# Plan of Action for Pillar Five of the Global Soil Partnership

Adopted by the GSP Plenary Assembly

## 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


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## Acronyms

| | |
|---|---|
| CAADP | Comprehensive Africa Agriculture Development Programme |
| CBD | Convention on Biological Diversity |
| CST | Committee on Science and Technology |
| CGIAR | Consortium of International Agricultural Research Centers |
| CIAT | International Center for Tropical Agriculture |
| CIMMYT | International Maize and Wheat Improvement Center |
| ELD | Economics of Land Degradation |
| ENSA | European Network Soil Awareness |
| EVS | European Voluntary Service |
| FAO | Food and Agriculture Organization of the United Nations |
| GEOSS | Global Earth Observation System of Systems |
| GDP | Gross Domestic Product |
| GHG | Greenhouse gas |
| GSBI | Global Soil Biodiversity Initiative |
| GSIF | Global Soil Information Facilities |
| GSP | Global Soil Partnership |
| GWP | Global Water Partnership |
| HWSD | Harmonized World Soil Database |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| IFA | International Fertilizer Industry Association |
| IIASA | International Institution for Applied Systems Analysis |
| IITA | International Institute of Tropical Agriculture |
| INM | Integrated Nutrient Management |
| INSII | International Network of Soil Information Institutes |
| IPCC | Intergovernmental Platform for Climate Change |
| IPR | Intellectual Property Rights management |
| IRRI | International Rice Research Institute |
| ISFM | Integrated Soil Fertility Management |
| ISO | International Standard Organization |
| IPBES | Intergovernmental Platform on Biodiversity and Ecosystem Services |
| ISFM | Integrated Soil Fertility Management |
| ITPS | Intergovernmental Technical Panel on Soils |
| IUSS | International Union of Soil Sciences |
| IYS | International Year of Soils |

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| LADA | Land Degradation Assessment in Drylands |
| MDG | Millennium Development Goal |
| NGO | Non-governmental Organization |
| OGC | Open Geospatial Consortium |
| PTF | Pedo-transfer Functions |
| PTR | Pedo-transfer Rules |
| QA/QC | Quality assurance and Quality Control |
| RSP | Regional Soil Partnership |
| RSPO | Roundtable on Sustainable Palm Oil |
| R&D | Research and Development |
| SCAPE | Soil Conservation and Protection in Europe |
| SOTER | Soil and Terrain Database |
| SDG | Sustainable Development Goal |
| SLM | Sustainable land management |
| SSSA | Soil Science Society of America |
| SSM | Sustainable Soil Management |
| SSS | Soil sampling, Sample preparation and Sample storage |
| SOC | Soil Organic Carbon |
| SPI | Science Policy Interface |
| SSSA | Soil Science Society of America |
| UN | United Nations |
| UNCCD | United Nations Convention to Combat Desertification |
| UNCED | United Nations Conference on Environment and Development |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USDA | United States Department of Agriculture |
| WGSIS | Working Group on Soil Information Standards |
| WOCAT | World Overview of Conservation Approaches and Technologies |
| WSC | World Soil Charter |
| WSD | World Soil Day |
| WRB | World Reference Base for Soil Resources |
| WWOOF | World Wide Opportunities on Organic Farms |

## Glossary

**Agriculturally productive soil** refers to soil with the suitability to produce certain yield of an agricultural crop or crops due to its inherent physical, chemical and biological properties.

**Agronomic biofortification** refers to the application of soil and foliar mineral fertilizers and/or improving solubility of mineral nutrients in the soil to promote nutrient accumulation in edible parts of food crops.

**Climate Smart Agriculture** refers to agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances the achievement of national food security and development goals.

**Food security** exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food.[1]

**Integrated Nutrient Management** refers to the maintenance of soil fertility and plant nutrient supply at an optimum level for sustaining the desired productivity by optimizing the benefits from all possible sources of organic, inorganic, biological and sustainable recyclable waste components in an integrated manner, to prevent environmental impacts from nutrient outflows.

**Integrated Soil Fertility Management** refers to a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity.[2]

**Nutrient Use Efficiency** refers to getting the maximum amount of nutrients applied to soils and crops into the harvested portion of a crop. This implies the recovery of nutrients supply through fertilizer application by the crop, through uptake of nutrients by the plant and depends on plant characteristics (transport, storage, mobilization and usage within the plant) and on the environment.

**Nutrition security** means access to the adequate utilization and absorption of nutrients in food, in order to be able to live a healthy and active life.1

**Potentially agriculturally productive soil** refers to soil that is not agriculturally productive, but can be transformed into agriculturally productive soil through the implementation and application of appropriate amendments and management practices.

**Region** indicates a Regional Soil Partnership (RSP) established under the GSP among interested and active stakeholders. The RSPs will work in close coordination with FAO Regional Offices

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[1] FAO. 2009. *The State of Food Insecurity in the World 2009*. Food and Agriculture Organization of the United Nations.

[2] Van Lauwe B. 2013. Integrated Soil Fertility Management – a concept that could boost soil productivity. *Rural 21*. 3:34-37.

to establish interactive consultative processes with national soils entities, regional soil science societies and relevant regional mechanisms under the related conventions. The following seven regions have been identified:

- Asia
- Africa
- Europe and Eurasia
- Middle East and North Africa
- North America
- Latin America
- Southwest Pacific

**Soil conservation** indicates the (i) preventing soil degradation processes such as physical soil loss by erosion or biological, chemical and physical deterioration; including, excessive loss of fertility by either natural or artificial means; (ii) a combination of all management and land use methods that safeguard the soil against depletion or deterioration by natural or by human-induced factors; and (iii) the branch of soil science that deals with soil and water conservation in (i) and (ii).[3]

**Soil contamination** implies that the concentration of a substance (e.g. nutrient, pesticide, organic chemical, acidic or saline compound, or trace elements) in soil is higher than would naturally occur (See also *soil pollution*).

**Soil functions** refer to the seven key functions of soil in the global ecosystem as:

1. Biomass production, including in agriculture and forestry;
2. Storing, filtering and transforming nutrients, substances, and water;
3. Biodiversity pool, such as habitats, species and genes;
4. Physical and cultural environment for humans and human activities;
5. Source of raw materials;
6. Acting as carbon pool;
7. Archive of geological and archaeological heritage.

**Soil pollution** refers to the presence of substances at concentrations above threshold levels where they become harmful to living organisms (See also *soil contamination*).

**Sustainable Production Intensification** refers to increasing food production or yields on existing farmland without adverse environmental impact and without the cultivation of more land.

**Sustainable Land Management (SLM)** means the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while ensuring the long term productive potential of these resources and the maintenance of their environmental functions.[4]

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[3] SSSA. 2008. Glossary of Soil Science Terms. Madison, WI, USA.

[4] UNCED. 1992. *The RIO Declaration on Environment and Development.* United Nations Conference on Environment and Development (UNCED), Rio de Janeiro, 3-14 June 1992.

**Sustainable productivity** means the ability to maintain productivity, at field, farm or territorial scale, where productivity is the output of valued products per unit of natural resource input.

**Sustainable land management (SLM)** means the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while ensuring the long term productive potential of these resources and the maintenance of their environmental functions.[5]

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## Executive Summary

Unprecedented stress is placed on soil as the human population and urbanization rates increase. Soil is a non-renewable natural resource and needs to be managed accordingly. While there are many different representations of the data collected to represent soils, the techniques and scales of analysis change throughout the world. There is therefore a need for harmonization of methods for the sustainable management and protection of soil resources.

To answer those challenges, the GSP was created to improve governance of the limited soil resources of the planet to guarantee agriculturally productive soils and support essential ecosystem services globally. Pillar Five provides the mechanisms for developing and exchanging globally consistent and comparable harmonized soil information, through soil profile observation and description data, laboratory and field analytical data, and derived products. Harmonization, which could be seen as a next step to standardization, provides the ability to describe, sample, classify, and analyze the soil in a way that allows the use of the results for later scientific use.

While there are many standards, the soil data cannot be compared within and between countries. Therefore, harmonization would reduce the amount of time, resources, transferring and collating disparate soils. The possible errors in translation, from a scientific and terminology point of view, will have consequences on the actions related to sustainable soil management, soil research, and soil policies. This harmonization practice will also facilitate the use of historical or legacy data to have a consistent database, generate knowledge about regional soils and train future scientists as well. The benefits of data harmonization will be felt on four different levels:

1. At a technical level: easy and efficient transfer between data bases, allowing easy analysis.
2. At local levels: easiness in comparing similar soil landscapes and best-practices in similar areas
3. At national levels: to facilitate investigation of soil degradations or opportunities between regions for a better use of natural resources
4. At international levels: to look at matters such as food security, biodiversity and desertification.

Harmonization would follow principles of cooperation (commonality, inclusiveness, efficiency and multi-linguality) and operations (interoperability, extensibility, scalability). This harmonization can be done by using reference laboratories to set standards. The standards should be made by examining existing practices for field sampling, preparation and measurement. A comprehensive web-based soil data exchange would facilitate communication between scientists and individuals on soil quality and management. The type of Governance to monitor this web-based soil data platform would follow the one from Pillar 4.

## Summary of Recommendations

**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, analyse and interpret soils.

**Recommendation 2:**
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. It builds on established harmonization principles as well as on current standardization and harmonization activities.

**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 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 USDA Soil Taxonomy until a new standard system is released. The GSP supports the development of the new Universal Soil Classification System.

**Recommendation 4:**
Review existing practices for field sampling, sample preparation and measurement (including laboratory standardization and QA/QC) and prepare specifications and guidelines for harmonized approaches to the determination of the main functional properties of soils (i.e. chemical, physical and biological).

**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).

**Recommendation 6:**
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.

# 1. Introduction

The Global Soil Partnership (GSP) was formally eastablished by members of the Food and Agriculture Organization of the United Nations (FAO) during its Council in December 2012. The Council recognized soil as an essential natural resource which is often overlooked and has not received adequate attention in recent years, despite the fact that production of food, fibre, fodder and fuel critically depends on healthy soils. The Mandate of the GSP is to improve governance of the limited soil resources of the planet in order to guarantee agriculturally productive soils for a food secure world, as well as support other essential ecosystem services, in accordance with the sovereign right of each State over its natural resources.

In order to achieve its mandate, the GSP addresses the following five pillars of action to be implemented in collaboration with its regional soil partnerships:

- Promote sustainable management of soil resources for soil protection, conservation and sustainable productivity;
- Encourage investment, technical cooperation, policy, education, awareness and extension in soil;
- Promote targeted soil research and development focusing on identified gaps and priorities and synergies with related productive, environmental and social development actions;
- Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines;
- Harmonization of methods, measurements and indicators for the sustainable management and protection of soil resources.

The Plans of Action for each pillar were formulated in an open and participatory format following strictly the Guidelines for the development of Plans of Action of the GSP Pillars as presented in the Rules of Procedure.

This report presents the proposed plan of action for the implementation of Pillar 5. It provides:

- a rationale for global harmonization of soil-related information
- a set of guiding principles for global harmonization
- discussion of the potential scope for harmonization across the soil domain
- recommended priority topic areas for immediate action
- initial discussion on implementation options
- a set of recommendations.

Pillar 5 provides the mechanisms for developing and exchanging globally consistent and comparable harmonized soil information. This refers to soil profile observation and description data, laboratory and field analytical data, and also derived products such as digital soil maps and soil property estimations, and interpreted information based on agreed and representative indicator sets. Thus, Pillar 5 is a basic foundation of Pillar 4, and an enabling mechanism for all GSP pillars providing and using global soil information.

This plan of action was developed by an international group of experts in data collection, processing, exchange and interpretation. A draft plan was discussed during a workshop in Rome (18-19th February 2014), revised and then provided to a broad community of global experts for review (March 2014).

The draft plan of action (PoA) was first submitted to the ITPS for its review and endorsement. After a very dynamic process in which ITPS recommendations were included, the present plan of action was endorsed by ITPS during its second working session in April 2014. In July 2014, during the second Plenary Assembly, the draft PoA was reviewed by the GSP partners, and endorsed after having condensed the initial 13 recommendations into 6 key recommendations. As the next step, implementation plans will be developed and facilitated by the GSP secretariat; it will regularly report to the Plenary Assembly about the progress of implementation.

## 2. Challenges for the harmonization of soil information

### 2.1 Restrictions and opportunities for harmonization

Despite the existence of many standards and reference materials for soil description, analysis and classification, a large part of the existing soil data is not comparable within or between countries. Harmonization allows data from different sources to be brought together under a commonly agreed framework, facilitating the exchange and use of soil data (Omuto *et al.*, 2012).

Without agreed harmonization processes, the availability, transferability and usability of soil data is severely restricted. Individuals, projects, countries and global organizations will all spend significant time and resources on finding, transferring and collating disparate soils data. Errors in translation and subsequent data analyses will be made, and consequent actions related to sustainable soil management risk being ineffective to the detriment of farmers, communities and the global society.

The limited degree of harmonization worldwide can partly be explained by a local focus of countries/institutions to collect and interpret data for specific applications. Other issues include:

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| **Restrictions to harmonization** | - Restricted access to, and limited familiarity with reference materials and standards.<br>- Lack of appropriate sampling and analysis equipment in some countries and projects.<br>- Lack of standards for modern and rather sophisticated analytical methods.<br>- Large variety of local and national survey guidelines and sampling schemes.<br>- Tendency of data providers to stick to well-established (inherited), conventional approaches.<br>- Lack of global correlation and harmonization methods (at various scales).<br>- Lack of capacity to quality-assure and harmonize legacy data.<br>- Lack of advice (guidance) and expertise.<br>- Language barriers. |

At the same time, rapid advances in technical and scientific developments offer new opportunities to data collection and processing of soil science information:

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| **New opportunities** | - Development of new measuring and data evaluation methodologies (e.g. spectroscopy, digital soil mapping and remote sensing) leading to continuous upgrades of existing data systems.<br>- Technical ability of data users to process large amounts of spatial data.<br>- Improved availability and quality of local data helps to optimize and target political responses to local conditions.<br>- Vast areas of land still lack appropriate information about soils; demand for new collection applying GSP principles.<br>- Progress in soil data exchange and data processing including use |

of geographic information systems and web services.
- Motivation to provide internationally comparable soil data: peer-review publications, synergies (cost-effectiveness) in model calibration and validation, data base building, reporting mechanisms such as the Global Earth Observation System of Systems (GEOSS).
- Increasing international research cooperation.
- Laboratory certification and quality assurance.

Without global leadership by Pillar 5, it is very likely that future data collection will remain segmented, preventing effective multi-national and global soil quality assessment and monitoring.

**Challenge 1:**

The majority of available soil data is extremely heterogeneous. Improving the knowledge about soils requires robust and harmonized data. This calls for a new, over-arching concept for harmonization.

## 2.2 Scope for harmonization: local versus global

Soil degradation is a wide-spread yet local phenomenon, but with trans-local effects: loss of fertile soils in one area increases pressures on soils in other areas; socio-economic drivers become increasingly globalized.

The benefits of data harmonization are many and relate to different users at different levels. At a **technical level**, harmonized soil data can be more easily and efficiently transferred between different data bases allowing all available data resources to be analyzed. At **local levels**, land management issues can be compared to similar soil landscapes and best-practice lessons learnt at one location transferred to other similar areas. At **national levels**, the severity of soil degradation or opportunities for further development can be investigated between regions and limited available resources used most effectively where needed. At **international levels**, data from all countries can be collated and applied to significant global issues such as food security, biodiversity and desertification. Climate change, for example, is a global phenomenon with local scale feedback mechanisms and effects. These frame conditions demonstrate that comparable data are needed at different levels. Information on the soil condition needs to be exchanged, interpreted and compared across national borders and globally.

**Challenge 2:**

Harmonization has benefits at all levels of use from local to global. It involves local data collection as well as the aggregated use of this data for larger areas. Data exchange is required to generate aggregated products and helps to fill data gaps. Harmonization becomes especially important where information is compiled from different sources.

## 2.3 Formerly collected ('legacy') soil data versus newly collected data

There is still no (accessible) soil data for large areas of land, although new and efficient measuring techniques are becoming available. Modeling soil variability through infra-red spectroscopy, digital soil mapping and remote sensing techniques may fill the gaps. However, they require a large amount of local soil data for model calibration and validation, which is expensive and labor-intensive to collect. Harmonization thus may provide a common framework to reduce duplication of effort. It also allows historic data (legacy data) to be translated from terminology and methods into new internationally agreed standards.

Alternatively, existing legacy or historic soil data from many countries still have not been collated, checked and harmonized in a consistent database (see also Leenars *et al.*, 2014). Irrespective of the nature of the data collated, harmonization of methods is needed for interoperability and application at a broader scale.

Very often, expert knowledge about regional soils is lost if experienced soil surveyors are not replaced after retirement; then, the only source of qualified information left is legacy data (including soil description). Legacy data may also support the training for the new generation of soil mappers.

**Challenge 3:**

Harmonization can be applied irrespective of the nature of the data collated (legacy versus new data) provided that any used standards are known and well documented. This will require agreement on the target standard(s) chosen for harmonization.

## 2.4 Who is concerned with harmonization, and who benefits from it?

Soil resources are often managed at local levels but may cause both on-site and off-site impacts (for example down-stream salinity, nutrient leaching, or mass movement). Mechanisms for harmonization of soil information are mostly applied to data collected at local level but it is also useful to apply local experiences and lessons from individual land management to other similar soil resources. In addition, the sustainable use of soils asks for a consistent view of local soil properties and hazards scaled up to larger planning and policy levels. Some more technical benefits may include value adding to existing historic soil data sets by incorporating them in a harmonized view with more recently collected data.

Local soil surveyors may face a barrier for contributing to harmonization. Local surveyors not using English may not fully understand the demand for their information and not know about tools or processes for contributing their data to other (international) reporting levels. Unfortunately, much local data are getting scattered and lost before publication.

Globally agreed harmonization mechanisms may remove the need for individual users to continually translate different data into something useful. The effort required of data providers may increase as they need to translate their data to the agreed recommendations before exchanging or publishing it.

**Challenge 4:**

Harmonization will benefit users within and external to the soil community at all levels from local to global, given that the corresponding data are made accessible and shared.

**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.

# 3. Approach to harmonize soil information

## 3.1 Definition of harmonization

Harmonization provides the ability to describe, sample, classify, and analyze the soil in a way that allows the combined use of the resulting data on a scientifically sound basis. Soil data and information derives from many sources, across time, projects, agencies, and countries.

Harmonization provides an agreed viewpoint through a set of managed (and manageable) procedures that permit the exchange and use of consistent soil data at the supra-national and global levels. Harmonization, as defined here, is not aimed at dictating how soil data providers and/or users should collate/process their data and information; rather it provides a mechanism for individuals to provide input to a globally consistent view. Many countries have developed procedures that are well-suited for application at national and sub-national level and that will evolve further. The challenge for the GSP is to provide mechanisms to harmonize all this disparate information into a consistent common form in order to facilitate use.

## 3.2 Areas of harmonization

Harmonization includes all aspects related to soil observation and measurement (both in the field at different scales and in the laboratory) and to soil data integration, analysis and interpretation. Harmonization is essential for efficient data management and exchange.

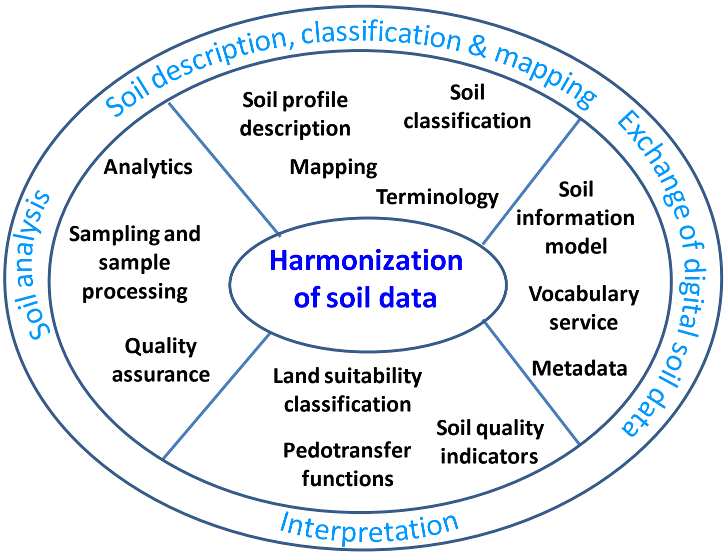


**Figure 1: Areas of harmonization**

Harmonization can be beneficially applied in all components from soil description and classification, through analysis and interpretation, to integration, assessment and reporting. The GSP Pillar 5 supports the vision that soil data and information from many sources can be brought together into a single consistent viewpoint to support the sustainable use of the world's limited soil resources.

The following **key priorities for harmonization** have been identified:

- **Soil Description**: well-defined and agreed soil features are described in terms of their specified observable properties using clear and decisive vocabularies such that data from different sources can be translated into a globally consistent data set.
- **Soil Classification**: a scheme for the classification of soils based on readily available soil property values can be applied at the global level such that data and information relevant to the description, development, management and communication of soils can be shared.
- **Soil Mapping**: while the spatial assessment of soil types and properties in maps fully falls under the auspices of countries and regions, harmonized approaches to update map data, to fill data gaps, and to aggregate the content of maps into smaller scales (Pillar 4) offer new opportunities to improve and utilize such data.
- **Laboratory Analysis of Soil**: appropriate methods and procedures used for analyzing the properties of soils are well defined and documented such that results from different analysis procedures can be translated and combined where necessary to provide globally consistent data.
- **Soil Information Exchange**: a conceptual soil feature information model provides the framework for harmonization such that the efficient exchange and collation of globally consistent data and information can occur.

- **Interpretation**: a globally applicable indicator set forms the basis for soil monitoring and reporting. Evaluation and conversion methods are needed to fill data gaps, but also to integrate differently coded and defined data.

## 3.3 Principles for harmonization

The following **principles** provide guidance for the harmonization initiatives of the GSP. Importantly they recognize the need for developing a consistent and coherent view of the world's soils based on the best available data and information, while respecting the needs, rights and processes of the many individuals and agencies that could provide data and information.

### a) Principles for Cooperation

These principles guide how GSP partners should work together. They do not establish mandatory restrictions but rather suggest cooperation and collaboration though:

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

**Inclusiveness** – Global efforts should encourage wide participation and support the needs of the broadest community of soil information users possible. All viewpoints should be considered, recognizing that global harmonization will not always be able to incorporate the specific individual needs of all users.

**Efficiency** – Harmonization should aim for maximum efficiency to help to minimize the individual requirements for bringing soil information together from many sources. It should evolve so that minimum effort is required to apply agreed standards and procedures.

**Multilinguality** – Globally agreed harmonization standards and references, including soil terminology will be made available in all main languages.

### b) Guiding principles for harmonization operations

Recommendations and implementation steps for harmonization will have maximum impact and the highest likelihood for local implementation and acceptance, if the following guiding principles are maintained:

**Interoperability** – data and information exchange is well documented and provides implementation specifications for automated soil data interoperability.

**Extensibility** – global harmonization defines an agreed level of common ground which can be further extended as required by countries, organizations or individuals to include more local concepts, solutions and approaches.

**Scalability** –Referencing between global harmonization mechanisms and national through to local soil information systems must be enabled. On that basis, improved access to local information will improve the production and availability of new global products (see Pillar 4).

Conformity to these principles will facilitate **comparability** as a basis to integrate data from different sources. These principles do not exclude data rights**. Intellectual property rights** for data products are covered by **Pillar 4**. **Quality assurance and quality control** (QA/QC) as well as **documentation** are overall minimum requirements. While in laboratories, QA/QC is widely established, documentation of methods (analysis, mapping) is lacking behind so that users of soil data lack ancillary information in order to harmonize and integrate data sets into larger scale evaluations. **Coding rules for data storage and data applications** (e.g. hazard maps) do not exist.

## 3.4 Standardization and Harmonization

A "standard" provides formal and explicit documentation and description of a procedure, process or expected level of compliance. As long as the application of standards has a voluntary status, standardization is only reached as far as parties agree to use those standards. Standardization may also be reached when national or international legislation demands the application of particular standards.

Harmonization is not necessarily related to formal standardization as other documents and guidelines (e.g. from the IUSS or FAO) could be a basis for agreement. Harmonization could be seen as a next step to standardization, where parties agree to apply a standard as the central concept to which soil data and information are translated.

Global organizations such as the FAO can have an important stimulating role in the acceptance of standards and consequently in the process towards harmonization.

## 3.5 Ongoing harmonization and standardization activities

Pillar 5 will coordinate with on-going activities in relation to harmonization of soil information that is important to the GSP. Activities within the International Union of Soil Sciences (IUSS) such as working groups for Urban Soils, Cryosols, Acid Sulfate Soils and Proximal Sensing are already actively engaged in the development of consistent processes, procedures and methodologies to support global harmonization. Of particular importance are the IUSS Working Group 'WRB', the IUSS Working Groups 'Universal Soil Classification' (Appendix 2) and 'Soil Information Standards' (Appendix 3).

For example, the WG WRB will present the 3$^{rd}$ edition of WRB during the World Conference of Soil Sciences in Jeju, Korea, 2014. The ISO Technical Committee 190 (Soil Quality) is an important international activity that has already expressed interest in future collaboration with the GSP Pillar 5.

It must also be noted that national harmonization activities are also ongoing in many countries (e.g. correlation with WRB, comparisons of texture triangles, and comparisons between old and new analytical methods). These activities must be reflected in the implementation of this plan of action Appendix 5 lists some important reference materials from these activities.

**Recommendation 2:**

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. It builds on established harmonization principles as well as on current standardization and harmonization activities.

# 4. Soil description, classification and mapping

## 4.1 Soil description

### a) New challenges to soil profile description

Soil can be considered at many levels, from a broad view of soil as a component of the total environmental landscape in which it exists, through a particular body of soil, to a specific expression of soil at a defined location. Soil may be described in terms of its properties as a whole, from an Earth's surface viewpoint, or with depth as a cross section or profile which have distinct layers or horizons that can be described with specific properties and morphology, and over time (monitoring). This is the most basic soil information. **Results from soil descriptions must be comparable** in order to serve as a consistent descriptive communication basis for professionals across the international community.

Soils are currently described in many ways**, lacking world-wide agreed definitions** (e.g. texture class) and structures to store and disseminate information about soils. Because of this, **valid and complete soil descriptions from different data bases cannot be easily exchanged and made available** to the broad user community. There is a need for improved international communication about the nature and properties of soil and harmonizing the way we describe and classify them.

Besides the traditional approach to soil description, there are also many **new technologies** which generate information related to visible soil properties (used in field during soil profile description). Examples are non-destructive sampling using optical sensors, electromagnetic or spectrometric devices applied proximally, from the air, or space. **Effort is required to understand how this information may support the description of soil profiles.** The requirements to calibrate, validate and interpret such data completely differ from the conventional approach to describe soil profiles.

Another important consideration in the description of soils is to **include information usable by the general public and non-scientific users**. Many handbooks for soil description are scientific, so that the broad public sector including landowners may be excluded from the terminology and method used to describe soils. Effort is needed not only to harmonize and improve the various existing approaches, but also to simplify such a system, e.g. in order to allow **crowd sourcing of new and innovative data**. It is important to have a **simplified understanding and terminology to describe soils and share lessons about its use and management**. For example farmers may talk about 'light sandy country' compared to 'red loamy soils' or the 'black cracking clay plains'. This requires a basic mechanism for communicating about different soil types, the properties and attributes of different soil and implications for management.

Considering these challenges, a generic soil profile description would allow soil science researchers, practitioners and other scientific disciplines to have a common descriptive language to communicate important scientific information. This availability will stimulate the use of soil information and result in many new applications. Soil description should identify and include all relevant soil features, and how they relate to other environmental and human features. That way 'soil' can be more broadly integrated with other domains.

### b) Soil profile description development

In 2006, FAO has published the 4$^{th}$ edition of a field book for soil profile description (FAO 2006). It is based on existing reference material in soil information systematics and soil classification, e.g. the Field Book for Describing and Sampling Soils (Schoeneberger *et al.*, 2002) and the Keys to Soil Taxonomy (Soil Survey Staff, 2003), the updated Global and National Soils and Terrain Digital Databases or SOTER (ISRIC, 2005) and the Revised World Reference Base for Soil Resources (FAO, 2006). Because of recent improvements of relevant reference material, and because of gaps detected during the last years of application, this guideline requires updating, In order to develop a **generic soil profile description handbook**, **agreements on definitions and codes for class-values** are required. Because many interpretations of soil data (e.g. based on PTF; compare Ch. 7) build on profile descriptions, a global system of generic profile properties is needed.

Besides FAO (2006), there are a number of guidelines for recording soil profile descriptions in English language that have been used successfully across many sectors of the international community and can be used as the basis for making harmonized soil profile descriptions. Included in this list are the USDA Soil Survey Manual (USDA 1993), USDA Field Guide 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), among others.

### c) ISO and IUSS activities

On the basis of the before-mentioned reference material, the ISO Technical Committee 190 (Soil Quality) has attempted to derive some generic reference material relevant to soil profile description:

- ISO 11074:2005 provides definition of terms used in the field of soil quality
- ISO 25177:2008 is a guide for describing the soil and its environmental context at a given site
- ISO 15903 provides a format for recording soil and site information.

These materials require urgent updating based on what will be achieved under Recommendation 6. Similar to other available soil quality standards, international participation is limited, and has restricted the application and acceptance of standards by a broader user community.

An important ongoing key activity for revising and improving soil description is the IUSS working group 'Universal Soil Classification'. It has developed tasks and assembled a group of experts to specifically work on the very distinct areas for building a consistent set of guidelines for field profile descriptions, horizon nomenclature, designations and definitions based on existing guidelines used in many international settings (see also Appendix 2).

## 4.2 Soil classification

Professional soil scientists have been working internationally for many decades to develop systems for soil classification and great progress has been made from before 1900 to the present time. **Soil classification is the naming of different types of soils based on a set of common or expected properties.** Classification is an aid to talk about the soil in a consistent, comparable way, and is applied at local, national and international levels, and at various levels of complexity and scientific consideration. Classification and consistent terminology allows land management lessons from one location to be shared with similar regions.

### a) Soil classification history

The system for global soil classification is based on many different national systems, of which there are over 50 throughout the world. Many of these are no longer being updated or have been abandoned; it is often cumbersome to correlate these systems because of definitional differences in concepts, in physical and chemical measurements and in organizational formats (Krasilnikov *et al.*, 2009). There are several classification systems that have been designed for wider application. Examples of these systems are the US Soil Taxonomy and the French Référentiel Pédologique. These overarching systems have been in development for many decades and have matured to the point where they are used in many parts of the world.

In the 1970s, the interdependency between countries on issues such as food supply and problems of land degradation became of international concern, so that FAO and UNESCO created the Soil Map of the World (1:5M) and developed the FAO Legend, which worked as a global soil classification system. In 1982, ISSS (now IUSS) established a Working Group for developing a framework for the correlation of soil classification systems, named International Reference Base for Soil Classification (IRB). In 1992, it was renamed World Reference Base for Soil Resources (WRB). The first edition of WRB was published in 1998, the second in 2006, and the third is just finished and will be released at the 20th World Congress of Soil Science in June 2014, Jeju, Korea. Because national systems deviate from WRB definitions and methods, it is difficult to unambiguously derive WRB soil names through correlation. Similarly, applying US Soil Taxonomy also provides difficulties as many countries do not follow the defined sampling procedures or analytical laboratory methods. However, European countries have made great effort to harmonize their national classifications with the WRB system, and they accepted WRB as a basic system for soil mapping (see also Baritz and Hudson, 2012). Such a correlation has also been introduced to the Japanese new soil classification system in 2011.

### b) Universal Soil Classification

There is now a renewed interest within the soil science community for the further development of a system of soil classification that can be applied across the world. Towards this means, in

2010, the IUSS approved a Universal Soil Classification System Working Group (see also Appendix 2). This group plans to contribute to the improvement of the WRB, US Soil Taxonomy and other national classification systems through the work of task groups. Gaps in soil classification clearly exist in national systems, for example in the cold, hydromorphic, salt affected, anthropogenic, and tropical soil groups. Work within the task groups is specifically designed to better define soil classification needs for national soil classification systems that can feed into a Universal Soil Classification System.

In addition to supporting the improvement of national soil classification systems, the Working Group has spent the last three years developing an overarching conceptual Universal Soil Classification System that is based on numerical classification concepts (e.g. Láng *et al.*, 2013).

This global system for allocating soil information will be at an overarching, aggregated level and allow its extension below as required for national, regional and local applications. The global classification should conform to GSP harmonization principles. It must be simple, ban exotic analytics, and it must be robust against artifacts from analysis and mistakes during field work.

## 4.3 Soil mapping

Soil maps have traditionally provided a communication mechanism to describe the types and attributes of soils occurring in certain areas. Soil maps have been created at small global and national scales, through to detailed large scales for smaller countries or regions. Besides conveying a general understanding of the properties of local soil types, these maps have been used as the basis of land planning and management decisions. Often however, the scale and detail of the information contained within the soil map, its legend or the associated descriptive report, is not at a resolution commensurate with the applied use.

Soil maps for large areas are often constructed as aggregates of many maps compiled at different times, using different methodologies, soil classification schemes and nomenclatures and representing different soil characteristics. The resultant map may contain un-reconciled country, state, region and project boundaries which interfere with the utility of the final product. Even though existing local maps cannot be harmonized, its content is often aggregated to planning or overview scales where data need to fit along borders - spatially and in content.

### a) Need for harmonizing soil maps in the global context

Pillar 4 recommends the creation of a series of data products as a global soil information system, in particular the improvements of the existing global soil polygon map using available national polygon data sets. These maps represent soil typological units defined in different ways (dominating soil, soil associations, soil parent material, soil regions, etc.).

A more recent approach has been to utilize modeling approaches such as digital soil mapping to estimate the continuous spatial variance of particular soil properties. Harmonization of the information content of these products will be facilitated through the mechanisms proposed in this Pillar 5 plan of action. The quality of predictive soil property maps (as grids) depends on the quality of the input data (covariates), especially soil. Digital soil mapping may also support the updating of "outdated" soil maps (e.g. Kempen 2012) or other approaches (De Witte *et al.*, 2013;

Van Engelen *et al.*, 2013). That means that new methods are available which could help to significantly improve legacy soil mapping data. Figure 2 presents an example of a harmonization concept for soil maps which requires agreed term definitions before map data from different sources can be combined. An in-depth analysis of harmonization needs and limitations for application can be found in Baritz and Hudson (2012).

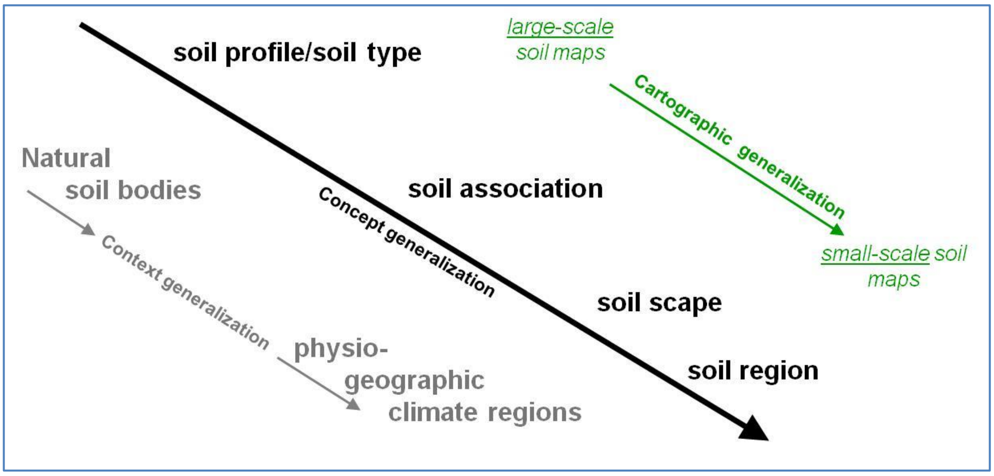


**Figure 2: Simplified nested system for harmonizing soil maps**

Harmonization of soil descriptions and classifications will provide a mechanism to translate existing map data to a common framework which will be able to be applied to aggregated maps. This has been the approach to the previous attempts to construct the Harmonized World Soil Database and the SOTER map of the world. Unfortunately the legacy data holdings of many countries cannot be easily reconciled to the adopted standards, such as the World Reference Base classification system, without considerable effort and access to pedological expertise. WRB (2014) provides rules for creating map legends using WRB at different scale levels.

**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 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 USDA Soil Taxonomy until a new standard system is released. The GSP supports the development of the new Universal Soil Classification System.

## 4. Soil sampling and analysis

Most of the responsive soil properties which are the foundation of soil condition assessments and monitoring are based on soil analysis. To identify soil degradation equally and ensure comparable levels of soil quality globally, harmonized analytical methods to characterize soils are needed. Efforts to harmonize analytical methods will facilitate the exchange of soil data and provide the basis for common assessments of soil health, quality or condition. Soil investigations span a wide range between soil physics (e.g. soil compaction, density, water retention), chemical properties such as concentrations of nutrients and contaminants, and reactions of soil organisms to specific stresses. Depending on the specific investigation objectives, specific data are needed and targeted experimental methods may have to be applied. Soil analysis involves a wide range of methods, from simple, less cost-intensive procedures in the field to very sophisticated procedures in the laboratory requiring specialized personnel and expensive instrumentation.

In general, for most soil types and properties a variety of analytical methods is available. The increasing need of soil data covering large areas is hampered by inconsistent and incomparable methods based on non-matching or diverging concepts. Soil analytical data which are derived from different methods cannot easily be compared given the great variety of analytical procedures and equipment used. Specifically, data about physical soil properties strongly depend on the state of the soil to be investigated. As an example, the infiltration rate of soils depends on soil texture, porosity of the soil, present humidity, heterogeneity of the soil and other properties. Therefore, data can only be merged if the experiments are based on concise protocols considering similarly such influences on the results. A different aspect is to set up a common calibration basis. This is done for soil IR-spectroscopy where the scientific community is trying to create a common protocol for the collection of laboratory spectra with the aim to develop data sets valid for larger areas, thus improving model calibration as well. To conclude, internationally agreed and validated protocols should be established to harmonize and, hence, merge existent soil data and evaluating the state of soil resources at regional to continental scales.

The list of ISO standards for soil analysis nowadays covers many soil chemical and physical analyses, including sampling and sample pretreatments. However, these standards may not be either partially or totally applied, because of deviating laboratory specialization and limited infrastructure (e.g. access to certain equipment and chemicals) or specific country needs. Very often, existing QA/QC procedures and analytical methods are incompletely documented or not readily accessible. Soil spectroscopy measurements require calibration against consistent laboratory methods when developing centralized spectral libraries. Certainly, improved QA/QC measures, such as establishing reference laboratories and using reference materials, but also improved training of personnel are key elements of the GSP approach to harmonization.

Experiences in soil analysis have shown that certain laboratories have broader experiences, are involved in method development, standardization and archiving. If this experience is shared with other laboratories, including the capacity to produce and share reference materials, and to organize and evaluate interlaboratory comparisons, then such laboratories may act as reference centres. This concept is useful for Pillar 5. Most likely reference laboratories have already experience converting between procedures, and set standards in QA/QC. Laboratories with that level of experience are also important in training personnel when it comes to QA/QC routines and the introduction of new methods and equipment. Figure 3 presents an overview of harmonization activities in and around laboratory analysis.

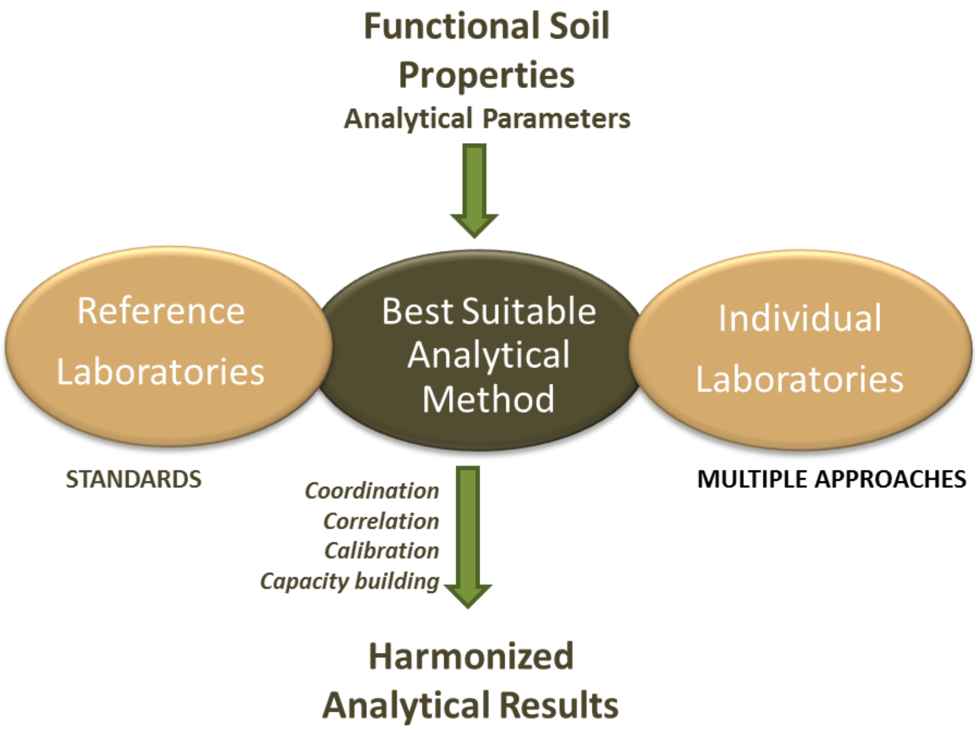


**Figure 3: Generalized approach for harmonizing soil analytical data**

To be most flexible to the diverse local or regional frame conditions in laboratory work, two main approaches can be distinguished. Ideally, a single standard or best suitable method is applied for analyzing a sample for a certain property. In reality, various circumstances affect deviations from such a standard.

<u>Approach 1:</u> Use of the recommended best suitable method for a given soil property
<u>Approach 2:</u> The recommended method under Approach 1 cannot be applied, therefore:

- develop conversions (towards the standard method) building on comparative analysis, e.g. analysis of archived samples; quantify the uncertainty;
- participate in inter-laboratory comparisons to develop conversions;
- archive samples for post re-analysis.

Reasons for not applying standards or not recommended methods is mostly historical and goes back to routines involved with a certain equipment and experience. For reasons of comparability, certain methods are maintained despite new developments. Such a situation asks for additional effort to develop conversions between a local method and, for example, a standard.

In any of the two approaches, the investigation goal and the respective soil properties for analysis have to be defined, and the analytical procedure to be selected. This chain from investigation goal to analytical procedure must be well documented including soil sampling, sample preparation and sample storage (SSS).

Additional support for the harmonization will be given by sample archives of reference soils (Kördel *et al.* 2009). Such concepts are relevant to consider physical properties (e.g. clay content, soil texture, particle size) influencing analytical results. Sample archives for reference soils will also facilitate round robin tests to qualify soil laboratories. On the other hand, a new system for data collection campaign may stimulate the communication of the soil society.

**Recommendation 4:**

Review existing practices for field sampling, sample preparation and measurement (including laboratory standardization and QA/QC) and prepare specifications and guidelines for harmonized approaches to the determination of the main functional properties of soils (i.e. chemical, physical and biological).

## 6. Interoperability - Exchange of digital soil information

Data on soils is collected and maintained by many organizations and individuals, within government, industry and private sectors; data are stored in data bases, sometimes information systems, using a variety of software solutions, storage models and terminology. The frame conditions for data collection and storage is usually specific to data producer's own needs and finding universally common data content, attribution or formats is unlikely. Attempts to insist on the use of a specific data base structure or minimum data set are likely to fail, as the needs and applications of soil data by different users are many and varied.

The exchange of globally harmonized soil data and information is expected to realize many benefits at individual, local, country and global levels. Largely these will be due to improvements in the efficiency and effectiveness of data access and collation activities, which are known to regularly consume up to 80% of project resources.

The publication of data assets via consistent web services will facilitate the retrieval and use of currently disparate data from existing individual collections. This will provide a significant value add to the considerable investment already made through the original data capture and subsequent data management activities. The development of a globally agreed soil information model will also facilitate improved data capture process for new data by providing a framework for new data which will be easily translated into the new agreed exchange standards. The innovative use of web data services will make soil data readily available to mobile devices and other new information systems technologies such that it can be easily and readily incorporated into a range of user developed applications.

### 6.1 Global soil information model

Global efforts to exchange harmonized soil data between individuals, projects, agencies and countries should focus on the development and implementation of an intermediary process which allows data from different systems to be translated and published to a common exchange standard. Recent developments in information and communication technology focus on web-based data exchange. Such published data, given that a certain degree of interoperability and harmonization has been implemented, can be translated for consumption in individual users' own applications, or collated and used within multi-source applications, such as for global food security or climate modeling. The core component for building a web-based data exchange infrastructure is the definition of common data features and their relations - a soil information model (Figure 4).

An agreed global soil information model driven would provide a framework for the efficient exchange and collation of globally consistent data and information. Well-established web data service standards, such as those of the Open Geospatial Consortium (OGC), provide a ready generic mechanism for specific domains, such as the soil community, to develop exchange procedures for publishing and exchanging its data assets. However, the consistent use of these exchange formats (e.g. WMS, WFS, WCS) by the soil community is predicated on the need for the community to develop and maintain internationally agreed data content standards.

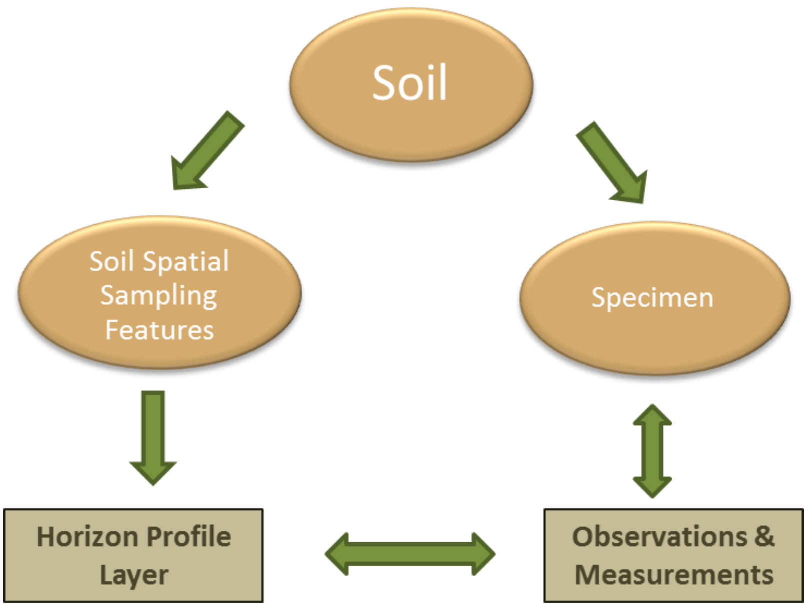


**Figure 4: Generic soil information model**

Web-based soil data exchange requires three main elements (Figure 5):

- a conceptual information model which defines the soil features of interest, their relationships and observable properties (see above Figure 3)
- a vocabulary service which explicitly defines the terms and vocabulary used to describe the soil features, their observable properties and the methods or procedures used to observe and analyze them; and
- metadata which describes the data sets, individual data elements and reported analysis results in a concise way such that the usability of data is facilitated.

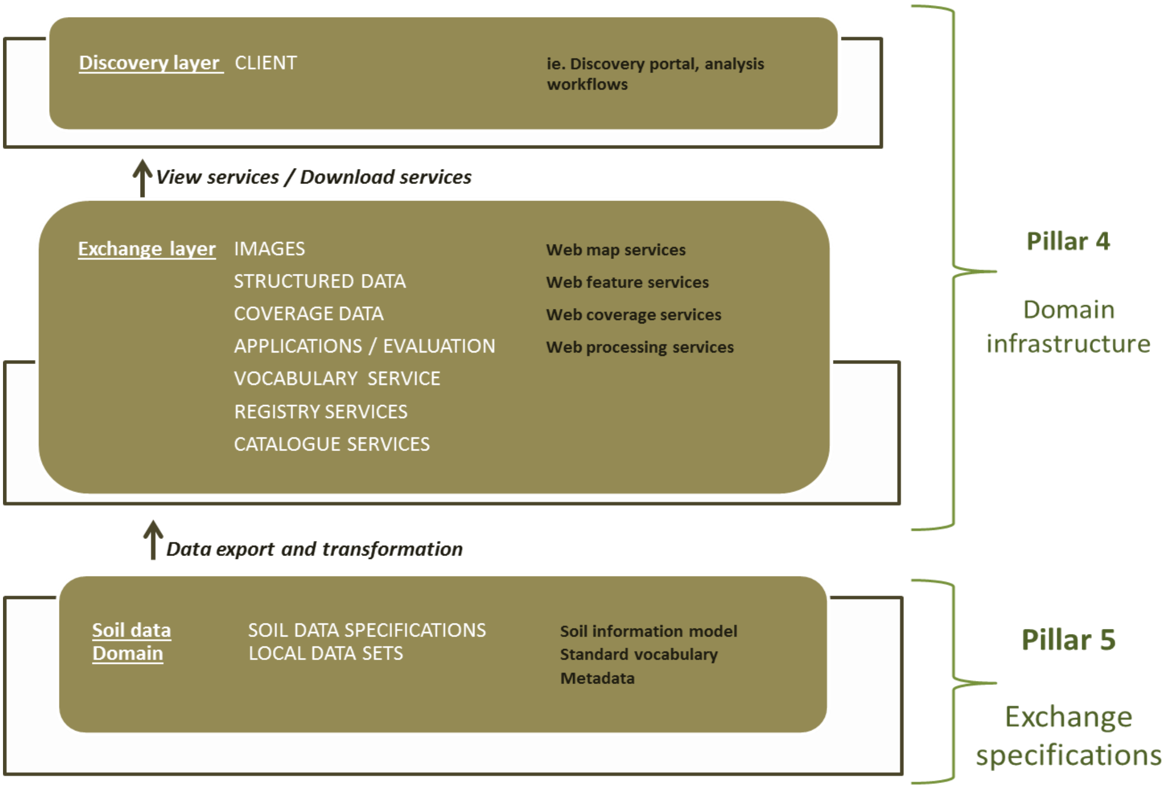


**Figure 5: Overview of information model driven system architecture**[6]

Web-based GIS and data exchange communicate large quantities of data to a large variety of users. Building on generic standards for web-based communication of spatial data sets, the soil domain is already mobilized. A number of such domain information models are currently being developed, many for projects or regional specific data exchange (such as for eSOTER, GlobalSoilMap, GSIF and INSPIRE) and some for wider exchange of more generic soil data (such as ISO 28258, or by the Australian Collaborative Land Evaluation Program and Landcare Research New Zealand). Some collaboration and coordination between these efforts occurs under the auspices of the IUSS Working Group on 'Soil Information Standards' (WGSIS) (see Appendix 3).

Development, governance and reference implementation of an agreed soil information model and associated vocabularies could be facilitated through the Global Soil Partnership (GSP) and the International Union of Soil Science (IUSS).

[6] See also: SEEGRID SISS https://www.seegrid.csiro.au/wiki/Siss/WebHome#SISS_Architecture; Mansourian, A., E. Omidi, A. Toomanian and L. Harrie (2010). Expert System to Support Functionality of Clearinghouse Services. Computers, Environment and Urban Systems 35(2): 159-172.

**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).

## 7. Interpretation and evaluation

Simplification and harmonization of soil data can contribute significantly to the reduction of the time and costs of exchange of knowledge dealing with sustainable soil management. Harmonizing data used in research and policy documents and regulating them with international standards also ensures data interoperability among the various parties engaged in global soil management mechanisms. In addition, data harmonization is a necessary step towards soil data sharing, decision support system automation and measuring agreed indicators for assessing the impact and performance of policies, programs and projects.

Based on the experiences and practices of various countries and regions, harmonization is also crucial to assist governments and other stakeholder in standardizing the methods and approaches (e.g pedo-transfer rules and functions) to provide information on soil resources. Additionally, using harmonized soil data will be the best way to facilitate the decision making process to choose the best possible land management practices in uncertain environments.

### 7.1 Soil indicators

Harmonization is often used in the context of soil data collection, describing soils in the field, sampling, analysis or soil information exchange. However, governments, civil society organizations, international development agencies and many other users usually cannot interpret complex raw soil data sets. A major task for them is assessing the impact and performance of their policies, projects and investments. Attempts to measure the effectiveness and the efficiency of policy prescriptions have been aided by the development of specific indicators that strive to capture a particular circumstance, situation or condition (e.g. agro-environmental indicators for soil protection, indicators for sustainable land management) (Bindraban *et al*., 2000; Dumanski and Pieri 2000; Bouma 2002). New methodologies for defining and interpreting indicators for soil monitoring were investigated by Huber *et al*., (2008).

In the context of GSP, the following types of indicators are distinguished:

| | |
|---|---|
| **Type I indicators** | to measure soil quality/health and loss (Pillar 5 soil monitoring) |
| **Type II indicators** | to assess the impact for sustainable soil management (SSM) (Pillar 1 SSM implementation) |

The definition of indicators strongly depends on its use and context. In many cases it was found that raw data are often missing, or lack in sufficient resolution. In some cases, pedo-transfer functions (PTF) help to fill gaps, in other cases new approaches need to be developed. Certainly, baselines and thresholds are required for interpretation. Figure 6 presents a possible methodology for defining operational soil indicators (Huber *et al.*, 2008).

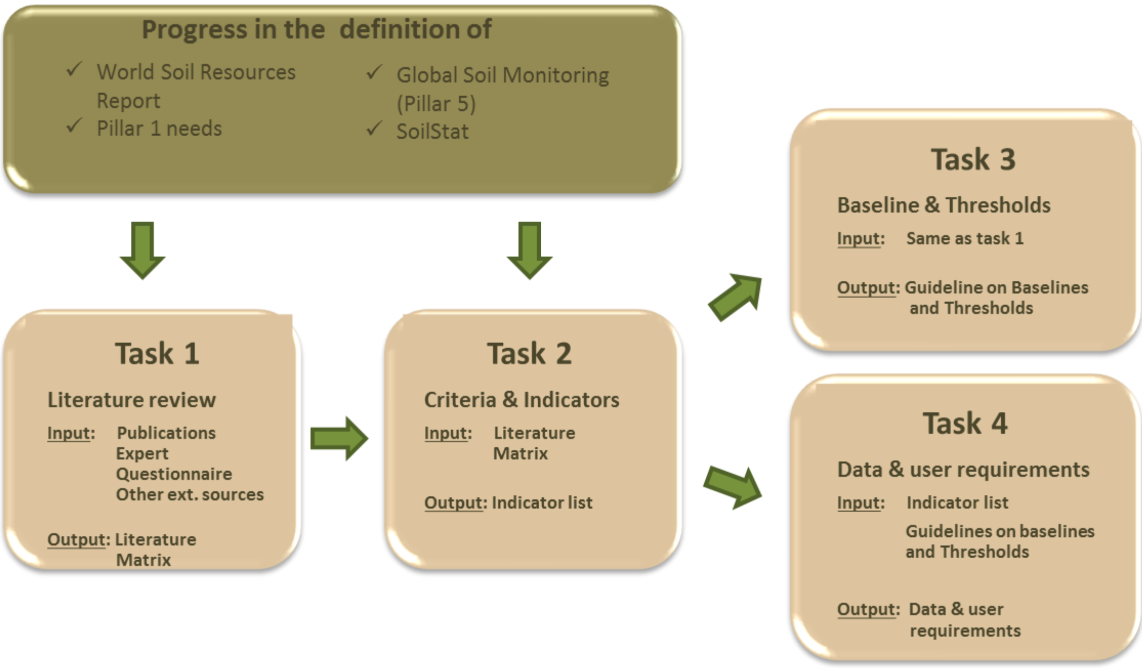


**Figure 6: Methodology for defining operational soil indicators (Huber *et al.*, 2008; modified)**

## 7.2 Pedo-transfer rules and functions

As mentioned before, information from soil profiles, laboratory analysis and maps has practical purposes. A change of the state of a given soil is the result of complex processes which need to be understood in order to control the triggers and the effects. While all levels of functional processes can only be fully investigated and measured at few locations, with enormous measurement intensity, additional models are needed to estimate parameters difficult to measure, and to extrapolate processes for larger areas. So-called **pedo-transfer functions (PTF)** are applied mathematical methods targeted to interpret further data from routine soil inventories (e.g. Wösten *et al.*, 1998; Wösten et al. 2001). If such inventories lack quantified data, then **pedo-transfer rules (PTR)** were developed; PTR are simplified approaches using soil classes as "carriers-of-soil-information" (see also Van Ranst 1995; Bouma *et al.*, 1998; Batjes *et al.*, 2007; FAO ,2012). The following kinds of pedo-tansfer functions can be distinguished:

- PTR and PTF to **map soil hazards** using soil profile date bases and soil maps (e.g. soil erodibility for assessment of soil erosion "risk") (e.g. Prasuhn *et al.*, 2013).
- PTR and PTF to **fill gaps in measured data**, and to **derive parameters (and indicators) difficult to measure** (e.g. bulk density, total soil porosity, field water capacity, potential rooting depth, hydraulic conductivity).

- PTF (and appropriate reference data sets) to harmonize **disparate analytical method values** to the future GSP-standard (best suitable method) (e.g. GlobalSoilMap, 2013, Appendix C).

These applied methods come along with data specifications which are confined to a certain nomenclature (e.g. texture class); this limits their application in areas with other soil mapping methods, soil profile descriptions and classification systems. This means that if PTF and PTR shall produce harmonized results across borders, then the soil property data (input) used must also be harmonized (soil description, classification ad analysis).

**Recommendation 6:**

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.

## 8. Governance

The development, use and maintenance of unified standards require a strong framework of governance. That is, a mechanism which provides for global agreement to the development and application (thus acceptance) of standards for soil description and classification, soil analysis, exchange of harmonized soil data, and interpretation.

Without an internationally mandated governance mechanism it is likely that harmonization efforts will fail in the short and long term as agreement to common harmonization goals will not be achieved, or if standards are not maintained then application of them will drift apart as individual users seek to adapt them to their own needs.

### 8.1 Interaction with Pillar 4 governance and link with other ongoing activities

The implementation of the GSP depends on voluntary contributions by governments, researchers and stakeholders. Existing activities are important, as they have often initiated crucial methodical steps. However, existing mechanisms lack acceptance and implementation at a broader scale so that speed and delivery of products lacks behind the needs. This is very clearly documented by the insufficient resolution, quality and age of existing international data sets. Therefore, a new, efficient and effective governance model through GSP is needed. Because of the high degree of overlap between core actors of Pillar 4 and 5, the governance approach of both Pillars shall be merged.

Governance for implementation of Pillar 5 has different levels of action.

1. At an overarching level, GSP could provide the mechanism to endorse the adoption of globally agreed harmonization rules.
2. Technically, harmonization procedures need to be developed, accepted and applied.

3. Organizations such as ISO or OGC could help to maintain documentation and version control of agreed standards/recommended procedures.
4. At more technical levels, working groups of the IUSS could develop and maintain specific harmonization elements, such as standards, protocols and guidelines for soil description, soil classification, soil analysis, and soil information exchange. The terminologies, vocabularies and code lists associated with these elements also need to be managed and controlled to ensure ongoing harmonization.

A core element of the Pillar 5 governance is the formation of networks with involvement of reference laboratories and data centres. It can be expected that voluntary commitments will be offered to GSP, and that the representatives of these institutions will be the main actors in the implementation of Pillar 4 and 5.

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## Appendix 1: Summary of challenges

**Challenge 1:**
The majority of available soil data is extremely heterogeneous. Improving the knowledge about soils requires robust and harmonized data. This calls for a new, overarching concept for harmonization.

**Challenge 2:**
Harmonization has benefits at all levels of use from local to global. It involves local data collection as well as the aggregated use of this data for larger areas. Data exchange is required to generate aggregated products and helps to fill data gaps. Harmonization becomes especially important where information is compiled from different sources.

**Challenge 3:**
Harmonization can be applied irrespective of the nature of the data collated (legacy versus new data) provided that any used standards are known and well documented. This will require agreement on the target standard(s) chosen for harmonization.

**Challenge 4:**
Harmonization will benefit users within and external to the soil community at all levels from local to global, given that the corresponding data are made accessible and shared.

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## Appendix 2: IUSS Working Group Universal Soil Classification

In 2010, the 'Universal Soil Classification System' Working Group was approved by the IUSS. The action of the working group includes two distinct areas of development and harmonization:

1. Compare guidelines for field profile descriptions, including for example, redoximorphic features, structure, color, consistency, texture, etc.

The objective is to prepare a dataset of soil profile descriptive options.

2. Compare and compile horizon nomenclature, designations and definitions.

The objective is to compile global master horizon designations, suffixes, and their definitions from legacy soil classification systems and a concise side-by-side comparison of master horizons and sub-ordinate distinctions.

### Progress in soil profile description development

The Working Group has already made many findings in harmonization potential from researching nomenclature from different national/international systems including:
- Nomenclature for eluvial, illuvial and organic horizons is almost universal.
- Pedogenic carbonates, gypsum, silica, soluble salts, slickensides, concretions, buried genetic horizons, gleying, strongly weathered horizons, strong cementation, ploughing, and

weak development are also widely recognized, although symbols for these properties often differ.

- Other properties are less cosmopolitan, such as anthropic disturbance, human-induced soil formations, cryoturbation, phosphorus accumulation, sulfides, unweathered material, low bulk density, lamellic features, and dry permafrost because of different environments among countries – e.g. cryogenic features are important for Canada and Russia and sulfides are important in Australia.

In the majority of systems, a very limited number of uppercase letters are used for master horizons, which are combined with one or more lower case letters used for indexes. Still, these symbols are often inadequate to reflect the up-to-date knowledge of soil features of the world. So, there is much potential for advancing soil horizon nomenclature for the Universal Soil Classification. We anticipate that this compilation and blending of existing systems, taking advantage of their diversity, will not only enhance international communication, but will also provide a greater understanding of soils across the globe.

## Progress in universal soil classification development

The concept of this Universal Soil Classification system is based on a data centroid approach. This involves analyzing databases from across the world, using accepted diagnostic feature concepts, to make allocations into logical clouds or clusters of points that recognize "Great Soil Groups." These will be equivalent to the great group level from U.S. Soil Taxonomy, along with similar levels in the World Reference Base, Australian Soil Classification, and other defined soil classification systems. The correlation potential between different soil taxonomic systems using soil taxonomic distance calculations has been documented by Lang and Fuchs (2013).

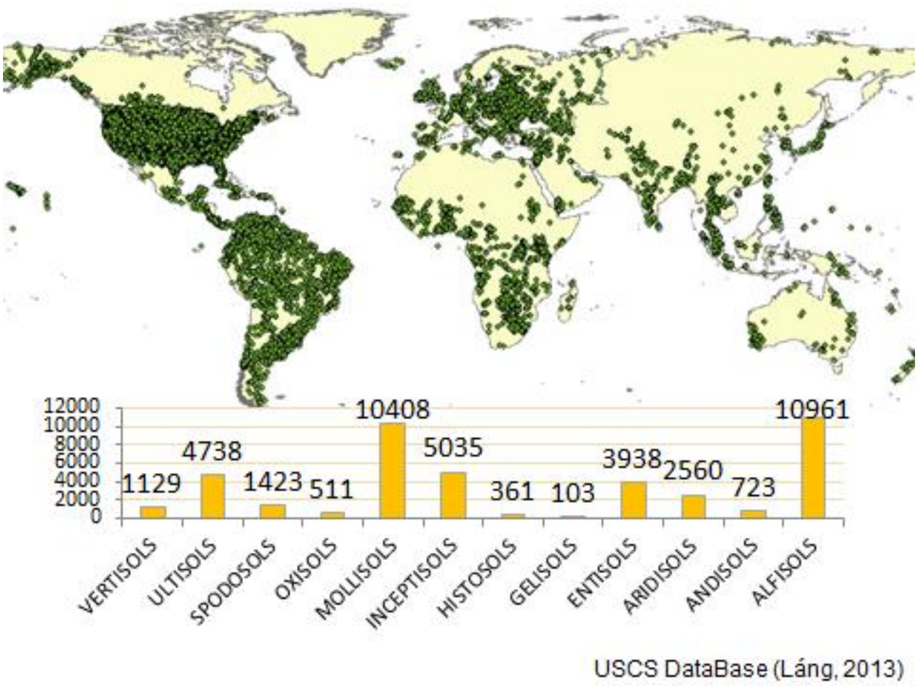


**Figure 7: Data points available for centroid calculations**

The Great Soil Groups will have taxa developed that can document more and less detail. Lower taxa in the system will potentially recognize anthropogenic features, family criteria, and other important use and management characteristics. Higher taxa in the system will be developed for meso- and macroscale applications. As more data are added to the system, taxonomic distance calculations can be used to determine if new categories are needed based on tolerances that are set. This system can then be more scalable based on the objective analyses of the data that are collected and entered into the system.

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## Appendix 3: IUSS Working Group Soil Information Standards

The IUSS Working Group on Soil Information Standards was established in 2010. The objective is to develop, promote and maintain internationally recognized and adopted standards for the collection, capture and sharing of consistent, harmonized soils data and information. The working group supports activities which focus on the exchange of digital soil information. This includes the agreement of a global soil information model.

### Definition of a Global Soil Information Model

A global soil information model is required to provide agreed definitions of the real world soil features (such as the soil, soil surface, soil layer, soil horizon, soil profile, soil sample or soil specimen) for which data is being exchanged. The model documents the relationship of features to each other and the observable properties of each feature (such as a classification, a color, or the amount of some chemical or physical property). The results of observations made on features at points in time and space, using specified procedures are reported using defined units of measure and other meta-data such that the exchanged data can be efficiently assimilated and used. The global soil information model will adopt the well established data patterns of the OGC Observations and Measurements framework for this model component ensuring that soils data is compatible with that defined by other similar communities of practice (e.g. geological and water data). Terminology that explicitly defines the features, observable properties and the procedures used are maintained in an associated vocabulary which ensures that data are able to be correctly understood and integrated by users.

### Cooperation with ISO

The recently published ISO standard for the exchange of soil related data (ISO 28258) provides a high level, meta-model for soil information. That is, for implementation, users must extend the model with their own features, observable properties and procedures, which may result in many forms of soil data being made available with little harmonization. The IUSS WGSIS has a plan to develop a fully attributed logical model, which specifies agreed information model components and manages a controlled vocabulary. The required vocabulary will initially contain elements relevant to the harmonization of soil description, classification and laboratory analyses which are the identified priorities of Pillar 5. Data which is compliant to the agreed global sol information model could be published by many sources and then brought together as a harmonized data set for multi agency, country or international analyses.

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## Appendix 4: Existing normative references

ISO 10381 series, Soil quality – Sampling

ISO 11074, Soil quality – Vocabulary

ISO 15903, Soil quality – Format for recording soil and site information

ISO 25177, Soil quality – Field soil description

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