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Long-Term Monitoring of Soil Physical and Biological Properties Pilot Project LAZBO

Abridged Version

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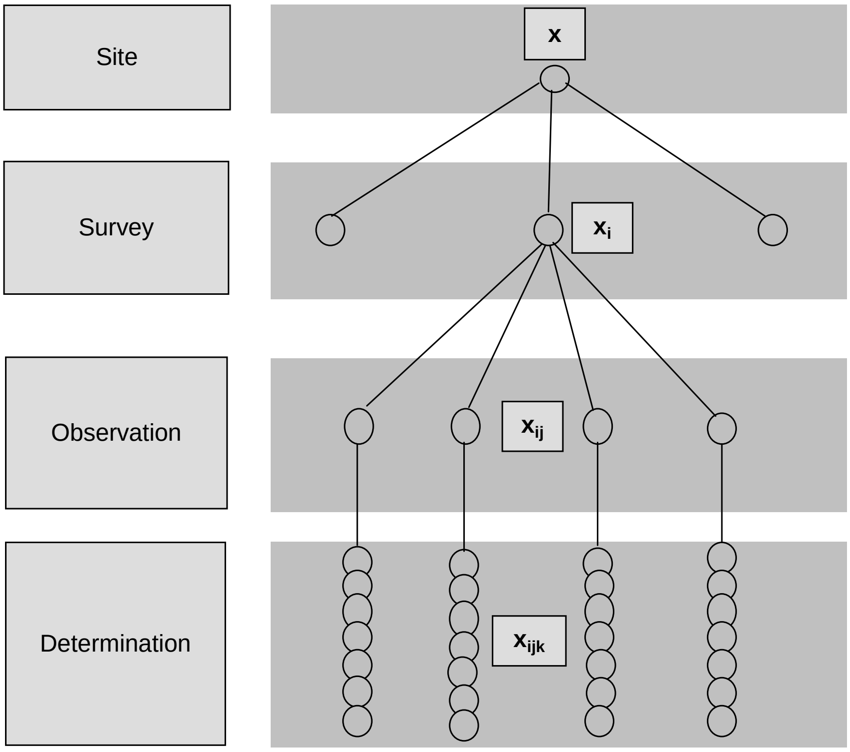

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NABO
Nationale Bodenbeobachtung
Observation nationale des sols
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Swiss Soil Monitoring Network
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Abridged Version

Introduction and Principles (Report Part 1)

Soil fertility is closely tied to soil physical and biological properties and their temporal development has been recognised as a decisive factor for sustainable soil use. Therefore, monitoring physical and biological soil properties became a legal duty within the amendment of the Environmental Protection Law (USG, 1983) and the new Swiss Ordinance relating to Impacts on the Soil (VBBo, 1998). Long-term monitoring observes soil physical and biological properties over space and time, helps to early detect and predict changes in soil quality, provides the legislature and implementing bodies with crucial information to support decision-making and allows them to take precautionary soil-protection measures. In addition, long-term monitoring makes a contribution to assess ecological sustainability (maintenance of natural resources), as stipulated in the new Agricultural Law (LwG, 1998) and in the Sustainability Ordinance (VBNL, 1998).

The already established monitoring program within the framework of the Swiss Soil Monitoring Network (NABO) is limited primarily to chemical soil contamination with inorganic and organic pollutants. Reasons are that previously issued legal provisions (VSBo, 1986) were limited to chemical pollutants only and validated methods and practical experience for determining physical and biological soil parameters over long periods of time were missing, as they were required within the framework of the NABO (VBBo Article 3) as well as for soil monitoring carried out by the cantons (VBBo Article 4).

Motivated by the need for sound methodological bases to establish a long-term monitoring program for soil physical and biological parameters, Agroscope FAL Reckenholz initiated a study within its 2000-2003 Working Program entitled “Long-Term Monitoring of Soil Physical and Biological Properties (LAZBO) - Pilot Project” (FAL Project No. 00.14.2.2). Aim of the study was to validate sampling design (only soil physics) and methods to determine soil physical and biological parameters suitable for long-term monitoring within the NABO reference network.

Parameters and methods to be studied were selected prior to the LAZBO Pilot Project based on recommendations from literature, as well as experience with methods already established at Agroscope FAL Reckenholz. Further selection criteria were sensitivity of the parameters to expected physical, chemical and biological impacts, their value to characterize soil functionality, as well as feasibility and effort of the method. From soil physical parameters, bulk density, total pore volume, pore size distribution (fraction of coarse, medium and fine pores), air permeability, precompression stress, penetration resistance and soil structural state were selected. For the soil biological parameters, the choice fell on microbial biomass, soil respiration and N-mineralization in the aerobic incubation test. All parameters were determined in the laboratory, except of the two field methods penetration resistance and soil structural state. The physical parameters were determined at two field sites, the microbiological ones at six field sites, (three arable and three grassland sites) each undergoing different crop-management.

For the LAZBO Pilot Project a research plan was outlined based on five procedural steps necessary to determine soil physical and microbiological parameters, which are: (1) sampling design scheme, (2) sampling technique of the field soil, (3) sample preparation, (4) storage, (5) conditioning (e.g. incubation, extraction) and analysis. The individual steps were grouped in three tiers denoted as **survey** (steps (1)-(5)), **observation** (steps (2) to (5)) and **determination** (steps (3) to (5)). For this three-tier hierarchical model an analysis of variance was introduced to assess accuracy of sampling design (only soil physics) and determination methods. In this study, "accuracy" was used as an umbrella term for **precision** and **trueness** expressed as variance and bias to quantify random and systematic errors of the determined values.

Determination values of the soil physical parameters were obtained in the laboratory from undisturbed core samples and, in case of penetration resistance and soil structural state, determined directly at soil profiles in the field. Soil microbial parameters were determined in the laboratory on sub-samples drawn at random from a mixed sample consisting of soil material collected from 25 pricks using a thin-core sampler from a 10 × 10 m test plot (see also Desaules & Dahinden, 2000). For the soil physical parameters, an observation value represented the average of four to ten determination values obtained from an individual test pit within a 10 × 20 m test plot. For the soil microbial studies, the mean of four determination values from the same mixed sample yields one observation value. For soil physics and microbiology, the mean of four observation values, origin from one test plot, yielded one survey value, which characterized a soil physical or biological parameter of a test plot at a specific point in time. A time series of survey values eventually yielded mean, variance and (possible) trend of the site value, the target variable for long-term soil monitoring.

A key step of the LAZBO Pilot Project was to quantify and analyse mean and variance of the survey values to increase survey accuracy by controlling and optimizing sampling design and determination methods but also to set the stage to answer the questions of primarily interest for soil monitoring: (a) what is the smallest difference between two survey values that can be detected significantly; (b) how many survey values are necessary in order to detect a relevant change in the mean site value; (c) how many survey values are necessary to detect the "background noise" of a site value (random deviation of the individual survey values from the mean site value), and finally (d) does the mean site value change significantly and relevantly with time, i.e. do the survey values have a trend in time? To analyse variance of the survey values and to answer questions (a) to (c), hierarchical analysis of variance and the two-sided confidence interval were introduced and applied within this study. With the analysis of variance, mean and variance of determination and observation values were calculated which allowed optimizing the number of determination and observation values within a survey in order to minimize variance of the survey value. To answer question (d) statistical models were introduced in this study to analyse time series started with the LAZBO Pilot Project and being continued within the ongoing LAZBO Test Phase.

Physical soil investigations (Report Part 2)

Bulk density, total pore volume, pore size distribution (coarse, medium and fine pore fraction), air permeability and precompression stress (from confined one-dimensional compression test) were determined in the laboratory using undisturbed core samples of two different sizes from top- and subsoil. Penetration resistance was measured with the "PANDA"-probe, a dynamic penetrometer, and soil structure was assessed by means of visual structure analysis at a soil profile in the field.

For the observation values, the study yielded coefficients of variation between 5% (bulk density, total pore volume) and 25% (course pore fraction). The rather high variability of the observation values can be explained by small-scale spatial heterogeneity of the soil properties (e.g. fraction of coarse pores) and is only caused to a small extent by random errors of the determination method. In general, the laboratory methods used to determine soil physical parameters were stable (coefficient of variance of only a few per cent), but can be further improved by systematic calibration. For example, standard specimens of porous material (sintered glass, metal or ceramics) of known pore-size distribution and permeability may be routinely measured together with soil core samples to quantify the bias of the methods. No storage effects on lab-measured soil physical properties were found for storage duration between four and 34 weeks. For the field methods, soil water content influenced the measurements, especially variability of the penetration values, and therefore has to be taken into account by standardisation or correction to reliably assess soil structural state.

Precision of the survey values can be increased by increasing accuracy of the determination methods and optimising the sampling design. As shown by the analysis of variance, an increase from four to ten observation values coupled with reducing the amount of determination values from ten to four would reduce variance of the survey values by 40 % for the same total amount of samples. It could be shown that distributing the test pits within the test plot in a stratified random instead of systematic pattern additionally reduces variance of the survey values.

The currently available values from three surveys of the years 2001-2003 provide an estimate for mean and variance of the two test sites. On the basis of three surveys no temporal trend could be detected. The analysis of variance, however, allowed estimating the amount of surveys necessary to determine a statistically significant effect. Finally potentially detectable effects were compared to relevant effects, estimated based on the recently proposed guidelines of the Swiss Soil Science Society (BGS, 2004).

Microbiological soil investigations (Report Part 3)

Samples were taken every year in spring according to the NABO procedure from test plots of 10 × 10 m at three arable and three grassland sites. For each test plot four mixed samples were collected. Each mixed sample was divided in four sub-samples for laboratory measurements. Parameters were selected according to recommendations for basic parameters both by the *Vollzug Bodenbiologie* (VBB) working group in Switzerland, and by other European countries: microbial biomass (BM), determined by the methods of substrate-induced respiration (SIR) and chloroform fumigation extraction (FE), soil respiration, and N-mineralization during aerobic incubation.

Validation was carried out by means of criteria required for a soil microbial monitoring system: (1) reference stability, (2) accuracy of the determination values, (3) accuracy of the survey values, (4) temporal changes in soil properties in the field, and (5) relevance. In order to evaluate reference stability and temporal change, the results of fresh samples were compared with those of the frozen samples, which were frozen after sample preparation and measured at various points in time after thawing.

The results for reference stability were depending on soil microbiological parameter. For microbial biomass BM (SIR), very good reference stability was found. Compared with the microbial biomass BM (SIR), for which the per-annum mean-value deviations of an observation (mixed sample) from the mean value of the three years was in maximum 5%, the reference stability of soil respiration with a maximum deviation of 10% can be described as relatively good. The same applies to the N-mineralization. In contrast, reference stability for microbial biomass C_{mic}/N_{mic} (FE) cannot be assessed conclusively, since the relevant test results are contradictory. In the long-term monitoring, considerable attention must be paid to the reference stability of determination methods. Based on experience within the LAZBO Pilot Project, regular cross-check with stable reference samples at short time intervals is advisable.

The precision of the determination for the microbiological soil parameters addressed in this study is good. Except for N-mineralization, all coefficients of variation were lower than 5% of using for four determinations per observation taken from one mixed sample in the laboratory. For N-mineralization, a coefficient of variation of 8% was calculated. As a further yardstick for judging the precision of a method, the distribution of these coefficients of variation showed that 75% of all coefficients of variation were smaller than 5%. Only very few observations have a coefficient of variation larger than 10%. The comparison between fresh and frozen samples showed that freezing should be dispensed since the risk of observations exhibiting greater coefficients of variation increases with the sample freezing and thawing.

Variance between four observation values from the mixed samples was larger than variance between the determination values of the four individual sub-samples taken from one sample. Here too, the comparison of fresh with frozen samples showed that the coefficients of variation of the frozen samples were larger. Exceptions were the values for microbial biomass BM (SIR), which exhibited an average coefficient of variance of < 5% for fresh and frozen samples. The results show that for the selected soil microbiological parameters a precise description of the test plots was possible based on four observations per plot. Regarding optimisation of sampling and measurement effort, a reduction from four to three observations and from four to three or two determinations would be possible without a substantial precision loss.

In terms of temporal changes of soil properties in the field, the results show that a comparison of the trends reveals few agreements and analogies between the different methods and the soil microbiological parameters. The exception is the microbial biomass BM (SIR), for which a similar trend could be detected for all sites. For the other three parameters, the trends of the curves show slight agreement, and are characterised by many random deviations or changes, possibly caused by unknown factors in the process of sample preparation.

For an assessment of the values measured and their changes over the course of time, comparison with an anticipated reference value was an important criterion. Currently, a reference-value model enabling the results to be given not as absolute parameters, but relative to a reference value typical for a site, is only available for the soil microbiological parameter microbial biomass BM (SIR). The evaluation of the data for microbial biomass BM (SIR) employing the reference-value model showed a relevant temporal change between survey values for one site.

To sum up, the results show that the soil microbiological parameter microbial biomass BM (SIR) is suitable for long-term monitoring in terms of all criteria studied. The other parameters suffer from different disadvantages for individual criteria and, therefore, in general cannot be recommended yet for long-term monitoring.

Conclusions, recommendations and prospects (Report Part 4)

To summarise, within the LAZBO Pilot Project the following aims were achieved:

1. Random and systematic errors of the selected methods to determine soil physical and microbial parameters could be estimated and are basically quantifiable.

2. The outlined and tested sampling, storage and analysis strategies enable reference-stable tests over at least one year. The influence of systematic errors on the parameter values due to sampling, storage and preparation can be minimized by means of calibrations and vigorous standardisation of the process.

3. A hierarchical sampling design was introduced and optimized for the soil physical studies.

4. Statistical models for analysis of variance and time series of survey values were introduced to analyse background noise and trend for parameters at a site over years to decades.

5. Feasibility and effort were quantified for sampling and measurements of surveys from three subsequent years.

The LAZBO Pilot Project demonstrated that variance and bias of methods to determine soil physical and microbiological parameters can be determined and, at least to a certain extent, controlled over a fairly long period of time employing suitable determination methods and sampling design. The study also confirmed the importance of the right time of the year for an optimal sampling. Narrow time windows for sampling soils with difficult workability might be a major obstacle to operate a larger soil physical monitoring network.

The chosen methods to determine soil physical parameters were feasible for both sites. An estimate on the necessary effort showed that for one survey approximately 22 working days have to be taken into account for laboratory tests on all selected parameters, including sampling and sample preparation. Two working days are necessary for the field testing. Depending on the aims of a monitoring for soil physical properties, the effort for sampling and laboratory testing can be reduced by 50% if just one core size is used (assuming the same total amount of samples). The methods chosen for determining biological soil parameters turned out to be feasible at all six sites. Approximately 22 working days must be budgeted per survey for the test programme at six sites. By reducing the amount of observations (mixed samples) from four to three and determinations (sub-samples) from four to three or two, the effort for laboratory testing can be reduced up to 40% without a substantial precision loss.

The ongoing LAZBO Test Phase (2004–2006) validates the optimised design for soil physical sampling as well as the statistical time series analysis outlined in the LAZBO Pilot Project. By the end of 2006, survey values from additional three years will be available providing more reliable mean and variability values for the individual sites to quantify their background noise and detect possible trends. By then LAZBO Pilot Project and LAZBO Test Phase will provide the methodological bases to monitor physical (NABOphys) and microbiological soil properties (NABObio).

Next steps would be to define specific aims for NABOphys and NABObio and, subsequently, assign a set of soil physical and microbiological “target parameters” to be monitored. Special emphasize should be given to target parameter sensitivity with respect to (negative) physical, chemical and biological impacts as well as the value of the individual target parameter to characterize relevant soil functions appropriately. Stratification of the test sites, e.g. distinction of “super sites” (sites where physical, chemical and microbiological parameters will be determined) and sites where only a limited amount of parameters will be determined will play an important role in outlining a monitoring plan. In addition to practical considerations (different requirements of physics and biology regarding test sites, optimum sampling and measuring effort, etc.), this raises the question to which extent chemical, physical and microbiological parameters can be determined at the same test site, plot or even individual sample, necessary to detect interactions between soil chemical, physical and microbiological parameters. Eventually, since for practical reasons it is impossible to run a comprehensive monitoring program including all conceivable risk constellations the question arises whether in addition to a core network based on the ongoing NABO monitoring program, problem-oriented cross-disciplinary research should also be included, in order to test potentially problematic constellations.

As an outlook from the soil physics point of view, a long-term monitoring program would provide the necessary reference system to assess, predict and prevent further physical soil deterioration. Especially slow deterioration processes with small but gradually increasing effects due to relatively small but frequent impacts, for example compaction or erosion, can only be detected with reliable reference values gained from long-term observations. Long-term monitoring of microbiological soil parameters would make a decisive contribution to observe and assess negative chemical, physical and biological impacts on the soil. Possible goals could be: (1) Monitoring the influence of diffuse impact on soil microbiological properties, (2) Monitoring of sites where pronounced chemical or physical impact has to be expected, or (3) Monitoring the influence of agricultural and forestry use, or even the use of recreational areas on soil properties. Depending on the goal of a soil microbiological monitoring, the choice of sites and target parameters as well as concomitant parameters like pH, organic carbon content and texture (which have to be determined in a sensible way) may differ. Finally, future long-term monitoring of soil physical and biological parameters should not only complement the existing National Soil Monitoring programme and therefore fill a critical gap in the overall approach of Swiss environmental protection legislation, but could also serve as a role-model of how to address pressing physical and biological soil-protection problems with a positive impact even beyond Swiss borders.

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Glossary

Accuracy	Umbrella term for precision and bias.
Background noise	Random deviation of the individual survey values from the site value.
Bias	Measure for systematic error of determination, observation, survey or site values.
Determination	Comprises the procedural steps preparation, storage and determination method, and is the third tier in the hierarchical sampling design.
Determination value	Individual value within an observation, measured from an undisturbed core sample (soil physics) or a sub-sample drawn from mixed sample (soil biology).
Determination method	Method for determining a value for a soil physical or biological parameter from an individual core sample (soil physics) or sub-sample of a mixed sample (soil biology), takes into account conditioning, treatment, incubation, extraction and analysis of the sample.
Observation	Comprises the procedural steps sampling, sample preparation, storage and determination method, and is the second tier in the hierarchical sampling design.
Observation value	Individual value within a survey, determined as the mean of the determination values obtained from one observation block (soil physics) or one mixed sample (soil biology).
Observation block	Sub-unit of the test plot, from which all individual samples for the *soil physical* studies of one observation were taken.
Precision	Measure for random error of determination, observation, survey or site values, expressed as *variance*.
Reference stability	Measure for the systematic error of a determination carried out at various points in time using the same method in the same laboratory *relative to a defined reference value*. Is of particular interest in this study for the influence of the sample storage on the determination values of the biological soil studies.
Reference value	Standard- or calibration value with known variation and (ideally) bias.
Relevance	Used in this study for the actual significance and extent of the change in soil physical and biological properties.
Survey	Comprises the procedural steps sampling design, sampling, sample preparation, storage and determination method, and is the first tier in the hierarchical sampling design.
Survey value	Individual value within a site, determined as the mean of the observation values from one test plot.
Sampling design	Hierarchical scheme for (a) the spatial arrangement of the samples taken in the field, and (b) the aggregation of determination values (third tier) into observation values (second tier) and survey values (first tier).
Sensitivity	Measure for the intensity of change of a soil parameter due to physical, chemical or biological impact (e.g. mechanical stress due to vehicle traffic, tillage, harvest operations, etc.).
Site value	Mean of the survey values determined at subsequent time steps.
Indicator value for soil functionality	Measure for a soil parameter to characterize soil functions, e.g. soil permeability as a measure for fluid flow and transport properties of a soil..
Stability	Measure for the systematic error of a determination, observation, survey or site value *compared to an (arbitrarily) defined reference valu*e.
Trend	(Significant) temporal change of survey values.