Protocol for the assessment of the impact of sustainable soil management practices

1. Introduction

The objective of this protocol is to provide a framework, based on a set of indicators, for government officials, NGOs, and other stakeholders involved in development projects, to determine if implemented soil management practices are sustainable and in line with the Global Soil Partnership's (GSP) definition of Sustainable Soil Management (SSM). The measurement of key indicators allows for evaluation of a soil's ability to maintain prioritized ecosystem services, and therefore improve farmers' productivity and income. This document is built on existing work of the FAO's GSP: the revised World Soil Charter (WSC) (FAO, 2015), The Status of the World's Soil Resources (SWSR) report (FAO and ITPS, 2015), and the Voluntary Guidelines for Sustainable Soil Management (VGSSM) (FAO, 2017).

The VGSSM defines Sustainable soil management (SSM) as:

"Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern".

Following this definition, the elements to be considered for the assessment of SSM are:

a) Supporting and provisioning services for plant growth for food, livestock, fibre and forestry;
b) Supporting services for below ground biodiversity;
c) Regulating services for water quality and availability; and
d) Regulating services to increase carbon sequestration and limit the emission of greenhouse gases.

In other words, SSM refers to the ability to grow food, fibre or energy crops, or undertake other human activities that impact on soil, in such a way as to avoid adverse effects on the soil or the wider environment, including waterways and biodiversity.

SSM supports a number of a Sustainable Development Goals (SDGs):

- Sustainable productivity (SDG 2: ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, and that progressively improve land and soil quality).
- Soil water availability (SDG 6: freshwater withdrawal as a proportion of available freshwater resources).
- Carbon capture (SDG 13: Take urgent action to combat climate change and its impacts).
- Soil degradation (SDG 15: Combat land degradation, halt biodiversity loss).

2. Sustainable Soil Management indicators:

Sustainable Soil Management indicators were selected, after consultation with stakeholders working in the field of soil science and agricultural development, in order to accurately assess the effectiveness of implementation of selected SSM practices in varying circumstances, including different soil types, climate, food production systems and available means.

The measurement of key indicators allows for the evaluation of a soil's ability to maintain the ecosystem services identified above (points a to d above). The selected indicators (Table 1) are the minimum set of parameters that should be analyzed in order to obtain an assessment of the impact of management practices.

1. Comparison to a baseline reference:

Given the great variability of soil properties, even within the same area, soil indicators cannot be defined as absolute values, thus it is recommended to use relative values. This means that value(s) obtained through the measurement of indicators following implementation of SSM measures must be compared with baseline values, established before SSM measures were instigated, and/or with an adjacent control where SSM measures have not been applied.

The baseline or control area samples must be taken in the same conditions and during the same period (same weather conditions, same stage of growing year). The soil samples must also be analyzed with the same laboratory methods.

2. Minimum set of SSM indicators:

The minimum recommended set of indicators for the assessment of the impact of management practices (Table 1) can be measured in the laboratory. These indicators were chosen as they are sensitive to change following the implementation of sustainable soil management practices, and can therefore assess, by proxy, the changes in selected soil properties that are crucial in sustainably managed soils.

Table 1. Key indicators that should be monitored to ensure the effectiveness of sustainable soil management practices

Indicator	Parameter/ metric	Laboratory methods[1]	Sample characteristics[2]
Soil productivity	Agricultural productivity or biomass (t ha^{-1})	Dry weight of vegetation quadrats, or yield measurements	Quadrat method or yield measurement
Soil organic carbon	% organic carbon	Walkley- Black method *http://www.fao.org/3/ca7471en/CA7471EN.pdf*	Representative soil sample (200 g)

[1] *The Global Soil Laboratory Network (GLOSOLAN) is working on developing standard and global methodologies for soil tests. For more information visit the following website:* http://www.fao.org/global-soil-partnership/pillars-action/5-harmonization/glosolan/en/

[2] *For sampling instructions for all the indicators cited, please refer to Annex 1. FAO Methodology available in the Guidelines for Soil Description (FAO, 2006)* *http://www.fao.org/3/a-a0541e.pdf*

Soil physical properties	Bulk density	Bulk density (kg dm^{-3})	Undisturbed representative sample with known volume
Soil biological activity	Soil respiration rate (gCO_2 m^{-2} d^{-1})	Soil respiration in dynamic closed chambers method (DC-method).	Representative soil sample (200 g).

1) **Soil productivity** is the soil's ability to produce biomass, whether for agricultural, forestry or environmental purposes. While productivity is an indirect indicator of the status of a soil, it is a critical indicator of the overall impact of SSM practices. For the SSM assessment, agricultural productivity should be measured using the same product (e.g., maize yield, forest biomass etc.), through total yield weight or an estimation of dry biomass per surface unit.

2) **Soil organic carbon (SOC)** is a commonly recognized indicator of the chemical, physical and biological status of a soil, responding to change through the implementation of SSM practices. SOC has a direct relationship with soil nutrient availability, soil structure and aggregate stability, soil porosity, water retention capacity, and the presence of macro, meso and micro soil fauna. For the assessment of SSM, SOC can be measured in the topsoil (30 cm) as a percentage of organic matter in the soil.

3) **Soil physical properties** are represented by soil bulk density (BD), which measures the mass of oven dry soil per unit volume. Changes in BD give an indication of changes in soil structure, porosity and compaction and indicate how readily water and plant roots can move through the soil. If required, soil porosity can be calculated from bulk density (BD), where porosity = 1 – BD/2.65. The common range for particle density is 2.55 to 2.70, so a value of 2.65 is generally used, but can be replaced with a real value if available.

4) **Soil biological activity** is a good indicator of life in the soil. Soil biological activity can be affected by chemical or physical circumstances, including salinity and pollution, and can reveal the persistence of soil degradation. Soil respiration is a reliable method for measuring biological activity in the soil. However, the biological characteristics of the soil are not commonly measured and some complementary analyses can be very useful, such as soil enzymes.

3. Additional SSM indicators for specific cases:

If soil degradation is caused by specific and identified threats, the latter can be measured through the use of additional indicators to more specifically assess the impact of the implemented management practices. For the measurement of additional indicators, this protocol does not recommended any specific laboratory or field methods, but it is important to be consistent and to use the same method for the comparison with baseline and control areas.

1) **Soil nutrients** are essential for high agricultural productivity, which can only be obtained when all nutrients are in the optimal supply range. **Plant available phosphorus** can be used as an indicator of chemical soil nutrients as it is a stable element, and its mobility in the soil is limited.

2) **Soil erosion**, or the displacement of the upper layer of soil, can be caused by wind, water or anthropogenic activities such as soil tillage. It can be measured in the field, by observing visible evidence of soil loss, in complement to the measure of topsoil SOM. In identified cases of soil

erosion, it is recommended to implement different assessment methods, such as the **direct measurement of erosion in gullies, rills, sheet wash, landslides** using erosion pins, **sediment yield downhill or in drains** using Gerlach boxes, **or undercutting of the soils around trees and fence-lines**.

3) **Soil Salinity** can be caused by natural causes (such as the geological/ lithological/climatic conditions of the area, or proximity to a coastal marine environment), and can also be caused by anthropogenic activities such as the use of salt-rich water in agriculture or the adverse impacts of poorly managed irrigation in dry regions. Halophytic plants, white scabs, an oily appearance or lack of plant growth are all signs of salinity in the field. Salinity can be estimated using **electrical conductivity (EC).**

4) **Soil biodiversity** reflects the variability among living organisms including a myriad of organisms not visible to the naked eye, such as micro-organisms (e.g., bacteria, fungi, protozoa) and meso-fauna (e.g., acari and springtails), as well as the more familiar macro-fauna (e.g. earthworms and termites). Soil biodiversity can be measured using enzymatic or metagenomic methods, but these are mostly used in research work rather than in routine analyses. Thus, a **count of macro and meso-organisms** are easy methods that can be implemented in the field and in the laboratory, to obtain an estimation of the soil biodiversity (diversity and richness). The **Berlese funnel** is a practical way to isolate soil invertebrates in a soil sample, especially arthropods.

5) **Soil pH** (acidity and alkalinity) gives important indication of availability of plant nutrients, and different crops thrive at different pH values. Soil pH may change in response to management activities such as fertilizer addition, irrigation that leads to accumulation of salts, and some forms of soil pollution. Soil pH may be measured in the field with simple indicators, or with standard laboratory measurements. It is relatively cheap, quick, and easy to determine. Amending low (acidic) pH can lead to greatly improved crop yields.

6) **Field indicators for evaluation** of **physical soil properties** can be a good complement to the minimum indicators set. **Soil infiltration rate** is a measure of how fast water enters the soil under non-saturated conditions. Water entering too slowly can reflect ponding conditions, soil compaction or erosion risk (surface runoff). **Soil penetration resistance** can be useful in estimating soil compaction. It gives an indication of root-impeding layers in the soil and can be used to compare relative strengths among similar soil types. Penetration resistance can also be used for determining hardpans, zones of compaction, or dense soil layers.

3. How to plan a SSM impact assessment:

Key considerations in planning a SSM impact assessment (Figure 1) include consideration of the study area, purpose of measurements, budget, people responsible for the assessment, location and timing of sampling, and record keeping requirements. The SSM impact assessment must necessarily include the <u>minimum set of indicators</u>, as well as any relevant additional indicator(s), given the location, soil type, land use, types of SSM practices used, and natural and off-site threats. The time lapse between two measurements will depend mainly on the nature of the practice to be assessed. The time can be 1 to 2 years if the practice focuses on soil fertility (fertilization plan, or micronutrients application). In this case, the yield may increase but the other indicators will not change significantly. In other cases of SSM practices, where the objective is to obtain long-term results, the positive impact may be observed within a larger timeframe, possibly 5 to 10 years after implementation.

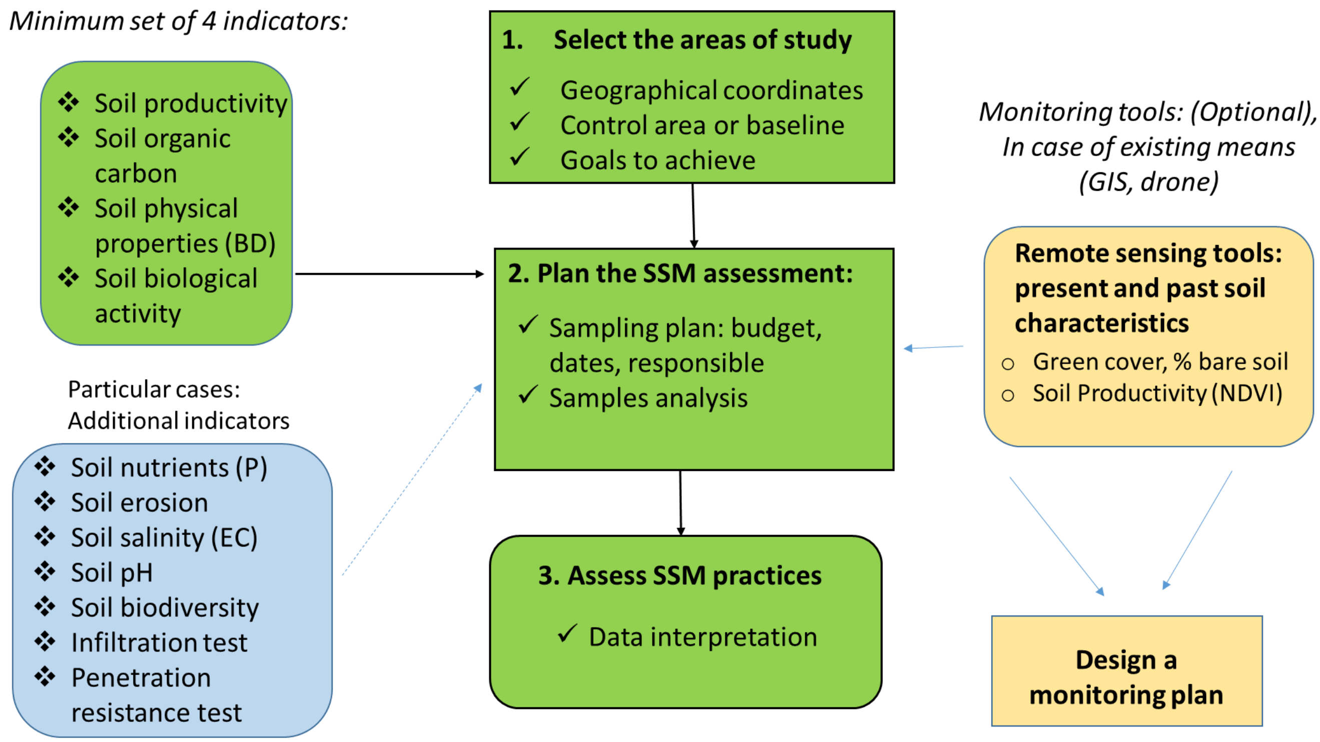

Figure 1. Process to plan a SSM impact assessment.

1. **Select the areas of study**

   - ✓ The selected areas must be representative of the management practice to be assessed. For example, in a productive area: select a representative area of the main crop (do not include rotations, associate crops or living fences).
   - ✓ The assessment must include a baseline (measured prior to implementation of the SSM practice(s) that are being assessed) and/or at least a control area.
   - ✓ Include remote sensing tools if possible, to delimit the study areas (Vegetation cover, soil moisture estimation or Normalized Difference Vegetation Index (NDVI)).

2. **Plan the SSM sampling design and a monitoring plan**

   - ✓ Specify the location of each point to assess (geographic coordinates).
   - ✓ Define the timeline for the field sampling.
   - ✓ The sample analysis can be completed with additional laboratory parameters and field observations. These can be, for example, soil pH or soil resistance to penetration.

   Ongoing monitoring plans can determine the effectiveness of changes generated by the implementation of SSM practices and evaluate the impact of soil management for sustainability in the short, medium and long-term.

   - ✓ Define reference areas for comparison (baseline or control area).

- ✓ Define the monitoring plan: frequency, indicators, specific goals and monitoring tools.
- ✓ Implementation of the remote sensing tools (if relevant and/or available). Previous estimation of biomass and soil moisture in different periods.

Plan the field missions (sampling + field observations) and provide improved frequency in the SSM assessment. Some parameters obtained by remote sensing or simple field observations can be combined within the assessment indicators, to quickly obtain intermediate measurements that can, in some cases, provide early warnings and allow adjustments to the SSM.

3. Sample the soil

- ✓ Fill a general information form.
- ✓ Include information about yields: quantity, frequency and variations.
- ✓ The baseline or control area samples must be taken during the same period (same weather conditions, same stage of growing year for baseline or between-year comparisons).
- ✓ Send the soil samples to the laboratory.

4. Assess the SSM practices impact

Table 2. Interpretation of Sustainable Soil Management minimum set of indicators to assess the soil impact of the SSM practice(s) implemented

Minimum set of indicators	Change considered as a positive impact on soil
Soil productivity (t ha^{-1})	Increase *Related to the crop or land use*
Soil organic carbon %	Increase The SOC value depends on the type of soil and the climate. With SSM practices, we can expect an increase of up to 20% depending on the initial state of the soil, as well as the management practices implemented.
Bulk density (kg dm^{-3}) (Porosity= 1-(BD/2.65)	Decrease The standard value for bulk density (BD) is around 1kg dm^{-3}, reflecting a porosity of about 50 -60% An extreme (undesirable) value is BD > 1.6 kg dm^{-3}, where porosity is < 45%
Soil respiration rate (g CO_2 m^{-2} d^{-1})	Increase <1.4 g CO_2 m^{-2} d^{-1} is considered as limiting conditions for biological activity, 1.4 to 3 corresponds to cultivated soils 3 to 5.7 g CO_2 m^{-2} d^{-1} is ideal in pristine soils **in the tropics, the values are higher.* *Low: ≤5.7 ; Moderate: 5.7-12.8 and Adequate >12.8 g CO_2 m^{-2} d^{-1}*