Food and Agriculture Organization of the United Nations

GLOBAL SOIL PARTNERSHIP

Implementation Plan for Pillar Five of the Global Soil Partnership

Harmonization of methods, measurements and indicators for the sustainable management and protection of soil resources

Providing mechanisms for the collation, analysis and exchange of consistent and comparable global soil data and information

IMPLEMENTATION PLAN

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Pillar 5 Working Group

Version 1.1

25.10.2017

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Versioning

Version 1.0	24.05.2017	Version for 5th GSP Plenary Assembly
Version 1.1	25.10.2017	Update: GLOSOLAN and P5 WG

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Acronyms

ANAB	ANSI-ASQ National Accreditation Board
ASPAC	Australia-Asian Soil and Plant Analysis Council
CEC	Cation exchange capacity
CMS	Content information system
EURL	European Union reference laboratory
GML	Geography Markup Language
GLOSOLAN	Global Soil Laboratory Network
GLOSIS	Global Soil Information System
GS SOIL	Assessment and strategic development of INSPIRE compliant Geodata-Services for European Soil Data
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
ICRAF	International Centre for Research in Agroforestry
ILPP	Inter Laboratory Proficiency Program
INSII	International Network of Soil Information Institutions
INSPIRE	Infrastructure for Spatial Information in the European Community
ISRIC	International Soil Reference and Information Centre
ISO	International Organization for Standardization
IUSS	International Union of Soil Sciences
JRC	European Commission Joint Research Centre
LUCAS	Land use - cover area frame survey
OGC	Open Geospatial Consortium
P5 IP	Pillar 5 Implementation Plan at global level
P5 PoA	Pillar 5 Plan of Action
P5 WG	Pillar 5 Working Group at global level
PT	Proficiency Test
PTF	Pedo-transfer functions
PTR	Pedo-transfer-rules
QA	Quality Assurance
QC	Quality Control
RESOLAN	Regional Soil Laboratory Networks
RIP	Regional Implementation Plan of the Regional Soil Partnership
RSL	Reference Soil Laboratory
RSP	Regional Soil Partnership
SEALNET	South-East Asia Laboratory Network
SDG	Sustainable Development Goals
SDF	Soil Data Facility of the Global Soil Partnership
SDI	Soil Data Infrastructure
SOP	Standard Operating Procedures
SOTER	Soils and Terrain Digital Databases
SPACNET	South Pacific Agricultural Laboratory Network
STS	Soil Thematic Strategy
SWSR	Status of the World's Soil Resources
ToR	Terms of Reference
USC	Universal Soil Classification
USD	US Dollars
USDA	United States Department of Agriculture
WoSIS	ISRIC - World Soil Information Service
WRB	World Reference Base for Soil Resources
XML	Extensible Markup Language

Foreword

This global Pillar 5 implementation (P5IP) follows the Pillar 5 Plan of Action (PoA), which provides the general framework for developing an over-arching system for harmonized soil characterization.

The Guideline for creating Regional Soil Partnerships (RSG) suggests that regional working groups are formed to coordinate the implementation of each pillar in the region. The chairs of these regional Pillar 5 working groups were invited to join a writing team to develop this global Pillar 5 implementation plan (P5 IP). The process was chaired by a member of the GSP Secretariat. In accordance with the procedure previously performed for Pillar 4, this writing team would become the Pillar 5 working group, which then guides the global-level implementation of Pillar 5.

GSP Pillar 5 Writing team

Global Soil Partnership Secretariat	Rainer Baritz (Chair)
Europe	Hakki Erdogan
Eurasia	Hukmatullo Ahmadov
NENA	Imad Ghanma
Africa (SSA)	Vinod Bhanooduth Lalljee
Asia	Audthasit Wongmaneeroj
South Pacific	Alison Collins
North America	Curtis Monger
South America	Jefé Leáo Ribeiro
Central America	Floria Bertsch
ITPS	Vinod Bhanooduth Lalljee

In order to further strengthen this implementation plan, various harmonization experts have contributed and acted as reviewers:

Reviewers and contributing authors:

- Luca Montanarella, Juan Comerma. Amanullah Khan (ITPS)
- Bert VandenBygaart, Carlos Cruz Gaistardo, Edoardo Constantini (Pillar 4 Working Group)
- John M. Galbraith (IUSS Commission 4: Soil Classification)
- Peter Schad (IUSS WG WRB)
- Frank Lame (ISO TC190)
- Nopmanee Suvannang, Christian Hartmann (SEALNET)
- David Medyckyj-Scott (Landcare Research and member of OGC Agriculture Domain Working Group)
- Niels H. Batjes (ISRIC)
- Marc van Liedekerke (EC-JRC)
- Feras Ziadat (FAO)
- Additional reviewers from the regional Pillar 5 WGs: Gerard Grealish; Siosiua Halavatau (South Pacific); Gergely Toth (Europe)

Executive Summary

Pillar 5 provides actions to implement harmonization of soil information and data for different areas of harmonization along the life cycle of soil data. The main areas of harmonization are soil profiles, soil classification and soil maps, soil sampling and analysis, interoperability of soil data, and interpretation and evaluation. The latter contains approaches to select and define soil indicators for monitoring, and methods to evaluate basic soil data (soil properties) in order to derive indicators, hazard indexes and land suitability functions.

In order to facilitate implementation, each area of harmonization has received a rationale which extends the Pillar 5 Plan of Action, and is then specified by actions. These are described and suggestions are made about the implementing institutions and resources needed.

The main task of Pillar 5 is to build an over-arching system for harmonized soil characterization. The system will consist of best practice recommendations, guidance materials and practical tools. Many methods and standards relevant for harmonization already exist; yet, many of these standards are not well-known, and capacity and experience to apply them is lacking. Therefore, the implementation of this plan is only partially a technical challenge, and to a large degree the building of national and local capacities to develop reliable quality-assured soil data and information about hazards and indicators.

Building capacity for harmonization will depend much on governments supporting and strengthening their technical institutions (e.g. installment of the proper information technology or laboratory equipment, partnering through meeting participation, incentives for standards etc.). However, it is a key action element of this implementation plan to facilitate networking and capacity development through cooperation and information sharing between experienced institutions and those with less experience. For example, the establishment of the Global Soil Laboratories Network would be a good example for improving the quality and comparability of soil analytical data.

This implementation plan reveals in depth the importance of existing activities of the International Union of Soil Sciences (IUSS) and of the International Organization for Standardization (ISO). Representatives of these organizations greatly contributed to the development of the Pillar 5 Implementation Plan. They will also play an important role during implementation (e.g. capacity on classification and interpretation).

Section 8 presents an overview and roadmap of all actions. It also contains information about how different elements of this plan are connected to Pillar 4 and the Global Soil Information System (GLOSIS). The time frame for this implementation plan ends 2020, corresponding to the Pillar 4 Implementation Plan. Not all actions, as identified here, will be completed during this implementation phase; experience with Pillar 4 shows that much time and effort is needed to a) identify and engage soil information institutions across the globe, b) establish operational working groups, c) involve relevant networks, and d) enable sufficient resources for implementation. Thus, the roadmap for the Pillar 5 Implementation plan has to be somewhat flexible and needs to be well-coordinated with Pillar 4 mainly.

This plan foresees the establishment of a Pillar 5 Working Group, Regional Soil Laboratory Networks, and the Global Soil Laboratory Network (GLOSOLAN).

1 Introduction

1.1 Harmonization to build the Global Soil Information System

Soils can only be sustainably managed and prevented from further degradation, and restored, if sufficient and reliable information becomes available about its current state, its susceptibility to hazards and threats, and its resilience to environmental change. Such information cannot be generated without standards and norms, and the availability of knowledge and experience to apply them. Harmonization is also important to make soil information comparable between different institutions, regions and countries.

Harmonization is most effective at the level of data generation (sampling, soil analysis, soil profile description), but very often has to be applied at later stages of information and data development (data exchange, indicators, soil evaluation). The Pillar 5 concept of harmonization areas thus follows the life cycle of soil data in a systematic form.

A large proportion of harmonization activities relates to data defined and exchanged through the Global Soil Information System (GLOSIS, see Pillar 4). Pillar 5 also involves the selection and definition of indicators, necessary for building a global soil monitoring system and SoilSTAT (see also GSP Pillars 1 and 4). The improved availability of harmonized soil data will also support soil research (Pillar 3; see also Hoffmann *et al.* 2017[1]).

1.2 Structure of this implementation plan

Harmonization, within the context of the GSP, can be defined as the provision of common standards of methods and measurements for the universal collation, analysis and exchange of global soils information.

This implementation plan follows the scope provided by the Pillar 5 Plan of Action (P5 PoA). The PoA has defined areas of harmonization along the life cycle of data: from field assessments (soil profiles), soil classification and mapping, sampling and analysis, exchange of data, evaluation and interpretation of data. Accordingly, the following key areas of harmonization are covered by this implementation plan:

- **Soil profiles, soil classification and soil maps** (section 2)
- **Soil sampling and analysis** (section 3)
- **Interoperability – the exchange of digital soil information** (section 4)
- **Interpretation and evaluation** (section 5)

1.3 Scope and challenges to harmonization

The following challenges were identified in the Pillar 5 Plan of Action (P5 PoA):

1. Develop an overarching harmonization concept.

[1] Hoffmann et al. (2017). Overview of relevant standards for the BonaRes-Programm “Soil as a sustainable resource for the bioeconomy”. Funded by the German Federal Ministry for Education and Research (BMBF).

2. Exchange data required to generate aggregated cross-border data sets using a variety of data sources.
3. Develop and agree on target standards for harmonization.

Harmonized and well-specified soil data sets, available as interoperable web services, are the core elements of the Global Soil Information System (GLOSIS; see Pillar 4). The necessary degree of harmonization can only be achieved if harmonization methods are in place and standardized.

The P5 PoA distinguishes six recommendations, two generic ones, and four specifically related to areas of harmonization.

> **Recommendation 1:**
> Develop an **over-arching system for harmonized soil characterization** as the central objective of Pillar 5. The system builds on and merges existing approaches to describe, classify, map, analyze and interpret soils.

Such an overarching harmonization concept involves and builds on solutions to improve the availability, transferability and usability of soil data. The fundamental aim is to generate comparability of data from within and between countries. The concept must take advantage of technical and scientific developments such as new opportunities for data collection and the processing of soils information.

1.4 Principles for harmonization

The second recommendation of the P5 PoA explicitly focusses on operating principles.

> **Recommendation 2 (P5 PoA):**
> As a mechanism for improving the comparability of soil data, all GSP members should be able to reference their information into the GSP harmonization system which includes legacy data as well as newly collected data, built on established **harmonization principles** as well as on current standardization and harmonization activities.

1. Principles for cooperation

Commonality – Support the most common requirements and needs for global harmonization; ensure maintenance of national information systems and identify and build on **common practices and approaches**.

Inclusiveness – Requires wide participation while also recognizing that it may not be possible to incorporate the specific individual needs of all users.

Efficiency – Minimize the effort which is required to apply agreed-upon standards and procedures.

Multilinguality – Must have agreed-upon harmonization standards, references, and soil terminology.

2. Guiding principles for harmonization operations

Interoperability – Data and information exchange will require implementation specifications for interoperable soil data. These should be well documented, tested, accessible to all GSP members at no cost and implementable.

Extensibility – Agreed-upon level of common ground, which can be further extended as required to include local concepts, solutions and approaches.

Scalability – Referencing between different harmonization approaches and between global-, national- and local-scale soil information must be enabled.

Conformity to these principles will support **comparability and integration** of data from different sources.

In this document, the idea of 'reference methods', 'best available techniques', 'best practice' and 'recommended standards' will be used. These recommendations must at the same time reflect 'good for purpose' or 'best for purpose' practices because of the diversity of operating conditions to be found locally, nationally and regionally. It is therefore important to allow for the existence of different methods / techniques with different characteristics with respect to time and costs when data from different GSP members are brought together, accepting that the results are not per definition fully comparable or can only be compared meaningfully by taking account of local, etc. characteristics (e.g. see also principle of efficiency).

2 Harmonized description of soil profiles, soil classification and soil maps

2.1 Background

Recommendation 3:
Reference systems for soil profile description, soil classification and soil mapping need to be developed. For that, the FAO (2006) Guidelines for Soil Description[2] should be reviewed with the aim to develop it further as a new generic field book. References for international soil classification will be the World Reference Base for Soil Resources or the USDA Soil Taxonomy until a new standard system is released. The GSP supports the development of the new Universal Soil Classification System.

The P5 PoA provides accurate guidance for the harmonization approach regarding soil description, soil classification and soil mapping. It refers to the World Reference Base for Soil Resources (WRB 2014, update 2015) and the USDA Soil Taxonomy (2014, Keys to Soil Taxonomy, twelfth edition). Regarding the new global 1:1M soil map, the Pillar 4 Implementation Plan recommends the use of WRB. However, methodological details for soil mapping and soil classification in the world soil map still need to be investigated by the Pillar 5 working group, which will involve experts from different fields of harmonization, in particular from ISO and IUSS.

2.2 Reference System for soil profile description

2.2.1 Harmonized soil profile description

The description of recognizable soil properties is the primary source for information about soils. The description, sampling, analysis and interpretation of soils are based upon the systematic descriptions of soil profiles. 'Systematic' refers to a harmonized approach, which identifies soil horizons and macromorphological properties in a broadly accepted form.

A common standard of how to describe soil profiles is at the core of an "over-arching system for harmonized soil characterization" (Pillar 5 Plan of Action, Recommendation 1).

A reference system for soil profile description consists of agreed-upon concepts, terms, codes and classes (thus representing a globally accepted nomenclature for soil description) defined so that national conversions or correlations become possible. It contains the following main elements:

1. It is applicable to any soil, thus can be used at any location in the world if national reference manuals are not available;
2. It is applicable as a field manual for international soil classification (see section 2.3);
3. It consists of the main soil properties, classified according to generic classes;
4. It provides generic and universal codes for data storage (also applicable for mobile applications);

[2] FAO (2006). Guidelines for soil description, fourth edition, UN Food and Agriculture Organisation, Rome (http://www.fao.org/docrep/019/a0541e/a0541e.pdf)

5. Countries are able to correlate nationally-defined soil properties (terms, codes, classes, definitions) to this reference guideline (serves as an entry point to international soil classification, see section 2.3).

Various national and international guidelines exist, which are in some cases directly linked to soil classification. That means that soil classification requires a soil description first (e.g. properties of soil horizons). In some systems, specific combinations of soil horizons determine soil types; in other cases, only those soil properties are needed which are directly correlated to diagnostic horizons and properties (e.g. WRB); nevertheless, a full soil profile description is needed.

Currently, at a global level, the Guidelines for Soil Description (FAO 2006) provides an accepted international reference to soil profile description. The Working Group for Universal Soil Classification (IUSS WG USC) has raised the need to revise and combine the FAO 2006 Guidelines with other systems, including the USDA, Australian, Brazilian, South African, and Chinese systems.

FAO (2006) is also the basis for ISO 25177 (2008) “Soil quality — Field soil description”. This standard has been under revision since 2013. The reasons for this revision, listed below, and its implementation by ISO TC 190, may provide guidance to Pillar 5 regarding the **improvement needs of FAO (2006):**

- The Guidelines provide only limited options for the survey of human-made materials.
- Survey of possible pollution is missing.
- Classification of non-natural soil materials and its characteristics is only provided to a limited extent.
- Texture is estimated with reference to mass percentages; other parameters have to be estimated as volume percentages.
- Encoding could be improved for digital storage and exchange of data (see section 3.2, ISO 28258).

In addition, considering the advances in lithological and geomorphological classifications in the last years, a revision of the terms related to parent material, substratum, and physiography, are needed.

2.2.2 Actions required to develop a generic field book for soil profile description

The following actions are required:

1. Requirements and gaps analysis:
   An investigation of user requirements, analysis of existing handbooks[3] and soil profile descriptions (desk review) and the collection of suggestions by experts (consultative process) are required in order to revise and update the current FAO Guidelines for Soil Description (2006). For example, it is necessary to develop a generic coding of soil properties[4], and to revise the parent material classification. An important requirement is that existing soil profiles (legacy) can be updated with a revised new soil profile description (GSP harmonization principles efficiency and extensibility).
2. Revisions and drafting of a new handbook for soil profile description based on FAO 2006, considering the revised ISO 25177, including application tests;

[3] Examples of national reference manuals and methods: USDA Soil Survey Manual (USDA 2017), USDA Field Book for Describing and Sampling Soils (2013), Australian Soil and Land Survey Field Handbook (2009) and the Soil Classification System of England and Wales (1980, 1984).

[4] See also Batjes, N.H., et al. (2017). WoSIS: providing standardised soil profile data for the world. Earth Syst. Sci. Data 9(1): 1-14. http://dx.doi.org/10.5194/essd-9-1-2017.

3. Development of a web-based tool to download and interactively use the new generic soil field book (includes the storage and download of soil profile descriptions);
4. Development of guidance for national conversions[5] to map selected soil profile properties according to the reference field book for soil profile description. (This might be a prerequisite to share Pillar 4 Tier 2 soil profile data sets.)

2.2.3 Budget and responsibilities

1. Requirements and gaps analysis: desk review, public e-consultation through the GSP soil portal: P5 WG (see section 6.1, governance), voluntary contributions by INSII member(s) and/or IUSS working groups: in-kind
2. Revision and draft of a new handbook for soil profile description: voluntary contributions by P5WG and/or IUSS, supported by INSII members and/or other experts: in-kind
3. Web tool including an app for mobile use: voluntary contributions by GSP partners are supported by a contractor: 20,000 USD
4. Guidance for the development of national conversion methods: IUSS, supported by P5 WG: in-kind.

2.3 Reference System for soil classification

2.3.1 Harmonized soil classification: ongoing activities

Knowledge about soil properties is a key requirement for many soil indicators. Soil mapping and evaluation depend on classified entities of the real world (soil profiles, soil mapping units). The diversity of soils in the real world is so large that easy-to-recognize properties are often needed to disseminate, integrate and share information about the complexity of soils. This is done by classifying soils. The Pillar 5 Plan of Action introduces the work item to develop a harmonized classification system. The plan acknowledges the important role of the IUSS Universal Soil Classification System Working Group (see also Appendix 2 of the P5 PoA). Looking at the working tasks foreseen, and the challenge to build a new system, the P5 PoA concluded that this work shall be supported.

Harmonization in the area of soil classification means:

a) Agreement and acceptance of an overarching, international reference system
b) Applicability of an international reference system to nationally classified soil profiles or soil mapping units
c) The fulfillment of criteria listed in Table 1.

The correlation between national soil classifications and WRB or US Soil Taxonomy is fraught with uncertainty, yet possible within certain boundaries of uncertainty and error (Krasilnikov *et al*. 2009). An initial effort in this direction has been undertaken in the framework of the SoilGrids[6] project. As indicated, international or global soil data bases do not require the full detail as compared to acquisition of local soil data (soil profiles, classification, soil maps). The successful mapping between a national and an international soil classification would ideally build on a common taxonomic unit for correlation between these systems.

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[5] Examples see Baritz and Hudson (2012)[12]

[6] See page 6 in: Hengl, T. et al. (2017). SoilGrids250m: Global gridded soil information based on machine learning. PLoS ONE **12**(2): e0169748. http://dx.doi.org/10.1371%2Fjournal.pone.0169748

The European GS Soil project[7] has successfully demonstrated that a mapping between national soil classifications and WRB is possible, but at a fairly coarse taxonomic level.

Table 1: Harmonization challenges to global soil classification

Criteria	WRB	Soil Taxonomy	Remarks
Enabling the correlation to national systems through a) Generic definition and hierarchy of taxonomic units, AND/OR b) Flexibility to apply different taxonomic levels	✓	✓	It is difficult to identify a common denominator (order/series, class, group, type, sub-type, variant/variety, phase)* Still, if primary character data are available, soil can be classified to various levels.
National experiences with correlations exist	✓ (Europe)	✓	Many countries outside Europe do not have national classifications in place, thus use WRB or US Soil Taxonomy or the French system
(Semi-)automated tools exist or are under construction	✓		Translation based on soil profiles described using the FAO soil profile description (may require the prior conversion of national soil profile descriptions)
The classification offers simple and pragmatic solutions to be applied in small-scale soil maps (< 1:250k)	✓	✓	IUSS Working Group WRB (2015). Soil Taxonomy was designed for making soil surveys for individual farmer's fields at any location.
A significant part of the world is mapped using the classification	✓		WRB adopted by IUSS, West and Central African Soil Science Association and European Commission as the common classification framework (WRB 2006[8]). WRB adopted in SOTER (Soil and terrain Database), Soil Map of the World, Soil Atlas of Africa, Soil Atlas of South America, Circumpolar Soil Atlas).
Older versions of the classification applied to soil map and soil profiles can be easily updated		✓	When characterizations are available, soils can be easily re-classified.
Guidance for international harmonization and application has been prepared; experiences with the updating of older (international) soil maps exist.	✓	✓	WRB: Examples from European countries compiled in Baritz and Hudson (2012) USDA-NRCS Lab Characterization Database
Referencing with the Referentiel Pedologique (AFES 1989; Baize and Girard 2008)	✓		The French system is also used in several West- and North-African countries as well as some South Pacific Island nations. The taxonomic categories resemble WRB.
Multilinguality	up to 8	4	Availability of translations: WRB 1998 in 7 languages, WRB 2006 in 8 languages, WRB 2014 in 7 languages
Is the system unambiguous, and easy to apply?	✓	✓	Soil Taxonomy is a hierarchical system from general orders to detailed families and series.
Does the system provide a comprehensive soil name, even if the dataset is incomplete?	✓	✓	

[7] http://inspire.ec.europa.eu/SDICS/gs-soil

[8] IUSS Working Group WRB (2006). World reference base for soil resources 2006. World Soil Resources Reports No. 103. FAO, Rome.

WRB has been explicitly built as a global reference system including guidance for applying it in soil mapping at different scales. WRB evolved from the FAO Legend of the Soil Map of the World, and will also be used as a reference system in Europe. The advantages for using WRB as the main reference system for GSP Pillar 4 products are also obvious (e.g. follow-up of international soil profile data bases, SOTER as one of the sources for the global soil polygon map). However, being inclusive and flexible, thus involving referencing solutions from the Soil Taxonomy and the French system are also important GSP harmonization principles, especially in light of the large USDA global database made available online free of charge.

Important ongoing activities:

- IUSS working groups for Urban Soils, Cryosols, Acid Sulfate Soils and Proximal Sensing
- IUSS Working Group 'WRB'
- IUSS Working Groups 'Universal Soil Classification' and 'Soil Information Standards'

2.3.2 Action: Components of a global reference system for soil classification

1. Development of a web-based classification tool for WRB and Soil Taxonomy:
   Such a tool has to be based on the FAO Guidelines for Soil Description, the 2017 Soil Survey Manual, and on analytical data.
2. Updating the web site "Soil Classification" of the FAO soil portal[9]:
   Such a web site also presents the recent and updated literature and reference materials for soil classification, capacity building, etc.
3. Encouragement of IUSS WG WRB und WG USC to continue the development and harmonization of soil classifications:
   Potential criteria for USC:
   - Build on the legend of the FAO Soil Map of the World as the basis for the definition of Reference soil groups and equivalent soil orders;
   - Limit qualifiers to primary qualifiers;
   - Simplify and merge US Taxonomy and WRB diagnostics.
4. Capacity building for field training:
   It is important that knowledge is made available about the application of international soil classification[10]. Experts active in the above-mentioned IUSS WGs could develop specific training and learning materials about soil classification.

[9] http://www.fao.org/soils-portal/soil-survey/soil-classification/en/

[10] Important reference publications:

Brevik, E.C. et al. (2016). Soil mapping, classification, and pedologic modelling: history and future directions Geoderma Volume 264, Part B, 15 February 2016, Pages 256–274.

Eswaran, H. et al. (2002). Soil Classification: A Global Desk Reference. CRC Press. 280 Pages, ISBN 9780849313394.

2.3.3 Budget and responsibilities

1.	Development of a web-based classification tool for WRB and Soil Taxonomy	Voluntary offer by INSII members and/or other experts and/or GSP-Soil Data Facility (SDF): in-kind
2.	Updating the web site "Soil Classification" of the FAO/GSP soil portal	FAO GSP Secretariat: in-kind
3.	Encouragement of IUSS WG WRB und WG USC to continue harmonization of soil classification	IUSS: voluntary (in-kind) contributions Membership P5WG
4.	Capacity building with field lectures	1 Workshop per 9 Regional Soil Partnerships (45 K USD for each workshop): 405,000 USD

2.4 Reference System for soil mapping

2.4.1 Challenges related to the development of the Pillar 4 Global Soil Polygon Map

The reference system for soil mapping is the basis for defining the methodical specifications for the development of a new global soil polygon map (see Pillar 4). It may also serve as a reference for developing regional cross-border soil maps at higher resolutions.

With regard to the harmonization of soil maps, the following characteristics and conditions need to be considered:

- The delineation methods for various kinds of soil maps are often unknown and biased to the expertise of the individual soil mapper.
- The quality of existing pre-GIS soil maps depends on analog data, which lack accuracy and comparability (topography, geology).
- National small-scale maps are often top-down maps, meaning, they are not aggregated from high-resolution maps (due to the lack of full coverage in many countries, for example, soil mapping may be focused on agricultural land only); thus the delineation procedure cannot be investigated unless full coverage of higher resolution maps becomes available.
- Soil maps provide legends with soil types. Soil mapping units are defined with varying accuracies; scale and map hierarchy are sometimes defined/considered (associations, complexes, components, landscapes, local forms, dominating soils, associated soils, etc.) (Figure 1 provides an example for a concept for harmonizing soil maps).

Figure1: Simplified nested system for harmonizing soil maps

- Map legends are sometimes stratified (e.g. according to soil regions); according to the understanding of some soil experts, aggregation of soil map units through scale requires a stratification.
- Aggregation of soil maps and change of scale requires geometric adjustment (generalization). This is conventionally done by hand using topographic maps (with details adjusted to the original resolution).
- Recent soil maps are stored in a GIS database, in some cases combined with soil properties (e.g. referring to the dominating soils based on a described or measured, typical soil profile).
- Advances in geology mapping and the availability of digital elevation models enable globally harmonized terrain data (land-forms and parent material). On that basis, the eSOTER[11] methodology seems to be a good instrument for harmonization. The methodology can also be applied to integrated existing soil maps (revisit map geometries and content with affordable effort).

2.4.2 Action

When developing methodologies, the GSP harmonization principles shall be considered, in this case in particular, extensibility, scalability, inclusiveness and efficiency. This means that existing soil maps which match the target scale shall be preferably incorporated. It also has to be considered that Pillar 5 provides the harmonization framework for soil polygon mapping, while Pillar 4 develops the mapping method and product specifications.

1. This Pillar develops a reference system for global soil polygon mapping, for which the following aspects must be considered:
   - Development of a template for the documentation of soil maps (Baritz and Hudson 2012[12]),
   - Generic definition of the global 1:1M soil mapping unit, considering a nested system of soil mapping units, in support of the Pillar 4 mapping specifications
   - Design of a proper stratification to integrate soil mapping units around the world;
   - Definition of a target specification (with Pillar 4),
   - Harmonization methodology to revise existing maps (generalization, aggregation),
   - Methodology to revise existing SOTER maps,
   - Methodology to fill soil mapping gaps (countries lacking national digital soil maps),
   - Integration methodology to develop a globally harmonized conceptual soil map 1:1M.
2. Some training will then be needed so that harmonized soil mapping, or harmonization of existing maps, can be conducted to meet the Pillar 4 specifications and the Pillar 5 reference system.

2.4.3 Budget and responsibilities

1. Development of a manual for harmonized global soil polygon mapping considering the criteria listed under section 2.4.2: voluntary contribution by INSII member and/or SDF, coordinated and supervised by the Pillar 4 and 5 working groups: in-kind
2. Trainings: 1 per RSP a 45,000: 405,000 USD.

[11] www.esoter.org

[12] Baritz, R. and G. Hudson (2012). D4.3 "Data Harmonization Best Practice Guidelines". Report of the GS Soil Project "Assessment and strategic Development of INSPIRE compliant Geodata-Services for European Soil Data". Project No. CP-2008-GEO-318004. Copies of the report: rainer.baritz@eea.europa.eu.

3 Soil sampling and analysis

3.1 Background

The Pillar 5 Plan of Action (P5 PoA) provides background on the need for harmonizing soil analytical data in order to provide comparable information between countries and projects, and in order to allow the generation of new harmonized soil data sets. These include not only soil profile data with essential soil properties, but also indicator-based assessments of environmental hazards and effects of climate change. The P5 PoA advises the use of standards wherever applicable. It recommends that any data about soil quality shall be accompanied by metadata. Based on additional information (e.g. about sampling procedures, analytical methods, sample preprocessing and storage), the differences and quality of soil analytical data from different sources can be judged. Ultimately, recommended standards are to be followed in order to obtain comparable results. When analytical data are based on different methods, it might be investigated to use conversion or correction factors, but note should be taken that this in most situations will only provide sufficiently reliable results if very general and broad data classes are used.

With regard to soil analysis, the objectives of Pillar 5 are thus the following:
- to support global and regional networking among soil laboratories.
- to support laboratories to apply ISO standards.
- to support laboratories to apply quality control procedures.

> **Recommendation 4** of the P5 PoA requires two main steps to be followed:
> Review existing practices for field sampling, sample preparation and measurement (including the application of ISO standards and QA/QC-procedures in the laboratory) (see **section 3.2**);
> Prepare specifications and guidelines for harmonized approaches to determine the main functional properties of soils (i.e. chemical, physical and biological) (see **section 3.3**).

3.2 Review of existing practices for field sampling, sample preparation and measurement

This review will compile the necessary background knowledge for developing a reference framework for the harmonization of soil analytical data sets.

3.2.1 Collection of existing analytical methods and local variants

Before guidelines for harmonized soil testing can be developed (based on recommendation 4, see above), existing common practices and standards, as well as available method compilations and recommendations, need to be compiled and compared. This includes sampling, sample preparation and sample analysis. Such a method overview would support the selection of recommended procedures (to be included in best practice guidelines, see section 3.3.1), but also the development of coding tables (see section 3.2.2, see also Ribeiro *et al.* 2015[13]).

Annex 1 presents selected well-known reference publications, including an overview of ISO standards (ISO Technical Committee 190, Soil Quality).

[13] Ribeiro, E. et al. (2015). Towards the standardization and harmonization of world soil data: Procedures manual ISRIC World Soil Information Service (WoSIS version 2.0). Report 2015/03, ISRIC – World Soil Information, Wageningen. http://www.isric.org/sites/default/files/isric_report_2015_03.pdf

In order to select applicable methods, it is essential to determine the purposes for which the data are to be applied, not only in general terms, but also with respect to the demands on quality (e.g. reproducibility and reliability). When these are defined, existing ISO standards (and other methods) can be assessed in order to identify best practices and reference methods.

The information provided in Annex 1 may be supplemented by additional information collected through the regional GSP network and interested partners. In particular, an overview of already existing common practices is needed.

Harmonization activities shall be focused on the parameters identified and needed in Pillar 4 (Global Soil Information System) and Pillar 5 (soil classification and indicators).

The following table provides an overview of relevant information needed to document soil analytical procedures (examples see Utermann *et al.* 1999, Annex 1). The criteria for the documentation of laboratory methods may slightly differ between soil analytical information systems/existing documentations. This collection of routinely applied laboratory methods, for main soil parameters, shall build on available method documentations and reference literature, exchanged in English language, and completed for a template which will be developed and completed as a CMS (content management system) or WIKI for soil laboratory methods.

Table 2: Documentation of soil analytical procedures (suggested criteria)

	Criteria to describe soil analytical methods
1	Name of the analytical method
2	Methodological principles including measuring unit
3	Quality characteristics (e.g. reproducibility and reliability, validation data) (for methods for which this is applicable)
4	Scope and limitations, difficulties and recommendations for use
5	Requirements for sampling, transport and storage
6	Sample treatment and preparation
7	Apparatus (analysis and additional devices)
8	Plausibility criteria (e.g. value range for typical soils)
9	Restrictions and methodological errors
10	Criteria for method selection
11	Bibliography (e.g. reference method, applications)

3.2.2 Coding of soil analytical data

The description of laboratory procedures is a prerequisite to understand the analytical data produced. This data is not captured in known metadata standards, and no standard procedure yet exists to document and exchange analytical information in soil databases. However, several laboratories have already developed their own coding systems.

In the frame of Pillar 4 (soil profiles, soil grids, and soil monitoring), soil property data will be shared. In order to understand the kind of analysis and processing done, this data can be supplemented using the code for soil analysis. The code may provide information about sampling, sample preparation, soil analysis and apparatus used (see Annex 2).

3.2.3 Action

The following **action** is required:

1. Design and establish a content information system (CMS) for the documentation of laboratory methods (including a template for information transfer between laboratories and the CMS). Consider linkages to metadata (codes; section 4.4) and vocabulary services (terminologies; section 4.3).
2. Populate the CMS: collect and exchange information about existing soil analytical procedures for a core set of soil properties.
3. Develop of a generic laboratory coding system for analytical metadata. The CMS will provide the necessary code lists.
4. Workshops and capacity building: one workshop per regional soil partnership; the task must be coordinated and sufficient expertise must be provided using consultants.

3.2.4 Budget and responsibilities

1. CMS for the documentation of laboratory methods: design specifications and template by Pillar 5 WG: in-kind; CMS implementation freeware (e.g. DRUPAL): 25,000 USD: maintenance by SDF (in-kind).
2. Collection and exchange of information about existing soil analytical procedures: members of the regional soil laboratory networks and GLOSOLAN (see section 6.2 and 6.3) (in-kind).
3. Development of a generic laboratory coding system: Pillar 5 WG, supported by ISO: in-kind.
4. Workshops and capacity building: workshops (9 RSPs, a 45,000 USD): 405,000 USD.

3.3 Specifications and guidelines for harmonized approaches to the determination of the main functional properties of soils

Following the P5 PoA, the following harmonization actions are suggested

- Best practice guideline for harmonized soil analysis (section 3.3.1, building on section 3.2)
- Establishment of reference laboratories (section 3.3.2)
- Establishment of a spectral library for NIRS/MIRS (section 3.3.3)
- Establishment of the Global Soil Laboratory Network (GLOSOLAN) regional soil laboratory networks (section 3.3.4)

3.3.1 Manual: Standards and best practice in soil analysis

The Pillar 5 Plan of Action seeks to compile, agree on and recommend standard soil testing procedures (or, according to the P5 PoA, the best suitable analytical methods). This is motivated by the fact that the variety of soil analytical procedures is still large, and the quality of its implementation varies as well, despite existing ISO standards.

Its application is often hampered due to cost for purchase (ca. 120-200 USD per standard) or other reasons (prescribed methods from stakeholders, available equipment, experience of laboratory staff; see also McLellan *et al.* 2013[14]). Soil laboratories may more closely interact with their national standardization bodies in order to receive more support to applying existing standards. The quality of information and acceptance of standards may also be improved by establishing robust communication strategies and exchange of information between laboratories.

Based on action under section 3.2 (existing analytical methods and metadata), a guideline with best suitable analytical methods will be developed. Wherever possible, this should build on available ISO-standards. An example, which has already been elaborated for the countries of the Asian Soil Partnership is the SEALNET manual on "Analytical methods for agricultural and environmental samples: soil, plant, fertilizer and water". Also, interlaboratory comparisons such as McLellan *et al.* (2013) conclude that a prescribed analysis protocol is important to improve comparability of soil analyses.

This manual shall comprise sampling, sample preparation, and soil analytical procedures, including soil chemical and soil physical analyses for a core set of parameters. The following core soil parameters shall be considered.

- pH
- Carbonate content
- Gypsum and salt content
- Electrical conductivity
- Organic C
- Total N and nitrate
- Phosphorous
- Potassium
- Cation exchange capacity
- Exchangeable Aluminum, Iron and Manganese
- Exchangeable bases
- Particle size distribution
- Bulk density
- Coarse fragments

The list of these parameters may be reviewed and extended later (see GlobalSoilMap[15]; SOTER[16]). Additionally, micronutrients are important for plant and human nutrition, such as B, Mn, Zn. With regard to soil monitoring, methods for soil biological parameters (e.g. abundance of earthworms, soil respiration) shall be considered as well.

Annex 3 provides an overview of analysis relevant for soil classification (WRB).

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[14] McLellan, I. *et al.* (2013). Harmonisation of physical and chemical methods for soil management in Cork Oak forests - Lessons from collaborative investigations. African Journal of Environmental Science and Technology Vol. 7(6): 386-401.

[15] GlobalSoilMap (2013). Specifications Version 1. GlobaSoilMap.Net products release 2.1.

[16] van Engelen, V. W. P. and J. A. Dijkshoorn (2013). Global and National Soils and Terrain Digital Databases (SOTER) - Procedures manual (Ver. 2.0). Wageningen, IUSS, ISRIC and FAO, 202 p. http://www.isric.org/sites/default/files/isric_report_2013_04.pdf

3.3.2 Reference soil laboratories

In each region, at best, in each country, one or more soil laboratories exist that cooperate internationally and are experienced and already accredited and/or certified[17]. Accreditation guaranties an international quality standard as well as the international acceptance of results and products. Accreditations are an official proof of competence and will only be awarded after an ISO assessment by an independent international accreditation organization. Accredited laboratories are expected to perform the following qualities (according to ANAB, web site visited 13. April 2017):

- qualified, trained, and experienced staff
- right equipment - appropriately calibrated and maintained
- adequate quality assurance and quality control procedures
- appropriate (sub-)sampling practices
- sound testing and/or inspection procedures
- accurate recording and reporting of data
- appropriate testing environment
- safety and disposal of hazardous wastes standards

In order to support the broad application of recommended methods at the best quality possible, regional information exchange, interlaboratory comparisons and trainings are needed. There, experienced national or regional reference laboratories play an important role. Most likely, such laboratories are already accredited following ISO 17025[18]. They can develop reference materials, organize and evaluate inter laboratory ring tests, and support analytical harmonization. They help validating data and measurements, and operate in national and/or regional networks.

3.3.3 Spectral library

Soil visible near- and mid-infrared (Visible-NIR/MIR) reflectance spectroscopy has been widely used for research and practical purpose; it provides fast and low cost results compared to conventional soil chemical analysis methods. The technique is mainly used in the laboratory, but its application in situ (using portable and handheld spectrometers), as well as from air- and space borne sensors, is growing. A single spectrum may contain comprehensive information on various soil components, and can be used to predict these simultaneously. Currently, published soil spectroscopic models cover a wide range of soil properties: soil water content, organic carbon, texture, cationic exchange capacity, total phosphorus, exchangeable K, Ca and Mg, total N, pH, total metal concentrations, and electrical conductivity.

The development of typical spectra for certain materials is challenging because of the huge variety of soils, laboratory equipment and sample preparation (e.g. % water content of air-dried samples, different grinding procedures, variation of particle sizes). In order to produce robust prediction models for soil properties over large areas, large spectral libraries are needed with quality controlled input and calibration. For example, spectra from a large representative global library would enable appropriate

[17] ISO/IEC 17025 (Accreditation), ISO 9001 (certification). Different accreditations refer to the production of reference materials or as provider of proficiency testings.

[18] Note: ISO/IEC 17025:2005 is for use by laboratories in developing their management system for quality, administrative and technical operations. Laboratory customers, regulatory authorities and accreditation bodies may also use it in confirming or recognizing the competence of laboratories.

validation of the reflectance information extracted from radiance data acquired from remote platforms. Also, soil monitoring could be majorly enhanced this way. Efforts such as the IUSS working group on Proximal Soil Sensing need to be supported.

Table 3: Overview of selected spectral libraries

Shepherd & Walsh (2002)	1,000 samples (eastern and southern Africa)
Brown *et al.* (2006)	3,768 samples (USA); 400 samples (globally)
ICRAF-ISRIC	4,436 samples from 785 soil profiles (world-wide)
Viscarra Rossel and Webster (2012)	21,500 samples from 4,000 soil profiles (Australia)
Stevens *et al.* (2013) (LUCAS Soil data)	20,000 samples (Europe, 23 countries)
Rapid Carbon Assessment (2013)	144,833 samples at 6,017 locations (USA)
USDA Kellogg Soil Survey Lab (2017)	100,000+ samples with corresponding analytical data (USA)
US Geological Survey (2017)	mineral, field, airborne, and spacecraft libraries (USA)
Africa Soil Information Service (2013)	17,000 samples from 60 sentinel sites (Sub-Saharan Africa)
Goge *et al*. (2012)	2,200 samples (France)
Knadel *et al.* (2012)	2,851 samples (Denmark)
Brodsky *et al.* (2011)	500+ samples (Czech Republic)
Vasques *et al.* (2010)	7,120 samples (Florida)
Suvannang *et al.* (2016)	7,433 samples(Thailand)
Costantini *et al*. (2016)	1,500 samples (Italy)

3.3.4 Regional soil laboratory networks

The challenge to improve the application of recommended procedures and laboratory performance can best be managed by region, where language barriers are lowest, and existing expertise and cooperations can be used. A good example is the South-East Asia Laboratory NETwork (SEALNET, Box 1).

Each country in each region may identify one or several leading soil laboratories, which may act as national reference centres for soil analysis. These could be laboratories which have quality control (QC) measures well in place, and which have participated in proficiency tests (PT)[19], and/or which are accredited. These laboratories would organize workshops, trainings and ring tests. They would advise other laboratories lacking QC and/or who have never participated in any proficiency testing.

The frame conditions to form regional laboratory networks may differ from region to region. For example, in Europe, the ICP Forests Soil Expert Panel has developed a series of ring tests among its members, based on a manual on sampling and analysis of soil (ICP Forests 2006, Part IIIa). Also, the European Council and Commission can establish so-called European Union reference laboratories (EURLs), as it has already done in the areas of animal health, public health and zootechnics, based on a number of legal acts (specifying the functions and duties of the designated EURL). For soil analyses, such an EURL does not exist. However, it may take over the role of a European reference laboratory, and act as a catalyst to set up such a network.

[19] Proficiency testing (PT) is the testing of unknown samples by different laboratories joining an approved PT program. PT is a tool laboratories can use to verify the accuracy and reliability of their analysis.

Box 1: Laboratory network in the Asian Soil Partnership

In the South-East Asian region, SEALNET has been established in 1995 with the objective to facilitate the sharing of experience among laboratory managers. The manual on "Analytical methods for agricultural and environmental samples: soil, plant, fertilizer and water" has been prepared. In 2014, SEALNET was revised and extended (SEALNET 2.0). Through cooperation with the Australia-Asian Soil and Plant Analysis Council (ASPAC), five SEALNET laboratories were offered to participate in the ASPAC Inter Laboratory Proficiency Program (ILPP) for 2016-2017. This will allow assessing the performances of these laboratories for soil testing, and subsequently support certification by ASPAC. These laboratories may be further developed as regional reference laboratories, further strengthening SEALNET for the region.

Objectives of SEALNET 2.0:

– calibrate and harmonize soil testing procedures and practices in laboratories of the ASEAN and SE Asian Nations (ASEAN) and in wider Asian regions in the context of the Asian Soil Partnership (through the definition and description of harmonized Standard Operating Procedures (SOPs) for key soil tests;
– set up a regional inter-laboratory proficiency program to implement QA/QC procedures and processes.

3.3.5 Action

Best practice guideline:

1. Develop a guideline for soil analytical reference procedures as an easy-look-up laboratory good practice.
   This requires an overview of commonly applied procedures (section 3.2.1). Reference publications and existing manuals (see Annex 1) must be studied, and recommended procedures to be agreed.

Reference soil laboratories (RSL):

Define the requirements for reference soil laboratories (RSL). Establish one or several reference soil laboratories in each regional soil partnership, if possible for each country. These laboratories will become drivers in the building of capacity in local soil laboratories. They will closely cooperate within the respective regional soil partnership and through the Global Soil Laboratory Network (GLOSOLAN).

1. Develop the requirements catalogue and procedure to designate RSL
2. Conduct soil ring tests: Regional Soil Laboratory Networks (RESOLAN; see section 6.2) and RSLs to decide on parameters, analytical procedures and timing and coordination of ring tests (e.g. at global or at regional level).

These laboratories, as well as national soil laboratories striving to become reference laboratories, will coordinate their activities globally (see Section 6.3 - GLOSOLAN).

Spectral library:

Involve many soil laboratories in the sharing of spectral data. The following activities need to occur:

1. Develop guidelines for collecting spectral data sets (incl. metadata scheme)

2. Analyse methodical laboratory-specific effects (ring tests, require reference material (such as bleached inert sand), and a standard soil sample to be prepared and distributed among laboratories); calibrate spectral data against reference soil analytical data, or new samples (by a reference soil laboratory)

Further:

3. Develop a global spectral library (database) of all samples present in the different archives and available for spectral ring tests, in order to develop robust models over large areas, and integrate it into Global Soil İnformation System (GLOSIS; see P4IP)
4. Workshops for the Guidelines for optimizing accuracy and consistency in the NIR spectroscopy.

Regional laboratory networks:

1. Establish Regional Soil Laboratory Networks (RESOLAN), building on existing initiatives: the network would primarily rely on one or several national soil laboratories with sufficient experience and/or representativity and nationally mandated function to represent the country of origin (see also section 6.1).
2. One regional meeting to take place per year/region with all interested soil laboratories

3.3.6 Budget and responsibilities

Best practice manual	
1. Global soil analytical reference manual	members of the Global Soil Laboratory Network GLOSOLAN – see section 6.3 (in kind)
Reference soil laboratories (RSL)	
1. RSL establishment	GLOSOLAN members (in-kind)
2. Ring tests (soil chemical analyses, soil physical analyses)	GLOSOLAN members (coordination of ring tests, in-kind) RESOLAN members (participation, in-kind) Cost per ring test: preparation and distribution of sample standards, monitoring and evaluation: 20,000 USD per RSP: 360,000 USD
Spectral library	
1. Guidelines for collecting spectral data sets; open access spectral library	GLOSOLAN (in kind)
2. Ring test and calibration	all interested soil laboratories (in-kind) Cost (see above): 20,000 USD per RSP: 180,000 USD
3. Global spectral library	spectral library: 30,000 USD (if possible: Soil Data Facility)
4. Workshops	In combination with RESOLAN meetings (see below)
Regional/global soil laboratory networks	
1. Identify national soil laboratories	GSP National Focal Points
2. Meetings of the regional soil laboratory networks (RESOLAN)	45,000 USD per RSP; 2 meetings 2017-2020: 810,000 USD
3. Annual GLOSOLAN meetings	3 meetings 2017-2020 a 45,000 USD: 135,000 USD

4 Interoperability - Exchange of digital soil information

4.1 Building blocks of the global soil information infrastructure

A fundamental principle of the Global Soil Information System (Pillar 4) is the exchange of soil and soil-related data, harmonized to the extent possible (see previous sections), through web services[20]. There are many de facto and de jure standards relating to web services. To date soil data have typically been published as spreadsheets and databases the form of which varies on a provider-by-provider basis. Communities that have shared data across systems have typically used web services based on ISO/TC 211 Geographic information/Geomatics and/or Open Geospatial Consortium (OGC) standards such as Web Feature Service, Web Coverage Service and Web Map Service. To provide a standards compliant web service, soil data need to go through a process of translation from the local database storage schema to an agreed soil data exchange schema. The data exchange schema is specifically designed for data exchange, not for data storage. Output formats from these services depend on the underlying geometry of the data. For example GML is a XML grammar defined by the OGC to express geographical features. A soil data exchange schema requires the existence of standard information model for the representation of soil data.

Recommendation 5:
To enable the exchange of digital soil-related data, agreement is reached on a global soil information model, vocabulary service and meta-data standards. Implementation of this model driven architecture will be consistent with the aspirations of the global soil information infrastructure (GSP Pillar 4).

Figure 5 in the Plan of action presents an overview about the components of a soil data infrastructure and considers the relationship between Pillar 4 and 5.

4.2 Global Soil Information Model

4.2.1 Concept and ongoing activities

Data can be exchanged in many different formats and structures. Exchange of data via web services requires

- that data can be retrieved without any access or implementation restrictions (e.g. spatial fit along borders; technical interoperability);
- a well-defined set of specified data encodings such as XML so that data sets can be exchanged and communicated (syntactic interoperability);
- data can be interpreted and exchanged meaningfully and accurately.

To enable interoperability of soil data exchanged through web services, 4 levels of interoperability need to be met:

- technical interoperability through the use of communication protocols such as HTTP;
- syntactic interoperability through the use of common data formats such as XML;

[20] A web service is a software system designed to support interoperable machine-to-machine interaction over a network. Web Services Glossary, W3C Working Group, http://www.w3.org/TR/ws-gloss/

– schematic interoperability through the use of common information exchange models; and
– semantic interoperability through the use of common vocabularies.

Schematic inoperability requires a common reference model, here referred to as the **Global Soil Information Model**. Such a model defines abstract concepts, data entities, relationships, behavior, operations and properties, which are intrinsic to those entities. Once the global soil model is in place, a soil application schema can be created which formalizes the information model to achieve interoperability. Data providers can then export/map locally stored data into the schemata and publish interoperable soil data as web services.

ISO 28258[21] provides a generic soil application schema. Other schemata have also been developed, nationally (e.g. Australia, New Zealand), project-related (SOTER, GlobalSoilMap), and for Europe (INSPIRE). As an example for an implementation specification, an ISO schema with two XML schema files (data file and property file) was developed by the European GS Soil project (2009-2012). It needs to be reviewed whether the GS Soil approach fulfills all requirements by the global community.

In 2017, a corrigenda of ISO 28258 is being prepared by the responsible ISO Technical Committee 190 (Soil Quality). Previous discussions about this standard raised the need for revision, building on activities of the Open Geospatial Consortium (OGC). Between 2015-2016, an initial interoperability experiment was conducted within OGC in order to show that it was possible to achieve interoperability between soil information systems, and identify the challenges and the future needs for standards development. This reconciled and tested existing data standards and OGC/W3C technology for the integration of soil data.

Several networks and institutions are devoted to promoting a global soil reference model for the exchange of digital soil data through web services: OGC Agricultural Domain Working Group, ISO/TC 190 Soil Quality, IUSS Working Group Soil Information Standards and various national institutions holding soil information. Recently, the Interest Group on Agricultural Data (IGAD) of the Research Data Alliance (RDA) also identified soil information as an important component of agricultural information, intended to support and promote the availability of interoperable soil data. This initiative is supported by the Global Open Data for Agriculture and Nutrition (GODAN)[22], a network of stakeholders of soil information. These above-mentioned activities are likely to promote or take the lead with respect to the tasks needed to develop an operational, widely agreed and well-tested approach to enabling the web-based data exchange under the Global Soil Information System.

It is important to mention that the implementation of the ISO conceptual model (and its revision) must be flexible to that new definitions and concepts resulting from Pillar 4 and 5 actions can be incorporated (versioning).

4.2.2 Action

1. Review previous standardization work for the exchange of digital soil data
2. Develop and agree on a common SoilML reference model and application schema
3. Test and implement the reference model

[21] Technical Committee ISO/TC 190, Soil quality. ISO 28258:2013(en) Soil quality — Digital exchange of soil-related data.

[22] A Soil Data WG in the programme for Global Open Data and Nutrition (GODAN) has been created in 2017 to connect model developers, users and data providers, with the aim to support the development, testing and acceptance of a common SoilML standard, and to ensure capacity development at the level of data developers and information system holders.

4. Develop a final standard
5. Provide technical solutions (i.e. mapping and translation tool)
6. Develop a cookbook
7. Capacity development

4.2.3 Budget and responsibilities

Actions		Who[1)]	Cost
1	Review existing data exchange standards for practical applications to build the Global Soil Information System, based on and implementing ISO 28258 by using the meta-data model defined there and extending it by adding necessary attributes to the soil features, considering the use cases and experiences collected by the OGC AG Domain WG and other soil data exchange activities, like in the European INSPIRE approach	Voluntary contributions by INSII members and/or contractor(s) with knowledge of the processes and reference standards mentioned under 4.2.1	25,000 USD
2	Develop a discretized SoilML reference model comprising an information model, logical model and application schema	Contractor with UML modeling skills	35,000 USD
3	Broadly test and implement the reference model: a) conformity or transformability with already existing national and international solutions; b) applicability of the global reference model; c) appropriateness for use cases	Coordination: SDF Implementation: INSII members	In-kind
4	Finalize and publish a joint ISO-OGC standard, based on the revision/extension of ISO 28258	Coordinated between ISO and OGC, review by P5WG/INSII, supported by contractor	10,000 USD
5	Development of user-friendly technical solutions to implement the model (transformation services)	Contractor(s)	45,000 USD
6	Cookbook	Contractor(s)	15,000 USD
7	Capacity development: trainings (1 per RSP a 45,000 USD)	INSII members	405,000 USD

[1)] Note that all activities (engagement of INSI partners, SDF, contractors) are specified and coordinated either by the P5WG or an ad-hoc INSII review team.

4.3 Vocabulary service

4.3.1 Concept and ongoing activities

The exchange of interoperable soil data through web services is the basic principle of the global soil information system. A successful implementation of a soil data infrastructure depends on the way data are described and classified. Besides the global soil information model and the related application schema, the following aspects are also important:

a) Metadata elements (or: metadata set) to describe various aspects of the data, e.g., title and abstract for publications (see section 4.4);
b) Values for metadata elements;
c) Definitions of concepts, properties, codes, features, relationships and taxonomies (semantics).

Such information can be free (e.g. name of the data set, abstract), or it may be taken from a ‘‘controlled vocabulary (e.g. a thesaurus that provides subject heading references for the metadata elements). A **controlled vocabulary** contains a restricted list of words or terms used for labeling, indexing or categorizing. A more structured kind of controlled vocabulary is a **thesaurus**; it provides information about terms and its relationships to other terms within the same thesaurus. The terms in the **thesaurus** are linked to existing and available information in the internet, which details their meaning and usage.

Controlled vocabularies must be actively managed in order to receive the maximum level of integrity and usefulness. It must also be possible to query the semantic information. This can be done through vocabulary services. Vocabulary services will be a fundamental and necessary component of the soil data infrastructure.

Examples of existing soil vocabulary services include:

- CRA-ABP[23]: Vocabularies for soil data as linked data. Basic reference material is the national Guideline for Soil Survey and Data Information. This local soil vocabulary was mapped to the agINFRA Soil Vocabulary and has been published. It can be considered as the Italian standard for the national soil database architecture.
- ISO 11074 (2015)[24] Soil quality – Vocabulary: it defines a list of terms used in the preparation of the standards in the field of soil quality (description of soil, sampling, soil assessment with respect to risk, hazard and exposure, soil protection, remediation, soil ecotoxicology.
- ISO 28258 (2013) Soil quality — Digital exchange of soil-related data: it lists and defines soil features

4.3.2 Action

1. Review and compile existing soil vocabularies
2. Develop a multilingual register of soil terms (features and properties) including explanations and links to authoritative sources.
3. Establish a process to maintain and govern the register of soil vocabularies

4.3.3 Budget and responsibilities

1. Review: INSII member input, coordinated by the P5WG (in-kind)
2. Multilingual register: voluntary contribution by regional data centres, or contractor (25,000 USD)
3. Maintenance: will depend and decided based on the global soil data infrastructure, built under Pillar 4 (in-kind)

4.4 Metadata

4.4.1 Concept and ongoing activities

Metadata is data describing data sets. It provides standardized information about a data set, for example, the maintaining institution through which the data can be accessed. It thus helps a user to find spatial data sets and related services and to indicate for which purpose it can be used. Besides the identification of the data source, metadata contain the geographic location, temporal reference, quality and validity, the provenance of the data, conformity with implementing rules on the interoperability of spatial data sets and services, constraints related to access and use, and organization responsible for the resource (Reznik *et al.* 2011).

[23] CRA-ABP: Agricultural Research Council – Research Centre for Agrobiology and Pedology.

[24] Technical Committee ISO/TC 190, Soil quality. ISO 11074:2005. Soil quality – Vocabulary.

"*Standardization is the only way towards interoperability. Since such metadata should be compatible and usable in a Community and trans-boundary context, it is necessary to lay down rules concerning the metadata used to describe the spatial data sets and services*" (Reznik et al. 2011[25]).

The commonly accepted standards for metadata are ISO EN 19115 (metadata elements) and ISO 19139 (metadata XML implementation). An overview and explanations of metadata elements in the ISO 19115 metadata profile is provided by Reznik at al. (2011). The report considers the complexity of soil information and how it can be traced through metadata standards, and where there are limitations in the standard profile. The Infrastructure for Spatial Information in the European Community (INSPIRE) provides an example for a soil-specific metadata profile[26].

The objective of this Pillar 5 activity is to provide an agreed metadata profile for soil data to all soil information institutions, and facilitate broad applications by providing user-friendly tools to apply this profile (metadata editor).

4.4.2 Action

1. Review the existing literature and experiences already collected about standard metadata profiles applied to soil data; consider the role of additional metadata needed to harmonize soil data, and to describe its quality.
2. Depending on outcome of 1), develop a metadata profile, or modify an existing profile, or use an existing metadata profile for the Global Soil Information System (GLOSIS).
3. Use/develop a metadata editor for soil data: analyze, compare and recommend proper tools for applying the agreed metadata profile.

4.4.3 Budget and responsibilities

1. Review: P5WG and/or SDF and/or voluntary INSII member(s): in-kind.
2. Development/modification of a metadata profile for GLOSIS): Contractor, 10,000 USD.
3. Metadata editor: voluntary offer by INSII members and/or regional data centers and/or SDF; if necessary contractor, 15,000 USD.

[25] Reznik, T. et al. (2011). D3.4 "Best practice guidelines for Creating and Maintaining metadata for soil databases". Report of the GS Soil Project "Assessment and strategic Development of INSPIRE compliant Geodata-Services for European Soil Data". Project No. CP-2008-GEO-318004. Copies of the report:: rainer.baritz@fao.org

[26] Thematic Working Group (TWG) Soil (2010). INSPIRE data specification on Soil – Technical Guidelines" version 3.0. http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_SO_v3.0.pdf

5 Interpretation and evaluation

One of the main objectives for the GSP **Pillar 4** is the establishment of a system for monitoring, forecasting and reporting periodically on the status of the global soil resources, referred to as SoilSTAT (Plan Action, Pillar 4). Also, the successful implementation of Pillar 1 (Sustainable management of soil resources) requires a monitoring of soil-related indicators, to develop incentives for sustainable soil management, and to quantify and validate the success of management practices.

During the meeting of the International Network of Soil Information Institutions (INSII), Rome, 08-10 Dec 2015, it was agreed that monitoring includes indicators derived from the repeated assessment of measureable soil and soil-related parameters, and that these indicators should back up future reporting such as the "Status of the World's Soil Resources" (SWSR) (including SDGs, soil threats, etc.).

Recommendation 6 of the Pillar 5 Plan of Action:

Review existing indicator systems and evaluation procedures and develop a harmonized approach based on common criteria, baselines and thresholds with the aim to monitor the state and response of soils under the effect of policies and management.

Following Figure 2, this task includes the following fundamental steps:

- Definition of indicators
- Filling of data gaps and derivation of indicators (soil evaluation)
- Interpretation of indicators using baselines and thresholds.

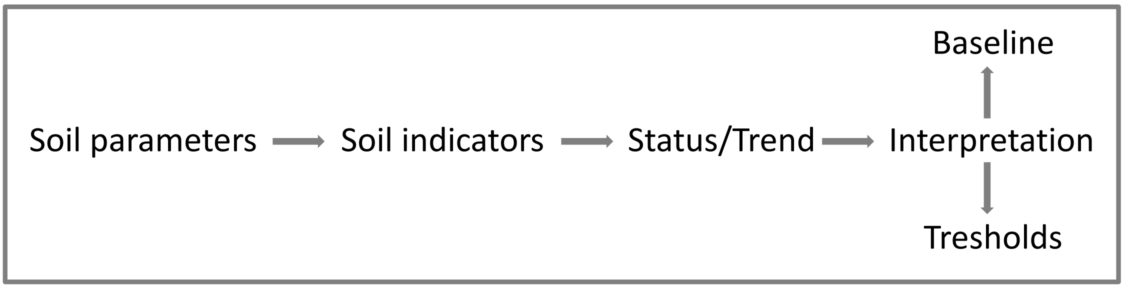

Figure 2: Scheme for soil evaluation

5.1 Indicator development and application

5.1.1 Methodical considerations for evaluation and interpretation

Currently, there is no globally agreed system of soil indicators. The Status of the World's Soil Resources report and the various UN reporting schemes including SGD provide the framework for soil indicator assessments. In addition, regional-level and national indicator concepts exist as well (e.g. EU Soil Thematic Strategy (STS), following the concept of soil threats). Soil characteristics are main components in land evaluation.

Indicators for soil monitoring

The most comprehensive overview of soil indicators for the monitoring of soil threats can be found in Huber *et al*. (2008)[27]. There, the following **definitions** are provided:

Indicator	An environmental indicator is a measure, generally quantitative (rate, index, factor), that can be used to illustrate and communicate complex environmental phenomena simply, including trends and progress over time (EEA 2005[28])
Baseline	Minimum or starting point of an indicator value (e.g. measurement which serves as a basis to which all following measurements are compared; a characteristic value for an element content in soil)
Threshold	An indicator value at which a critical soil status is reached, which limits or threatens sustainable functioning of the soil.

Depending on the variety of soil types and the variability in environmental conditions and land use, baseline and threshold values may have to be set differently for different areas. However, Huber *et al.* (2008) stress the importance of common definitions and methods for estimation and interpretation.

'Interpretation' involves the assessment of change in relation to a baseline are of interest, as well as comparisons with thresholds to assess soil condition.

Soil Quality

Soil quality refers to the ability of soils to perform certain functions depending on its physical, biological and chemical properties; its performance is influenced by natural (e.g. slope steepness) and/or anthropogenic (e.g. drainage installations) factors (see also Vrščaj and Baritz 2011[29]).

According to Toth *et al.* (2007) [30] soil quality evaluation helps to identify the ability of soils to perform its functions, and to indicate the direction and magnitude of the response of soils to external influences. The assessment of soil quality and its related indicators and processes are the basic principle of soil monitoring. Three soil quality-related indicators were suggested by Toth *et al.* (2007): Soil Quality Index, Soil Threat Index, Soil Sustainability Index.

Soil and Land Evaluation

Land evaluation is concerned with the assessment of land performance when used for a specific purpose (FAO 1976) [31]. It is based on an assessment of "land", which is the physical environment (climate, soils, vegetation, hydrology, relief), and additional economic and social aspects of land use. It serves

[27] Huber, S. et al. (eds) (2008). Environmental Assessment of Soil for Monitoring: Volume I Indicators & Criteria. EUR 23490 EN/1, Office for the Official Publications of the European Communities, Luxembourg, 339 pp.

[28] EEA (2005). EEA core set of indicators, Technical Report, 1/2005, European Environment Agency.

[29] Vrščaj, B. and R. Baritz (eds.) (2011). D2.5 "Best practice guidelines for developing a content framework for interoperable soil data in Europe". Report of the GS Soil Project "Assessment and strategic Development of INSPIRE compliant Geodata-Services for European Soil Data". Project No. CP-2008-GEO-318004. Copies of the report: rainer.baritz@fao.org

[30] Tóth, G. et al. (2007). Soil Quality and Sustainability Evaluation -An integrated approach to support soil-related policies of the European Union. EUR 22721 EN. 40 pp. Office for Official Publications of the European Communities, Luxembourg.

[31] FAO (1976). A framework for land evaluation. FAO Soils Bulletin 32, Food and Agriculture Organization of the United Nations. Rome 1976.

land management planning, guiding decisions on land use. Land use planning involves sustainable soil management, so that this activity is closely connected to GSP Pillar 1.

Soil is a basic resource in land use planning (Sys *et al.* 1985)[32]. It requires an assessment of characteristics for soil quality and soil functioning (see Table 4). In order to determine these characteristics, comparable procedures needed to be defined, for example pedo-transfer functions Type 3 (see section 5.2.1).

Table 4: Soil characteristics and land evaluation (based on Sys et al. 1985 and UNEP 2016[33])

Aspects of land use planning	Soil characteristics
– Choice of crops	– Natural soil fertility
– Land use pattern on marginal soils	– Agricultural value of soils; soil suitability of marginal soils
– Management of specific soils	– Mechanical workability of clay-rich soils (Vertisols)
– Land improvement works (drainage, irrigation, levelling and grading, erosion control)	– Susceptibility of soils for degradation processes (e.g. erosion by wind, erosion by water)
– Type of irrigation	– Soil permeability and soil water holding capacity
– Type and quantity of fertilizer to be used	– Soil fixation rate for P; exceedance of critical thresholds for N
– Optimization of ecosystem services	– Soil carbon status, nutrients, CEC etc.

One of the core principles of land evaluation is land suitability, which strives to match land use requirements with environmental conditions, in order to balance economic and social benefits, needed technical inputs, and hazards (e.g. erosion, land degradation). Land suitability requires resource surveys, in particular land and soils, its properties (e.g soil type, soil depth, soil texture, soil organic carbon content, base saturation and CEC, micronutrient content, and acidity such as pH and acid cations) and characteristics (e.g. plant available soil moisture, workability of soil, soil salinity, soil toxicity, oxygen availability in the rooting zone; see also Table 4).

Important land suitability assessments are:

- Suitability of land for irrigation
- Degradation hazard
- Flooding hazard
- Land productivity
- Nutritive value of soils

Each land suitability and soil quality assessment may have its specific data requirements, and how they are evaluated (rule-based models) and interpreted (thresholds). Many countries have developed their own systems of land evaluation, for example criteria for land suitability criteria in the rain-fed, rangeland and irrigated agro-ecosystems[34]), so that there are many different soil quality assessments in place as well.

32 Sys, I.C. (1985). Land evaluation. State University of Ghent. 1985

33 See also: UNEP (2016) Unlocking the Sustainable Potential of Land Resources: Evaluation Systems, Strategies and Tools. A Report of the Working Group on Land and Soils of the International Resource Panel. Herrick, J.E. et al. UNESCO. ISBN: 978-92-807-3578-9.

34 Ziadat et al. 2014, Similarity and Suitability Analysis to Assist the Out-Scaling of Sustainable Water and Land Management Practices in West Asia and North Africa. Research Report No. 11. ICARDA, Beirut, Lebanon. 79 pp.

5.1.2 Catalogue of soil health indicators

The SWSR refers to two indicator systems, GLASOD[35] and the Soil Thematic Strategy (EU STS) of the European Commission. The report highlights the importance of soil and indicators for soil functions in relation to ecosystem services. This means that the indictor selection must be taken so that at the end, by combining indicators for example, conclusions about ecosystems and other societal benefit of soil must be possible (soil resilience to climate change, role of soils in flood prevention, soils as nutrient source for crops, etc.).

Table 5: Overview of broadly discussed soil indicators

Degradation types/soil threats	GLASOD	EU STS	ENVASSO Indicators (extended)	Data sources	Indicators mentioned in SWSR
Water erosion	X	X	– Soil loss [t ha^{-1}] – Observed erosion features [type/amount per area]	Define erosion features (type, size; shape, degree) Data: modelling, measurements, estimates	Soil loss
Wind erosion	X				
Overblowing	X		deposited soil [to/ha]	Define features	
Soil organic matter	X	X	– Topsoil organic matter (SOM) or carbon (SOC) content – SOC stock [t/ha] – Peat stock [t/ha] – C/N ratio	Consider human-induced causes: Land cover change, Wild fires, Crop residue burning, Exogenous organic matter, Organic farming, Cultivation practices, climate change	C pool: Organic C stocks SOM concentration
Salinization	X	X	– Salinity state: total salt content [% EC] – Exchangeable sodium [pH unit ESP %]	Direct measurements Indirect assessment via mapping of potential salt sources	Spatial distribution of salt-affected soils
Acidification	X	(X)	– Top soil pH – % exchangeable acid cations (Mn, Al, Fe)	Direct measurements	– pH – acid neutralization capacity
Loss of nutrients	X	(X)	– % exchangeable basic cations – % trace elements (includes micronutrients)	Direct measurements	Soil fertility: % nutrients, pH Nutrient balances: applied and excess N, P (fertilizer consumption, nutrient loss)
Pollution	X	X	– Heavy metal content [mg/ha] – Critical loads exceedance	Diffuse contamination	Contaminated land area
			– Progress in the management of contaminated sites	local contamination classification of sites	
Compaction and physical degradation	X	X	– Soil density – Air capacity – Susceptibility to soil compaction	Indirect assessment derived from soil condition and ground pressure through soil management practices (tillage, machinery, etc.)	
Waterlogging	X		– rH – Water content in the soil (%)	Amount of water per volume of soil	
Subsidence of organic soils	X				

[35] Oldeman, L.R. *et al.* (1990). Global Assessment of Soil Degradation GLASOD Wageningen: International Soil Reference and Information Centre; Nairobi: United Nations Environment Programme. -I11., October 1990, second revised edition.

Table 5 (continued)

Degradation types/soil threats	GLASOD	EU STS	ENVASSO Indicators (extended)	Data sources	Indicators mentioned in SWSR
Loss of soil biodiversity		X	– Macrofauna (Earthworms) – Mesofauna (Collembola) – microbial respiration	– Spec abundance [density/area] – Species diversity – CO2 measured [g/kg soil]	
Landslides		X	– Occurrence of land slides	Landslide types	
Soil Sealing		X	– Sealed area	Sealing degrees	
Soil Degradation/Desertification		X	– Susceptibility to desertification – Wild fires – SOC on desertified land – Soil degradation index	see also MEDALUS project legacy soil and vegetative data proportion between the degraded soil surface and surface with stable soils, at rest or with good agricultural practices	
Water cycle			– Amount of water per volume of soil – Soil Drought Severity Index	MDSI, modified by JRC (soil moisture factor is replaced by a parametric estimation of moisture based on field data.	Soil moisture (not further defined)

Additional comments to Table 5:

- Monitoring requires the assessment of trend per time interval
- A monitoring system requires baselines and thresholds in order to assess trend and to evaluate a change in quality.
- There is feedback e.g. between soil organic matter and various other indicators. Thus, soil organic matter can be seen as a meta- indicator.
- Under the EU STS, the delineation of hazard zones for soil degradation (or priority areas) has been proposed; further management programmes and monitoring shall focus on these areas.
- Evaluation objectives, methods and metrics need to be defined in order to derive comparable indicators from measurements or other observed parameters
- SWSR highlights the importance for spatially explicit assessments (maps);

This table will form the starting point to develop an indicator system for GSP soil monitoring.

5.1.3 Action

1. Develop a literature review on soil-related characteristics/indicators in land suitability assessments and other environment-related reporting schemes: clarification of terminology (soil quality, soil characteristics, spatial modelling, rule-based models, data demands, recommended applications, policy supported).
2. Develop a global repository of soil evaluation procedures, including input parameters, methods, output and evaluation criteria. Distinguish soil assessments in different land evaluation schemes and land classifications (WIKI technology or CMS).

5.1.4 Budget and responsibilities

1. Literature review on soil-related indicators: P5WG and voluntary INSII members (in-kind).
2. WIKI-Indicators (or CMS see section 3.2.3): technical implementation by voluntary offer of INSII member, or SDF, or contractor: 25,000 USD.

5.2 Method repository of pedo-transfer rules and functions

5.2.1 Background

Soil evaluation may involve various kinds of rules and models, applied to basic soil parameters, described (soil profiles) and analysed (soil samples). These procedures help to:

- estimate and predict soil properties
- derive indicators
- interpret soil properties for certain purposes

The results can be used in policy support, environmental monitoring, and land evaluation.

Pedo-transfer functions (PTF) and **pedo-transfer-rules (PTR)** are procedures (evaluation models, predictive algorithms, rules) using easily available soil property data (e.g. from soil profile descriptions), with the following aims:

Type 1 to fill gaps in measured data (e.g. depth functions), and to derive parameters (and indicators) difficult to measure (e.g. water holding capacity, rootable soil zone)

Type 2 to harmonize disparate analytical method values to the future GSP-standard (e.g. systematic comparison between recommended best suitable methods or standards, and a local variation of a standard or alternative method)

Type 3 to derive complex soil functions and indicators (e.g. susceptibility to soil erosion)

An example of systematic approach to Type 1 PTR is the European Soil Database. A series of pedotransfer rules (PTR) were compiled and applied, going back to Van Ranst *et al.* (1995)[36]. Ad-hoc AG Boden (2000, 2004)[37] has compiled and harmonized a large national compendium of Type 1 and 3 PTR (including approaches for soil quality assessments, which can be used in land evaluation[31] [32].

Soil hydrology is a well-known area where pedotransfer functions (PTF) are developed for and applied. PTF parameterize hydrological processes by using the available information from soil profiles (Pachepsky and Rawls 2005[38]).

5.2.2 Action

The following **<u>action</u>** is required:

1. Method repository (WIKI-methods; or CMS see section 3.2.3) to compile and exchange method descriptions for common PTR and PTF (input data, algorithms, target applications, output)
2. Test applications for indicator mapping with soil profile data
3. Report: harmonization and development needs for PTF

[36] Van Ranst, E. et al. (1995). Elaboration of an extended knowledge database to interpret the 1:1,000,000 EU Soil Map for environmental purposes. In: King, R.J.A. et al. (eds). European land information systems for agro-environmental monitoring. Pp. 71-84. Luxembourg, Office for Official Publications of the European Communities. EUR 16232 EN.

[37] Ad-hoc-AG Boden (2000, 2004): Methodendokumentation Bodenkunde. – 2. Auflage, Geol. Jb. Reihe G, Heft SG1.

[38] Pachepsky, Y. and W.J. Rawls (eds) (2005). Development of Pedotransfer Functions in Soil Hydrology, Volume 30. Elsevier Science 2005.

5.2.3 Budget and responsibilities

1. WIKI-methods: voluntary offer/contractor (combined with planning section 5.1.4)
2. Test applications for indicators: INSII, in-kind
3. Guidance for harmonization and development needs for PTF: P5 WG (see section 6.1, governance), INSII writing team

6 Governance

6.1 Pillar 5 Working Group and the International Network of Soil Information Institutions

The Pillar 5 Plan of Action (P5 PoA) suggests a governance model for implementation, which strongly follows the Pillar 4 model.

Most of the harmonization activities are best implemented by the institutions collecting, processing, hosting and disseminating soil data. In the Global Soil Partnership, with the aim to build and contribute to the Global Soil Information System (GLOSIS), these institutions have formed a network (**International Network of Soil Information Institutions, INSII)**. INSII includes nationally mandated soil information institutions as well as any other organization holding and sharing soil data in the context of Pillar 4. The INSII members are also likely to be the main implementing institutions for harmonization (see also P5 PoA).

The complexity of action and the required expertise in the different areas of harmonization is large. It is thus important to plan efficiently, and to be inclusive to experts from supporting networks such as ISO and IUSS.

Table 6: Examples of networks and working groups important to Pillar 5

Area of harmonization	Networks related to Pillar 5	Area of representation
Soil description, classification and mapping	IUSS Working Group 'WRB' IUSS Working Group 'Universal Soil Classification' ISO/TC190	global
Soil analysis	ISO/TC190	global
	Regional soil laboratory networks (see section 6.2)	regional
	Global Soil Laboratory Network (GLOSOLAN)	global
	IUSS Working Group on Proximal Soil Sensing	global
Soil Information modelling	IUSS Working Group 'Soil Information Standards' ISO/TC190 OGC Agriculture Domain WG GODAN Soil Data WG	global
Soil indicators and soil monitoring	National References Centres Soil of the European Environment Observation Network	regional

The realization of this implementation plan needs to be coordinated by a working group, which will be – similarly to the governance of Pillar 4 - the **Pillar 5 working group (P5WG)**.

P5WG consists of the following members:

- **Regional Pillar 5 chairs:** coordinate global action with the harmonization activities in the 9 regional and subregional soil partnerships;
- **Representative of ITPS:** receive advice and scientific guidance by the Intergovernmental technical panel on Soils (ITPS);
- **Representative of ISO**: ensure compliance of guidance with existing standards; request new standards and join the revision process of existing standards where needed;
- **Representative of IUSS**: support relevant IUSS WGs, test and apply guidance resulting from IUSS WG results (see also Table 6 for IUSS WGs mainly concerned by Pillar 5);
- **Soil Data Facility (SDF)**
- **Chair of Pillar 4**: to ensure that activities between Pillar 4 and 5 are well-aligned, and to ensure that INSII is involved and guided consistently.
- **Chair of the Global Soil Laboratory Network (GLOSOLAN)**
- **GSP secretariat**: to ensure that Pillar 5 is well-embedded and coordinated with all GSP Pillars; to enable feedback and success control from overviewing all GSP activities, and to coordinate and enable support measures.

The P5 WG will be composed of 16 members; it will select a chair among its members per consensus.

Annex 4 lists the Terms of reference for the P5 WG.

⇒ **Tasks for GSP Focal Points and other GSP members:**

- to identify national soil information institutions, in case this has not been done yet
- to support national harmonization experts in joining the regional Pillar 5 working group, and to support the chair of that working group to join the global P5 WG

Experts need to be able to participate in meetings and allocate sufficient amount of work time to the tasks laid out in this implementation plan.

6.2 Strengthening regional networks of soil laboratories

Regional soil laboratory networks (RESOLAN) will be established, where such an activity does not yet exist. Any interested soil laboratory can join the respective network in its region. At best, such networks already exist, such as SEALNET in Asia, which already closely cooperates with GSP members in the region. The establishment of such networks depends active GSP focal points and other GSP-partners interested in high-quality, reliable soil analysis, and who identify and support **national/institutional soil laboratories.**

Reference laboratories will be the key drivers for regional action. The regional activities shall be communicated and compared, thus coordinated to the degree possible, through the Global Soil Laboratory Network – GLOSOLAN (see section 6.3).

⇒ **Tasks for GSP Focal Points and other GSP members:**

- to identify and to support national/institutional soil laboratories
- to identify and to support a national soil reference laboratory

Support mainly involves participation in meetings, and sharing information about current laboratory practices. Participants are encouraged to revise and implement recommended procedures.

6.3 Global Soil Laboratory Network (GLOSOLAN)

Harmonization of soil analysis besides ISO standardization activities is not well-established and coordinated in many parts of the world. While there is progress in some regions (such as South Asia and the Pacific), networks and individual laboratories require more support. Soil information from the different sources globally is hardly comparable.

For practical purposes, language, the use and extension of existing cooperations, etc., the main harmonization activity on soil analysis will be at regional level. Therefore, the main scope of harmonizing soil analysis will by the individual soil laboratory closely cooperating in a regional network (see section 6.2). In each region, one or several reference laboratories are the drivers for action, facilitating and coordinating harmonization of soil analysis. Ideally, such a reference laboratory will be available in each country.

In order to globally coordinate the activities described in section 3 (soil sampling and analysis), the Global Soil Laboratory Network (GLOSOLAN) will be established which is composed mainly of the regional (and national) soil reference laboratories. GLOSOLAN can be joined by any interested soil laboratory. It will meet once a year jointly with INSII, or separately.

⇒ **Tasks for GSP Focal Points and other GSP members:**

- In addition to tasks mentioned in section 6.2, enable at least one national laboratory to build the competencies of a reference soil laboratory (to be defined, see section 3.3.2), and to participate and engage in global coordination.

Annex 4 lists the Terms of reference for GLOSOLAN.

7 Procedural guideline for implementation

7.1 Contracting, consultation, peer review and consensus process

The main resource for implementing harmonization is based on in-kind activities of institutions, tasked with the building of soil information systems following national and/or institutional demands. The global dimension relates to the effect that while these institutions profit from international cooperation, trainings and respective learning materials, more reliable and better representative information is shared across borders thus generating benefit for many national and international stakeholders.

It can be expected that through sufficient seed funding for the initiation of action, such as the development of guidelines and tools, broader participation and engagement in this implementation plan is catalyzed. Even if contracting is planned, action needs to be a) coordinated (P5WG in-kind), and b) supported and implemented (INSII, GLOSOLAN, in-kind). This model of cooperation will require significant efforts and investments at institutional as well at regional and global levels.

With this P5IP, contracts to experts are foreseen, for example, to conduct status quo assessments (e.g. of laboratory methods) and to develop easy-to-apply web tools to allow better sharing of meta information. Specifications for these contracts have to be developed, the delivery of products monitored and quality-checked. This is one of the tasks of the P5WG (see Annex 4). Where extensive review is necessary, the P5WG can involve additional reviewers on in-kind basis (ITPS, INSII, P4WG or other experts).

7.2 Versioning of the Pillar 5 implementation plan

The following activities affect the definition and description of actions, their cost estimates and road mapping:

- Requirements through Pillar 4 action; progress of GLOSIS implementation
- Availability of resources to both Pillar 4 and 5
- Offers but also limitations by GSP partners
- Detailed review of this plan by the national focal points, INSII and GLOSOLAN members (3rd INSII meeting 2017, 1st GLOSOLAN meeting 2017)
- Discussion with the GSP Soil Data Facility (SDF), and
- Feedback and pace of activities in ISO and IUSS WGs
- Revision of the Pillar 4 roadmap, which is likely to happen because of delays.

These activities and developments will require updating of this implementation plan.

7.3 Interaction with the regional implementation plans

The implementation planning of the Regional Soil Partnerships (RSP) follows the Pillar 5 Plan of Action. Therefore, it is guaranteed that their plans will follow the same recommendations and structure as used there. The following table provides an overview of activities already planned by the RSPs.

Currently, 7 out of 9 regional and subregional soil partnerships have already developed a regional implementation plan (RIP). It is important that these plans are well-aligned with each other with the global level. It is critical that planned and ongoing regional level activities do not duplicate efforts, rather its implementation is strengthened through this global plan.

In general, in the RIP, the need for capacity development and international cooperation through workshops and trainings is stressed. More detailed aspects are summarized in Table 7.

Table 7: Summary of regional Pillar 5 activities (Sources: regional implementation plans)

RIP	Product Description	Activity Description
AfSP	Harmonization procedure for soil description	- Establish Harmonization Committee (workshops): 8-members: soil classification experts from the four sub-regions*) - Develop a list of common regional soil description parameters
	Field meetings for correlation	- Conduct quality checks on soil data sets - Follow up on the African Regional Sub-Committees for Soil Correlation and Land Evaluation (1970s and 80s) - Improve international cooperation
	Network of well-equipped and/or ISO certified soil reference laboratories	- Develop an inventory of facilities and capacities - Establish at least one ISO certified reference laboratory per sub-region (Western, Central, Eastern and Southern Africa)
	Harmonization aspects in Pillar 4	- harmonized procedures for data relevant to soil texture - harmonized procedures for a soil sampling and analysis programme

Table 7 (continued)

RIP	Product Description	Activity Description
Eurasia	Terminology, soil classification, methods, indicators and procedures	– Special focus: saline and sodic soils – Conversion tables and software for translating data from one system to another
	Standards for saline and sodic soils	
	Harmonization aspects in Pillar 4	– Manual for field sampling, laboratory analyses, sources and methods of processing remote sensing data, place and form of storage of data
NENA	Soil description, sampling, and analysis	– Create regional working group of soil information and harmonization – Adapt WRB
	Criteria for soil health and land degradation	– Promote the adoption of LADA/WOCAT methods
	Land evaluation criteria	– Identify and share harmonized land evaluation methods and practices
Central America	Soil sampling and analysis	– Inventory of laboratories and methodologies – Establish a network of laboratories including reference laboratories and a portal to facilitate the exchange of information and comparison of results
	Sustainable soil management	– Design verifiable indicators for biophysical and socio-economic impact
South America	Monitoring the quality of laboratory analyses	– Analysis of reference samples – Inventory of the soil analysis laboratories and methods
	Criteria and methods for agro-ecological interpretation	– Conduct and evaluate inventory of national surveys – Develop common criteria regarding the intensity of sampling
	Methodologies for measuring soil degradation and soil quality	– Implement the LADA methodology – Define land degradation indicators – Application of degradation indicators to the agro-ecological zones defined in Pillar 1
ESP	Soil description, classification, mapping	– Revision of the European soil mapping guideline – Develop a European soil map legend based on WRB – Improve national WRB correlation methods
	Soil Analysis	– Europe-wide network of soil laboratories – Establishing soil reference laboratories – Develop best practice recommendations and procedures for soil sampling, storage, analysis
	Soil Information model	– Test and implement INSPIRE, analyse remaining harmonization needs
	Indicators	– Develop a soil indicator concept about the state and response of soils under the effect of policies, management and climate change

Table 7 (continued)

RIP	Product Description	Activity Description
ASP	Soil description and classification	– 6-member committee representing all the sub regions – Standardize soil test interpretation for site specific nutrient management
	Soil mapping, and soil database manage-ment	– New technologies for multi- purpose soil survey and mapping (polygon and raster maps) – Promote and use predictive soil mapping methods – WRB and USDA taxonomy systems are advised – Border harmonization – Collection of reference soil profile databases – Establish soil museum – web-services and mobile applications
	Soil analysis/ ASP la-boratory network	– Inventory of facilities and capacities – Concretion of a network of laboratories including reference la-boratories to facilitate the exchange of information and quality control assessment – Establish national and regional reference laboratories – Develop ISO 17025 system for national and regional reference laboratories – Prepare certified soil reference materials – Guidelines on harmonized soil test methods and interpretation and quality control – Preparation of Standard Operating Procedure (SOP) for key soil analysis parameters
	Guidelines for exten-sion officers	– Transfer site-specific nutrient management (SSNM) knowledge to community soil and fertilizer management centers (CSFMCs) – Provide soil analysis services using a soil testing kit – Develop fertilizer and soil amendment recommendations
	Soil evaluation	– Soil suitability for agricultural and engineering management
PSP[1)]	Harmonization proce-dure for soil descrip-tion	– Develop a soil reference manual with islands soils classified ac-cording to the systems used on the region (FAO, French, US Taxonomy, Australia Systems) – Conduct training in use of these soil classification as prerequi-site to the actual harmonization and preferably the use of the Soil Taxonomy soil characterization system – With capacity in the countries – implement harmonization
	Soil Analysis	– Revive SPACNET[2)] – Establish soil reference laboratories and subscribe to ASPAC – Develop best practice recommendations and procedures for soil sampling, storage, analysis – Evaluate and calibrate soil tests – Calibrate plant analytical methods
	Soil information	– Set up Pacific Soil Portal
	indicators	– Develop soil indicators for sustainable soil management as well as for monitoring the quality of ecosystem services

[1)] For the Pacific Soil Partnership (PSP), the RIP has not been developed yet. However, a preliminary list of actions was provided by the secretariat of the Pacific Community (SPC; S. Siosiua Halavatau, written communication, 2017).

[2)] SPACNET is a network of soil and plant laboratories in the Pacific Region which has subscribed to ASPAC in order to improve laboratory management and quality control (http://www.spacnet.info/).

8 Summary of Actions

Table 8 presents an overview of all actions foreseen in the different areas of harmonization. **The implementing partners** are:

Members P5WG Members GLOSOLAN	Need to be ready to actively engage in tasks, review literature and compile recommendations etc.
Members of INSII	Upon voluntary engagement, selected tasks can be led or offered by any INSII member; INSII members are the main implementing institutions of all actions.
SDF	Because P5 is not part of the ToR for the SDF, contributions by the SDF still need to be discussed.
Members of ISO and IUSS working groups	ISO and IUSS WGs operate on a voluntary basis; for IUSS activities, no time frame for deliverables exists. It needs to be discussed with the relevant WGS, interested in cooperation/support to the GSP.
Other GSP partners/experts	Any other expert/institution may readily join Pillar 5 action.

The time frame for this plan is 2017-2020. Table 9 presents a preliminary roadmap and highlights relationships between areas of harmonization and between Pillar 4 and 5. Cost estimates represent minimum basic estimates to catalyze cooperating and further in-kind input from GSP partners. More accurate estimates have to be developed by the P5WG through detailed road mapping:

Current cost estimates:	**Technical tasks/contractors:**	**280,000 USD**
	Interlaboratory ring tests:	**540,000 USD**
	Meetings:	**2,565,000 USD**
Total sum:		**3,385,000 USD**

Table 8: Implementers and cost of Pillar 5 Actions

Harmonization activities		Implementing body/institution/network	Estimated minimum resources
	Detailed road mapping	P5WG	In-kind
Soil pro-files	Requirements/gaps	P5WG and/or IUSS WG, voluntary contributions by INSII members	In-kind* Web tool: 20,000 USD to supplement in-kind action
	Handbook	P5WG and/or IUSS WG, supported by voluntary contributions by INSII members	
	Web tool	Voluntary contribution by INSII members and/or other experts, and/or SDF	
	Guidance conversion	IUSS experts, supported by P5WG	
Classifi-cation	Web tool	Voluntary contributions by INSII members/other experts and/or SDF	In-kind
	Web site	FAO GSP Secretariat	
	IUSS classification work	IUSS WG, supported by INSII members	
	Capacity building	1 workshop per RSP	405,000 USD
Soil Maps	Manual	Voluntary contributions by INSII members and/or SDF and/or consultant	In-kind
	Capacity building	1 workshop per RSP	405,000 USD
Soil analysis	CMS methods (1-3 section 3.2.3)	1) P5WG, 2) CMS implementation, 3) technical maintenance by SDF	1) 2) In-kind; 3) 25,000 USD
	Input to CMS	Contributions by GLOSOLAN and RESOLAN	In-kind
	Coding design	P5WG, supported by ISO	In-kind
	Capacity building	1 workshop per RSP	405,000 USD
	Best practice	GLOSOLAN	In-kind
	Reference Soil Laboratories	GSP Focal points (nomination)	In-kind and national co-funding
	1-Guidelines, 2-Spectral Library	1) GLOSOLAN, 2) contractor and/or SDF	1) in-kind; 2) 30,000 USD
	1-Ring tests, 2-calibration	1) GLOSOLAN, 2) RL	1) in-kind; 2) 540,000 USD
	RESOLAN meetings	2 meetings per RSP (during the duration of this P5IP 2017-2020)	630,000 USD
	GLOSOLAN meetings	1 Meeting per year (45,000 USD per meeting)	135,000 USD
Interoperability	Review	Voluntary contributions by INSII members/other experts/SDF/contractor	Support funding: 25,000 USD
	1-Draft model, 2-Testing, 3-Final	1) Contractor and/or SDF, 2) INSII members, SDF, 3) P5WG/ISO/OGC	1) 35,000; 2) in-kind; 3) 10,000 USD
	Tools	Contractor and/or SDF	45,000 USD
	Cookbook	Contractor and/or SDF	15,000 USD
	Capacity building	1 meeting per RSP	405,000 USD
	Vocabulary (1-3 section 4.3.2)	1) P5WG and/or SDF and/or other volunteer, 2) contractor, 3) INSII members	a) in-kind; b) 25,000 USD; c) in-kind
	Metadata (1-3 section 4.4.2)	1) P5WG and/or SDF and/or other volunteer, 2), contractor, 3) contractor	a) in-kind; b) 10,000; c) 15,000 USD
Evaluation	Review indicators	P5WG supported by INSII members	In-kind
	WIKIs	Contractor and/or SDF (combined with CMS soil analysis)	25,000 USD
	Testing	INSII members	In-kind
	Guidance	P5WG	In-kind

* funding and contracting is needed if in-kind offers are insufficient

Table 9: Time table of Pillar 5 Actions and linkage with Pillar 4

Harmonization actions		2/2017	1/2018	2/2018	1/2019	2/2019	1/2020	2/2020	1/2021	Cross-link with P4 and P5 activities
	Detailed road mapping									P5WG, coordinated with P4WG
Soil pro-files	Requirements/gaps									–May cause updating of P4 Tier 1/Tier 2 soil pro-files (decision by INSII needed) –updating of SoilML, vocabulary, metadata
	Handbook									
	Web tool									
	Guidance conversion									
Classifi-cation	Web tools									–In case of USC: SoilML, soil vocabulary and metadata may be updated –Tools help to exchange a higher # of harmonized soil profiles
	Web site									
	IUSS WGs									
	Capacity building									
Soil Maps	Manual									P4 specifications by Q2 2017 (likely to be delayed)
	Capacity									
Soil analysis	CMS Soil Methods									– Actions to improved soil analyses will improve all soil data exchanged – Updating soil vocabulary and metadata
	Input to CMS									
	Coding design									
	Capacity building									
	Best practice									
	Reference Soil Laboratories									
	Guidelines (Spectral Library)									
	Ring tests and calibration									
	RESOLAN meetings									1x year (per RSP)
	GLOSOLAN meetings									1x year (combined with INSII)
Interoperability	Review									– SoilML needed to share soil data through web services (all GLOSIS products)
	1-Draft model, 2-Testing, 3-Final		1)	2)	2) 3)					
	Tools									
	Cookbook									
	Capacity building									
	Vocabulary (1-3 section 4.3.2)		1)	2)	3)					
	Metadata (1-3 section 4.4.2)		1)	2)	3)					
Evalua-tion	Review indicators									– P4: Concept note monitoring /SoilSTAT: (end of 2016, delayed) – Improves coverage of indicators for soil threats (SWSR)
	WIKI									
	Testing									
	Guidance									

Annex 1: Reference literature about soil analysis

1. Reference books (selection)

Bloem, J., D.W. Hopkins and A. Benedetti (eds) (2006). Microbiological methods for assessing soil. CAB International 2006. ISBN 0-85199-098-3

Blume, H.-P., B. Deller, K. Furtmann, R. Leschber, A. Paetz and B.M. Wilke (2000). Handbuch der Bodenuntersuchung [*Handbook of soil investigation*]. 7602 pp, ISBN 978-3-527-19080-5 - Wiley-VCH, Weinheim.

Burt, R. (2011). Soil Survey Laboratory Information Manual (SSIR 45) - Companion reference to the *Laboratory Methods Manual*, SSIR No. 42. Sampling methodology, descriptions of KSSL data sheets, and other information to help users of lab data.

Burt, R. (2014) Soil Survey Laboratory Methods Manual. USDA-NRCS Soil Survey Investigations Report 42 version 5, 2014.

FSEP [Forest Soil Expert Panel] and FSCC [Forest Soil Coordinating Centre] (2003). Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Part IIIa - Sampling and Analysis of soil. Upgrade of the 4th edition of the ICP Forests manual. Version 4.0. UN/ECE Convention on Long-Range Transboundary Air Pollution Effects on Forests. Ghent, 2003.

Gilabert de Brito, J. and L.A. Nieves (1990). Manual de métodos analíticos para caracterizar perfiles de suelos [*Manual of analytical methods for characterizing soil profiles*]. Fondo Nacional de Investigaciones Agropecuarias, Maracay (Venezuela), Instituto de Investigaciones Agrícolas Generales: IIAG. Unidad de Servicios Analíticos. 187 p.

Hartge, K.H. and R. Horn (2009). Die physikalische Untersuchung von Böden: Praxis Messmethoden Auswertung [*Measuring the physical parameters of soils: Methods, Application, and Assessment*]. 4edition, 178 p. ISBN 978-3-510-65246-4.

Hoskins, B.R. (1997). Soil Testing Handbook for Professional Agriculturalists. Maine Forestry & Agricultural Experiment Station University of Maine. http://anlab.umesci.maine.edu/soillab_files/faq/handbook.pdf

Klute, A. (ed.) (1986). Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monograph 9 (2nd Edition). Amer. Soc. Agron. Madison, WI.

Jones, J.B (1999). Soil Analysis Handbook of Reference Methods. CRC Press, 264 Pages. ISBN 9780849302053.

Page, A.L. et al. (eds.), Methods for soil analysis. Part 2. Chemical and microbial processes. Amercian Society of Agronomy, Madison, Wisconsin, USA.

Pansu, M. and J. Gautheyrou (2006). Handbook of Soil Analysis. Mineralogical, Organic and Inorganic Methods. Springer Verlag. ISBN: 978-3-540-31210-9 (Print) 978-3-540-31211-6 (Online).

Rayment, G.E. and F. R. Higginson. (1992). Australian Laboratory Handbook of Soil and Water Chemical Methods.

Sims, J.T. and A. Wolf (eds.) (1995). Recommended Soil Testing Procedures for the Northeastern United States. Northeast Regional Bulletin 493. Agricultural Experiment Station, University of Delaware, Newark, DE.

Sparks, D.L. (ed) (1996). Methods of Soil Analysis, Part 3. Chemical Methods. Soil Science Society of America Book Series Number 5. American Society of Agronomy, Madison, WI.

Ryan, J., G. Estafan and A. Rashi (2001). Soil and Plant Analysis Laboratory Manual. International Centre for Agricultural Research in the Dry Areas (ICARDA) and the National Agricultural Research Centre (NARC). 172 pp.

Soil Science Division Staff (2017). Soil survey manual. C. Ditzler, K. Scheffe, and H.C. Monger (eds.) USDA Handbook 18. Government Printing Office, Washington, D.C.

Tugel, A.J., S.A. Wills, and J.E. Herrick (2008). Soil Change Guide: Procedures for Soil Survey and Resource Inventory, Version 1.1. USDA, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Utermann, J., A. Gorny, M. Hauenstein, V. Malessa, U. Mueller and B. Scheffer (ed) (2001). Labormethoden-Dokumentation. [*Laboratory methods for soil testing*]. 215 p. Geologisches Jahrbuch Reihe G, Band G 8. ISBN 978-3-510-95864-1.

Van Ranst, E., M. Verloo, A. Demeyer and J.M. Pauwels (1999). Manual for the soil chemistry and fertility laboratory. Analytical methods for soils and plants, equipment, and management of consumables. University of Ghent. ISBN 90-76603-01-4.

Van Reeuwijk, L.P. (ed.) (2002). Procedures for Soil Analysis. 6th edition. ISRIC Technical Paper 9. ISRIC, FAO, Wageningen, Rom. http://www.isric.org/Isric/Webdocs/Docs/ISRIC_TechPap09_2002.pdf

2. Laboratory Guidelines (Examples)

- http://anlab.umesci.maine.edu/soillab_files/faq/handbook.pdf
- http://aes.missouri.edu/pfcs/soiltest.pdf
- http://www.hannainst.com.au/manuals/manHI_3896.pdf
- http://agsci.psu.edu/aasl/soil-testing/soil-methods)

3. ISO standards on soil quality

Soil quality and pedology in general

- Vocabulary: ISO 11074:2015
- Pedology: Standards catalogue
- impact from soil contaminated with petroleum hydrocarbons: ISO 11504:2012
- Pretreatment of samples for determination of organic contaminants: ISO 14507:2003
- Format for recording soil and site information: ISO 15903:2002
- Guidance on the establishment and maintenance of monitoring programmes: ISO 16133:2004
- Requirements and guidance for the selection and application of methods for the assessment of bioavailability of contaminants in soil and soil materials: ISO 17402:2008
- Measurement of radioactivity in the environment: ISO 18589-1:2005; ISO 18589-2:2015; ISO 18589-3:2015; ISO 18589-4:2009; ISO 18589-5:2009; ISO 18589-6:2009; ISO 18589-7:2013
- Procedure for site-specific ecological risk assessment of soil contamination: ISO 19204:2017
- Field soil description: ISO 25177:2008
- Digital exchange of soil-related data: ISO 28258:2013

Examination of soils in general

- Sampling - selection of sampling standards and sampling techniques, sampling planning, safety, packaging and transport, Quality control, recording and controlling, pretreatment in the field, sampling of soil gas:: ISO 18400-series
- Sampling of soil invertebrates: ISO 23611-series
- Guidance on long and short term storage of soil samples: ISO 18512:2007
- Pretreatment of samples for physico-chemical analysis: ISO 11464:2006
- Preparation of laboratory samples from large samples: ISO 23909:2008
- Measurement of the stability of soil aggregates: ISO 10930:2012
- Parameters for geochemical modelling of leaching and speciation of constituents in soils and materials: ISO 12782-series

- Guidance on the choice and evaluation of bioassays for ecotoxicological characterization of soils and soil materials: ISO 17616:2008
- Guidance on leaching procedures for subsequent chemical and ecotoxicological testing of soils and soil materials: ISO 18772:2008
- Guidelines for the identification of target compounds by gas chromatography and mass spectrometry: ISO 22892:2006

Physical properties of soils

- Dry matter and Water content (ISO 11465:1993)
- Pore water pressure (ISO 11276:1995)
- Temperature (Taylor and Jackson, 1990)
- Permeability (ISO 17892-11:2004)
- Porocity (Danielson and Sutherland, 1990)
- Particle Density (ISO 11508-1998; 17892-2:2004)
- Bulk density (ISO 11272:1998)
- Particle size distribution (ISO/TS 17892-2:2004)
- Specific Electrical Conductivity (ISO 11265:1994)

Chemical characteristics of soils

- Soil pH and Exchangeable Acidity (ISO 14254:2001)
- Redox potential (ISO 11271:2002)
- Organic Matter Content, Organic Carbon (ISO 14235:1998)
- Total Nitrogen (ISO 11261:1995; ISO 13878:1998)
- Calcium Carbonate content (ISO 10693:1995)
- Available Phosphorous (ISO 11263:1994)
- Exchangeable elements: Potassium, Calcium, Magnesium, Sodium (ISO 11260:1994; ISO 13536:1995)
- Cation Exchange Capacity (ISO 11260:1994; ISO 13536:1995)
- Available metals (Cu, Zn, Mn and Fe) (ISO 14870:2001)
- Total Sulfur (ISO 15178:2000)

Biological properties of soils

- DNA from soil samples ISO 11063:2012
- Laboratory testing for biodegradation of organic chemicals ISO 11266:1994
- Inhibition of reproduction of Collembola (Folsomia candida) by soil contaminants ISO 11267:2014
- Effects of pollutants on earthworms ISO 11268-series
- Effects of pollutants on soil flora ISO 11269-1:2012; ISO 11269-2:2012
- Nitrogen mineralization and nitrification in soils ISO 14238:2012

Hydrological properties of soils

- Determination of water content in the unsaturated zone: ISO 10573:1995
- Determination of the water-retention characteristic: ISO 11274:1998
- Determination of unsaturated hydraulic conductivity and water-retention characteristic: ISO 11274:1998/Cor 1:2009
- Wind's evaporation method: ISO 11275:2004
- Determination of pore water pressure -- Tensiometer method: ISO 11276:1995
- Determination of soil water content as a volume fraction using coring sleeves: ISO 11461:2001
- Characterization of soil related to groundwater protection: ISO 15175:2004
- Soil water and the unsaturated zone: ISO 15709:2002

- Determination of soil water content as a volume fraction on the basis of known dry bulk density: ISO 16586:2003/Cor 1:2009
- Determination of hydraulic conductivity of saturated porous materials: ISO 17312:2005; ISO 17313:2004

Other standards related to soil quality

- Characterization of excavated soil and other soil materials intended for re-use: ISO 15176:2002
- Guidance on the ecotoxicological characterization of soils and soil materials: ISO 15799:2003
- Characterization of soil with respect to human exposure: ISO 15800:2003
- Guidance on the determination of background values: ISO 19258:2005
- Guidance for burial of animal carcasses to prevent epidemics: ISO 28901:2011

Annex 2: Example for deriving a laboratory code

(summarized and translated from Krone and Utermann 2011)

1. Sampling code	1	Sample material (e.g. mineral soil)
	2	Sampling procedure (e.g. satellites)
	3	Type of sample (e.g. mixed)
	4	Sampling device (e.g. 15x15 cm frame)
	5	Material of sampling device (e.g. steel)
	6	Material of transport device (e.g. PE plastic bag)
	7	Transport conditions (e.g. average temperature)
2. Sample preparation	1	Storage (e.g. temperature)
	2	Drying (e.g. temperature)
	3	Initial crushing of the sample
	4	material of the crusher
	5	Type and material of the sieve
	6	Mesh size
	7	Grinding (e.g. apparatus)
	8	Material of the grinder
	9	Type of Filter (e.g. soil water samples)
	10	Mesh size of filter
3. Analysis code	1	Code of method (according to reference literature, e.g. ISO)
	2	Chemical medium
	3	Extraction method
	4	Final treatment (e.g. filter)
4. Apparatus code	1-6	Depending on the apparatus, different specification are needed (can be provided via a menu describing each type of apparatus/measurement system)

Krone, F. and J. Utermann (2011). Die bodenkundliche Labor- und Profildatenbank [*The soil profile and soil analytical data base*]. Soil Information System FISBo-BGR. Documentation. Federal Institute for Geosciences and Natural Resources (BGR), Hannover. Tgb.-Nr.: 10192/11. 19 p (unpublished).

For each item in the above list, a code list with options was prepared. An MS-ACCESS data base tool was then developed which uses the code lists to generate the final laboratory code for each soil analysis.

Annex 3: List of soil analysis needed for WRB

(acc. to Schad 2017, written communication)

Parameter	used for	WRB
texture	argic, cambic, chernic, ferralic, irragric, mollic, natric, nitic, plaggic, protovertic, umbric, vertic	horizon
	abrupt textural difference, albeluvic glossae, aridic, geric, lithic discontinuity, retic, sideralic, takyric	property
	Vertisol, Acrisol, Lixisol, Arenosol	RSG
	Acric, Alic, Arenic, Areninovic, Clayic, Clayinovic, Hyperalic, Hypoargic, Lixic, Loaminovic, Luvic, Profondic, Protoargic, Siltic, Siltinovic, Vetic	qualifier
bulk density	anthraquic	horizon
	andic	property
	Laxic, Murshic, Protoandic	qualifier
pH	spodic, thionic	horizon
	geric	property
	hypersulfidic, sulfidic	material
	Aceric, Alcalic, Carbonatic, Dystric, Eutric, Hyperdystric, Hypereutric, Hyperthionic, Hypothionic, Orthodystric, Orthoeutric, Posic	qualifier
organic carbon	chernic, ferralic, fragic, fulvic, hortic, irragric, melanic, mollic, plaggic, pretic, sombric, spodic, umbric	horizon
	aridic	property
	fluvic, mineral, organic, soil organic carbon	material
	Ferralsol	RSG
	Aeolic, Carbonic, Garbic, Humic, Hyperhumic, Ochric, Profundihumic, Protoaridic, Protospodic, Rustic	qualifier
carbonate	calcic, cambic, chernic, irragric, mollic	horizon
	sulfidic	material
	Gypsisol, Calcisol	RSG
	Hypercalcic, Hypocalcic, Rendzic, Somerirendzic	qualifier
cation exchange capacity	chernic, ferralic, hortic, mollic, nitric, plaggic, sombric, terric, umbric	horizon
	aridic, sideralic	property
	Chernozem, Kastanozem, Phaeozem, Acrisol, Lixisol	RSG
	Acric, Alic, Columnic, Dystric, Eutric, Ferralic, Hypersideralic, Lixic, Luvic, Mesotrophic, Sodic	qualifier
exchangeable bases	chernic, ferralic, hortic, mollic, natric, plaggic, pretic, sombric, terric, umbric	horizon
	aridic, geric	property
	Chernozem, Kastanozem, Phaeozem, Acrisol, Alisol	RSG
	Acric, Acroxic, Alcalic, Alic, Argisodic, Columnic, Dystric, Eutric, Eutrosilic, Hyperdystric, Hypereutric, Hypermagnesic, Hypernatric, Lixic, Luvic, Magnesic, Mesotrophic, Oligoeutric, Orthodystric, Orthoeutric, Protosodic, Sodic, Vetic	qualifier

Parameter	used for	WRB
water-dispersible clay	ferralic, nitic	horizon
	Ferralsol	RSG
soil water content at 1500 kPa	Hydric	qualifier
Coefficient of linear extensibility (COLE)	argic, natric, protovertic	horizon
gypsum	cambic, gypsic, petrogypsic	horizon
	Gypsisol	RSG
	Arzic, Hypergypsic, Hypogypsic	qualifier
exchangeable Al	ferralic	horizon
	geric	property
	Acrisol, Alisol	RSG
	Acric, Acroxic, Alcalic, Alic, Dystric, Eutric, Hyperalic, Hyperdystric, Hypereutric, Lixic, Luvic, Mesotrophic, Oligoeutric, Orthodystric, Orthoeutric, Vetic	qualifier
Fe: dithionite-citrate-bicarbonate	hydragric, nitic, petroplinthic, plinthic	horizon
	Ferritic, Hyperferritic	qualifier
Mn: dithionite-citrate-bicarbonate	hydragric	horizon
Al: acid oxalate	spodic	horizon
	andic, vitric	property
	Aluandic, Protoandic, Protospodic, Silandic	qualifier
Fe: acid oxalate	nitic, petroplinthic, plinthic spodic	horizon
	andic, vitric	property
	Protoandic, Protospodic, Rustic	qualifier
Si: acid oxalate	Aluandic, Silandic	qualifier
Al: pyrophosphate	Aluandic, Silandic	qualifier
electrical conductivity	salic	horizon
	aridic, takyric	property
	Hypersalic, Protosalic, Salic	qualifier
phosphate retention	andic, vitric	property
	Protoandic	qualifier
optical density of oxalate extract (ODOE)	spodic	horizon
melanic index	fulvic, melanic	horizon
weatherable minerals	ferralic	horizon
anions in soil solution: Cl, SO4, HCO3	Carbonatic, Chloridic, Sulfatic	qualifier
fulvic acid carbon	spodic	horizon
gibbsite	Gibbsic	qualifier
micromorphology	argic, natric	horizon
organic carbon in pyrophosphate	spodic	horizon

Parameter	used for	WRB
phosphorous in citric acid	anthric	property
	ornithogenic	material
phosphorous in sodium bicarbonate	hortic	horizon
phosphorous Mehlich-1	pretic	horizon
slaking in 1 M HCl	duric, petroduric	horizon
slaking in concentrated KOH or NaOH	duric, petroduric	horizon
sulfidic S	hypersulfidic, hyposulfidic, sulfidic	material
toxic conc. of metals or org. compounds	Toxic	qualifier
turns redder on ignition	Carbic	qualifier
water-soluble sulfate	thionic	horizon
	Arzic	qualifier
TiO2, ZrO2	lithic discontinuity	property

Annex 4: Terms of reference Pillar 5 Working Group (P5 WG)

The different areas of harmonization, the complexity of tasks and the necessary experience to be shared require strong coordination. It is also important to align Pillar 5 deliverables with the timing of Pillar 4 actions building the Global Soil Information System (e.g. indicators for monitoring; see section 8). These tasks will be fulfilled by the Pillar 5 Working Group.

Implementation of harmonization actions will be concentrated on institutions collecting and distributing soil data. The core partners of Pillar 5 are therefore the members of the International Network of Soil Information Institutions (INSII).

Tasks of the P5 WG:

- Establish a detailed roadmap for Pillar 5 implementing action, directly following the 5th GSP Plenary Assembly
- adjust and further refine the funding requirements for actions following the discussion with INSII and other actors of this plan, and coordinate with Pillar 4;
- ensure that this plan is implemented: actively involve GSP members (in particular INSII), involve additional experts, coordinate with networks;
- actively connect partners and institutions;
- overview progress and link between global-level and regional implementation processes;
- overview and quality-assure all action items foreseen in the P5IP, especially if contractors are involved; in the latter case, closely support the GSP Secretariat;
- directly engage in the implementation of activities mentioned in this plan (see Table 8):
  - Section 2: requirements and gaps analysis; handbook,
  - Section 3: CMS requirements and design,
  - Section 4: finalization of the SoilML exchange standard,
  - Section 5: review of indicators;
- support mobilization of sufficient resources, especially regarding capacity building.

Composition of the P5 WG:
See section 6.1.

Chair and time frame:
The P5 WG will select a chair per internal consensus. The time frame is three years in accordance with the first phase of the Pillar 4 and Pillar 5 implementation plans. The Chair of Pillar 5 will participate in the P4 WG.

Meetings:
The P5 WG will meet regularly in connection with the annual INSII meeting. In between these meetings, electronic means shall be used to arrange for regular coordination. Members of the P5 WG take the lead for different areas of harmonization, so that during implementation, and depending on actions and the roadmap, smaller teams of two or three experts may be formed, for which coordination and physical or virtual meetings can be arranged more easily.

Annex 5: Terms of reference Global Soil Laboratory Network (GLOSOLAN)

The harmonization of soil analysis is a specialized working area. While many INSII members have the core competency in several work areas for harmonization, it cannot be taken for granted this is also valid for soil analysis. For that reason, the Global Soil Laboratory Network (GLOSOLAN) will be formed. In order to build the necessary capacity and quality in soil analysis, capacity building and partnering is considered most effective at regional level, where language barriers are reduced, travel is easier, and thus partnering between institutions is more effective. Regional networks of soil laboratories (RESOLAN) will be formed wherever the regional soil partnership enables it. Reference soil laboratories play a key role coordinating harmonization tasks for soil analysis in each regional network. GLOSOLAN will facilitate global coordination, and establish the linkages with data needs at different levels of the Global Soil Information System.

Tasks:

- contribute to the execution of the Pillar 5 Implementation Plan by serving as a strategic decision making and implementation body;
- exchange information and experiences from laboratory operations
- promote the use of standards/recommended procedures
- organize and coordinate ring tests and calibration exercises, and accompany the quality assessments for GSP Pillar 4 related datasets (soil profiles, soil monitoring);
- support the establishment of soil reference laboratories able to transfer knowledge and share experiences in form of capacity building as well as production and sharing of reference materials in the framework of organizing and evaluating inter-laboratory comparisons;
- identify, promote and, if needed, develop standards/recommended procedures;
- coordinate activities among the RESOLANs supported by the GSP Secretariat in order to ensure harmonization at a global level;
- convene an annual meeting to monitor progress on Pillar 5 implementation plan in respect to soil analysis;
- appoint a Chair for a period of 2 years, extendable via GLOSOLAN decision to a second term;
- monitor the harmonization progress for soil analysis

Composition of GLOSOLAN:

- national soil laboratories, mandated and supported by the GSP national focal points
- any soil laboratory and members of regional soil laboratory networks