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## Evaluation report for Thunen institute, The German Agricultural Soil Inventory

Nicolas P. A. Saby, Claudy Jolivet, Bas van Wesemael, Heikkinen Jaakko,  
Lars Elsgaard

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Evaluation report for Thunen ins  
The German Agricultural Soil Inventory

Nicolas Saby, Claudy Jolivet, Bas van Wesemael, Heikkinen Jaakko, Lars Elsgaard,



**Authors**

Nicolas Saby, Claudy Jolivet, unité Infosol, INRAE, Orléans, France

Bas van Wesemael, Earth and Life Institute, UCLouvain, Belgium

Heikkinen Jaakko, Natural Resources Institute, Luke, Finland

Lars Elsgaard, Department of Agroecology, Aarhus University, Denmark

# 1. Backgrounds and Goals

The German Agricultural Soil Inventory (BZE-LW) is running a general project evaluation as this network is currently in the phase between the first and second sampling campaign, the latter starting in 2023.

A one-day meeting was held in Braunschweig to discuss the general results of the first campaign and the organisation planned for the next campaign. The following scientists were present:

- Bas van Wesemael, Earth and Life Institute, UCLouvain, Belgium
- Nicolas Saby, unité Infosol, INRAE, Orléans, France
- Claudy Jolivet, unité Infosol, INRAE, Orléans, France
- Heikkinen Jaakko, Natural Resources Institute, Luke, Finland
- Lars Elsgaard, Department of Agroecology, Aarhus University, Denmark
- Axel Don and Christopher Poeplau, Thünen Institute

This report gathers some general comments and ideas organised according to the list of questions raised before and during the workshop.

## 2. Central questions to be discussed

### 2.1. What is the general opinion on the first soil inventory?

General comments:

The German agricultural soil inventory (BZE-LW) was designed (nationwide coverage of network, sampling depth intervals coincide with IPCC guidelines, well documented site history) in such a way that it strongly contributes to the development of the national greenhouse gas (GHG) inventory, which was the main aim of the network. The first soil inventory focused on soil organic carbon (SOC) stock monitoring. Data can be used to estimate accurate baseline SOC stocks but also to develop and to validate modelling tools to estimate GHG emissions from agricultural soils. The network is so extensive that it might even be possible to estimate SOC stock changes based on the direct SOC measurements in the future.

The inventory consists of a set of 3,104 agricultural sites, selected along a 8 x 8 km systematic grid and sampled during the 2009-2018 period with the following characteristics:

- GPS geo referencing + metal marker to ensure retrieval in the future,
- Results from comprehensive questionnaire on practices filled in by the majority of the farmers,
- Payment of 100 € compensation for farmers,
- Reconstruction of historical land management based on various sources,
- field work: 3 operators in the field including a soil scientist, 9 teams.
- 1 soil profile 1m x 1m x 1m for soil description, 5 or more layers sampled and analysed, integrating complexity of soil layer and pedogenic horizons,

- 2 bulk density measurement repetitions per layer,
- 8 satellite cores with percussion sampler (finally not used due to bias).

BZE-LW sampled more than 33,000 layers from the 3,104 sites! A set of 215 core sites was also used for complementary analyses.

Generally, the BZE-LW has done an impressive scientific valorisation with a large range of topics and strongly focused on carbon.

Compared to many other networks in Europe, which were initially planned to observe e.g changes in soil fertility or productivity, BZE-LW was set up with a focus on SOC . This included also determination of rock fragment fractions in order to allow for proper SOC calculations. Sampling design allows the calculation of SOC stocks based on both equivalent soil mass and fixed depth methods.

Questions and recommendations :

- Use of a grid with a small distance between nodes is very important, it ensures a large flexibility of the network to compute global and local statistics (Design Based and Model Based approaches for computing statistics)
- The combined use of fixed depth increments and horizons is very valuable.
- Thorough investigation of the different aspect of the SMN (NIRS model, process based model, comparison between measurements)
- Like many SMN's in Europe, it was noticed that information on the minimum detectable change (MDC) is missing. MDC is the minimum change in a C stock over a given period of time required to be considered statistically significant.
- A task to provide **feedback** to farmers should be implemented.
- It is possible to better investigate the uncertainty of the statistical estimator of the mean and the total of the carbon stock using more sound statistical techniques following a design-based approach. see (Brus and Saby, 2016)(Design Based estimates of the sampling variance)
- Use of registers for agricultural subsidies to determine the cropping history, farm type etc. might be considered, as it allows for a more uniform/systematic/cost-efficient approach compared to farm questionnaires.
- Plough depth is usually 15-20 cm. Sampling increment used 0-10 cm,10-30 cm,30-50 etc, so 10-30 cm falls in the middle of typical plough depth. It might be better to match the sampling depth with the one of the plough layer while ensuring to be able to report to the IPCC standard depth of 0-30 cm.
- Extremely comprehensive sampling procedure, but also demanding to carry out in the field and time consuming. Balance between the data quality and the time spent to collect the data?

## 2.2. What is the general opinion on the new sampling design?

This is an ambitious new campaign!

General comments:

The general objective is the detection of SOC changes and their drivers. A 10 years sampling interval has been retained. Complete resampling of around 3,000 sites (except very organic ones MOMOK<sup>1</sup> and lost ones), likely budget cuts, Thünen suggests to dig 4 soils pits per site at a distance of 2 m to minimise local variation, 0-50 cm depth only, ie 3 layers, which means to measure 24 times the Bulk Density. They plan to ask a single operator to dig and sample 4 soil profiles 0,8x0,8x0,6 cm. This modified setup ensures minimisation of uncertainty in the SOC stocks, while its design allows for sampling in the future.. The data on sampling and soil profile description will be collected as much as possible using a tablet template (connected / disconnected mode). No further assessment of rock fragments which remain constant in time.

If temporal trends in SOC are the main interest, it's important to take the samples the same way as during the first sampling campaign. With this respect soil pit sampling is justified, even though soil pit sampling might have some disadvantages (soil disturbance, relatively small number of subsamples per plot, possible spreading of subsoil material on the surface soil) in comparison to more commonly used soil core sampling. However, soil pit sampling also certainly has some advantages such as lesser degree of soil compaction and it allows better visual examination of the soil profile. Obviously the Thünen group has done a lot of pre-testing to check that results based on the soil pits are reliable and to calculate how many pits are needed. In soil pit sampling the number of subsamples is relatively low and thus it is very critical to locate sampling plots accurately, which is not a problem in this case as locations are determined using differential GPS and there are metal markers on the soil.

Questions and recommendations :

- Huge work, 4 pits is a lot of work for 1 man in the field. Is it realistic and manageable? Mechanical digging or by hand? Note that the pits are small.
- Analyse some samples from the first campaign together with the series of the 2nd campaign to assess analytic bias and ensure consistency in the time series.
- Important to take into account small scale heterogeneity when resampling
- Which temporal strategy of resampling?
- Ensure an optimal distribution of the sampling in the space time domain?

## 2.3. What is your experience and recommendation for dealing with small scale heterogeneity at sampling points?

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<sup>1</sup> Moor Monitoring für Klimaschutz (peat soil monitoring for climate mitigation)

The general approach to deal with small scale heterogeneity is to repeat the measurements and bulk them to overcome the problem. Favouring a compositing approach helps to reduce local spatial variability (auger sampling to avoid compaction with percussion auger)(Guerrero and Lorenzetti, 2021), but issues occur with the evaluation of bulk density variance.

Another issue is the large number of subsamples per plot, which is of course a problem in sampling based on soil pits.

Area of the sampling plot should be as small as possible. But size of the sampling plot depends also on how accurately sampling plots can be located. If the localisation is accurate, then the sampling plot can be smaller. If location is determined using maps or normal GPS, then subsamples have to be collected in a bigger sampling plot. In the German inventory they have extremely precise locations (metal markers and coordinates are determined using differential GPS).

(Lark, 2012) has shown that both the precision and the consistency of data collected on an aggregate support are better than data on a core support.

Following the discussion during the meeting, BZE-LW defined a new design presented in the figure below.

This new design might increase the scatter of the data a bit as the sites are a bit further apart from the central soil pit than in the original design, but it is probably less sensitive to systematic errors and provides a clear plan where to sample not only in this second sampling campaign but also for future campaigns. It is also possible to assess the uncertainty of the mean if the carbon content of individual samples per pit is measured. This system has similarities to the current design of the Danish SOC monitoring program, which is based on soil corings rather than pits, though.

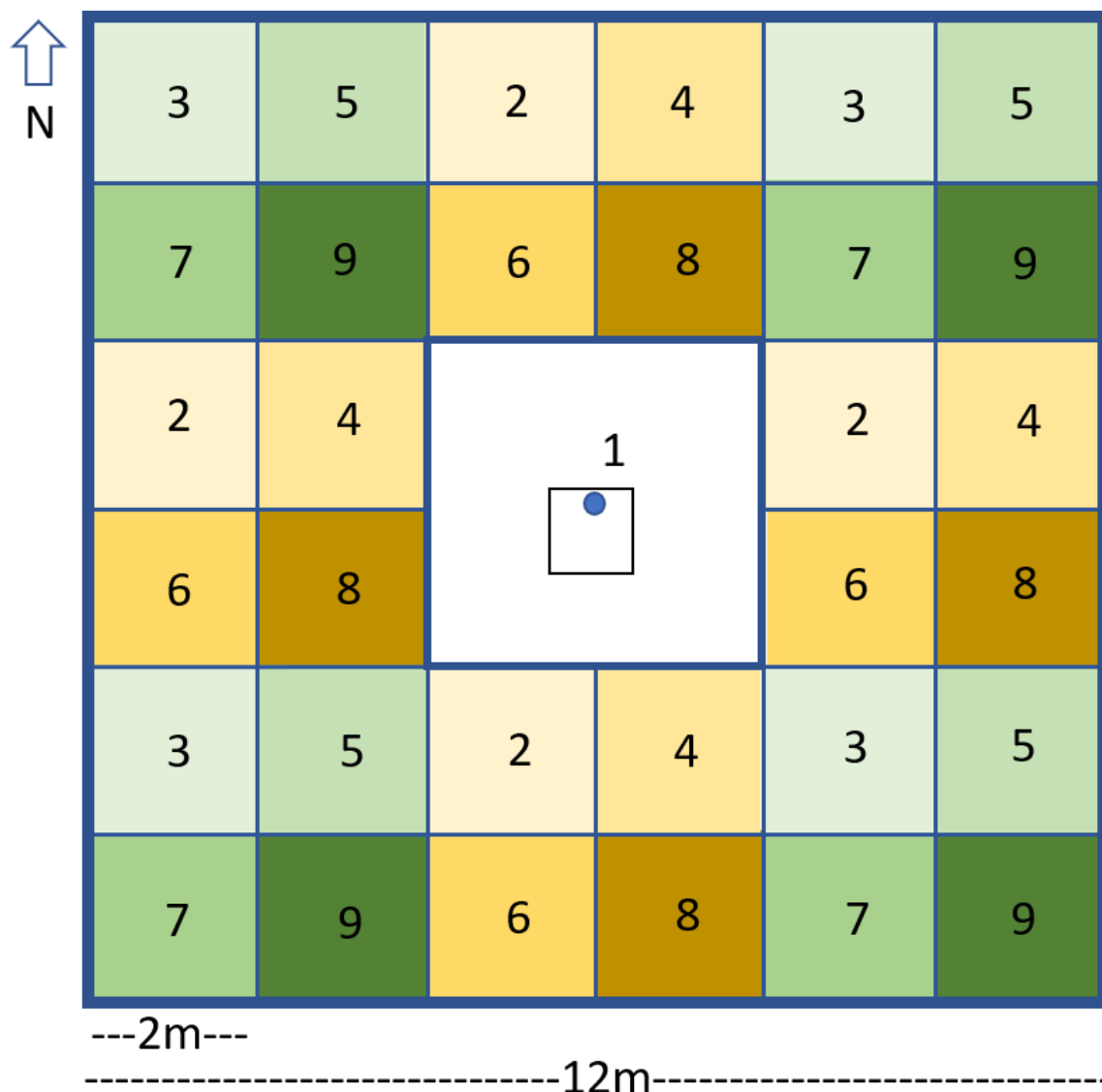


Figure 1: New sampling design, the blue dot is the marker in the soil and the numbers are the inventory rounds

## 2.4. Is it worth analysing each profile separately, or should we consider pooling?

Analysing each profile separately gives access to variance evaluation and possibility to fit a linear mixed model with longitudinal data. Thus, it's better than pooling but implies a stronger financial effort, especially with the large number of sites to cover in the national inventory. Instead, one could use composite samples and collect a MIR spectrum before compositing the samples and assess the variability based on the spectral prediction of SOC content. Two recent studies provide some inputs on the subject (Guerrero and Lorenzetti, 2021; Viscarra Rossel and Brus, 2018).



If understood correctly, at least in some soil pit pre-testing experiments, the profiles were analysed separately. Maybe that information could be used to see if it's worth analysing the profiles separately or not. It is probably better to take many subsamples per plot and pool them than to take a few subsamples and analyse the profiles separately.

## 2.5. What is your experience and recommendation for dealing with soil disturbance of previous sampling campaigns at sampling points?

Use real time correction GPS with centimetric accuracy to relocate sampling points whenever possible. In forest or uncovered areas use metal or passive marker (such as 3M ball markers, avoid metal interference)

50 cm northwards from the first soil profile could be insufficient to avoid previous soil disturbance (deposits of deeper soil horizons around the soil pit spread with successive soil tillage, change in water circulation, vegetation alteration for instance). One or two meters should be recommended.

Separating the subsoil and topsoil in the field when digging the soil profile and then back filling the pit in the same order.

## 2.6. How (in which direction) should the row of profiles be shifted when the point is located on a hillslope?

General principle: shift the row of profiles along the hillslope, in order to have pits at different altitudes, involving the soil variability, during the successive campaigns.

But: need to be appreciated by the soil scientist in the field regarding local geomorphology (change in the gradient, cross slopes, concavities, convexities) and soil variability (depth, horizon development, stone contents, etc.). Difficulty to assess the spatial variation in situ. Avoid that the profile shift corresponds to the spatial trend.

Indeed, based on the discussions related to this issue, a new sampling design was considered (checkerboard approach), as presented in Fig. 1. This would also be applied for hillslopes.

## 2.7. Is it advisable to leave out the subsoils (50-100 cm) in the second Inventory?

It sounds reasonable to say that carbon content of subsoils is generally low and not sensitive to changes. However, changes can occur in case of deep ploughing or subsoiling. Or by management changes that include increasing use of deep-rooted crops. Climate change is also susceptible to affect soil mineralization conditions and to provoke substantial loss in subsoil carbon content but probably in a longer period of time than 10 yrs (see experiment by (Soong et al., 2021)).

## 2.8. Is it necessary that soils are resampled in the same season (stage of management) or not?

It is usually admitted that it is better to sample when the soil is wet or close to the field capacity. it could avoid some seasonal effects. However, the state of management is not supposed to have an impact regarding long time monitoring of soil carbon stocks. Indirect effects could occur if the soil is not sampled at the same water content: difficulties to sample at the same depth between the first and the second campaign, or less accurate sampling for bulk density measurement, for instance. These constraints could be avoided when sampling is conducted at field capacity (but constraints related to the stage of crop development may make it difficult to organise a sampling campaign when the crops are fully grown).

In agricultural soils there is also clear seasonal variation in the root biomass and in the amount of aboveground litter, which could have some impact on SOC measurements. However, this is largely counteracted by carefully separating living biomass from soil. Yet, also in this sense it is advisable to take samples in the same season. Anyway, in agricultural land there is such a lot of variation due to changes in cultivated crop species and growth stage due to variation in annual climate that probably there's no reason to have plot specific timing for the sampling, but rather identify a period of a few months when the conditions for sampling are considered to be optimal.

## 2.9. Should we shift sampling points (search for new), if original points are not available anymore due to land use change (to urban) or missing permission for sampling by farmers?

In France, we decided to replace the lost sites in case of artificialisation or missing permission for sampling by farmers, in order to avoid a progressive reduction of the number of monitoring sites. New sites are replacing lost ones, but soil parameter evolution is not computed between lost and new sites. From a statistical point of view, it is possible to use these observations to better explore the spatio-temporal domain. This inevitably makes the calculation of evolution more complex because one must take into account the reasons inherent to the loss of the site (artificialisation means no more C stock).

If there is some rough idea how many points are not available in the next sampling campaign, one option would have a certain number of extra plots, which will be sampled anyway to replace the missing points. In any case it would be good to have some systematic random approach, for which desktop-based design would be preferred rather than an ad hoc decision in the field.

If geostatistical approach is considered in the future, (Wadoux et al., 2019) recommend adding close points to better estimate the spatial correlation at small distances.

In Denmark, the contact to landowners is via the farmers national advisory service, and no system is in place for replacement of sites that are no longer accessible. With the new EU GDPR regulations quite a number of sites have been lost due to difficulties in obtaining the required permissions for individual land owners. So, a proactive plan for how to deal with sites that are no longer accessible is highly recommended.

Also, it might be good to think about the definition of agricultural land. Agriculture is anyway evolving all the time and for instance nowadays there's probably more water protection zones, biodiversity fields and not that actively cultivated fields than in the past (kind of grey area whether they belong to cropland or grassland or some other land use type). When selecting the new points, the whole sample population might shift to some direction just because the definition for agricultural land is changing.

## 2.10. It is worth to create new sites to explore spatio temporal space, but how to use it?

It is useful for model-based estimates like mapping using kriging.

As the differences cannot be computed, these observations will contribute to the estimate of the spatial means and their uncertainty at each campaign. The covariance cannot be computed. In the set of basic space-time design, the supplemented panel is implemented this approach (Brus and de Gruijter, 2011)

Nevertheless, it could be interesting to have a number of sites that are followed more closely in time (seasonal or annual). Even though differences on SOC can generally not be documented statistically on an annual basis, it could be valuable with several data points over, e.g., a 10-year period to obtain better certainty in the trend, that would otherwise only rely on interpolation between two data points (for a sampling frequency of 10 years).

## 2.11. Which additional (somewhat SOC/SOM-related) parameters could and should be measured (e.g. soil structure parameters)?

The aggregate stability could be assessed using the wet sieving method of Le Bissonnais (Le Bissonnais, 2016). This should not necessarily be measured for each sample point by wet sieving. Shi et al (Shi et al., 2020) have demonstrated the performance of visNIR spectroscopy for assessing the mean weight diameter based on the wet sieving technique.

Landmark protocol for infiltration capacity approach

There is a rapid development of soil spectral libraries. Several initiatives are launched (Glosolan, IEEE P4005 and Soilspe4GG) in order to define an analytical protocol for soil spectroscopy and facilitate exchange of spectra between spectral libraries through the use of internal soil standards. Both visNIR and MIR techniques are used. In particular the visNIR techniques offer spatial extrapolation. Hyperspectral satellites have been launched (PRISMA) or are in preparation (SBG, EnMAP, CHIME). In the future visNIR spectral libraries would offer the possibility to calibrate a SOC prediction model that can then be applied (using an internal soil standard) to predict SOC for bare cropland pixels in the hyperspectral imagery. Currently, the Worldsoils project (<http://www.world-soils.com>) is developing an operational for SOC prediction based on the multispectral Sentinel 2 signal. For this multispectral instrument, the calibration is directly on the satellite spectrum and SOC content of the corresponding pixel.

Stable C Rock-Eval

Water content

Biological parameters as determinant of organic carbon stock evolution, soil structure, porosity, etc.?

Simplified fractionation protocols have been developed based on wet sieving over 50 micrometers and measuring the SOC content in the fine fraction. This allows to separate the mineral associated fraction (MAOM) from the labile fraction (POM; (Just et al., 2021)).

DNA extraction for soil microbiomes (bacteria, fungi, macrofauna)

Black carbon, biochar

Mineralogy (especially clay mineralogy might be interesting in relation to SOC)

## 2.12. What is the minimum size of a stratum to detect differences? How is the actual MDD (after resampling) in other inventories? How can MDD be estimated beforehand without resampling?

It will depend on the variance of the stratum and the number of points. This could be assessed using the Minimum Detectable Difference (MDD) approach.

MDD is based on the variance of the difference which can be approximated or assessed by repeated sampling (huge work) and replicates. However, one can already get an estimate of the variance based on the existing sampling campaign. This variance can then be used to estimate the MDD.

## 2.13. Which synergies with LUCAS are used in other National Soil Inventories and shall be explored for the German inventories?

The number of well-established national soil monitoring programmes is limited, although some countries are starting such an initiative. As the German soil monitoring programme has already started, it is crucial to follow the same protocol as during the previous analyses. Therefore, it is difficult to exploit synergies with LUCAS or other national SMN's.

Recently, the JRC has launched an initiative for a European Soil Observatory. Obviously, it will be crucial for the German SMN to remain involved in this initiative. In the meantime, the discussions already started within work package 6 of the EJPSoil project to find possible ways of collaboration between EJP SOIL partners and the next LUCAS campaign:

- Comparison of data resulting from national and LUCAS SMS,
- Comparison of sampling protocol,
- Derivation of a method to use SMS data resulting from different sampling designs to derive global statistics,
- Quantifying the source of uncertainties of the different sampling protocol to quantify the MDD.

## 3. Conclusions

Germany has started an impressive soil monitoring network, based on the thorough sampling of profile pits and a comprehensive analysis of all variables allowing the assessment of SOC stocks integrated to a fixed depth, by equivalent soil mass or by soil horizon. The results have been exploited in an impressive number of publications in high quality journals. This report is based on discussions for the planning of a new sampling campaign of the existing network. Suggestions are given on mitigating the impact of local variability in SOC and potentially extending the SOC related parameters to be included. Overall, the protocol of the first campaign should be followed as much as possible, albeit limiting the sampling depth to 50 cm.

After all, changes in SOC in the subsoil (> 50 cm) are not to be expected within 10 years (period between the two sampling campaigns). Although coordination with the EU soil observatory and other national initiatives is crucial (as already developed through the EJPSoils network), the protocols of the original campaign should be maintained as much as possible in order not to compromise the monitoring of SOC over time. However, since the planned campaign is the first resampling in the German SMN, it has been possible to discuss and optimize the spatial design of this resampling, which then lay down the standards for subsequent stock takings in the future.

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