at the same time.

Both methods have advantages and drawbacks, especially in terms of accuracy. In both cases, it is clear that the monitoring of soil erosion is very expensive and technically complex.

Consequently, the number of sites for monitoring *sensu stricto* has to be limited, and an **indicator based approach** is suggested. The actual area affected by soil erosion is the best indicator of state (Gobin et al., 2003). The area at risk is an important surrogate indicator, and can be estimated using an appropriate tool (model), together with the necessary spatial data sets to define the boundaries of these areas. Trends in soil erosion can be estimated from periodic estimates. This implies:

- the choice of a good model;
- high quality input data; and
- testing and validating the model at carefully selected erosion monitoring sites.

The recommended scale for the modelling is 1:250,000. The model should be able to simulate scenario's of soil erosion under changing climatic conditions and, most importantly, under different land uses and land management practices leading to changes in vegetation cover.

In summary, the Working Group on Soil Erosion proposes an **indicator based approach**, combining an **assessment of soil erosion risk** at a European and national scale with **measuring actual soil erosion rates** at a limited number of representative sites (= monitoring *sensu stricto*).

2. Choice of a model

The proposed indicator of state to support a European soil protection policy, i.e. the area at risk of soil erosion in Europe, should ideally be determined by means of a unique methodology. The main advantage is that model results will be at least comparable and of relative value. The accuracy of the result will mainly depend on the accuracy of the input data (see point 3). A second constraint is the ability of the model to account for soil loss by processes such as gullying, landslides, snowmelt erosion, wind erosion, tillage translocation, sub-surface erosion, etc., which are often of high local relevance.

In order to cope with the assessment of soil loss by different processes in different regions, several options exist:

i. Combining different soil erosion processes in one model and developing a single soil loss map at a European scale.

This is the most ambitious, but also the most complex option. The option is not realistic at the short term, given the current knowledge gaps on the potential interactions of the many different soil loss processes. Even at the long term, the feasibility of such approach can be questioned.

ii. Developing individual models and maps at a European scale for the most relevant soil erosion processes.

This option is more realistic, however not currently available. It could be considered as a research priority on a short to medium term time scale.

iii. Carrying out a **'qualitative expert assessment'** of a currently available European soil erosion map, such as produced by the PESERA model, allowing the identification of areas where predictions of the model at a European scale over- or underestimate soil losses due to the fact that specific erosion processes are not taken into account or for any other reasons. This type of 'practical validation' can be based on a comparison with national and sub-national maps (using models/methods that deal with locally relevant soil erosion processes) and on local expert knowledge of the terrain.

This option is strongly suggested by the WG on Soil Erosion, as it makes the best use of currently available technologies at the European scale, and is the most feasible at the short term. Acknowledging national modelling efforts and local expert knowledge will also increase the positive involvement of Member States in the Soil Strategy.

The WG on Soil Erosion forbears from promoting a specific model, and refers to the report on WP2 'Nature and Extent of Soil Erosion in Europe', where several approaches are discussed. However, we recommend the three most recent approaches for further consideration, i.e.:

- the USLE approach;
- the INRA approach;
- the PESERA approach.

Of these models, PESERA is the most conceptually appropriate because it takes into account:

1. Runoff and eroded sediments separately, which are the two main components of the global erosion process;
2. Daily frequency distribution of rainfall, month by month, which allows the model to account for both regular and exceptional events;
3. Dynamics of crusting and vegetation cover month by month;
4. Other climatic information such as freezing days etc., that in part determine for snow effects.

Other models, such as USLE and INRA do not take these aspects into account. Hence, the PESERA model seems a promising tool for decision-making in Europe. The WG on Soil Erosion acknowledges that modelling needs to be improved, both conceptually to account for different soil loss processes and by increasing the accuracy of input data. It is expected, however, that this will continue to progress very fast.

3. Data needs

3.1 Land use data and land management data (vegetation cover)

Vegetation cover is considered as the most important parameter for policy making purposes, as this is the only parameter that will be directly affected by a policy. It is acknowledged that modelling changes in soil erosion rates due to changing land use and land management requires information at a national or even regional scale, and down to the field parcel level. However, a Pan-European dataset meeting these requirements of spatial resolution and accuracy only exists for agricultural land under Community aid schemes. At present, a combination of several existing data sources, as proposed by the members of the WG on Soil Erosion, may lead to the compilation of such a dataset covering the entire land surface of Europe. The main data sources or data collection methods are:

3.1.1 Data collection methods

- **Remote sensing at a European scale**

The best available data source is the CORINE land cover project, but both the temporal and spatial resolution are problematic. Updating the data is time consuming and very costly, and therefore limited to a frequency of about 10 years. The first CORINE project dates from 1990, from which the European land cover database is derived, with up to 44 land use classes. The European land cover database is currently being updated by the joint 'Image 2000 and CORINE land cover 2000' project. The result is a general picture of broad land use classes as observed in a particular year. Within arable land, for instance, no distinction can be made between different crops, nor can land management practices be identified. Hence, this dataset can be used to derive a soil erosion indicator for European policy makers, revealing general trends in soil erosion due to land use change over a longer period, but not dealing with local management interventions (Gobin et al., 2004). This could partly be overcome by correcting the CORINE land cover database with other data sources, e.g. agricultural statistics (census data) or agricultural parcel data collected for area payments under the CAP (see below).

Using remote sensing technologies for monitoring vegetation cover resulting from a specific land use and land management requires a very high spatial and temporal resolution, as well as considerable field-verification/ground-truthing. As an example, at least three coverages per year would be needed in order to distinguish between different crops. Such an intensive monitoring scheme is not realistic for the whole of Europe, but could be carried out for selected representative areas. The results could then be extrapolated both in time and in space, requiring crop growth models for temporal extrapolation and the subdivision of Europe into agro-ecological zones for spatial extrapolation. Agro-ecological zones are soil erosion zones characterised by specific climatic and environmental conditions, and by typical forestry and agricultural production systems, including pasture. In such agro-ecological zones, which may cross national borders, soil loss is caused by a given set of processes and can be attributed to certain climatic and environmental conditions and human influences. The development of such a map has been recommended by the WG on Soil Erosion as a priority research topic.

- **Agricultural statistics and census data at national and European level**

In all Member States, information on land use is obtained each year from the annual agricultural and horticultural census, where farmers are asked to fill in a questionnaire asking for a range of information. The data are not geo-referenced, but collected at the farm level so can be located in a particular municipality, catchment, etc. Whilst giving an idea of the extent to which certain crops are grown and a rough idea of regional trends, it will not provide the data to field scale. Moreover, information may be collected at different levels of detail in different countries. Especially, data on land management and specific erosion control measures are often not recorded (e.g. Austria, UK, Belgium…). In Switzerland, farm census data were used to develop a soil cover indicator at national level every 4 years, describing soil cover intensity by crops during the year and the use of soil-protecting tillage practices with reduced intensity (linkage to USLE soil use and management-factors C and P).

At the European level, the nomenclature of territorial units for statistics (NUTS) provides the means to spatially present agricultural statistical survey and census data. These data cover all Member States and include information of crop type and area, farm size, farming income, crop yields, livestock type and number at the NUTS 2 and 3 levels (i.e. regional level). The last available datasets are from 1997 and 1998 (Gobin et al., 2004). The compilation of European land use statistics through this means could be of more use if data were provided at the local, i.e. NUTS 4 and 5 levels.

- **Agri-environmental programmes**

In several Member States, information on land management and specific erosion control measures is collected through agri-environmental programmes, e.g. the Austrian programme for an environmentally sustainable agriculture (ÖPUL). This may be an important complementary data source. In Norway all farmers receiving subsidies provide information about their production systems (crops, tillage, yield etc) and management methods on farm and field level. Subsidies are given for reduced soil tillage, sedimentation ponds, vegetative bufferzones, changing cereal area into permanent pasture, repairing hydro-technical equipment. Therefore data information is collected at the field level and stored in a database, allowing trends in agricultural practices related to erosion to be identified.

Alternatively, much information will be required at the farm level for compliance with the new CAP requirements and with various other regulations and Directives. In England, the Government is developing a new computer-based system, called the Whole Farm Appraisal, which will contain information on actual practices such as reduced tillage, livestock management, etc., and is also likely to include details of practices that farmers are carrying out to meet cross-compliance requirements under the CAP. However, this will not be introduced fully until after 2007.

- **Geographical databases on land use (and land management) on an individual field basis collected for area payments under CAP regulations**

In all EC member states, detailed information on vegetation (crop) cover is available on an individual field basis as defined by the Council Regulation (EEC) No 3508/92 of 27 November 1992. This regulation established an Integrated Administrative and Control System (IACS) for Community aid schemes. Land Parcel Identification System (LPIS) represents a key component of the IACS, used by authorised institutions for the administration and control of subsidies in agriculture. LPIS is based on the spatial identification and registration of so-called production blocks, which are defined as continuous areas of farming land delimited with relatively stable natural borders. LPIS national databases contain main attribute classes that include a unique parcel number, area, crop type and details of aid applications. Airborne images in the form of digital orthophotos and vector boundaries identify agricultural land parcels.

- **Using a sampling scheme and extrapolating data to larger areas**

In Norway, a grid system (3 x 3 km²) is used to monitor the change in agricultural landscape, producing statistics on national and county level with a 5 year time interval (i.e. the time needed to cover the whole country). At grid points hitting agricultural land, aerial photographs are taken from a

1 x 1 km area, with the grid point as a centre. Land use and landscape elements (stone walls, farmer roads, waterholes etc) are identified on the pictures and the information is stored on a database. Each year, 10 % of the plots are visited in the field to calibrate the interpretations. A similar system is under development for the monitoring of landscape quality, biodiversity and cultural landscape elements. From each grid in an 18 x 18 km net, aerial photographs are taken (1 x 1 km plots). The programme will produce statistics about all Norwegian nature and landscape types.

- **LUCAS**

See under point 5.

3.1.2 Proposal

Several examples were provided by the members of the WG on Soil Erosion, illustrating how the above mentioned data sources on land use are combined to produce a national or sub-national dataset. Some initiatives:

✓ In Germany, a soil cover indicator was derived from the Corine land cover database, corrected with statistical data from the Main Representative Survey to assess the actual erosion risk on a regional scale (Erhard et al., 2003).
✓ In Norway, orthophoto's are used to update RS land use maps at the scale of regional projects.

A homogeneous Pan-European dataset could be obtained by compiling national datasets, but problems with comparability of land use classification systems between countries may arise, and standardisation will be a prerequisite. *This approach would, however, be very resource intensive and it is questionable whether it is necessary to gather detailed information on both land use and land management for the whole of Europe.*

An alternative, perhaps more efficient, approach has been proposed by the German Federal Institute for Geosciences and Natural Resources in its Final report (Task 6) for the 1999 subvention to the European Topic Centre on Soil (Düwel and Utermann, 1999). Figure 1 summarises the proposed approach.

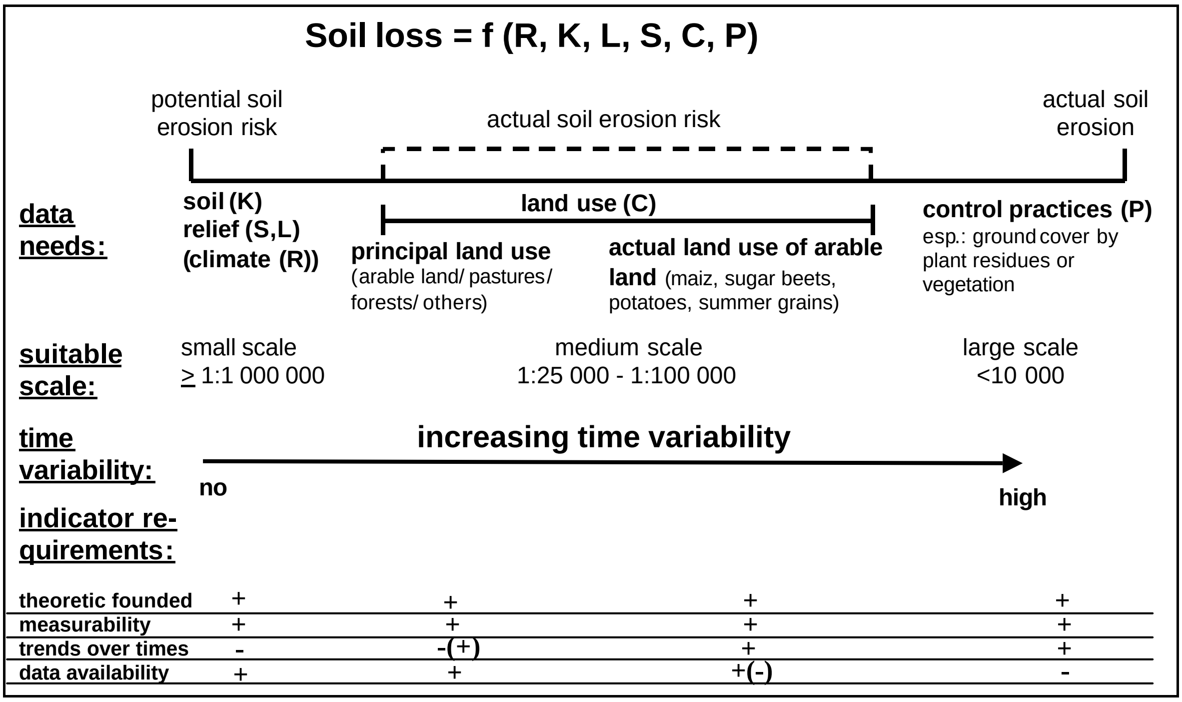


Fig. 1: Indicator based approach for monitoring soil erosion

Following this approach, the **first step** should be to identify areas with a high potential of soil erosion risk with regard to soil erodibility and relief. The **second step** is to identify areas where there is a high risk of actual soil erosion, taking into account the principal form of land use (e.g. arable land). A **third step** is the monitoring of ground cover in these high risk areas, derived from actual land use and control practices (or land management), allowing an assessment of the state of soil erosion by water through modelling.

It should be possible to meet the data needs for the first and second step (soil erodibility, relief and principal form of land use) at a **European level**. Data on ground cover, based on land use and land management is only needed for **high risk areas** , so efforts can be considerably reduced. This implies the suggestion that 'action-driven' monitoring is should be limited to high risk areas.

3.2 Meteorological data

For the PESERA model, data are needed for the following meteorological parameters:

- ✓ Mean daily rainfall;
- ✓ Daily potential evapotranspiration;
- ✓ Daily minimum and maximum temperature.

These data are needed at a resolution of 10 km x 10 km. They are currently best available at national scale (more accurate than MARS data). These national data then have to be compiled at a European scale.

3.3 Topographic data

Modelling soil erosion at a European scale requires a DTM with a recommended resolution of 250 m. The currently available DTM has a spatial resolution of 1 km, from the EROS database in the USA (Gobin et al., 2004).

3.4 Soil data

The European Soil Information System (EUSIS) provides a harmonised and spatial coverage of soil types and descriptions, based on FAO nomenclature, at 1:1m scale (ca. 1 km x 1 km) in all European participating countries. The database enables spatial data queries, data extraction and thematic mapping (Gobin et al., 2004).

A minimum dataset needed for soil erosion modelling at a European scale consists of:

- ✓ Surface texture;
- ✓ Soil depth;
- ✓ Soil type.

This information should be available at a scale of 1:250,000.

For this purpose, the harmonisation of existing soil databases at regional, national and European levels, and the compilation at a 1:250,000 scale, are necessary. For parts of Europe, soil information is available at this scale. In some Member States, however, major soil mapping efforts will be necessary, given the limited amount of available soil data and the coarse scale of available soil maps. New mapping initiatives have to be carried out according to a standardised method and legend. This reveals the urgent need for co-ordination at a European level. At present the European Soil Bureau Network is co-ordinating the efforts to improve EUSIS. The WG on Soil Erosion strongly suggests the whole process of data collection and harmonisation be steered by the European Commission.

The accuracy requirements of the soil data depend on the type of model and the scale of the modelling (European or national/regional). More detailed soil information may be required at larger scales. In Germany, for example, the ad hoc working group "Permanent Soil Monitoring of the Joint Federal States Working Group for Soil Information" recommends a number of parameters for consideration by the Länder when installing and operating permanent soil monitoring sites in Germany, based on a stratified approach (selecting representative sites, unlike using a grid). In its report "Permanent Soil Monitoring, Installation and Operation of Permanent Soil Monitoring Sites" (Barth et al. 2000), the following mandatory and optionalparameters are proposed:

- Mandatory physical soil parameters:
  - ✓ Grain size distribution (i.e. soil texture)
  - ✓ Bulk density
  - ✓ Solid substance density
  - ✓ Pore size distribution
  - ✓ Saturated hydraulic conductivity (Ks) - laboratory measurements
- Optional physical soil parameters:
  - ✓ Unsaturated hydraulic conductivity (Ku) - laboratory measurements
  - ✓ Hydraulic conductivity (Ks and Ku) - field measurements
  - ✓ Penetrometric (or cone) resistance
  - ✓ Aggregate stability
  - ✓ Soil-water content, volumetric
  - ✓ Soil-water tension
- Mandatory chemical parameters of the soil solid phase (selection):
  - ✓ C_{tot}, C_{org}

Annex 1 specifies the recommended method, sampling site, environmental relevance, time interval of measurement, and connection.

In the WG on Soil Erosion, the measurement of aggregate stability is strongly suggested by some members, while others are rather sceptical and propose to explore the possibility to use pedotransfer functions to derive this parameter from basic soil parameters. The advocates of measuring aggregate stability point to the fact that (i) it is an integrative soil property which combines the effect of texture, mineralogy, OM amount and quality, salinisation and/or sodication, etc., and (ii) it is directly related to soil crusting (and resulting reduction in infiltration) and erodibility, so it is able to reflect both short term and long term changes of soil influence on erosion. According to them, aggregate stability is the easiest way to monitor the effect of land use and management on soil sensitivity to erosion. Some members suggest this parameter is measured on arable lands in “seedbed” condition, which corresponds to the condition of maximum vulnerability of soil to erosion. The main arguments of the opponents are (i) the high spatial and temporal variability of this soil property, (ii) the important differences that are found when determining this parameter with different methods, and the difficulties that will arise in any attempt to find a unique determination method that is widely accepted.

Also, for erosion in areas covered with snow and where the soil is frozen during the year, aggregate stability is an important factor related to soil erodibility. Compared to areas without frost and snow it seems that aggregate stability has an even stronger seasonal variation. Therefore, there is a need for agreement both on methods for aggregate stability-rainfall erosion and on methods for aggregate stability-snowmelt erosion. Methods used for determination of aggregate stability should therefore also include determination of aggregate stability during winter period (this is a research gap).

Furthermore, the WG agreed that hydraulic conductivity and bulk density are also useful parameters to help identify soil compaction problems (which results in an increased erosion risk).

4. Monitoring soil erosion *sensu stricto*

Within the proposed 'indicator based approach', measurements of actual soil erosion rates are essential to calibrate and validate the model used for assessing soil erosion risks in Europe. A model can only produce sensible results when it is properly calibrated and validated in the region where it is applied, and when accurate input data are available. On the other hand, measurements of actual soil loss provide the best indicator of soil erosion in a certain area. Depending on the measurement methods used, one can obtain state indicators and/or impact indicators. State indicators may reflect both the severity and the extent of soil erosion. Provided that the measurements are sufficiently representative, values can be extrapolated to the agro-ecological zone in which the measurements have been carried out, providing an alternative for model assessment. In summary: measuring actual soil loss is not only important for calibrating and validating models, but also has a very important value in itself.

The Working Group on Soil Erosion strongly suggests that maximum use should be made of existing sites which are continuously but independently being set up by different research groups in Europe but without any co-ordination at a European level. **We recommend that first, use is made of existing data and only in cases where existing data are insufficient should additional monitoring be carried out.** Efforts need to be made to see whether the different methodologies used in the different countries allow the comparison of the results at a European level, or whether the data only have a value at a national/regional level.

Measurements of soil erosion rates are suggested at two levels: at the plot scale and at the catchment scale. A **nested approach** is recommended, i.e. plot sites should be preferably located within the geographical boundaries of the monitored catchments.

4.1 Measurements at the plot scale

Measurements at the plot scale provide point data and are not suitable for providing information on the extent of soil erosion at national scales, given their poor spatial representativeness. However, fully instrumented plot sites are useful for studying the processes causing soil erosion. Long term datasets of soil erosion measurements at plots in different agro-ecological environments may be used to test model concepts. For instance, the equations of the PESERA model have been calibrated on such measurements (Gobin et al., 2004).

For erosion processes where European models still have to be developed, e.g. snowmelt erosion, input from plot scale measurements is absolutely vital for development, calibration and validation. Also, for studying the effects of climate change on soil physical parameters related to erosion, the plot scale is necessary.

With regards to soil erosion monitoring at the plot scale, there are two projects currently on-going within Europe. The projects, SOWAP and GECAP, are collaborative between EU-Life Environment, academia, NGOs and industry, and cover Spain, Southern France, Italy, UK, Belgium and Hungary, with further sites to be constructed this year in the Czech Republic and Northern France. The projects not only measure erosion under conventional practice but also investigate options for soil and water conservation. More information can be found at www.sowap.org.

4.2 Measurements at the catchment scale

Measuring soil loss at the catchment scale can be done by one, or ideally a combination, of the following methods (explained below):

- Mapping visible erosion features;
- Continuous measurement of sediment transport at the outlet of small catchments;
- Measurement of sediment deposition in ponds, lakes or reservoirs.

An important issue is the selection of catchments where the measurements will be carried out. As already stressed, use should be made of existing sites. However, a representative sample should be obtained for the whole of Europe. In theory, the selection of catchments or test regions could be based on the best available soil erosion risk map for Europe, and on a map with agro-ecological zones (to be developed for Europe). A representative sample of test areas (catchments) would mean that all agro-ecological zones are represented by at least one test site, depending on the size of the zone, and on the variability of landscapes within an agro-ecological zone. Moreover, the selected areas should be characterised by a moderate to high erosion risk. In Switzerland, for instance, such an approach has been adopted to select a maximum of 10 test regions in which detailed model calculations and mapping of erosion damage will be carried out. As Switzerland has a total area of 41,284 km², this means a density of about 1 test area per 4,000 km², whereas the density with respect to the area at risk of soil erosion will be even higher. In Norway, a programme for monitoring erosion and water quality was established in 1992. Soil erosion and the loss of nutrients are monitored in 10 small watersheds dominated by agriculture. In six areas the amount of pesticides in the water is also monitored. In Spain, the Experimental Erosion Monitoring and Evaluation Station Network (RESEL), set up in 1995, is aimed at monitoring erosion and hydrological processes in a network of stations representative of erosion landscapes of greatest interest in the Spanish territory (a total of 40 experimental catchments and plots). This network intends to establish a database at the national level in relation to erosion processes, hydrological cycle and water quality, which enables real data to be used to design preventive actions and use and management plans in areas liable to desertification.

However, it is likely that the main driver for erosion monitoring will come from the Water Framework Directive (WFD). Such monitoring will be conducted on a catchment basis but only in those catchments where soil erosion is identified as being responsible for the decline in biological and chemical water quality. Catchments where soil erosion is a pressure will be identified on the basis of historical local knowledge from inspections of water bodies, water quality data and risk assessment. The WG on Soil Erosion is convinced that, if our goal is to protect the soil and not just the water, the method for catchment selection described above should be adopted.

- **Mapping visible soil erosion features**

The mapping of visible soil erosion features allows for a relatively reliable assessment of severe (linear) erosion forms and sedimentation, whereas sheet erosion can only be estimated. However, to quantify these features it needs to be performed at a sufficient temporal resolution. One inspection per year is certainly inadequate, but seasonal inspections based on timing of agricultural management practices could provide a detailed picture. At the same time, data about land use and land management practices in the catchment should be monitored.

A very nice example can be found in Switzerland, based on 7 years experience with soil erosion damage mapping. Mapping of the test areas is normally carried out four times a year:

- ✓ in spring before tillage, for soil erosion occuring over winter time;
- ✓ in early summer after tillage and drilling, for soil erosion under low vegetation cover;
- ✓ in late summer, for soil erosion after thunderstorms;
- ✓ in late autumn after drilling of winter-wheat.

For each 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 is assessed and quantified by using results for soil losses from field measurements. Additional information concerning off-site damage, water inflow and wheel tracks is also registered and stored in a data base. Furthermore, the monitoring programme also includes interviews with farmers every 5 years.

A comparable methodology exists in Germany (DVWK, 1996). In Lower Saxony (Germany), mapping in selected catchments is carried out at the end of each winter as well as an additional survey after an important soil erosion event. The mapping includes not only the various erosion forms but also vegetation and special protection measures as well as questioning farmers in the region.

In Norway, the Agricultural Environmental Monitoring Programme (JOVA) combines soil erosion mapping with monitoring water quality at the outlets of selected agricultural catchments. Water quality measurements include nutrients, pesticides and suspended solids as a measure of soil erosion. Geo-referenced information on crop type and farming activities is available at the field parcel level on an annual basis, as provided by the farmers. Mapping of visible soil erosion features is performed by visiting each field after the winter season and after heavy rainstorms causing erosion events during the year. For each erosion rill, its length, mean width and mean depth are surveyed and the volume of soil loss determined (similar to the example from Switzerland). Because the same fields are visited each year it is possible to relate erosion features to farming practices and to the location in the catchment. The combination of sediment measurements at the outlets of catchments, detailed farming information at the field scale, and the erosion mapping in the same catchments, provide a monitoring system that allows the identification of erosion sources and forms, the extent of erosion and the effects of management practices. More than 10 years of erosion damage mapping exists.

An advantage of 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, failure of hydro-technical equipment etc.), to identify the pathways of eroded material from the field to off-site objects (e. g. surface waters) and to assess off-site damage. A drawback of this method is its strong dependence on weather conditions. Therefore long-term investigations over 10 or more years are necessary in order to make reliable assessments of long-term average soil losses, which can be compared to the results of model calculations. Therefore, mapping can be considered as a resource intensive but very valuable tool. In the example of Switzerland, an experienced surveyor maps a 200 ha arable test area in one day.

This method allows the derivation of a state indicator on both the extent and the severity of soil erosion, as well as a pressure indicator, e.g. on land (mis)-use, and an impact indicator, e.g. on off-site damage. In addition, long term data can serve to calibrate and validate models.

- **Continuous measurement of sediment loads at the outlet of small catchments**

The measurement of sediment loads in streams is a useful tool for assessing the state and impact of soil erosion, as well as for model validation, provided that the data are used cautiously and, if necessary, combined with suitable techniques to trace back the sediments to their origin.

The main uncertainties with linking sediment load measurements with actual soil loss in the field arise from the fact that:

- ✓ an unknown part of the eroded soil may be deposited on its way to the river; and
- ✓ an unknown fraction of the sediment originates from the river bed and the river banks (within channel sources).

In addition, processes other than rill and interrill erosion may be responsible for the delivery of sediment to rivers, such as mass movements, gullying, tunnel erosion, etc. In Nordic countries and in the Alps, sediments can also originate from glaciers. Obviously, this has to be taken into account when using sediment load data for validating models.

Estimates of both suspended sediment and bed load are needed. Suspended sediment in most instances is derived from the land, as opposed to within-channel sources, and thus is a relatively good measure of soil erosion. Studies throughout Europe (e.g. Owens et al., 2000) have demonstrated that in rural and agricultural landscapes usually > 50 % and often > 80 % of the suspended sediment load being actively transported by rivers is derived from the erosion of the land surface. It is nevertheless important during any monitoring programme to determine from where the sediment has come from, i.e. its sources, as this will provide vital information on the amount that has derived from soil erosion.

Several techniques exist to measure suspended sediment load and bed load. A lot of data may already exist in the archives of water power and river authorities. Sediment concentration and discharge may be measured using turbidity monitors and automatic water samplers (sediment) and pressure-transducers or gauged sites (discharge). The obvious advantage of monitoring suspended sediment is that it would link to the Water Framework Directive (WFD). As such, monitoring sites, sampling procedures and protocols would follow protocols either already existing within the WFD or currently being developed by the WFD Expert Group on AMPS (Analysis and Monitoring of Priority Substances). In addition, the European Sediment Research Network (SedNet, www.sednet.org) is, amongst other things, reviewing available methods to measure sediment loads in rivers and methods to identify sediment sources.

To obtain a picture of the spatial distribution of the sources of soil loss within a watershed, there are only a few appropriate methods:

- The most straightforward and probably the most reliable, but highly resource intensive, method is mapping visible erosion features, as explained above, and as illustrated by the Norwegian approach.
- Alternatively, the use of environmental radionuclides (for instance caesium-137; ^{137}Cs) are costly and in addition, their accuracy may be a problem. The majority of members of the WG on Soil Erosion agree that these methods should not be recommended as standard methods for monitoring purposes. According to those in favour of the radionuclide approach, there exists some potential to use such tracers to assemble information on erosion rates in different environments and soil types in Europe and as a means to monitor changes in soil erosion through the use of repeated surveys at key sites. A multi-radionuclide approach is to be recommended because different radionuclides provide information on erosion rates over different time periods, such a decades (^{137}Cs) and storm-event (^{7}Be). The use of radionuclides as tracers complements the information obtained by plots and catchment studies, and monitoring of river sediment, and could form part of a nested monitoring approach.
- Another method is sediment fingerprinting. This method has been carried out for the Environment Agency for England and Wales to assess the source of sediments in salmonid fisheries, and in particular to verify whether the sediment is derived from river banks or fields. Such data, whilst useful for identifying sources, is not useful for identifying extent.
- A last option to be considered is the use of a sediment delivery ratio, although many uncertainties exist, which may be worth further investigation in research projects. Research questions might be:
  - ✓ What is a reasonable area of a catchment with regard to costs, reliable measurements and representative results?
  - ✓ What is the correct sediment delivery ratio?
    - this could involve a review of the literature, or
    - comparative measurements of sediment loads and soil losses from fields in the catchment.
  - ✓ Is the sediment delivery a sensitive indicator of soil erosion due to land use changes?

  (cfr. Final report on Task 6 of the Technical Annex for the 1999 subvention to the European Topic Centre on Soil)

- **Measurement of sediment deposition in ponds, lakes or reservoirs.**

For this approach, the same principles that apply for the interpretation of data on sediment loads in rivers are valid. Sedimentation data from ponds and reservoirs are often used to validate soil erosion models. For instance, Van Rompaey et al. (2003) validated the soil erosion risk map of Italy, based on the USLE (Grimm et al., 2003), using sedimentation records from lakes and reservoirs, provided by the experimental Institute for Soil Study and Conservation of Florence (MiPAF). Also, model results from USLE, INRA and PESERA at a European level were validated with sediment data from reservoirs in Belgium, Czech Republic, Italy and Spain (Van Rompaey et al., 2003b). Recently, the OECD (2001) Joint Working Party on Agriculture and Environment adopted the recommendation to use such data for the derivation of off-farm sediment flow state indicators.

5. Comments on LUCAS with respect to monitoring soil erosion

LUCAS is an EU-wide land use/land cover area frame statistical survey, based on a regular grid of 18 km by 18 km (Bettio and Kayadjanian, 2003). Each year between May and July, about 100,000 sampling points across the EU are visited in order to collect data on land cover and land use, as well as on the environment. In autumn, more detailed information on farming practices is gathered through farmer interviews. The field survey in spring includes the observation of existing ‘visible’ erosion features at sampling points falling in cropland. The presence of rills and gullies is observed within the so called 'extended observation window', i.e. a circle with a radius of 20 m around the sampling point.

The results of the first LUCAS survey conducted in 2001 show the limitations of this qualitative assessment of soil erosion. No soil erosion was detected at a relatively high percentage of sampling points, and the spatial distribution of soil erosion did not correspond to the generally accepted trends within Europe. Bettio and Kayadjanian (2003) attribute this essentially to the timing of the field work, and acknowledge that modifications and adaptations would be necessary to better respond to the needs of harmonised data at the European level. Nevertheless, they state that LUCAS may contribute to this aim:

- as an existing operational European survey platform on which data gathering on soil erosion could be based, respecting the complex character of soil erosion processes throughout Europe;
- as an ancillary data source of issues closely linked to soil erosion, such as land cover and, by means of the farmer's interview, information on agricultural practices, farmers perception, etc.

Another advantage of LUCAS is that it can be easily extended to any other country, especially candidate countries and provide a standardised assessment of soil erosion.

The Working Group on Soil Erosion acknowledges the potential advantages of LUCAS, but identified the following problems related to (i) its conceptual basis, being an area frame statistical survey, and (ii) the way it is currently assessing soil erosion. Obviously, it is difficult to suggest improvements to the conceptual basis (as shown below), apart from suggesting an alternative approach. In contrast, some of the current modalities could be modified in order to improve the assessment of soil erosion in Europe using LUCAS, as indicated below by the symbol 'U".

i. Conceptual basis

The observation of soil erosion at point locations and the distribution of the monitored sites according to a fixed grid are inconsistent with the recommendations of the WG on Soil Erosion:

- ✓ To measure soil erosion in selected catchments, according to a nested approach of measurements at the plot scale and at the catchment scale instead of **point observations** as carried out through the LUCAS survey;
- ✓ To measure soil erosion in these catchments (by means of the methods listed in point 4.1 and 4.2), in order to obtain a quantitative result (average soil erosion rates) and not just to observe the presence or absence of soil erosion features as prescribed by LUCAS, resulting in a **qualitative assessment** of soil erosion. Moreover, the visual assessment by LUCAS is not able to account for sheet erosion;
- ✓ To determine the distribution of monitoring catchments according to the best available soil erosion risk map and a delineation of agro-ecological zones for Europe in order to obtain a representative set of test areas (catchments), i.e. by means of stratified sampling instead of a **random distribution of observations** as obtained by the fixed grid of LUCAS, which does not take into account the complex landscape and climate patterns influencing soil erosion processes.

U' *One suggestion to improve the conceptual basis of LUCAS could be to enlarge the 'extended observation window' to an area suited for soil erosion observations, e.g. the (smallest possible) catchment around the observation point. However, the size of the catchment would depend largely on the local topography, with larger catchments in flatter areas where it is less worthwhile to measure soil erosion. This modification would, however, imply the monitoring of about 100,000 catchments (i.e. the number of observation points), not all of which would be useful to increase our knowledge of soil* *erosion in a particular environment. Hence, a lot of unnecessary measurements would be done, significantly affecting the efficiency of the system. In contrast, a smaller number of representative catchments at well selected locations according to the WG's recommendations would provide a more cost efficient alternative.*

ii. Current modalities

a. The main problem identified is the **fixed time schedule of LUCAS**, implying only one observation of soil erosion per year in spring time, the sites being sampled one after the other. Given that the occurrence of soil erosion is strongly dependent on both weather and vegetation conditions, its temporal distribution is highly variable across Europe, which is characterised by significant climatic and vegetation gradients. Hence, **the identification of soil erosion features strongly depends on the time of sampling, and the current time scheduling of the LUCAS survey may lead to unreliable results**. For instance, at the moment of sampling, the farmer may have just restored damage by ploughing, or soil erosion may occur the day after sampling, etc., so no visible signs of soil erosion would be detected. In contrast, the WG on Soil Erosion recommends a high temporal resolution of measurement, i.e. high frequency or continuous measurements (see point 4.2). For instance, when mapping visible erosion features in selected catchments, seasonal inspections based on the timing of agricultural management practices and particular weather conditions would provide sufficient accuracy. The same applies to any monitoring system for soil erosion, also to a grid system.

U' *A potential improvement of LUCAS consists of modifying the time schedule of the field visits, implying a higher frequency adapted to area specific conditions with respect to vegetation cover, farming practices and weather conditions. Consequently, this may involve a different time scheduling for different areas (agro-ecological zones) within Europe.*

b. The LUCAS survey is currently lacking the measurement or description of parameters affecting the soil erosion process, rendering the observation of the presence or absence of soil erosion features meaningless.

U' *A potential improvement of LUCAS would require the measurement or description of relevant (i) soil parameters and (ii) 'landscape' parameters such as slope, slope length, vegetation cover and soil surface conditions (e.g. crusting), and the presence of erosion control measures.*

c. The training of the surveyors in recognising soil erosion features and in understanding soil erosion processes are extremely important. The results of the first survey showed significant operator bias. Surveyors must have the same idea of what 'a soil erosion feature' is.

U' *A potential improvement of LUCAS would require the training of the surveyors in the basics of soil science and in particular in the understanding of soil erosion processes and in recognising soil erosion features according to clear definitions.*

d. The information obtained from the farmer interviews concerning land management is often not precise and only covers part of the observation points (about 6 %).

U' *A potential improvement of LUCAS would require increasing the number and thoroughness of farmer interviews.*

Conclusion

It can be concluded that significant modifications are required to make LUCAS provide a reliable picture and meaningful information on soil erosion in Europe, inevitably leading to increased financial investments. Before deciding to use and therefore to modify LUCAS for soil erosion monitoring in Europe, the cost of the required modifications should be estimated. The advantage of

making use of an existing system, already financed by the European Union, may be undermined when accounting for these additional costs.
The question is whether it is useful to allocate more resources to this system, given that, in the opinion of the Working Group on Soil Erosion:

a. its conceptual basis means it is not the best option for monitoring soil erosion; an attempt to improve the concept could render it extremely expensive and inefficient;
b. an alternative concept based on stratified sampling, as proposed by the WG on Soil Erosion, would probably fit better to the needs of a multi-purpose and action-driven monitoring system for soil erosion in Europe in a more cost efficient way.

6. Monitoring salinisation and sodication

In a first step, areas susceptible to salinisation and sodication should be identified. Monitoring should only be carried out in those areas. The following parameters are suggested:

6.1 An Indicator of Salinization

Soil salinity is generally measured on an aqueous extract of a saturated soil-paste by measuring the electrical conductivity, ECs. Because the ECs and the total salts concentration of an aqueous solution are closely related, ECs is commonly used as an expression of the total dissolved salt concentration of an aqueous sample.

In order to determine ECs, a saturated soil-paste is prepared by adding distilled water to a sample of air-dry soil while stirring and then allowing the mixture to stand overnight to permit the soil to fully imbibe the water and the readily soluble salts to fully dissolve. A conductivity meter is then used to measure the electrical conductivity, Ecs.

6.2 An Indicator of Sodication

The *Exchangeable Sodium Percentage* (ESP), represents the amount of exchangeable Sodium expressed as a percentage of the Cation Exchange Capacity (CEC).
The ESP is defined by the relationship:

$$ESP = (exch.Na^{+}/CEC)\times 100$$

The exchangeable sodium is determined by difference from leached Na^{+}, determined using a flame photometer, and the amount of soluble Sodium, determined from the saturation extract.
A useful and easier to measure index for predicting the tendency of an incoming soil solution to bring the soil at a value of ESP in equilibrium with the SAR of the applied solution is the Sodium Adsorption Ratio (SAR), defined by the relationship:

$$SAR = [Na^{+}]/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$$

where all the concentrations are in meq/l. SAR is expressed in terms of ion concentrations rather than of ion activities. The SAR of the saturated extract of the soil can be considered a measurement of the hazard of soil sodication.

7. Monitoring on site impacts

On site impacts of soil erosion and salinisation or sodication may be connected to soil quality and soil functions. Soil quality is an intuitive concept that refers to how well the soil performs its (ecological and human-related) functions, e.g. a soil's filter and buffer capacity, or its production function.

Indicators of soil quality are measurable soil attributes that provide a sound basis for assessing the impact of soil erosion on the soil system itself (on site). The WG on Soil Erosion recommends the monitoring of a minimum data set of physical, chemical and biological variables that allows us to quantify soil quality and to derive an on site impact indicator for Europe (Table 1).

Table 1: Minimum data set of soil attributes for the quantification of soil quality and for the derivation of an on site impact indicator for Europe (García Álvarez et al. 2003; modified from Doran and Parkin, 1994; Larson and Pierce, 1994).

Soil quality indicators	**Related soil functions**
Physical properties	
Texture	Water and nutrient retention and transmission
Soil and rooting depth	Potential estimated production
Infiltration and bulk density	Potential leaching and erodibility
Field capacity and water retention (water holding capacity)	Transmission and erodibility
Chemical and physico-chemical properties	
Organic matter (total organic C and N)	Soil fertility and stability
Soil pH	Chemical and biological activity thresholds
Electrical conductivity	Microbial and vegetation activity thresholds
Extractable N, P and K	Available nutrients for plants
Sodium content	Assess the risk of dispersion and crusting
Exchangeable cations, particularly Na, K, Ca, Mg	
Biological properties	
Microbial biomass (C and N)	Potential microbial catalic
Potential mineralisable N (anaerobic incubation)	Soil productivity
Soil respiration, water content and temperature	Microbial activity measure

For instance, the <u>production function</u> of a soil is certainly damaged by soil erosion. In Mediterranean countries this may even lead to a complete loss of this function and a subsequent abandonment of a site. In temperate regions, however, this is rarely happening. The most important influence of decrease of soil productivity due to erosion that we have determined was not due to decreased availability of nutrients, but a lack of water availability (Strauss and Klaghofer, 2001) due to loss of topsoil. Thus valuable indicators are <u>water holding capacity</u> and <u>rooting depth</u>. According to the slow nature of the soil erosion process, these features could be measured at specified points at intervals of 10 years. However, they can also be used to monitor effects of past erosion on soil.

8. Monitoring air quality

With respect to the impact on air quality, methods are well established to monitor air pollution from particulate matter/dust that could be used to monitor sediments derived from wind erosion. However, due to the largely rural occurrence and unpredictable nature of wind erosion events, it is unclear whether such measurements would be practical or meaningful.

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Annex 1. Soil parameters for monitoring as proposed by the ad hoc working group "Permanent Soil Monitoring of the Joint Federal States Working Group for Soil Information" (Germany)[1],

Table 1: Soil physics studies

a) Mandatory study parameters

Parameter	Method	Sampling site	Environmental relevance	Interval	Connection
Grain size distribution	DIN 19 683-2 ISO 11277	Soil pit, core area	Filter properties Erodibility	once	Basis for the interpretation of chemistry and physics parameters
Bulk density	DIN 19 683-12 ISO 11 272	Soil pit	Soil compaction	once	Volume reference of substance contents, pore size distribution
Solid substance density	DIN 19 683-11	Soil pit	Soil compaction	once	Pore space
Pore size distribution	DIN 19 683-5 ISO 11276 ISO 11274	Soil pit	Water balance, soil compaction	once	Density, water and substance transport
Saturated hydraulic conductivity (Ks) (laboratory measurements)	DIN 19 683-9	Soil pit	Substance shift, ground water protection, soil compaction	once	Structural designation, water and air transport

Continued on next page

[1] Permanent Soil Monitoring, Installation and Operation of Permanent Soil Monitoring Sites, Barth et al. 2000.

b) Additional optional study parameters

Parameter	Method	Sampling	Environmental relevance	Interval	Connection
Unsaturated hydraulic conductivity (Ku) (laboratory measurements)	PLAGGE (1991), KRAHMER (1987) SCHINDLER (1980) HENSELER & RENGER (1968)	Soil pit	Water balance, substance shift	once	Structural designation, water and air transport
Hydraulic conductivity (Ks / Ku) (field measurements)	Site study ELRICK, REYNOLDS (1992)	Monitoring field / border area	Ground water protection, substance shift, soil compaction	once	Substance transport, compaction
Penetrometric resistance	SCHREY (1991)	Monitoring field / border area	Soil compaction	1 - 5 years	Storage density and permeability
Aggregate stability	HARTGE & HORN (1996), DIN 19 683-16	Core area	Soil erosion (on arable land)	1 - 5 years	Erosion, substance transport
Soil-water content, volumetric	Capacity measurement (TDR or microwave probe, BRANDELIK ET AL. 1996)	Monitoring field / border area	Soil-water balance	$\leq$ 1 week	Substance transport
Soil-water tension	HARTGE & HORN (1996)	Monitoring field / border area	Substance transport	$\leq$ 1 day	Substance transport

Table 2: Chemical parameters of the soil solid phase

a) Mandatory parameters (selection!!!)

- Inorganic parameters -

Parameter	Method	Sampling point	Environmental relevance	Interval	Connection
$C_{tot.}$, C_{org}	DIN 19 684-2 DIN ISO 10 694	Soil pit, core area	Humus degradation (release of substances), humus accumulation Soil erodibility	> 5 years	C/N, pH, exchange capacity, soil water, climate, substance dynamics, soil microbiology