E

Global Soil Partnership
Plenary Assembly

Sixth session
Rome, 11-13 June 2018
Protocol (guidance document) for the Assessment of Sustainable Soil Management (GSPPA:VI/2018/3 Add.3)

A. Introduction

The importance of sustainable soil management (SSM) to the United Nations system and all international organizations is unambiguously stated in the Revised World Soil Charter (FAO, 2015):

> The overarching goal for all parties is to ensure that soils are managed sustainably and that degraded soils are rehabilitated or restored.

The work of the Intergovernmental Technical Panel on Soils (ITPS) has led to four documents: the Revised World Soil Charter (WSC) (FAO, 2015), The Status of the World's Soil Resources (SWSR) report (FAO and ITPS, 2015), the Voluntary Guidelines for Sustainable Soil Management (VGSSM) (FAO, 2017) and the Global Assessment of the Impact of Plant Protection Products on Soil Functions and Soil Ecosystems (PPP) (FAO and ITPS, 2017). These documents establish both a definition for sustainable soil management and a high-level overview of what types of practices constitute SSM. In the PPP, the definition of SSM is used to assess the impact of plant protection products on ecosystem services and soil functions.

The objective of this document is to provide guidance about how the sustainability of soil management can be assessed. The intent is to provide a starting point for regional and local assessments of SSM carried out under the Pillars of the Global Soil Partnership.

The FAO Definition of Sustainable Soil Management

The definition of SSM in the revised WSC (p. 4) is:

> Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by the soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity

For SSM, the main object being assessed is management - the deliberate actions that humans take to treat or modify soils for some purpose. If these actions cause significant harm to ecosystem services provided by the soil or to soil functions or biodiversity, then soil management is considered to be unsustainable.

This definition has two distinct parts. First, to be sustainable, soil management must maintain or enhance the ecosystem services provided by the soil (which are summarized in Table 1.2, SWSR). Although all services provided by the soil are important, the WSC recognizes that "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." (p.4). Put more simply, soil management that maintains or increases yields but which leads to unacceptably high greenhouse gas emissions or contamination of water bodies is, by definition, unsustainable. The inclusion of ecosystems services in the definition, while novel for FAO, follows many years of research on ecosystem services and soil (reviewed in Baveye, Baveye and Gowdy, 2016).

The second part of the definition states that management that leads to maintenance or enhancement of services is not sustainable if it causes significant impairment of either soil functions or biodiversity. This part of the definition is more similar to traditional definitions of SSM insofar as it is soil-centric, rather than focusing on the effects of soil management on the surrounding environment.

The concept of ecosystem services has continued to evolve since the new definition of SSM was adopted. Recently the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has adopted the concept of nature's contributions to people (NCP) to address some shortcomings in the ecosystem services framework (Diaz *et al.*, 2018). The NCP framework recognizes both the beneficial and detrimental contributions of ecosystems to people and re-balances the importance of culture vis-à-vis natural science and economics. The ecosystem services discussed in our document can be readily mapped to the NCP categories (Diaz *et al.*, 2018, Figure S2, S3).

B. Soil Health/Quality Assessment vs. SSM Assessment: An Example using Earthworms

At first reading, the definition of SSM is similar to other, more established concepts in the soil science community. In Canada, for example, there was a major emphasis in the 1990s on soil health in agriculture: "…the soil's fitness to support crop growth without resulting in soil degradation or otherwise harming the environment" (Acton and Gregorich, 1995, p. 14). Soil health was viewed by these authors as an interchangeable term with soil quality, a concept that was more rooted in the US and European soil science literature.

The soil science community has put considerable effort into developing lists of indicators of soil health/quality. In North America, the definition of minimum data sets for indicators often follow the work of Larson and Pierce (1991, 1994) and well-cited sources include ten (Doran and Parkin, 1994) to twelve (Carter et al., 1997) soil attributes to be assessed. The paper by Gregorich *et al*. (1994) lists nine soil attributes to be included in a minimum data set for assessing soil organic matter. The comprehensive JRC report on soil threats in Europe (Stolte *et al.*, 2016) list 34 indicators and 61 potential methods to assess the twelve soil threats they consider. The well-developed Australian Soil Quality website (soilquality.org.au) provides comparative information for 14 indicators (3 biological, 6 chemical, and 5 physical).

One measure of soil biological health/quality that is commonly suggested is an indicator based on earthworms. Specifically measures such as abundance, biomass, or speciation have been suggested. Standard tests for the toxicological effects of pesticides on soil biology use measures of abundance and biomass of *Eisenia fetida* (*Lumbricidae*) to assess the impact on earthworms (reviewed in PPP , FAO and ITPS, 2017).

The simplest soil health indicator is a simple presence/absence assessment on a set volume of soil. Assessment of abundance (i.e., number of earthworms per set volume) is more time consuming, as is a biomass assessment. Speciation is probably only viable as a research-level tool. Once the earthworm indicator has been selected and assessed, the value recorded has to be compared to some range to determine if the value recorded is healthy or not. This relates to the point made by Kibblewhite, Ritz, and Swift (2008) – ideally there has to be a range established for the appropriate population and the specific value that is assessed can be compared to this range. It is difficult to assess the health of a particular soil in the absence of such a range for comparable soils developed under similar agro- ecological conditions.

An SSM assessment differs markedly from these soil health/quality assessments. In an SSM assessment, the effects of a particular management measure (or a suite of measures) is assessed for its probable effect on the particular soil property – earthworms in this case. For example, it has been well established that tillage has a significant negative effect on soil organisms with larger body sizes, including earthworms (e.g. Wardle, 1995; Briones and Schmidt, 2017). Hence implementation of aggressive soil tillage will likely lead to a decrease in earthworms; adoption of reduced or no-till will likely lead to an increase in earthworms. Adoption of reduced or no-till may require more aggressive use of herbicides to control weeds – an example of the type of trade-offs often required in SSM. In the judgement of the ITPS (as summarized in the PPP paper), the effects of herbicides for weed control on earthworms are minor, and hence the benefit of the adoption of no-till for earthworms outweighs the possible negative consequences of increased use of herbicides on earthworms. Other measures, such as mulching in no-till, can also minimize the need for the use of herbicides.

The question of what are the acceptable impacts of human use of soil on ecosystem services, soil functions, and biodiversity must also be addressed for SSM assessments. In the example discussed above, the ITPS decided that the minor impact of herbicides on earthworms was acceptable given the other benefits of no-till (PPP, FAO and ITPS, 2017). In contrast, a definition of acceptable level of impact based solely on biodiversity could find that any management measure that reduces earthworms no matter how minor is unacceptable. At the other end of the range, an advocate for conventional tillage could argue that the negative effect of the management-induced reduction of earthworms on soil functions and other ecosystem services is minor. In this argument, these minor effects on soil functions do not threaten any ecosystem services in the foreseeable future and hence the management practice (conventional tillage) is sustainable based on this measure. Hence the decisions about acceptable impacts are made in a socio-cultural context but science-based evidence is a critical component of the decision-making process.

C. Information required for an Assessment of Sustainable Soil Management

The application of the SSM definition can be illustrated for the three services specifically targeted in the World Soil Charter (supporting and provisioning services for plant production, regulating services for water quality and availability and regulating services for atmospheric greenhouse gas composition). These map to Food and Feed Material NCP and Regulating NCP in the IPBES framework (Diaz *et al.* 2018).

Specification of Management

The object being assessed is the management that is in place or is being proposed for a specific area. For agriculture, the management regime may include considerations of tillage, crop rotation, residue management, nutrient and manure inputs, drainage, timing of farm operations, and various pest control measures. For forestry or agroforestry the regime may include specific issues such as harvest methods, site preparation for replanting, and log handling methods as well as some of the nutrient and pest control measures. These lists are not meant to be exhaustive but only to illustrate the diversity of measures to be considered. In some cases, the measures can be directly observed (tillage, residue management, crop selection); in others record keeping by land managers is required (e.g. pesticide regime, fertilizer inputs, timing of field operations). The Land Utilization Type classification presented in the FAO's (1976) Framework for Land Evaluation specifies many of the elements that need to be assessed.

Identification of Threats to Ecosystem Services, Soil Functions and Biodiversity

Identifying the threats both to ecosystem services and to soil functions and biodiversity is an essential first step in the sustainability assessment. In addition, there needs to be some idea of what constitutes an acceptable level for each threat. In this context acceptable means that although the specific threat may be actively affecting the soil, the effect on ecosystem services, soil functions or biodiversity is minor enough that the services or functions will continue for at least several generations of land managers. This time horizon recognizes that many elements of management and indeed land use generally will change through time and hence reassessment of SSM through time is essential. It is not meant to permit severe degradation of the soil over the time span.

The main threats to soil functions and biodiversity were initially established by Blum (1990) and are commonly identified as soil erosion, nutrient imbalance, organic carbon loss, loss of soil biodiversity, compaction, sealing and land take, salinization and sodification, contamination, soil acidification, and waterlogging. These threats were the basis of the regional evaluation of the status of soils presented in the 2015 SWSR report (FAO and ITPS, 2015). These ten threats plus two additional ones (desertification and landslides) were also comprehensively addressed for countries in the EU (Stolte *et al*., 2016).

The threats to ecosystem services provided by the soil have not been as fully established. The most fully developed system is the Agri-Environmental Indicators reporting system implemented by the OECD (STATS.OECD.ORG). The OECD database has data from 41 countries, although the coverage for each country is often incomplete. The indicators include nutrient balance, greenhouse gas emissions, soil erosion, water quality and quantity, ammonia, NOx, and SOx emissions, and agricultural land area.

In Table 1, a preliminary list of threats for the three primary ecosystem services listed in the WSC has been compiled. The processes threatening each ecosystem service have been identified, along with a possible indicator of the action of the threat. The final column attempts to establish if an acceptable level for the threat has been codified, and at what level (e.g. national regulations, catchment or watershed level guidelines, and individual land manager) the decision about what constitutes an acceptable level is commonly made. The example shown in the final column is based on the regulatory framework in Canada and needs to be established for each assessment.

The differences between Table 1 and published lists of indicators for soil health or soil threats are striking. For example, the JRC report (Stolte *et al.,* 2016) list 34 indicators and 61 potential methods to assess the twelve soil threats they consider. Indicators for the transfer of contaminants from soil to surface waters and groundwater and for GHG emissions are not on the JRC list (or in any of the soil health/quality indicator lists previously referenced). The same criticism can be made for the regional summaries presented in the SWSR (FAO and ITPS, 2015) – only the state and trend for the main ten soil threats are considered, not for the soil-provided ecosystem services. Hence full implementation of the WSC definition of SSM requires a re-thinking of the indicators that are typically considered.

Specification of Acceptable Levels of Threats

The definition of what constitutes acceptable levels for the impacts on soil-provided ecosystem services is a complex one. The definition is most stringent for chemically based definitions of water quality where thresholds for acceptable levels of chemicals such as N, P, and pesticides in surface waters and groundwater exist (Table 1). In many countries there are programs to sample water quality and hence locations where acceptable water quality thresholds are exceeded are known; the percentage of sites exceeding threshold is the basis of the OECD indicator. It can be complex, however, to link current water chemistry to current soil management in a watershed due to the persistence of chemicals in soil, vegetation, and floodplains – typically termed legacy effects.

For GHG emissions and SOC loss, it is far less common to have nationally regulated levels of acceptable emissions or of sequestration or losses of SOC. National inventories of emissions used in the OECD database are based either on emission factors or more complex modelling because the direct measurement in the field is too complex for implementation beyond the research level. Since thresholds for GHG and SOC do not exist it is more realistic to consider the trend in emissions associated with different management regimes – SSM should lead to a decrease in overall GHG emissions or to stabilization or increases in SOC levels.

The OECD database also includes information on the national N and P balance by totaling all inputs and then calculating losses through crop harvest and export. Any N and P in excess of crop needs is potentially available for harmful processes such as surface water eutrophication or N_2O emissions. Excess soil N beyond crop requirements is also required, however, to build up soil organic matter levels in the process of carbon sequestration.

Finally, the decisions about acceptable levels of threats to soil functions that support plant production is typically done by the land manager based primarily on economic grounds. In many countries this takes the form of decisions about inputs such as synthetic fertilizers to offset declines in (for example) the nutrient supplying power of soils. Management decisions about irrigation or soil drainage are made to overcome limitations to soil water availability or excess water. The decision of a producer to adopt organic management is based, in part, on a desire to enhance the biology of the soil. In each case it is typically the land manager who is making decisions about implementation with (perhaps) assistance from government programs or private advisory services.

D. A General Standard for a Sustainably Managed Soil

According to the VGSSM (FAO, 2017), a sustainably managed soil would have:

1) Minimal rates of soil erosion by water, wind, and tillage;
2) Soil structure that is not degraded (e.g. soil compaction) and provides a stable physical context for movement of air, water, and heat, as well as root growth;
3) Sufficient surface cover (e.g. from growing plants, plant residues, mulches, etc.) present to protect the soil;

4) Stores of soil organic matter that are stable or increasing and ideally close to the optimal level for the local environment;
5) Availability and flows of nutrients that are appropriate to maintain or improve soil fertility and productivity, and that minimizes their loss to surface and ground waters and to the atmosphere as greenhouse gases;
6) Soil acidification, salinization, sodification and alkalinization that are minimal or absent;
7) Water (e.g. from precipitation and supplementary water sources such as irrigation) that is efficiently infiltrated into the soil, stored to meet the requirements of plants and drained from the soil when excess soil water occurs;
8) Contaminants that are maintained well below toxic levels, i.e. those which would cause harm to plants, animals, humans and the environment;
9) Soil biodiversity present that provides a full range of biological functions;
10) Management systems for producing food, feed, fuel, timber, and fibre in place that rely on optimized and safe use of all inputs, including pesticides; and
11) Soil sealing that is minimized through responsible land use planning.

This general standard incorporates the information on the threats to both the main ecosystem services and to soil functions and biodiversity.

E. Stages in the Assessment of the Sustainability of Soil Management

1) Compilation of information on current or proposed management.
2) Identification of management-related threats to soil-provided ecosystem services and to soil functions and biodiversity.
3) Compilation of science-based information on acceptable levels of threats to soil-provided ecosystem services and to soil functions and biodiversity.
4) Compilation of local knowledge on acceptable levels of threats.
5) Linkage of current or proposed management to identified threats (e.g. effect of tillage on earthworms as developed above).
6) Comparison of probable effects of current or proposed management to acceptable levels of threats.
7) Assessment of socio-economic and cultural implications of current or proposed management measures.
8) Implementation of changes to management to achieve acceptable levels of threats or initiation of efforts to overcome barriers to adoption of such changes.
9) Recognition of achievement of sustainability.

Outcomes of the Assessment

The assessment of sustainability of soil management would result in two general outcomes. In the first, the soil management currently being applied could be assessed to determine if it is sustainable. This would occur if, for example, a land manager desired to be certified as practicing SSM. If the current management was deemed to be sustainable (i.e., stage 6 showed that no identified threats were operating at unacceptable levels) and was economically and socially acceptable (i.e., stage 7) then no changes to management would be required. The same would be true for proposed management changes to an existing management regime (e.g. a change in tillage implements or in fertilization application) that passed stage 6 and 7 – no barriers to implementation exist and the change could be implemented.

In the second outcome, the current or proposed management contains practices that are deemed to be unsustainable in stage 6. In this case, alternative practices would need to be evaluated for both their effect on the threat and their social, economic, and cultural acceptability.

The VGSSM (FAO 2017) provides a high-level starting point for evaluation of alternative management options. For example, the evaluation in stage 6 might find that the effects on water quality of a current management regime or proposed management practice was unacceptable. The transfer of chemicals to surface water bodies is the major process (Table 1) that threatens water quality regulation by the soil. The levels of evaluation of management options are illustrated in Figure 1 for options to address the transfer of chemicals to surface waters. First, overall approaches to reduce the threat are identified – runoff reduction and reduced chemical exposure to runoff in this example. Second, general management options to achieve the threat reduction are identified – maintenance of cover crops or residues on the soil surface in the example shown. Third, specific management options (in this case all drawn from the VGSSM) are identified to achieve the general management option. Finally, the appropriateness (including socio-economic and cultural) of each option at the local level would be assessed, and specific technical advice offered for how it could be implemented.

In some cases there may not be viable technical options available, or the options available are not socially, culturally, or economically acceptable. In this case the management is not sustainable, and efforts need to be initiated to remove the barriers to adoption that have been identified.

There is considerable information on more specific approaches to assessment available from the literature and from previous approaches to assess land capability and suitability. The most useful FAO source is the framework used for land evaluation (FAO 1976, 2007), which has highly pertinent information on the management information required and the characterization of land units as well as various approaches to stakeholder engagement. There are also more recent, structured approaches to this style of assessment such as Multicriteria Decision Analysis (Davies et al. 2013, discussed in Baveye et al. 2016).

Involvement of Stakeholders

Different players are involved in the stages. The need for different perspectives is well developed in the new IPBES NCP framework (Diaz et al., 2018). They distinguish between generalizing and context-specific perspectives. The generalizing perspective is typical of the natural sciences and economics and seeks universally applicable results. The context-specific perspective is typical of local and indigenous knowledge, where the production of knowledge does not explicitly seek to be valid beyond specific geographical and cultural contexts.

The generalizing perspective is important for Stages 1, 2, 3 and 5. Stage 1 is most effectively done by government or NGO research/extension workers with ready access to government websites and reports where the information is contained. They would also be involved in stage 5, where the literature on effects of management on ecosystem services, soil functions and biodiversity is summarized and applied to the local context.

Stages 4, 6, 7 and 8 are ideally carried out within a context-specific framework by land managers working in conjunction with government or NGO research/extension workers to facilitate the process and provide the information required. The term “land manager” is intended to capture a range between individual or corporate land ownership through to communally managed lands.

Obviously the key group of stakeholders is the land managers who would initiate the process and implement the changes. The major question that needs to be fully explored is “why would land managers bother with the process?” Ideally of course land managers would assess sustainability and implement SSM for its own reward, but the literature on adoption of management would suggest that a more complex set of considerations comes into play.

One possible rationale for land managers to participate would be a certification option associated with stage 9. If financial rewards could be linked to the award of certification through public or private sector measures then an incentive for participation and implementation exists. The wide-spread adoption of sustainability standards in the forestry sector could provide guidance in this process.

Figure 1: Example of stages for determining management options to address threats to soil-provided ecosystem services

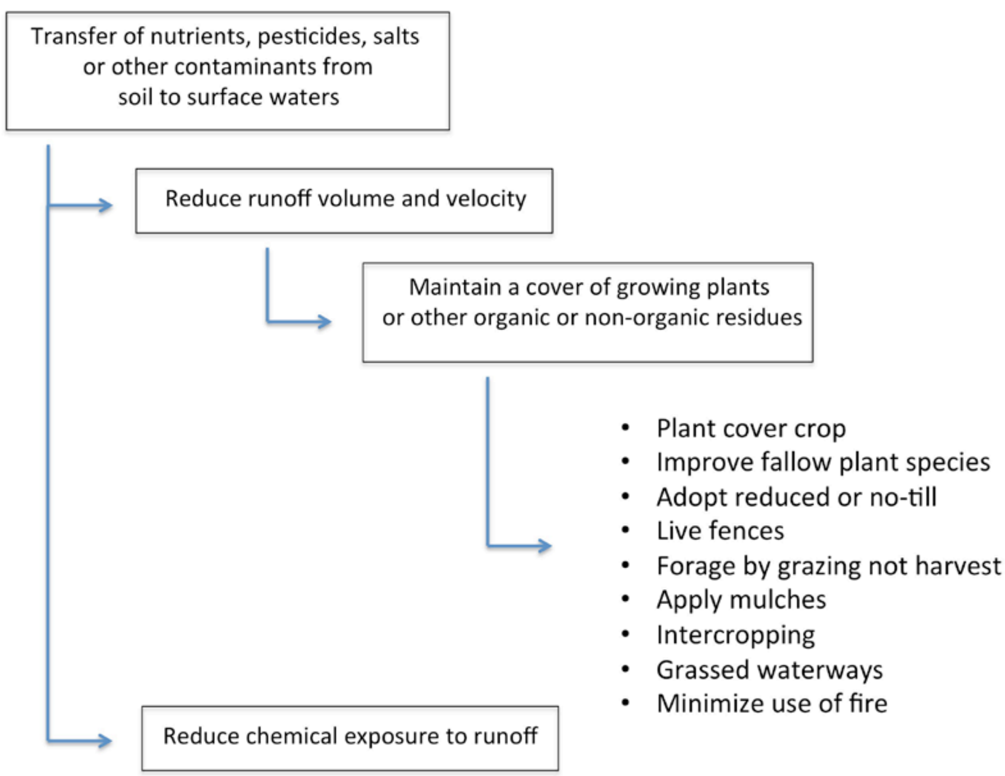

Table 1: Processes that threaten four primary ecosystem services provided by the soil. The example in the final column is drawn from the Canadian regulatory framework.

Ecosystem Service	Process Threatening Ecosystem Services	Indicator	Where is acceptable threshold set?
Regulation of water quality	Transfer of nutrients, pesticides, salts or other contaminants from soil to surface waters	Concentration of nutrients, pesticides, salts, or other contaminants in surface waters (OECD) Percentage of monitoring stations exceeding water quality thresholds (OECD)	National surface water quality regulations for aquatic organisms and human health
	Transfer of sediment from soil to surface waters	Concentration of sediments, turbidity	National surface water regulations for sediment concentration, turbidity
	Transfer of nutrients, pesticides, salts and other contaminants from soil to groundwater	Concentration of nutrients, pesticides, salts, or other contaminants in groundwater (OECD) Percentage of monitoring stations exceeding water quality thresholds (OECD)	National groundwater quality regulations for aquatic organisms and human health
Regulation of water quantity	Increased runoff due to reduced water infiltration into soil	Increased flooding in catchment, changes in stream flow	Catchment-based regulations
	Decreased aquifer recharge	Falling groundwater table	Catchment-based regulations
Regulation of greenhouse	Increased emissions of N_2O	Measured or modeled N_2O emissions and % from agriculture	National GHG Inventory

gases		(OECD)	
	Increased emissions of CH_4	Measured or modeled CH_4 emissions and % from agriculture (OECD)	National GHG Inventory
	Loss of soil organic matter	Decrease in SOM/SOC stocks	National GHG Inventory
Provision of food, fibre, and fuel supply	Significant increase or decrease in soil water availability	Increase in incidence of drought or water-logging	Land manager decision
	Decrease in nutrient supplying power of soil	Decrease in plant-available nutrients in soil	Land manager decision
	Decrease in ability of soil structures (aggregates, horizons) to support gas and water flow and root growth	Change in soil water balance Decrease in germination and root growth	Land manager decision

References

Baveye, P. C., Baveye, J. & Gowdy, J. 2016. Soil “Ecosystem” services and natural capital: Critical appraisal of research on uncertain ground. *Frontiers in Environmental Science*, 4: 1-49.

Blum, W.E.H. 1990. The challenge of soil protection in Europe. *Environmental Conservation*, 17:72–74.

Briones, M. J. I. & Schmidt, O. 2017. Conventional tillage decreases the abundance and biomass of earthworms and alters their community structure in a global meta-analysis. *Global Change Biology*, 23:4396-4419.

Carter, M.R., Gregorch, E.G., Anderson, D.W., Doran, J.W., Janzen, H.H., & Pierce, F.J. 1997. Concepts of soil quality and their significance. In E.G. Gregorich & M.R. Carter eds. *Soil Quality for Crop Production and Ecosystem Health.* Developments in Soil Science 25. Amsterdam, Elsevier Ltd, pp. 1–20.

Davies, A. L., Bryce, R., & Redpath, S. M. 2013. Use of Multicriteria Decision Analysis to address conservation conflicts. *Conservation Biology*, 27:936-944.

Diaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R. *et al.* 2018. Assessing nature’s contributions to people. *Science*, 359: 270-272.

Doran, J.W. & Parkin, T.B. 1994. Chapter 1. Defining and assessing soil quality. In J.W. Doran, D.C. Coleman, D. F. Bezidcek, & B.A. Stewart. 1994. *Defining Soil Quality for a Sustainable Environment.* Madison, Soil Science Society of America Special Publication Number 35, pp. 3–22..

FAO. 1976. *A framework for land evaluation*. Soils Bulletin 32. Rome, FAO. 72 pp.

FAO. 1993. *FELSM: An international framework for evaluating sustainable land management*. Rome, FAO. 85 pp.

FAO. 2007. *Land evaluation. Towards a revised framework*. Land and Water Discussion paper 6. Rome, FAO. 107 pp.

FAO. 2015. *Revised World Soil Charter*. Rome, FAO. 5 pp.

FAO. 2017. *Voluntary Guidelines for Sustainable Soil Management*. Rome, FAO. 16 pp.

FAO and ITPS. 2015. *Status of the World’s Soil Resources Report*. Technical Summary. Rome, FAO. 79 pp.

FAO and ITPS. 2017. *Global assessment of the impact of plant protection products on soil functions and soil ecosystems*. Rome, FAO. 32 pp.

Gregorich, E.G., Carter, M.A., Angers, D.A., Monreal, C.M., & Ellert, B.H. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Canadian Journal of Soil Science*, 74:367-385.

Kibblewhite, M.G., Ritz, K., & Swift, M.J. 2008. Soil health in agricultural systems. *Philosophical Transactions: Biological Sciences*, 363: 685-701

Larson, W.E. & Pierce, F.J. 1991. Conservation and enhancement of soil quality. In Evaluation for sustainable land management in the developing world. ISBRAM Proc. No. 12, Vol. 2, Technical papers, Bangkok, Thailand.

Larson, W.E. & Pierce, F.J. 1994. Chapter 3. The dynamics of soil quality as a measure of sustainable management. In J.W. Doran, D.C. Coleman, D. F. Bezidcek, & B.A. Stewart. 1994. *Defining Soil Quality for a Sustainable Environment*. Soil Science Society of America Special Publication Number 35. pp. 37–52..

Stolte, J., Tesfai, M., Øygarden L., Kværnø, S., Keizer, J. , Verheijen, F., Panagos, P., Ballabio, C., & Hessel , R. (editors), Soil threats in Europe*; JRC Technical Reports*. EUR 27607 EN; doi:10.2788/488054 (print); doi:10.2788/828742 (online)

Wardle, D.A. 1995. Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. *Advances in Ecological Research*, 26:105-185.