Detailed guidance for field work

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Contact details

Director of Coordinating Institute – ISRIC: Rik van den Bosch

Project Coordinator: Mary Steverink-Mosugu

Address: Droevendaalsesteeg 3, 6708 PB Wageningen (Building 101), The Netherlands

Postal: PO Box 353, 6700 AJ Wageningen, The Netherlands

Phone: +31 317 48 7634

Email: mary.steverink-mosugu@isric.org

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Author	Jeroen Huising, Johan Leenaars, Adam Csorba, Vera Felix da Graca Silva
Contributors	Mary Steverink-Mosugu, Erika Caskine-Micheli, Bas Kempen, Arwyn Jones, Gabriel Moinet
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Abbreviations

AEZ	Agro-Ecological Zone
AFSIS	Africa Soil Information Service
ARC	Agricultural Research Council, South Africa
BUNASOLS	Bureau National des Sols, Burkina Faso
BD	Bulk density
CEC	Cation Exchange Capacity
EC	European Commission
EC	Electrical conductivity
EU	European Union
FAO	Food and Agriculture Organisation (UN)
FARA	Forum for Agricultural Research in Africa, Ghana
LCCS	Land Cover Classification System (FAO)
LDSF	Land Degradation Surveillance Framework (AFSIS)
LUCAS	Land Use and Coverage Area Frame Survey (EC)
FNSSA	Food, Nutrition, Security and Sustainable Agriculture
GSP	Global Soil Partnership
IBEC	Interbalkan Environment Center
ICRAF	International Centre for Research in Agroforesty
IFA	Institut Facultaire des Sciences Agronomiques de Yangambi, DRC
IITA	International Institute of Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
IRA	Institut des Régions Arides, Tunesia
ISRIC	International Soil Reference and Information Centre
JRC	Joint Research Centre – European Commission
MIR	Mid-Infrared (part of the EM spectrum)
PTF	Pedotransfer function
KALRO	Kenya Agricultural and Livestock Research Organization
ODK	Open Data Kit
RCMRD	Regional Centre for Mapping of Resources for Development
SOC	Soil organic carbon
SGS	SGS Hungary Ltd

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SSU	Secondary Sampling Unit
SU	Stellenbosch University
SZIU	Szent István University
TSU	Tertiary Sampling Unit
VIS-NIR	Visible Near Infrared
WRB	World Reference Base for Soil Resources
WU-DOW	Wageningen University, Department of Environmental Sciences
WUR	Wageningen University & Research
WP	Work Package
XRD	X-ray diffraction
XRF	X-ray fluorescence

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Executive Summary

The Soils4Africa project will need to develop operational procedures for conducting its field campaign. This includes standard protocols and standard operating procedures for the field survey (sample collection and field observations) as well as guidelines for the organization and execution of the field campaign. This deliverable provides the guidelines based on which the technical specification of the fieldwork and the protocols and standard operating procedures are developed. At the same time, it explains how the field camping will be organized and implemented and provides the requirements for the management tools to be developed.

The conditions for the field campaign are the following:

- Survey of 20,000 sampling locations within agricultural land across continental Africa for assessment of soil properties, to be done within a one-and-a-half-year timeframe, including 250 sampling locations for assessment of heavy metals contamination and pesticide residues (with an additional 50 sampling locations in hotspot areas for the latter)
- Data from the field survey needs to allow making inferences on soil quality (i.e., needs to be relevant for the quantification of the selected soil quality indicators)
- Allow for repeated measurement on the sampling locations to assess change in soil properties and soil quality

This requires having numerous field teams working in parallel within each of the regional hubs. And this implies that the selection of the service providers, vetting them, training them, and providing instruction and monitoring progress is part of the process of conducting the field campaign. Also, it implies the use of simple protocols and for making field observations and collecting soil samples that do not require specific skills and experience and that do not require direct supervision in the field to assure that the observations are done correctly. Recording will be done electronically to assure accurate and reliable data. To carry out field work, use will be made of simple tools and implements that are readily available to all teams.

For this purpose, we designed the fieldwork such that at the 20,000 baseline sites (or standard monitoring sites) only disturbed soil samples are taken at 0-20 cm and 20-50cm soil depth, using either a spade or soil auger, to determine basic soil physical and chemical properties, like soil texture, pH, soil organic carbon, nutrients (primary, secondary and micronutrients), electrical conductivity EC and other. Soil properties that are more complex to assess, like bulk density and water holding capacity, for example, will be predicted from the basic soil properties using pedo-transfer functions (PTF). And, to establish and validate these PTFs, applicable in the African context, we will make use of the 250 reference sites at which these more complicated measurements will be made and at different depth intervals. We will also make use of the reference sites to investigate the use of MIR spectra for predicting these complex soil properties, as a special form of PTF.

At selected reference sites the soil profile will be escribed to investigate whether diagnostic elements of the World Reference Base for Soil Resources (WRB) classification system are relevant for expressing soil quality, as well as to evaluate the implication of using fixed depth intervals, rather than the variable depth associated with soil diagnostic horizons, on the assessment of soil quality. Furthermore, state-of-the-art field-based spectroscopy technology will be tested for possible future use. This includes a hand-held visible near-infrared scanner and portable X-ray fluorescence spectrometer.

The soil samples of the reference sites will be standardly analyzed for heavy metal contamination and for pesticide residues. For the latter, samples will be taken from 0-2 cm and 0-20cm depth, for which a separate protocol will be developed.

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At all sites, observations on terrain condition and land use and management will be made. The terrain conditions will refer to surface stoniness, soil drainage class, effective soil depth and groundwater level. The observations on land use will refer to the land use class and to crops observed in the field, as well as presence of livestock and signs of grazing. Included as well are the size class of the parcels and field pattern. Land management observations refer to ploughing and use of inputs, and soil and water conservation measures implemented. Observations on water management are included as well. These observations are based on visible signs of these process or practices solely. For the reference site a simple questionnaire is devised to get information on input use and use of pesticides especially.

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1. Background, Objective and Purpose

The purpose of this activity is to provide detailed guidelines for the field work, based on which protocols and standard operating procedures for the field work will be developed (Task 4.2). The guidelines specify the requirements for, and general specification of, the field campaign. This activity is part of WP3, which concerns the design of the soil information system in all its aspects, and it is identified as Task 3.5 with deliverable 3.3 as the corresponding output. This deliverable determines which observations are to be made in the field and provides specifications for the collection of soil samples. These guidelines are meant in the first instance for the 20,000 sampling sites that will be used as a baseline for future monitoring of soil qualities. Guidelines are likewise provided for the sample collection and field observations for the reference sites.

At the refence sites the project will make more detailed observations and measurements that will help to understand complex properties and relationships. These data will be used to develop functions for estimating or predicting other soil properties that are otherwise difficult to assess and will not be measured directly at the monitoring sites. The data from the reference sites will also be used to develop and evaluate the methods for deriving indicators. In addition, at the reference sites we will assess soil contamination by heavy metal and pesticide residues. These are parameters of special interest for soil quality assessment but due to technical/logistical and budgetary constraints cannot be measured in all samples. Guidelines for field observations and sample collection at the reference sites are included in this report.

For developing the guidelines for the field work, we need to consider the indicators selected in T3.1 and the resulting data requirements regarding soil properties. The soil properties for which information is required depends on the methods that we will use for deriving the selected soil quality indicators. An important question in this context is the depth at which soil samples are collected and whether and which observations and measurements of the sub-soil are needed for the assessment of soil qualities, where LUCAS only takes topsoil samples, for example.

Another question is which parameters are considered permanent and which are assessed only once to provide the relevant contextual information and which parameters are intended for repeated measurement to monitor change. At the same time there are considerations concerning the practicality of the sample collection and field measurements given the conditions in Africa that may have implications for the type of observations that can be done and for the level of detail and accuracy of these observations. Consequently, the soil quality indicators we select need to be adjusted to what is feasible to be observed from the field and the methods for deriving the soil quality indicators needs to be adjusted to these conditions as well. Therefore, determining the minimum set of soil parameters and developing guidelines for the field work is an iterative process involving simultaneous discussion on the sampling design, soil quality indicators, samples analysis and data analysis as well as the overall system design. The outcome of these discussions is presented in D3.1 'Methods for deriving selected soil quality indicators' [1], D3.2 the sampling design, D3.4 guidelines for the laboratory analysis and D3.5 the user requirements for the IT infrastructure. In this report we present the type of field observations for the fieldwork and provide specification of the sample collection for the standard monitoring sites and the reference sites.

Another consideration is the amount of soil sample to be collected; we want to transport only the necessary amount of soil to avoid high costs which may also affect the sustainability of the program in the long run. How much soil needs to be shipped depends on the lab methods and techniques that will be used for the soil analyses at the reference soil lab, and on the analyses that can be done locally. Only the minimum amount of soil is to be sent that is needed for the analyses that are to be done in the reference laboratory of ARC in the RSA. The same applies for soil samples to be sent to WUR and USDA-NSSC-KSSL reference lab for analysis of pesticide residues.

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Because not all samples will be subjected to wet chemistry, the selection is done prior to shipping the selected soil samples.

Sample preparation and storage of the soil samples is considered part of the field campaign and will be done locally in as far as facilities are available and guidelines need to be developed for the sample preparation and storage. This requires deliberations with task force T3.6 that provides the guidelines for the laboratory analysis.

A further aspect of the guidelines for the field campaign concerns observations related to terrain conditions, land use and land cover. This project aims to provide a system to monitor and evaluate soil quality in relation to intensification of agricultural use, identifying threats to the soil resource and opportunities for sustainable intensification. This requires information on terrain condition, land use and land management. This refers to erosion, to whether the land is irrigated or fertilised, or to intensity of cropping, for example. For Africa that information is not readily available. In the sampling design, stratification based on land use or farming systems is considered because we want to provide a baseline for future reporting on changes in soil qualities for the different land use systems including intensified management practices. But the information from existing data sources will not be specific enough to allow for a meaningful evaluation of changes in soil qualities with reference to land use. Hence, guidelines will be developed for collecting data on terrain condition, land use and land management by means of direct observation in the field. There will not be enough time available for interviewing the farmer on land use history, agricultural practices during survey of the standard monitoring sites. The farmer will have to provide consent to the field team accessing the land and possible implications of that consent not being given will have to be considered.

An important consideration with regards to all observations, as well as the sample collection, is the accuracy and precision of the measurements and reliability of the observations made in the field and the implications this may have on the accuracy of soil quality indicators and ultimately on the reliability of statements on soil quality and changes therein. Spatial variability is an important aspect in this. The discussion on how to address this spatial variability and measurement error overlaps with the discussion on the sampling design. It is a discussion on the scale of observation, which may be different for land use (incl. management) and land cover than for soil and terrain. For the soil sample we take subsamples that we bulk to cover the local, short distance variability that covers an area of a certain size, $25m^2$ in our case. On the other hand, it can be questioned whether an area of $25m^2$ (the size of the tertiary sampling unit, TU) is adequate for observations on land use and land cover, especially when the land use is not cropland and there are no clear field boundaries. We have to make provision for observations on land use and land management beyond the TU (adjust the scale). With respect to the room for error in the observation itself, we aim to limit the number of observations in the field, and to keep them as simple as possible and to leave little room for interpretation by the field surveyor. This has shaped the guidelines for the field campaign to a large extent.

For developing guidelines for the fieldwork, we took advice from LUCAS. However, that gives partial answers because the context and framework of LUCAS is different from the Soils4Africa project. Especially, LUCAS has a very elaborate component on land use and land cover (the monitoring of which was the original objective for starting the programme). The instructions for surveyors of LUCAS [2] is too specific and elaborate to be of practical value for developing the instructions for surveyors of the Soils4Africa project. We can borrow a page from the approach used by AFSIS as described in the Land Degradation Surveillance Framework (LDSF) [2], which is still quite elaborate and complex. We have also borrowed elements from later but similar initiatives, which seem to have moved towards more limited number and simpler observations in the field. For developing the guidelines for the field campaign of the Soils4Africa project, all these sources have been consulted and the information reflected upon.

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2. Approach and process

The approach, for developing detailed guidelines for field work, has been to review the protocols adopted by LUCAS and AfSIS (both first and second phase), and to reflect on recent experience with implementing projects directed at soil inventory and mapping. The framework of the Land Use/Cover Area frame statistical Survey (LUCAS) is very well described in the Technical reference document C1 – Instructions for Surveyors [3]. The Technical Reference Document C2 [4] provides the corresponding template of the field form and ground document. A soil component has been incorporated in the LUCAS survey of 2015 for the purpose of soil quality modelling and monitoring. Remarkably, very little observations are made in the field in relation to soils, apart from stones and plant residues at the soil surface. However, observations on soil erosion are included as a separate section.

The Land Degradation Surveillance Framework (LDSF) [2] also minimizes field observations related directly to soils. The framework records rock, stone and gravel cover of the soil surface and rooting depth restrictions; it assesses soil texture by hand in the field and records visible signs of erosion as well. It conducts elaborate measurements in the field on soil infiltration capacity and collects samples for soil bulk density assessment following the cumulative mass method. Subsequent protocols of AfSIS Phase II did not include such detailed observations and was restricted to collection of soil samples only and scouting for crops and livestock.

Land use and land cover are recorded in detail in the LUCAS approach. In AfSIS originally, land cover was recorded at the higher level using a general description of the land cover classes with characteristics of the vegetation recorded in detail (cover percentage of the various vegetation structural layers, and density and height of tree and shrubs, as well as presence of exotic species). Later protocols replaced these measurements with recording the type of crops present at the location.

The purpose of the survey determines what needs to be surveyed. However, while implementing a program the purpose may change and objectives adjusted. This often renders much of the recorded data superfluous or unsuitable for monitoring purposes. This may have been true for LUCAS and AfSIS. To prevent this happening in Soils4Africa, We are trying to prevent such by defining the minimum set of parameters, reviewing the actual and possible application of the data for the parameter under consideration and rejecting it when these cannot be clearly identified.

Based on the comparison of the AfSIS and LUCAS approaches and reflecting on experiences from other initiatives a proposal for the specifications of the field observations and measurements was made, reflecting on the relevance and the accuracy and reliability of the possible observations. On the one hand, relevance is determined by the relative importance of the observation for assessing and evaluating soil qualities. On the other hand, the relevance is determined by the level of specificity required and level of accuracy and precision that can be obtained. The variability in the measurement of a certain soil property may be too large to allow for the monitoring of change in the property within a certain time horizon, rendering it irrelevant. These are obviously important considerations in designing a robust soil quality monitoring system.

The proposal for the soil parameters, terrain, land use (agricultural product and management) and land cover characteristics to observe and the underlying reasons for the choice of these parameters were discussed with the various task forces, the core team of WP3 and with the teams of the sub-regional hubs. The conclusion reached on the specifications are presented in this document.

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3. Specifications of field observation and sample collection (standard monitoring sites)

Soil physical and chemical parameters for topsoil and subsoil samples

Table 1 provides the list of physical and chemical soil properties that are part of the minimum set of soil parameters to assess. In red are the soil parameters that are mentioned in the Soils4Africa proposal as the minimum set. We have included additional soil parameters that are considered by the LUCAS program and AfSIS project, but not all. For example, 'coarse fragments' and 'electrical conductivity' (EC) are mentioned by LUCAS, but LUCAS also mentions clay mineralogy which has not been adopted.

Table 1 Minimum set of soil physical and chemical parameters to be determined by analysis of soil samples for the 20K sampling sites

Soil parameter	Specification	Topsoil (0-20cm)	Subsoil (20-50cm)
Coarse fragments	2mm – 63 mm (volume fraction)	✓	✓
Soil texture - % sand	< 2mm	✓	✓
Sol texture % silt	0.002 – 0.063mm	✓	✓
Soil texture % clay	< 0.002mm	✓	✓
Bulk Density*	by PTF	✓	✓
pH (H2O)		✓	✓
pH (CaCl2)		✓	✓
Soil organic carbon (SOC)	%	✓	✓
Total Nitrogen (TN)	%	✓	
P-available	ppm	✓	
Ca-exchangeable	$cmol^+/kg$	✓	
Mg-exchangeable	$cmol^+/kg$	✓	
K-exchangeable	$cmol^+/kg$	✓	
Na-exchangeable	$cmol^+/kg$	✓	
H+ exchangeable	$cmol^+/kg$	✓	
Al3+ exchangeable	$cmol^+/kg$	✓	
(Mn2+ exchangeable)		✓	
S-available	ppm	✓	
Cation Exchange Capacity (CEC)	$cmol^+/kg$	✓	
Effective Cation Exchange Capacity (ECEC)	Exchangeable bases and exchangeable acidity	✓	
Zn	ppm	✓	
B	ppm	✓	
Cu	ppm	✓	
Fe	ppm	✓	
Electrical conductivity (EC)	dS/m	✓	

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Carbonates content	ppm	✓	
P-sorption	ppm	✓	
Discarded/rejected			
Structural stability (aggregation)			
Water dispersible clay			
Clay minerology			
Moisture retention pF 2.5	(by PTF)		
Moisture retention pF 4.2	(by PTF)		

Soil properties like 'Aggregate stability' have been rejected because the cost implications for the sample collection are too high in view of its relevance and importance as an indicator of soil quality. It requires additional and separate soil samples to be collected involving extra work in the field. The soil samples cannot be dried or ground and need to be processed different and separate from the other samples collected from the same location. It would be impractical to ship them for analysis at the reference lab, and we do not have standard methods for the analysis and interpretation of the results (how to interpret the difference in the distribution of the different size classes of water stable macro aggregates). This means it is impractical and not very relevant for collecting samples for these analysis for the 20,000 soil sampling sites. However, it could be considered for the reference sites for research purpose, to develop an improved method of analysis, to investigate its relevance as an indicator for soil quality for future use. The objective could also be to investigate methods of predicting soil aggregate stability using MIR scanning.

The same considerations underlie the rejection of the other soil parameters listed. 'Water dispersible clay' requires separate measurement in the lab apart from the standard texture analysis (sand, silt and clay), standard methods have not yet been defined and it is also not clear how the result need to be interpreted. It is likely associated with aggregate stability as well. If considered a potentially very important (part of an) indicator it would be further investigated for the reference sites.

Clay mineralogy seems a relevant parameter to characterise soils, but more as a permanent feature, rather than as a parameter for monitoring change. It does require a separate technique and specific equipment to determine the minerology that is not readily available. It is therefore difficult to justify including it in the minimum set of soil parameters, though it does not require additional soil to be sampled.

Moisture retention at different levels of pore water pressure (or matrix suction) is used to determine available water for plant uptake and porosity. It is probably a relevant soil parameter to consider in assessing and monitoring soil quality, but it requires rather specific core samples to be taken in the field and the method of analysis is also rather elaborate requiring specific equipment, rendering it impractical to be considered as a soil parameter suitable for the standard monitoring purpose.

Parameters like aggregate stability or available water could be termed as integrated soil quality parameters, or indicators in themselves, because these properties are determined by other basic properties of the soil, such as textural properties, soil organic carbon content and other. Therefore, it is likely we could establish PTFs for assessing these properties (if the mechanisms are understood) and therefore that these properties could be predicted using MIR. This has been the approach of AfSIS in which the parameters of the moisture release curve have been calibrated to spectra and in which the PTF estimated moisture release curve parameters have calibrated to spectra. Good results have been obtained in predicting water holding capacity form NIR spectra

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(with the accuracy of the prediction of the volumetric water content at field capacity and at permanent wilting point depending on soil order) [5]. The reference sites could be used for developing and improving the prediction models based on the MIR spectra for the African context.

Explanation of individual soil parameters

Coarse fragments

Coarse fragments play an important role in the soils of Africa, especially for soils developed on steep slopes, on the basement rock complex and for soils with plinthite. Measurement of coarse fragments is important to make the necessary correction on the soil chemical and physical properties (including soil organic carbon) that are determined for the fine earth fraction. The correction should be made based on the volume % occupied by the coarse fragments in de soil [6]. Direct measurement of the volumetric percentage is a quite elaborate process. Accurate and precise assessment is not required given the variability in the field, and predicting volumetric percentage is best done based on the weight percentage of the coarse fragments (weight of the coarse fragments (>2mm) divided by the total weight of the soil sample, which can be easily determined from the sieving of the soil during the preparation of the soil samples.

The correction factor is dependent on the bulk density of the fine earth fraction and the specific weight of the coarse fragments. The equation to determine the correction factor to apply to the chemical and physical soil parameters as determined for the fine earth fraction is as follows:

$$F_{conv} = 1/(1+(BD_{fef}/SG_{cf})*CF_{w/w})) \quad (1)$$

Whereby BD_{fef} is the bulk density of the fine earth fraction, SG_{cf} is the specific gravity of the coarse fraction and $CF_{w/w}$ is the weight percentage of the coarse fraction of the soil. Considering the range or specific gravity for quartzite and schist, probably the most prominent mineral in the coarse earth fraction besides iron concretions (1.78 g/cm3), we can assume a specific density of 2.7 g/cm3. Assuming a BD of the fine earth fraction of 1.35 g/cm^3 the conversion factor to determine the volumetric percentage is 0.5. Validation of this approach at the reference sites needs to indicate whether these assumptions work in practices or whether we would need nor precise corrections which would require assessment of the specific gravity of the coarse fragments and evaluated whether there is a need for simple methods for estimating specific gravity of the course fragments. With respect to the PTF for predicting BD, we need to assure that coarse fragments are considered.

Bulk density (BD)

Bulk density (BD) is an important soil parameter to establish. BD is used a.o. to calculate soil carbon and nutrient stocks which may be a more robust soil parameter as indicator of soil quality for comparing between sites and to evaluate change. BD is also an important parameter used in predicting other functional properties like soil compaction, hydraulic conductivity, water holding capacity and others. Wendt and Hauser [7] have argued that to evaluate carbon stocks (as well as other soil parameters) these should be quantified based on equivalent soil mass rather than per fixed depth. This implies repeated measurements of multiple soil layers are required to account for the possible change in bulk density over time as result of the various land management practices. To explain changes in SOC under different management practices and to provide information on the changes in the location of SOC in the soil the Australian government recommends sampling to 30cm depth with a sampling strategy where soil layers 0-10cm and 10-30cm depth are being sampled [6]. The effect of land management practices on the BD introduces a dependency of carbon stock taking on the time of sample taking. All in all, assessment and monitoring of BD is a complex issue with a lot of ramifications.

Using BD as an indicator of rooting restriction similarly implies measurement of multiple soil layers, and for which alternative and easier measurements are available (e.g., depth at which soil augering is restricted). A BD of 1.6 g/cm3 is generally considered to restrict root growth, but that

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is not a sharp boundary and will depend on the type of soil and especially the type of texture. See Leenaars et al., 2018 [20] for criteria to evaluate rootability and rootable depth.

Thus, establishment of BD requires an elaborate sampling procedure for accurate assessment and then the reliability is still limited with a coefficient of variation (CV) typically ranging between 10 to 15 percent. The above indicates that it is difficult to get reliable and accurate estimates of BD and questions the relevance of measuring soil BD, with the error in measurement contributing to increased error in calculating carbon stocks or other stocks. Therefore, measuring of BD will not be part of the protocol for the observations for the 20,000 standard sampling sites, but will rather be predicted using pedo-transfer functions (PTF).

PTFs for estimating BD are generally based on SOC%, sand, clay and/or silt fractions. Apart from SOC% these are permanent or static soil characteristics, and the question is whether other parameters like SOC% to clay% ratio do not provide a more solid basis for the evaluation of SOC content and monitoring change. For calculating stocks, the coefficient of determination (r^2) reported for the various PTF for predicting BD is around 0.55 and a standard error of prediction of around 0.14 (see [8] and [9]), which may result in an error in C-stock calculation of 10% or more. Comparing with the error in direct measurement it may be an acceptable alternative.

The reference sites will be used to develop the PTFs that are relevant for the African context (soils) and to establish the right equations to calculate carbon stocks based on the measurements done at the 20,000 standard sampling sites. We mentioned already above that in the PTF for predicting BD the coarse fragments should be considered as independent variable.

Secondary and micronutrients

Secondary nutrients and micronutrients are not mentioned as parameters the soil samples will be analysed for in the grant agreement (GA) for the Soils4Africa project. Neither are they included in the protocols of LUCAS (see Jones et al., 2020 [10]). The LUCAS protocols mention Sulphur being measured in connection with possible overload in soil only. That is, in connection with soil contamination. In the African context, secondary and micronutrients (as well as the macronutrients N and P) are widely reported as limiting. That applies to Ca and Mg, but certainly to S as well. With respect to the micronutrients, Zinc, Boron and Manganese are widely reported to be limiting (see Kihara et al., 2016, [11]). Moreover, with the use of spectral techniques for predicting nutrient concentrations, secondary and micronutrients are included by default and with the techniques used for the wet chemistry analysis these nutrient concentrations are also automatically measured (without any implications for the soil sampling), such that there is no reason why not to include these in the set of soil parameters.

Soil organic carbon methods of analysis

The methods for laboratory analysis are determined by TF3.5, but an important condition in connection with the fieldwork is that no different methods for nutrient extraction are used and that no different techniques are used for measuring nutrient concentration, which would result in additional cost for the field work as well as for the cost of lab analysis.

With reference to the carbon analysis, if Walkley Black is going to be used for the standard analysis, it should be noted that the recovery of carbon with Walkley Black is not complete. For this reason, a standard correction factor of 1.33 is applied to get the actual SOC%. However, in several studies this is shown to vary strongly between 1.1 to 1.8, depending on the type of soil, agroecology, and type of vegetation. This would warrant additional research into the correction factor to apply in the African context, for which the references sites could be used.

CEC and ECEC

CEC is mentioned in the Soils4Africa GA as possible additional soil parameter to consider. LUCAS does include measurement of CEC and it should be included in the Soils4Africa program because it

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is an important parameter that determines soil fertility. In cases of more acidic soils, which are quite prevalent in the tropical soils of Africa, the Effective Cation Exchange Capacity (ECEC) is a more relevant measure. The ECEC is defined as the sum of exchangeable bases plus sum of exchangeable acidity (H^+, Al^{3+}, Mn^{2+}).

Layout for soil sample collection and sampling depth intervals.

Soil depth intervals for sample collection

Soils will be sampled at 0-20 and 20-50cm depth intervals. This is consistent with the approach taken by AfSIS. The LUCAS soil component provides for sampling of the topsoil only and for this a depth of 15 to 20cm is also taken. It is only for the 2018 survey that sampling for bulk density assessment was added for part of the sampling locations and which is done at depth intervals of 0-10, 10-20 and 20-30 cm. The IPCC has decided that carbon stocks are defined as the carbon held in the first 30 cm of the soil (a depth of 30cm is used for national carbon accounting). As such, it would be convenient to sample and measure SOC at a 0-30 cm depth interval. However, this is impractical and would also not benefit the accuracy of the measurement of soil carbon stocks, especially in Africa where SOC% are generally quite low and concentrated in the upper 10 cm of the soil. The arguments that soils are being ploughed, and herewith also mixed, to 20 cm depth and more and that soils with A horizons of more than 20 cm regularly occur does not hold true for Africa in general. The carbon stocks would be underestimated for these types of soils if measurement is only done for the soil layer to a depth of 20 cm, but to accommodate for such situations in Africa, soils are sampled at 20-50 cm depth as well.

Sampling soil to a depth of 30 cm rather than to 20 cm would 'dilute' the concentration. Given a detection limit of around 0.1% and a reproducibility of the measurement results within the same order of magnitude [12], the error margin in measuring SOC in soils with low and very low carbon concentrations becomes quite large and herewith the capacity to detect change also becomes more limited. Saby et al (2008) [13] even mention a detection limit of 0.2% (2g C/kg soil). To achieve a 0.3% increase in SOC over 0-30 cm would require at least 20 tons of organic matter per ha to be supplied. This is not a realistic prospect and therefore presents another argument for reducing the depth at which topsoil samples are collected. More detailed measurement will be conducted at the reference sites, from where a method will be developed to predict soil carbon stocks for the 0-30 cm soil layer using data from the 0-20 cm and 20-50 cm soil layers samples at the standard soil sampling sites.

Nutrients will only be analysed for topsoil samples, whereas texture, pH and SOC will also be analysed for the subsoil samples. This is because the subsoil, is relevant for the water balance in the soil; soil acidity is often more manifest in subsoil and may be masked in the topsoil samples. For accurate assessment of soil carbon stocks in soils with thicker organic and A-horizons, the subsoil is relevant as well. For assessment of the acidity of the subsoil, the pH is considered to provide sufficient indication, and measurement of exchangeable H^+, AL^{3+} and Mn^{2+} is not necessary. The parameters that are measured at the different depths are indicated in table 1. We will have to consider what the budget allows, but we have the option of having the MIR analysis done locally if this can be done according to specifications. The MIR analysis will also provide predictions of the nutrients, besides the pH and SOC.

Back-up sampling plots

Samples are collected for the tertiary sampling units (TSU) as defined by the sampling design. The TSU corresponds to a 25m^2 cell randomly selected within the secondary sampling unit (SSU), which represents a one-hectare area. In each SSU, one TSU will be sampled. Two back-up TSUs within the SSU are provided in case the initial sampling plot is not accessible or not suited for sample collection. This could be the case if permission is denied to sample at the specified location by the farmer or landholder, or if the point is a rock outcrop for example or used for other purposes than

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for agriculture use. The surveyor will record the relevant observations on soil, terrain and land use and indicate the reason why the site could not be sampled.

Soil samples are collected from the *designated* sample plot. *Only* if it is not possible to sample this plot for any reason, then this plot is discarded and replaced by a back-up plot. This should be the first back-up plot from the list provided. If this back-up plot also cannot be sampled, then the second back-up location can be used.

Other properties are recorded at each of the three sites to get a proper description of the terrain, land use and land cover characteristics of the SSU. All the sampling plots (the designated and the two back-up plots) will have their unique identifier and will be recorded with the observations for each of those point.

Given the small size of the SSU (one ha) possible restrictions may well apply to the whole SSU. Five back-up SSUs that are all located within the 2 km x 2 km sampling cluster are therefore provided as well. If a *designated* SSU cannot be sampled at all, then this sampling unit is replaced with by the first SSU on the back-up list. If this back-up SSU also cannot be sampled, then the second SSU on the back-up list is selected, etc.

Layout of the sampling plot

A Soils4Africa sampling plot measures 5 m x 5 m. In this sampling plot, four soil samples are taken in the intercardinal directions from the plot center. This means that the points where the soil samples are collected are at the centre of the four 2.5 m x 2.5 m sub-squares; in other words the sampling points are configured like the four eyes on a die. With such configuration we cover the sampling plot as optimally as possible so that the composite sample that is made up of the four sub-samples represents the soil conditions prevailing at a 5 m x 5 m sampling plot as good as possible.

Taking soil samples

For the topsoil sample collection, it is recommended to use a spade the way it is described by LUCAS. This is the most generic method that would work in most circumstances and conditions (e.g., in case of very sandy soils), but will be difficult or time consuming if there is very dense vegetation or in case of standing crop. Alternatively, the soil auger can be used. For the subsoil samples, the soil auger is preferred, because too much time would be required to dig mini pits to 50cm depth. The protocol and standard operating procedures will document both methods. Depth is measured from the soil surface, which is defined as the surface of the mineral soil. That is, litter layer, possible vegetation and vegetation residues are not included, and should be carefully removed before soil sample area taken.

Soil is collected from each of the subsampling locations, bulked and thoroughly mixed. At least 500g of soil is taken for each sample. A secure method for labelling and bagging of the samples needs to be devised such that the risk of losing the label and/or the soil is minimized. This will probably involve double bagging and using two labels per soil sample. Barcodes will be used for labelling of the soil samples and these will be randomly generated. It is not practical and prone to errors using labels that refer to the sampling point location ID.

Clear alternative instructions must be given in case of a ploughed field or a field with a standing crop. Samples will have to be taken in between the ridges to minimize the effect of possible fertilizer application. No damage to the crops or harvesting of any plant may be caused by the sampling. All points should be located at least one meter from the edge of the field.

Soil and terrain observations in the field

The soil and terrain observations will concern soil depth restrictions (0-120 cm, bedrock permitting), visible erosion, stones at the surface and soil drainage class. General landform

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characteristics, like whether it is undulating, rolling or hilly, will not be recorded because it is difficult to define unambiguously and requires some experience to estimate correctly. There are generally overlapping ranges for the lower and upper classes of slopes for the various categories and there is often confusion about the area extent for which the landform needs to be defined. Moreover, there are quantitative methods for determining landform characteristics using a DEM.

However, indicating slope classes at the actual sampling location is relevant because these observations are relevant in connection with the observation in connection with erosion and the visible signs hereof that can be observed. The idea is not to bring instruments to the field for actual measurement of the slope steepness and clear and practical instructions need to be given how slope steepness classes can be reliably indicated in the field. For the same reason it is relevant to indicate the position with the local topography (in the immediate surrounding which provides a level of detail that cannot easily be obtained otherwise. Clear guidelines and instructions must be given to determine the topographic position making use of illustrative materials.

Observations on surface stoniness will include some indication of the size classes of the stones and the surface cover percentage. Stones can have a severe impact on land preparation already when the surface cover % is very low, depending on the size of the stones and this is reflected in the definition of the stoniness classes. For the size classes of stones, we will adopt the international standard for this (ISO, [18]). We will use the standard definition of the FAO for the stoniness classes [19]. Clear guidelines and instruction materials need to be provided making use of much illustrative material to allow for an accurate assessment of the stoniness class [14].

Soil drainage class can be identified based on clearly visible signs, the presence of mottles and the depth at which they occur in contrast to a uniform colour of the soil or very gradual change of the colour with depth. The soil colour will not be recorded but the mentioned signs will be recorded for each depth interval separately (0-20, 20-50 and 50-120 cm). Also the observed depth of groundwater can be recorded.

Visible signs of erosion have to do with the different forms of erosion: sheet, rill, and gully, but also mass movement and redeposited soil as well as wind erosion. The challenge here is to identify and quantity or classify the severity of the types of erosion. LUCAS addresses this by recording visible signs in the four cardinal directions and within 500m distance and classifies the rill and gully based on the count of the number of rills or gullies. This procedure seems elaborate and complicated. In contrast, in the IITA survey protocols it is only recorded whether visible signs are present yes or no at the sampling location, but recording change is hardly feasible in this way. In AfSIS visible signs are recorded at each of the subplots (which are at larger distance than 2 m form the central point), but all observations are done by the same well-trained team. Based on the data thus generated AfSIS has been able to map probability of erosion occurring and that can in principle be used for monitoring purpose. That is, based on repeated observations for the same location in principle the probability of erosion having increased could be mapped. For the standard 20000 sampling locations effective assessment of erosion is not considered feasible, but the reference sites should be used to investigate a method that allows for a semi-quantitative assessment of soil erosion and herewith of monitoring soil erosion.

Soil depth restrictions (indicative for soil rootability restrictions) will be assessed by recording the depth (cm) at which it is no longer possible to drill the standard soil auger (Edelman type) any further applying strong force (auger depth restriction). If auger depth restrictions are expected to occur within 120cm these measurements should be done for each sub-sample point. There are very little observations on effective soil depth and these observations will be very useful.

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Table 2 Parameters set for the soil and terrain observations for the 20000 standard sampling sites

Parameter	Description
Surface stones/stoniness	Cover percentage by the different size classes (gravel, cobbles, and boulders)
Soil drainage class	Presence/absence of mottles at various depth intervals
Groundwater depth	Depth of groundwater per depth interval
Effective soil depth (restrictions)	Auger restriction using Edelman type soil auger
Soil organic horizon / litter (depth)	?
Slope: steepness	Estimation of slope class
Topographic position	Selection from categories provided

Land use and land cover related observations

Land use and land cover information is needed as contextual information for the evaluation of soil qualities and changes herein, as this project intends to develop a SIS for monitoring soil qualities in the context of sustainable agricultural intensification. Moinet et al. [1] state that soil quality, or the capacity of the soil to function, is defined by the conditions of land use amongst others. (Land use is defined as the combination of the agricultural produce (e.g., crop) and the management applied). There is no existing reliable and detailed information on land use intensity and therefore field observations to determine this need to be included in the survey protocols. In the methods for deriving selected soil quality indicators [1], no information is given on the parameters for land use and land cover, other than "land use information including management intensity regime". LUCAS provides very detailed instructions for recording land use and land cover. 'Land use' indicates the socio-economic use of the land (e.g., agriculture, forestry, etc.) without specifying anything on the intensity of the use. Fallow land is recorded. Land management information refers to grazing only and there is data recorded on water management that can be used as an indicator of land use intensity to some extent.

The specifications for the land cover classification of LDSF are based on the Land Cover Classification System (LCCS) of the FAO [16], but it focuses on land cover types and uses classifiers that are not coding for land use intensity directly. Other than LUCAS and LCCS, we have the guidelines for soil description by the FAO that includes sections on Land use and vegetation [21]. It is generic in that it covers all land uses and not only agricultural, and it describes land use and vegetation in broadly defined classes making use of extensive lists of land use classes, crop codes and vegetation types. For the Soils4Africa project we will use a different approach that uses classifiers, based on the system developed for the Conservation and Sustainable Management of Below Ground Biodiversity project (CSM-BGBD) that was likewise adapted from the LCCS framework but designed to provide information on land use intensity [17].

Land use and land cover needs to be recorded at each of the three alternative sampling locations (the original selected TU and the two alternative TU locations within the SU), basically because observation on land use requires a different scale than observations on soil.

The first observation is on miscellaneous land use type, which refers to land that for various reasons is not used or not suited to be used for agricultural purpose but may be part of the agricultural land. This may refer to rock outcrop, badland, or pits for example. It serves to describe the terrain in general and to identify other land uses in the area and provides for a control mechanism for whether sampling is done at the right locations. It also serves for verifying the reason for rejecting the original sampling location identified by the sampling design.

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For the current land use, we define several categories that combine classifiers for cultivated and managed terrestrial areas, the life form of the crop and purpose of use. In this way we distinguish between cropland used for commercial and subsistence purposes, range and grassland managed and rangeland for extensive grazing purpose, orchards and plantations woodlands and land that is being fallowed or left idle, and aquatic systems. Subsequently, the crop type and/or the type of livestock and signs of grazing are indicated. LUCAS, LCCS and other classification systems allow for recording of crop combination, if there is more than one crop. For Soils4Africa the crops that are present are recorded without further reference to the cropping system. For the signs of grazing, we can refer to what has been specified by LUCAS, but which needs to be adapted for the African context. The same applies to the classifier 'spatial aspect – size', which refers to the size class of the parcel or field and the spatial distribution, which can be either continuous, clustered, or scattered (in case fields constitute less than 50% and 20% of the area respectively) and to the pattern (referring to the shape and arrangement of the fields) which can be regular or irregular pattern. All these need to be described and categorized in terms that are relevant to the African context. Management regime and intensity of use will be derived from classifiers for land use and land cover, land and crop management, water management and conservation practice and in as far as this cannot be directly observed the common practices in the area is recorded (e.g., with respect to use of inputs).

Land cover and vegetation might be relevant to describe, for grazing areas especially, but also for some types of annual and permanent cropping. In the African savanna zone trees within arable land is quite common. For plantation crops like tea and coffee it is relevant to indicate the use of shade trees for example, and in general it is relevant to indicate the percentage of bare soil as indicator of land degradation and erosion risk. This is probably best done by recording the land cover percentage for the various vegetation layers. For the cover rating we make use of the classification system by Braun-Blanquet (1928) that defines 5 classes: bare, <4%, 4%-25%, 25%-40%, 40%-65% and >65%. The instructions need to be accompanied by illustrative materials to identify the proper cover class. While testing the field survey protocols, we will confirm whether such observations on vegetation cover are feasible and meaningful. Assessment of shrub and tree density, as is done in many surveys, are considered time consuming and less relevant for our purpose.

Table 3 Parameter list for the land use and land cover, and land management observations for the 20000 sampling sites

Parameter	Description
Land use and land cover	
Miscellaneous land use type	Selection from list of miscellaneous land use
Current land use	By categories adapted from the LCCS dichotomous phase
Crop type	Selection from a list of crop types
Livestock	Selection from a list of types of livestock
Grazing signs	Selection from a list of predefined signs of grazing
Parcel size	Selection of size class adjusted to African conditions
Field pattern[1]	Shape and arrangement of parcels: regular and irregular
Land cover	
Herbaceous land cover	Land cover percentage class according to Braun-Blanquet
Shrub land cover	Land cover percentage class according to Braun-Blanquet
Tree (I)[2] land cover	Crown cover of trees up to 12m in height according to Braun-Blanquet

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Tree (II)[2] land cover	Crown cover of trees > 12m in height
Management (Land and Crop)	
Signs of ploughing	Confirmation of sign of different categories of ploughing
Plough direction	Along contour, in slope direction or tangent
Use of inputs	Signs of use of different categories of input: organic (including crop residues) and inorganic fertilisers; synthetic pesticides will be included for the reference sites
Water management	
Water supply	By category: rainfed, residual moisture (post flooding), or irrigation
Type of irrigation	Selection from list of categories
Delivery channel	Selection from list of categories
Soil and water conservation	
Conservation measure category	No conservation, vegetative or structural
Type of conservation measure	Select from list: stone lines, (stone walls), Bench terraces, Graded terraces, Contour bunds, Graded bunds, Grass strips, other

[1] Possibly best assessed through the interpretation of satellite imagery in which case the observation in the field is not needed, apart from when this is done for validation purposes

[2]. Shrubs are defined as woody plants to a height of 3m, Tree (I) we define as woody plants to a height of 12m and woody (II) is woody vegetation more than 12m in height.

For the cultural practices (land and crop management, water management) we will include information that can be obtained by visual inspection in the field. Information that requires interviewing the landholder or farmer will not be considered. LUCAS only records whether signs of ploughing are present, and if present the plough direction. For Soils4Africa we will record whether the land has been tilled, and if so whether by hand, animal traction or by mechanical means, which can generally be observed from the appearance of the ridges in the field, even if they are old.

Information on the use of inputs can generally not be obtained from visual signs in the field. In LUCAS signs of crop residues are recorded. For the Soils4Africa we will record the type or organic input used of which crop residue is one. It is also recorded whether inorganic fertilizers are (likely) used. This may be difficult to observe, but it is often known whether the use of fertilizers is common practice in a particular area. Also, it can be deduced from the appearance of the crop, which would have implications for the timing of the survey. On the data sheets options should be provided to indicate whether it is not known, whether it is likely and whether it can be positively confirmed that inputs are used. 'Inputs' does not refer to the use of agrochemicals for weed and pest management for the standard monitoring sites. For the refence sites a short questionnaire will be used for obtaining information on the use of agrochemicals

For water management the type of water supply will be recorded (rainfed, post-flooding – residual moisture, irrigated), the type of irrigation (surface/gravity or pressure – drip, sprinkler and other) and possibly the delivery system as is indicated in LUCAS. The source of irrigation as is recorded in LUCAS is not considered of sufficient relevance to be included.

Like in the LDSF we will record whether soil and water conservations structures/measures are present and whether these are vegetative or structural. In second instance Soils4Africa will provide the option to list the type of conservation measure that are observed in Africa: stone lining/walls,

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bench terrace, graded terrace, bunds, grass strips and other. The field guide should contain pictures and illustrative material to correctly identify the type of conservation practice.

4. Specifications of field observation and sample collection at reference sites

Among the 20.000 "baseline" locations 250 so called reference sites will be selected, where additional measurements will be performed. The importance of these extra measurements is that they provide information on additional soil properties that play key role in the determination of soil quality indicators and are supporting the development of the methodology of estimation of soil functioning. Types and purposes of observations at the reference sites:

1. The performance of additional measurements and at additional sampling depth intervals (fixed depth and genetic horizons). Additional measurements (e.g., bulk density) will be performed to help understand complex properties and to develop functions for predicting certain soil properties (like bulk density) from otherwise easily and routinely measured properties at the "baseline" soil sampling locations. Additional fixed depth samples will be used for specific additional measurements such as the investigation of pesticide residues contamination in soils as an indicator of soil quality.
2. Full soil profile description and soil classification. The building blocks (diagnostic elements as complex properties) of the World Reference Base for Soil Resources (WRB) will help the development of the methodology of the expression of soil qualities and soil quality indicators as well as of the functionality of soils.
3. Investigation of alternative, modern, field spectroscopy-based technologies for possible future applications. This activity makes the in-situ determination of key soil properties possible and improves the efficiency of the data collection and soil function estimation by deriving integrated properties from the measurements. The applied technologies include visible-near infrared and X-ray fluorescence spectroscopy.
4. Observation and information collection on land management practices including organic matter input, fertilizers and pesticide applications. This observation will help to understand changes and responses of soils (properties) to management.

Observations at reference site for integrated soil property assessment

Soil bulk density is an important parameter that we will not measure directly at the standard monitoring sites. Rather, BD will be predicted from basic soil properties like soil texture and SOC content. For this purpose, pedo-transfer functions (PTF) will be used. Much work has been done on developing these PTFs, but relatively little in Africa. To this end core samples will be taken at the reference sites to determine BD and statistical analysis is done to derive the relevant PTF.

BD is used to determine stocks, primarily of soil organic carbon. These are generally specified for a depth of 0-30cm. For the Soils4Africa project, at the standard monitoring sites, we will sample from 0-20cm and from 20-50cm and the question is, therefore, to what extent it is possible to get accurate estimates of soil carbon stocks, based on these observations. To evaluate this, observations on BD, soil texture and SOC are needed for 0-20cm, 20-30cm and 30-50cm depth layers, while at the same time protocols for the observations at the standard sites are followed.

Bulk density is a property that determines hydrologic properties of the soil, like moisture retention capacity, hydraulic conductivity, drainage capacity and other. Also, for this purpose the development of PTFs is important because regular measurement of water retention capacity for many distributed observation points is not feasible. To this end water retention capacity for soil depth layers 0-20cm and 30-50cm will be measured at the reference sites. We will investigate also

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to what extent water retention capacity (or moisture content at pF2.5 and pF4.2) can be predicted from the MIR spectra, which is a special kind of PTF.

Besides developing the pedo-transfer functions themselves, the question is what the influence is of measurement error for the independent variables on the dependent variable, in other words what the prediction accuracy is, and to determine what the implications are for monitoring of these properties (possibility to detect change).

We also want to investigate the relevance of soil mineral composition and total elements for the monitoring of soil quality, for application in the pedo-transfer functions or for improving the accuracy of prediction of soil properties based on the MIR spectra. For this purpose, MIR measurement, XRD and XRF will be done on all samples from the reference sites. This is to determine the MIR spectra, the mineralogy, and the total elements respectively.

This result in the following parameters and corresponding methods to be observed for the reference sites.

Table 4 Additional parameters for the reference sites

Parameter	Method of observation
Soil BD 0-20 cm	Soil cores (100cm^3) bulked for 4 sub-samples
Soil BD 20-30 cm	Soil cores (100 cm^3) bulked from 4 sub-samples
Soil BD 30-50 cm	Soil cores (100 cm^3) bulked from the 4 sub-samples
Moisture content at pF2.5 0-20cm	Soil cores (undisturbed soil sample) from 3 sub-sampling location
Moisture content at pF4.2 0-20cm	Undisturbed soil sample (soil cores) from the 3 sub-sampling location
Moisture content at pF2.5 30-50cm	Undisturbed soil sample (soil cores) from the 3 sub-sampling location
Moisture content at pF4.2 30-50cm	Undisturbed soil sample (soil cores) from the 3 sub-sampling location
Multispectral analysis 0-20cm	MIR (Bruker alpha)
Multispectral analysis 20-30cm	MIR (Bruker alpha)
Multispectral analysis 30-50cm	MIR (Bruker alpha)
Minerology 0-20cm	XRD
Minerology 30-50cm	XRD
Total elements 0-20cm	pXRF
Total elements 30-50cm	pXRF
Pesticide residues concentrations (0-2cm & 0-20cm)	Determined in laboratory, using LC and GC methods

The Soils4Africa will adopt a practical approach in that the above measurements are done only where the local labs with capacity to conduct these analyses are available. Or, in other words, we will select reference sites in countries where this capacity is available. Due to cost considerations these samples will not be shipped to the lab in RSA.

Guidelines for pesticide residues assessment in soils

As mentioned above, due to technical and budgetary constraints, pesticide residues can only be determined in a sub-set of samples. Reference sites are assumed to a mixture of real-field conditions, so having pesticide residues' analyses in these samples will not only allow a further

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characterization of the reference sites but also give a snapshot of current pesticide contamination status in African soils. 50 additional soil samples from the initial 20,000 samples will be selected to explore worst-case contamination situations (hotspots). These samples will be selected based on previous findings in literature and/or local evidence of very high use of pesticides.

As pesticides tend to accumulate on the soil surface an additional soil depth should be considered: 0-2cm depth. In each of the 250 reference sites plus the 50 hotspot locations, 2 pesticide samples should be collected: 0-2 cm and 2-20 cm deep. Hereby the 0-2 cm soil sample will be split in two parts, with one part used for the analysis directly and the other part being added to the 2-20cm soil sample to get a sample representative of the 0-20cm depth layer. In this way dilution factors of pesticides can also be estimated. This will be reflected in the protocols, but otherwise the same protocol as for the standard monitoring sites will be followed (e.g., regarding the sub-samples)

Pesticide determinations will be done in Wageningen University & Research laboratories, Netherlands. WUR has an extensive analytical infrastructure and experience in the development and application of ultra-trace target and non-target analytical methods. The S4A soil aliquots for pesticide determination (of 50-100 grams/depth) should be shipped to the Netherlands right after sampling. If needed, these aliquots can be stored under cold (4ºC) and dark conditions, for a maximum of 24h, until shipping. For longer periods between sampling and shipping, deep freezing (-20º) is recommended. Shipment should be done by Fast Courier Service/ Express post, in containers with ice, dry ice, or frozen ice packs. If this is not possible in some locations, an alternative storage and shipping procedure (involving drying the samples) can be discussed before the sampling time with the WUR team.

Soil profile description and classification

At the reference sites full soil profile description and classification according to the World Reference Base for Soil Resources (WRB) will be performed. For this purpose, soil pits of 150 cm depth will be dug and the soil, as well as the site, will be described in detail using the FAO guidelines for soil description which includes the distinction, designation, description and sampling of soil horizons and the recording of horizons, properties and materials that are diagnostic for the WRB. Note that this activity requires experienced pedologists.

Our major assumption is that the building blocks of the WRB system can provide crucial information on the functionality of the soil. By determining the diagnostic units (horizons, properties, materials) the reference soil group (RSG), principal and supplementary qualifiers, we will have the opportunity to apply the already elaborated system of the WRB for the estimation of soil quality indicators and functions.

This activity will result in a set of described soil profiles that supports the 1.) integration possibility of full soil profiles into the Soil Information System 2.) enhanced soil quality indicator and soil functions estimation 3.) better understanding of soil conditions of a given area (e.g., the area covered by the extent of a Primary Unit)

In-situ spectral measurements

On the reference sites *in-situ* visible — near-infrared (VIS-NIR) and X-ray fluorescence (XRF) spectroscopic technologies will be used to acquire integrative measurements on a wide range of soil properties. However, the samples collected from the baseline locations are going to be analysed by a middle-infrared spectroscopy in the laboratory, on the field VIS-NIR devices will be used due to the portability and flexibility of the technology.

VIS-NIR spectroscopy is a widely used technology for the characterization of a wide range of physical and chemical properties of the soils. The spectra recorded in the 350 – 2500 nm spectral range are very rich in information because the spectral "fingerprint" of each spectrally active

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constituent appears in the recorded curves. The absorption features appearing in the spectra are related to processes taking place on atomic-molecular level in organic and inorganic materials as well. These constituents determine key soil properties such as cation exchange capacity, base saturation, electric conductivity and pH. Thus, by recording a single spectrum of a soil sample, the derivation of a wide range of soil propertied will became possible.

XRF spectroscopy is based on the interaction of X-rays emitted by the instrument and the atom present in the soil constituents. The technology provides a multi-element analytical approach to a routine and non-invasive analysis of the soils in evaluating the elemental composition of the samples. Portable XRF (pXRF) devices are capable to determine a wide range of elements on the field (Mg, Al, Si, K, Ca, S, P, Ti, Cr, Mn, Fe, Co, Ni, Cu, W, Zn, Hg, As, Pb, Bi, Se, Th, U, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb). The determination of the concentration of these elements plays key role not only in the identification of contamination hotspots but provides information of soil forming processes that resulted in the elemental re-distribution in subsurface horizons.

On the reference sites both VIS-NIR and XRF measurements will be performed 'in-situ'. The major consideration when using spectroscopic methods on the field is the need and method of sample preparation. To achieve the acquisition of the most reliable data in laboratory conditions, the preparation of samples is performed according to strict protocols.

Information collection on management practices

The collection of information on management will be based on the conduction of interviews, questionnaire survey among the farmers. Data on agricultural management practices are key for informing or possibly explaining the impact of management on soil quality and productivity. The parameters need adaptation to African context and scope of the project. Information on land use and land use history, land preparation, planting, weeding, irrigation, nutrient input, pesticide use, pest management will be recorded using simple questionnaires that require Y/N answers mainly.

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4. Additional considerations and discussion

Use of equipment

The equipment for taking soils samples will be a spade or soil auger. The spade will have a straight bottom and straight sides and the protocol as described by LUCAS will be used. The soil auger we will use is the standard Edelman type, either those intended for use with sandy soils or the combination type which is suited for different types of soils. We assume the Edelman type soil augers are readily available for each of the countries and where this is not the case these should be provided.

For taking samples at the reference sites additional equipment will be required, for example for taking the soil bulk density samples. We will use standard equipment for these kinds of measurements (standard soil cores). We will not distribute the equipment but depend on partners that have these available. This implies that for the selection of the reference sites we will be dependent on the partners, whose skills are also required for the observations planned for the reference sites

In addition, we will use android phones for recording the data in the field, using an app like ODK collect. There will be no recording on paper. Data will be uploaded via internet implying the need for internet connection, which is not available everywhere, and certainly not in the rural areas. A back-up system is therefore required (taking an extra phone to the field, ensuring that it can be charged (using a power bank for example). It also means that an effective communication system should be put in place, and all should be checked before going to the field.

The same is true for navigating to the designated sampling locations in the field, for which we need alternative solutions. When a GPS is available these can be used, and the field technician must know how to use them. An alternative solution is using a GPS app for the android phone, of which there are several available. Preferably, there should be maps that help the teams to navigate to the various sampling points. For this the use of Google Maps or other applications could be considered and would need to be investigated.

Clearly, the biggest challenge is in organising, planning, facilitation, and coordination of the field activities, both at the short term as well as for the whole duration of the field campaign. For these guidelines, instruction and protocols will also need to be developed.

Timing of the field work

The field work will be conducted during the rainy season, mainly because some soils may become very hard when dry which makes it practically not feasible to conduct the sampling. Moreover, observations, whether related to soil and terrain conditions, land use and land cover are best done during the rainy season. This depends very much on the type of soil, the AEZ and the land use, and one might deviate from this rule if circumstances call for it and if it helps the planning.

This means that observation and sampling will be performed while there is a standing crop in the field in many cases. Provisions need to be made in the protocol if this requires adjustment in the sample collection or the way the observations are done in the field. We will follow LUCAS in this partly, but still maintain the Y-shaped sampling frame. Sampling will be done between the rows. For tree crops other protocols will be followed, especially for the sampling for measurement of pesticide residues which are best detected when samples are taken at the base of the trees because of the wash-off of fungicides and insecticides from the trees.

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Planning, facilitation, and coordination of the field work

The regional hub coordinators, through their national contacts in the hub countries, will be responsible for the following:

- Planning, organization, and management of the field campaign in their respective regional hubs
- Facilitate, oversee and coordinate the implementation of the field campaign in the respective countries
- Manage the data collected in the field
- Aggregate the soil samples at national or regional centers, sample preparation and shipment of the samples to the reference lab in RSA.
- Do additional analysis on the soil samples

The Soils4Africa project will provide management support tools to facilitate the implementation of these activities, referring to administration, activity management and data management, as well as all required instruction and training materials.

For the implementation of the field survey, we will make use of existing organisations, public and private entities, that will act as service providers. These service providers preferably will have a presence in the area for which they will do the field observations and sample collection, to increase the efficiency of the fieldwork. This can apply to regional centres of the national agricultural research organisation, to government extension services, to NGOs who have at least a little experience in doing this kind of survey or even to private companies with activities on the ground. Advantage can possibly be taken of agricultural research and development programmes and projects that are carried out in the area of concern.

The regional hub coordinators, through their national contacts, will have the responsibility for recruiting the service provider, make all the required contractual agreements and manage the contracts.

The regional hub coordinators through their national contact, will have to instruct the service providers on how the survey is to be conducted. That is training on the protocols and standard operating procedures, as well as on the use of the electronic tools for data recording.

The regional hub coordinators, through their national contacts, will provide technical backstopping and monitor progress of the fieldwork. The progress will be followed through monitoring the data being uploaded to the ODK data server. Technical support will also be provided online, but at the same time use will be made of other communication channels to provide that support. Field checks need to be carried out to assure that the field work is done correctly, and that the data is reliable. There will be a system in place that will allow to monitor the whole process of handling and processing of the soil samples, from sample collection, sample preparation, shipment of the samples, analysis in the lab to recording the results.

Field data management

For the recording of data in the field use will be made of ODK Collect, which is an open-source Android app that replaces paper forms in survey-based data gathering. It allows for the registration of coordinates at the location where the soil samples and data are collected, it allows for reading of QR codes that will be used for labelling of the soil samples (the soil sample ID). Meta-data like date and time of data recording and record ID as well as the date and time of uploading of the data is recorded automatically. For data entry use will be made of drop-down lists from where the right option is selected, rather than relying on the manual entry of the data.

For the data standards to be applied, we will rely on the vocabulary and coding system provided by the FAO (e.g., AGROVOC and FAO guidelines for soil description). However, this will need to be

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confirmed and eventually decided by the system design team. To assure correct data entry integrity rules will be implemented in the data form and will be applied upon entry of the data in the ODK forms. A second step in the control of the data integrity will be done on the data that has been uploaded to the ODK server. Only when the records have passed the second step in the quality control procedure the data can be transferred to the database of the Soils4Africa information system.

Field campaign coordinators will have access to the data on the ODK server through which they can monitor the progress of the field survey. The system can flag records for which a large time lapse has occurred between the recording of the data in the field and the data upload, to draw attention to cases where problems may have occurred. Similarly, it can be flagged if the coordinates of the actual sampling location deviate from the location of the designated sampling point, to address possible problems with locating and navigating to the designated sampling locations.

Because of the dependency on the use of smart phones and/or tablets, provision must be made for a back-up smartphone and/or battery (or possible use of a powerbank) to minimize the risk of failure of data recording in the field. Similarly, provisions must be made for backing up the data even before the field teams have been able to upload the data, to anticipate possible problems with internet connection, which are quite prevalent in Africa and especially in remote locations. The provisions will need to be clearly stated and will be made part of the protocols and the standard operating procedures for the field survey.

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