Plan of Action for Pillar Four of the Global Soil Partnership

Adopted by the GSP Plenary Assembly

Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines

Pillar Four Working Group:

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Acronyms

CBD	Convention on Biological Diversity
FAO	Food and Agriculture Organization of the United Nations
GSP	Global Soil Partnership
IPCC	Intergovernmental Panel on Climate Change
IPBES	Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services
ITPS	Intergovernmental Technical Panel on Soils
IUSS	International Union of Soil Sciences
RSP	Regional Soil Partnership
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
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

Unprecedented demands are being placed on the world's soil resources. By 2050 they need to support a food production increase of over 70%. However, arable land is finite and soil degradation widespread. Major crops are reaching yield plateaux and better soil management is needed to conserve nutrients, improve water-use and reduce emissions. Climate change compounds the situation. The Global Soil Partnership (GSP) was created to meet these challenges – it aims to improve governance of the limited soil resources of the planet to guarantee agriculturally productive soils and support essential ecosystem services. More specifically, it recognizes that better soil information is essential because we manage what we measure.

The Plan for Pillar Four of the GSP essentially addresses the development of an enduring and authoritative global system to monitor and forecast the condition of the Earth's soil resources. This global soil information system has three primary functions:

1. Answering critical questions at the global scale (e.g. is there enough arable land with suitable soil to feed the world?)
2. Providing the global context for more local decisions (e.g. transnational aspects of food security and degradation of natural resources)
3. Supplying fundamental soil data for understanding Earth-system processes to enable management of the major natural resource issues facing the world (e.g. climate change, food security, biodiversity loss). These data need to be comparable with other fundamental data sets including those for weather, climate, net primary productivity, biodiversity, land cover and geology.

The Plan for Pillar Four analyses six key design considerations that affect both the feasibility and eventual utility of the global soil information system.

1. The degree of integration between global, national and other systems
2. Choices between distributed versus centralized designs
3. The degree to which the system provides access to comprehensive versus harmonized minimum data sets
4. Finding the optimal balance between the mapping and monitoring components of the system
5. Ensuring roles and responsibilities are clearly defined with clear incentives for data providers
6. Establishing mechanisms to take full advantage of advances in soil measurement and data analytics.

This Plan of Action has its origins in an international workshop convened by FAO in Rome during March 2012. The workshop considered the status of current methods for soil survey and monitoring, existing soil information systems, and future directions for Pillar Four[1]. The meeting anticipated the formal establishment of the GSP and commissioned the preparation of a

[1] www.fao.org/fileadmin/user_upload/GSP/docs/GSP_SoilInformation_WorkshopReport.pdf

draft plan of action for Pillar Four with a view to it being considered by the Intergovernmental Technical Panel on Soils which was established by the First Plenary Assembly of the GSP in June 2013. After a period of intense review, the ITPS endorsed the Draft Plan of Action for Pillar Four[2] and it was submitted to the Second Plenary Assembly of the GSP. The Plenary Assembly consolidated the original 23 ITPS recommendations into four higher-level recommendations. This final version of the Plan of Action for Pillar Four was endorsed by the Plenary Assembly of the GSP on the 24th of July, 2014.

The four recommendations are as follows:

Recommendation 1: An enduring and authoritative system for monitoring and forecasting the condition of the Earth's soil resources should be established under the auspices of the Global Soil Partnership to meet international and regional needs.

Recommendation 2: The global soil information system should use soil data primarily from national and within-country systems through a collaborative network and the distributed design should include facilities for incorporating inputs from the new sources of soil data and information that are evolving rapidly.

Recommendation 3: The global soil information system should be integrated into the much larger effort to build and maintain the Global Earth Observing System of Systems (overseen by the Group on Earth Observations[3]) and close attention should be given to issues relating to the protection of privacy, intellectual property rights and terms of use.

Recommendation 4: Implementation of the global soil information system should include a training program to develop a new generation of specialists in mapping, monitoring and forecasting of soil condition, with an emphasis on countries where improved soil knowledge is essential for food security and restoration and maintenance of ecosystem services.

In accord with the Terms of Reference of the GSP, the GSP Secretariat will facilitate the preparation of a detailed implementation plan and it will provide regular reports on progress to the Plenary Assembly.

2 www.fao.org/3/a-ml036e.pdf

3 http://www.earthobservations.org

1. Introduction

The Global Soil Partnership (GSP) was formally established by the FAO Council in December 2012. It has five pillars of action:

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

This report presents the Plan of Action for Pillar Four. It provides strategic guidance on design options and pathways for building the global soil information system. Pillar 4 has close and natural links with activities in Pillar 5. It also provides information to support Pillars 1, 2 and 3.

This Plan of Action has its origins in a workshop convened by FAO in Rome during March 2012. The workshop considered the status of current methods for soil survey and monitoring, existing soil information systems, and future directions for Pillar Four[4]. The meeting anticipated the formal establishment of the GSP and commissioned the preparation of a draft plan of action for Pillar Four with a view to it being considered by the Intergovernmental Technical Panel on Soils which was established by the First Plenary Assembly of the GSP in June 2013. The original workshop request was for a report that addressed the following topics in relation to Pillar Four:

- Governance and structural organization
- The links between global soil information and end-users
- Primary soil data and spatial data products including accuracy issues.
- Reporting on global soil health: soil capacity and functions.
- Technical monitoring
- Global monitoring network
- Archives, references and standards

A working group of experts was asked to prepare the report. The members were:

- Africa: Martin Yemefack
- Asia: Ganlin Zhang
- Europe: Rainer Baritz
- Latin America: Aracely Castro
- Middle East and North Africa: Rachid Moussadek

[4] www.fao.org/fileadmin/user_upload/GSP/docs/GSP_SoilInformation_WorkshopReport.pdf

- North America: Jon Hempel
- Oceania[5]: Neil McKenzie (Chair)
- Secretary: Ronald Vargas

The working group prepared its draft report with careful attention being given to the mandate of the GSP which is to improve governance of the limited soil resources of the planet in order to guarantee healthy and productive soils for a food secure world, climate change mitigation as well as support other essential ecosystem services, in accordance with the sovereign right of each State over its natural resources. The issue of sovereignty extends to data and information insofar that the global soil information system has to support the integrity of national information systems but at the same time produce a harmonized global view.

In May 2013, a Draft of the Plan of Action was sent out for review to GSP partners, soil information institutions, and to the participants of the Rome workshop. In total, 260 comments, 45 text proposals and various editorial comments were received. Comments addressing similar issues were condensed, so that at the end, 134 comments were processed. A protocol lists the changes done, and the responses of the writing team to each comment; those comments considered to be out of scope for this report were summarized in a short note to FAO.

The draft plan was considered by the Intergovernmental Technical Panel on Soils in July 2013. After another phase of intense review, the ITPS endorsed a draft Plan of Action for Pillar Four and it was submitted to the Second Plenary Assembly of the GSP in July 2014.[6] The Plenary Assembly consolidated the original 23 ITPS recommendations into four higher-level recommendations and incorporated comments and suggestions. This report is the final version of the Plan of Action for Pillar Four endorsed by the Plenary Assembly of the GSP on the 24th of July, 2014.

The Plan of Action begins with a summary of the primary reasons for having a global soil information system. This is followed by a set of design issues and key decisions that need to be made.

2. Why do we need a global system for observing and forecasting soil condition?

There is a growing awareness that soil resources are finite and require careful management to ensure food security and maintain essential ecosystem services. A prerequisite for sustainable management is reliable information on soil resources and in particular, on how different soils respond to various forms of land use and management.

Around the world, millions of people profitably use existing soil information to either produce more food or protect environmental assets or both. People currently gain access to soil information through a variety of channels and some countries now have district or national soil

[5] Ammended subsequently to South-West Pacific

[6] www.fao.org/3/a-ml036e.pdf

information systems, many of which are online. Each of these systems is tailored to meet the needs of users working across a restricted range of soils and land management systems. They employ a wide range of technical standards and often target specific scales. This raises the question: why do we need a global system for observing and forecasting soil condition if these systems are being developed for specific purposes? There are three compelling reasons or applications for such a system.

Application 1: Answer critical questions at the global scale

A global system for observing and forecasting soil condition is needed because there are critical questions that have to be answered at the global scale. There is a qualitative appreciation of the pressures on global soil resources but limited consistent evidence on their condition and trajectories of change. In short, the world's soils need to support at least a 70% increase in food production by 2050[7] but there are fundamental uncertainties:

- Is there enough arable land with suitable soils to feed the world?
- Are soil constraints partly responsible for the often large gaps between actual and potential crop yields?
- Can changes to soil management have a significant impact on the seemingly unsustainable global demand for nutrients?
- To what extent and cost can changes to soil management contribute to climate change adaptation, particularly at the scale of smallholder agriculture?
- Can changes to soil management have a significant impact on atmospheric concentrations of greenhouse gases without jeopardizing other functions such as food and fiber production?
- How will the extent and rate of soil degradation threaten food security and the provision of ecosystem services in coming decades?
- Can water-use efficiency be improved through better soil management in key regions facing water scarcity?
- How will climate change interact with the distribution of soils to produce new patterns of land use?

Application 2: Provide the global context for more local decisions

A comprehensive global view is also needed to deal with the transnational aspects of food security and degradation of natural resources. Because of trade, most urbanized people are protected from local resource depletion. The area of land and water used to support a global citizen is scattered all over the planet. As a consequence, soil degradation and loss of productivity are not just local or national issues – they are genuinely international.

A global context provides international organizations, governments and other stakeholders with an understanding of how land use decisions in one district, country or region have consequences elsewhere. Examples of policies that need this type of context include those relating to bio-fuels,

[7] FAO 2012. World agriculture towards 2030/2050: the 2012 revision. (Alexandratos N., and Bruinsma J.). ESA Working Paper No. 12–03, June, FAO, Rome.

carbon farming, urban expansion and any form of intervention that affects land use and relevant ecosystem services across large areas. For these issues, most local responses require global context.

Application 3: Supply fundamental data sets for understanding Earth-system processes

In terrestrial systems, soils play a central role in determining the stores, flows and transformations of energy, water, carbon, nutrients, solutes, contaminants and genetic material. An ability to estimate the functional properties of soils in time and space is therefore crucial to our scientific understanding of Earth-system processes. This process-understanding has scientific value in its own right. It also provides the essential foundation for managing the major natural resource issues facing the world (e.g. climate change, food security, biodiversity loss). At present, the scientific quality of global data sets on soils compares poorly with other fundamental data sets such as those for weather, climate, net primary productivity, biodiversity, land cover and geology.

An indication of the current status of global and regional soil information is provided by Omuto et al. (2013)[8]. It highlights that the soil information infrastructure in most countries is inadequate and fragmented. Existing information systems do not provide the required data and information to assess the condition of soils or their response to land management. The ITPS recommended that a prerequisite for sustainable management of soil resources is access to information on their distribution, condition and rates of change, from local through to global scales. All countries have a responsibility to obtain and act on this information to ensure the soil resources of the world continue to provide the ecosystem benefits and wealth necessary for a secure and prosperous future.

Recommendation 1: An enduring and authoritative system for monitoring and forecasting the condition of the Earth's soil resources should be established under the auspices of the Global Soil Partnership to meet international and regional needs.

3. Decisions on system design

The three primary reasons for having a global soil information system are compelling. However, the design of the required system is far from straightforward. At least six broad issues need to be discussed and resolved.

[8] Omuto C, Nachtergaele F, Vargas Rojas R (2013). State of the art report on global and regional soil information: Where are we? Where to go? Global Soil Partnership Technical Report, Food and Agriculture Organization of the United Nations, Rome.

Issue 1: Degree of integration between global, national and other systems

Soil data and information can be used for many purposes from local through to national and global scales. For efficiency, the systems of measurement and analysis need to be integrated across this hierarchy of scales so that data collected at lower levels feed through to analyses at the higher levels. The alternative of having a separate data gathering program for the global system is not desirable because it would be expensive and inefficient. If methods and data across countries cannot be sufficiently harmonized then it may become necessary.

The dramatic advances in web-based technology make the integration of local, national and global systems possible. However, data and information have to be collected and managed according to consistent standards to enable integrated analysis. A central task for the GSP is to develop, manage and facilitate the use of these standards so that data can be shared at low cost – most of this activity will be coordinated together with Pillar Five.

The ability to incorporate local-scale information into the global system (and *vice versa*) is important but it does not mean that the global system should contain all the information held by these subsidiary systems. This would make the global system unmanageable. Furthermore, most soil-related questions are strongly conditioned by local factors (e.g. particular types of soils and soil forming factors, systems of land use, availability of inputs) and many locally specific variables are recorded. It is essential to have well-designed systems for aggregating between scales and this requires good documentation, harmonization, quality control and representative data – their absence has been one of the main factors preventing the development of the global system (see Issue 3 below).

It is important to differentiate the purpose of the global soil information system and the related within-country systems. A general operating principle is that a query requiring soil information should be handled by the smallest, lowest, or least centralized authority capable of addressing that matter effectively. Otherwise, unrealistic expectations will be placed on the global system and it will become unmanageably complex. The primary purpose of the global system is to address the three applications outlined in Section 2.

More specifically, the ITPS recommended that the design and operation of the global soil information system should use soil data primarily from national and within-country systems and should focus on delivering products and information services for regional and global purposes including progress towards the Sustainable Development Goals and supply of data to other disciplines to ensure more integrated analysis. Agreements about harmonization requirements to ensure data can be compared and aggregated across scales are therefore essential.

Recommendation 2: The global soil information system should use soil data primarily from national and within-country systems through a collaborative network and the distributed design should include facilities for incorporating inputs from new sources of soil data and information that are evolving rapidly.

Issue 2: Distributed versus centralized design

The Group on Earth Observations (GEO) provides the forum and mechanisms for building global environmental information systems.[9] This includes achieving international consensus on system architecture, developing standards, and promoting the best practices for gathering, analyzing and supplying information on earth systems (e.g. oceans, atmosphere, land cover, forests and biodiversity). The soil community has been slow to engage fully with this major international effort partly because of the absence of global-scale projects and incentives for data holders. However, the development of Pillars Four and Five within the GSP now provides a natural mechanism for engagement.

A clear consensus has emerged through the work of GEO and related international initiatives on the design and implementation of environmental information systems. The emphasis is on interoperable systems and web-based delivery of information services. The principles of interoperability apply within domains (e.g. the match between soil mapping data along borders) and between domains (e.g. soil, climate, land use) to ensure they can be easily processed and queried together. The global soil information system can advance quickly by participating in the Global Earth Observing System of Systems (GEOSS) and learning from closely related initiatives on Global Land Cover, Global Geology (OneGeology) and Global Forest Observation. The activities in these initiatives (including global soil data) have been combined into Task IN-02-C2 'Development of Regional/Global Information and Cross-cutting Datasets'.[10] A related and important achievement, which also supports this task, is the development of ISO 28258 on the exchange of digital soil-related data.

Recommendation 3: The global soil information system should be integrated into the much larger effort to build and maintain the Global Earth Observing System of Systems (overseen by the Group on Earth Observations) and close attention should be given to issues relating to the protection of privacy, intellectual property rights and terms of use.

The considerations of previous sections further specify the options for the design of the global soil information system. An independent global database without direct links to national or regional databases is not practical because countries are the main providers of data. At the other extreme, a federated international system with more than 190 nation states providing component data services without coordination is also unlikely to be successful. The main problem being that many countries still do not have the technical capacity and infrastructure for providing updated soil information and reliable web-services into the global system.

A middle course is therefore necessary. It requires a federated system with a mix of arrangements for delivering data sets and web-services tailored to match the capabilities of data holders (e.g. research bodies, national facilities). In some parts of the world, good collaborative arrangements may allow a leading country or institution to provide the soil information system

[9] http://www.earthobservations.org

[10] http://www.earthobservations.org/ts.php?id=136

and services on behalf of several other countries. Such arrangements are to some extent already operational in Europe. They are being developed for nations in the Pacific region with good prospects for similar arrangements in other parts of the world (e.g. Middle East, West Africa, Latin America). Brokering these arrangements is best done through the Regional Soil Partnerships that are being developed through the GSP. There may still be the need for some global information services to be provided by a single agency (e.g. supply of a consolidated global data set such as the Harmonized World Soil Database). The OneGeology project provides a good model with several agencies taking responsibility for managing the world portal for geology data.

The ITPS recommended that global soil information system should be comprised of consistent spatial data sets and services provided by a mix of institutions. However, national soil agencies should play a key role as facilitators for the collection, management, quality assurance and provision of data. In some cases, organizations could act on behalf of other countries through mutual agreement.

Issue 3: Comprehensive versus harmonized minimum data sets

Soil is a complex material and hundreds of different soil properties can be measured according to an even larger number of measurement methods. This complexity has the potential to stall the global effort on improving access to harmonized soil information. On the other hand, there is huge missed potential if specifications for a global effort are too restrictive.

There have been many proposals for standard data sets to be collected in soil and land resource surveys. Agreement on the ideal or optimum data set is rare, even for districts with a limited range of land uses. However, it is fairly straightforward to reach consensus on a minimum data set (Nix 1984). A major effort is required to define the minimum data sets for the global soil information system. This has already been done for some products (e.g. GlobalSoilMap). Even though these specifications were designed by a sub-set of the main data providers world-wide, it takes into account the data requirements of important user groups, especially those using simulation models for wide range of applications.

The second issue relates to the multiplicity of measurement methods even for standard soil properties (e.g. approximately 20 methods are used to measure pH). Data products delivered by the global soil information system require an agreed measurement and correlation standard. The latter specifies how to translate data obtained using different methods onto a common basis. This does not stop countries from using measurement methods that are locally appropriate. It simply requires the ability to translate results into a harmonized system. It does, however, require a worldwide reference database to support the harmonization process.

The intention is for the global soil information system to rely on harmonized data systems to ensure global consistency. Data from contributing organizations need to conform to mutually agreed standards with defined procedures for translation between measurement methods using a global reference system (refer to the Pillar Five Plan of Action for a thorough discussion on the principles and reasons for adopting this approach).

Issue 4: Balancing the effort between mapping and monitoring

The global soil information system has to address questions with a geographic and temporal dimension. Detecting and forecasting soil change through time is technically more demanding than mapping (Section 6), but is of crucial importance for most practical applications, particularly those relating to the major global multilateral environmental agreements (e.g. UNFCCC, CBD, UNCCD).

Development of a comprehensive and operational monitoring capability within the global soil information system is still at an early stage. Funding constraints dictate that a balance has to be struck between investing in the more operational aspects of delivering spatial information versus the development and design tasks needed for monitoring. The design of the system is complex because different indicators and soil parameters have different rates of change in space and time, along with different responses to land management and environmental change.

The ITPS has proposed a stepwise approach to monitoring starting with the establishment of reliable baselines for selected soil properties in priority regions. The effort (e.g. sampling frequency, number of measurements) devoted to operational monitoring at the global scale will be based on these initial investigations and supporting environmental monitoring and modeling.

Issue 5: Roles, responsibilities, and incentives for data providers

The global soil information system is unlikely to be successful if national soil-information agencies are treated simply as data suppliers, and if potential other data providers (industry, research, land managers) are excluded. National systems are an important mediator for providing digital soil information according to agreed international specifications. Additional costs are associated with the assessment of new data sets, data management, quality assurance, inter-laboratory comparisons, and data delivery into the global system. Costs are also involved with developing and improving new regional and global data products. However, if managed well, the global program will provide benefits for participating institutions. Some of the primary benefits of being a partner to the global soil information system should include the following.

- Adoption of standards for system design and web-based delivery will save costs and avoid duplication for each country
- Adoption of data formats supported by the global soil information system will provide access to a range of third-party tools such as farming-system models, hydrologic models and other 'apps' for mobile devices
- Training and capability development delivered via Pillar Four (and Pillar Two) will directly strengthen national and local soil information delivery
- Participation in the broader international technical and scientific community involved in Pillar Four will also generate within-country benefits (e.g. more efficient adoption of best practices for all aspects of digital soil mapping)
- Countries will be able to ensure that the international assessments of soil resources for their jurisdiction are based on the best available data rather than outdated or incomplete data sets (as is often the case now)

  Better decision-making based on the knowledge of current and forecast soil conditions.

The ITPS emphasized the need to achieve net benefit for all partners involved in the global soil information system and to monitor this through regular engagement and review. An important aspect is to ensure all data contributors have open access to all data within the global soil information system.

The details of the investment and funding model for Pillar Four will be determined during the implementation phase for this Plan of Action (Section 9). It will follow similar successful models used for related global systems (e.g. weather, climate, land cover, agricultural statistics). The initial investment is anticipated to come from a leading group of countries with the longer term funding being determined by the ability of countries to contribute.

Issue 6: Opportunities created by technical advances

A large amount of soil information is collected world-wide. The dramatic advances offered by new technologies (e.g. proximal sensing of soil properties, molecular biological techniques, temporal-remote sensing, geophysical remote sensing, digital terrain analysis, web-services, crowd sourcing) represent a remarkable opportunity for providing better soil information for practical purposes. However, the technologies also provide major challenges for the scientific and technical communities. There is a risk that the diversity of data sources may make integration and harmonization more difficult than in the past.

The really significant opportunities created by technical advances, beyond the new systems of measurement and mapping, relate to the potential to source and integrate data from a much broader spectrum of data providers. Paradoxically, capturing the benefits from these diverse providers and users of soil information requires careful planning to ensure systems are harmonized and synergistic.

The ITPS recognized the need for the global soil information system to be open to new approaches and methods. They recommended that a strong relationship should be built between leading international research groups and Pillar Four so that the global soil information system benefits from the latest scientific and technical advances.

4. People and systems

Context

The global soil information system requires a full-time leadership and coordination team, resourcing for technical and scientific activities, and mechanisms for supporting the operational system. It will not evolve quickly enough through voluntary processes and in-kind support from various national institutions. Existing operational facilities at national, regional and global levels should play a predominant role for delivering the necessary coordination and supporting activities to a global system. There should also be a strong emphasis on regional partnerships in keeping with the principles and spirit of the GSP.

Leadership and technical support teams

At a minimum, the following teams are needed to develop and run the global soil information system.

- A leadership group responsible for strategy and governance and overall management (see Section 8) and with clear lines of accountability to the GSP Plenary Assembly, the ITPS,other Pillars of the GSP, and regional partnerships.
- A communication and liaison team responsible for relationships with all participating organizations and clients
- A training and capability development team (see below)
- A small operational team running the facilities and providing technical services including those relating to information and computing technology, soil laboratories (e.g. advice on quality assurance and accreditation), and pedology.
- A broad support network of technical and scientific specialists based in contributing organizations.

The ITPS recommended that implementation of Pillar Four required the immediate establishment of full-time leadership and technical support teams to enable the supply preliminary data products by 2015 and to ensure the global soil information system is fully operational by 2018.

Training and capability development

The technical capability for soil data acquisition and information delivery has to be rebuilt in most parts of the world. This should involve education and training, provision of physical infrastructure (e.g. laboratories and computing systems), development of standards and establishing professional networks. The primary task is to establish technical teams with sufficient critical mass. Experience in successful programs around the world indicates the team requires skills in:

- Field survey and monitoring
- Laboratory measurement (including spectral analysis)
- Digital soil mapping and web-based services
- Land evaluation (especially in relation to farming systems and forestry)
- Communication and extension.

The number of such teams per country depends on its size and complexity. In some regions, several small nations may be serviced by a single team if a suitable agreement can be reached (e.g. Pacific nations). Large countries may have five, ten or even more such teams. Experience has also shown that it is more effective to have a smaller number of permanent teams rather than a major project-based effort with a large number of teams for a fixed period of a few years. This is especially critical to the success of monitoring programs. The regional teams need to be coordinated and financed by national and international scientific and technical agencies.

The proposed education and training activities should produce a new generation of specialists in mapping, monitoring and forecasting of soil condition. As a consequence, partners of the global soil information system should eventually have access to improved information on the distribution and trends in soil resources for their regions as well as global context to assist them achieve more sustainable systems of land use.

Recommendation 4: Implementation of the global soil information system should include a training program to develop a new generation of specialists in mapping, monitoring and forecasting of soil condition, with an emphasis on countries where improved soil knowledge is essential for food security and restoration and maintenance of ecosystem services.

Spatial data infrastructure

Web-based delivery of soil information requires a significant investment into the expertise and facilities for analysing and managing large and complex information resources. Fortunately, the global soil information system can take advantage of the principles and practices developed by the Global Earth Observing System of Systems, but also other existing spatial data infrastructure while using OGC- and ISO-standards (e.g. INSPIRE in Europe). More specifically, the following elements need to be developed.

- **Exchange Schema (SoilML)**: Building on the new ISO 28258 for the exchange of digital soil-related data will allow owners of soil data to publish via the Web. This new standard still requires tests by a broader community of soil data holders in order to gain acceptance and to become routinely applied. This task is now also part of the work program of the Working Group Soil Information Standards (WG SIS) of the International Union of Soil Sciences (IUSS).
- **Web Services**: Web services for digital soil data should be established to provide easy access to the standard data products specified below.
- **Dynamic web portal for global soil information**: Such a portal should provide best practice knowledge, metadata, links to data products world-wide, and also host a world soil viewer. It should provide information to the user in a seamless fashion that is customized to suit their needs. It should include not only global products, but also act as a hub for national, regional and other user-specific soil information.
- **Build catalogs**: These should provide summaries of the availability of data at various sources and they are needed to ensure the web-based services are delivered efficiently.

The general aim for building a global soil data infrastructure is to ensure that soil data and information are freely available on the web and in a format that can be readily used for a wide range of purposes. This availability will stimulate the use of soil information and result in many new applications. The web-based architecture will also create the opportunity for new sources of soil data to be efficiently shared (e.g. infrared spectroscopy, molecular biological techniques and *in situ* monitoring systems). Pillar Five of the GSP addresses design and implementation of the systems required to build the necessary infrastructure.

5. Data products

It is essential to have orderly specification and delivery of global soil data products. This is especially important for users working on issues such as climate change, land use, farming systems and other topics where simulation modeling is used as the primary form of analysis (especially in the absence of soil observing and monitoring systems).

Simulation modeling is essential for analyzing many of the complex issues relating to food security, ecosystem function and climate change. The data model for the soil component in most simulation studies (e.g. grid size, number of soil layers, soil variables) cannot be changed easily and modelers need to have a clear understanding of the current and planned data products so they can engineer their models accordingly.

Three primary data sets form the core of the global soil information system and they describe soil grids, polygons and profiles. The following sections describe recommendations and tiers for developing these data sets.

Other forms of soil knowledge are also important but they tend to have a more local or regional focus. The need to build a global system is less urgent for these forms of soil knowledge and in some cases, difficult to justify even though they may relate in various ways to the three applications outlined in Section 2. Examples include the following.

- Information on pedogenesis and landscape evolution provides essential context for natural resource management but the qualitative models, detailed process understanding and chronologies of landscape development often have a local or district focus. Documentation via scientific journal papers and technical bulletins is an effective mode of communication.
- Information on interactions between different forms of soil management and soil function is important for sustainable land management. Again the information is strongly dependent on local context and a range of economic, cultural and social factors. Publications on best-management practices provide one means of information delivery. Preparation of a global knowledge base, while conceivable, is not the highest priority for Pillar Four.
- Traditional knowledge relating to the soil and land has great significance in regions where there is long cultural association with the land. Again, existing modes of investigation and information sharing are effective.

The ITPS recommended that Pillar Four should support the ongoing development and maintenance of three primary data sets central to the global soil information system (global soil grids, polygons and profiles) to be defined according to specifications responding to end-user needs.

The Global Soil Grid

Soil data in a grid format are important because they are compatible with other forms of biophysical data (e.g. land-cover, vegetation, terrain, remote sensing). The recommended approach involves a pragmatic and short-term solution of improving of the existing global data products and then adopting a staged approach to eventually achieve a fine-resolution global soil grid using digital soil mapping. This approach and the assessment of users needs for global data products are based on the following.

- User experiences about the FAO world soil map and the Harmonized World Soil Database (HWSD).
- Stakeholder questionnaire about data needs (basis for the FAO 2012 report on soil information needs[11]).
- Experience from the discussions about the GEO task Global Soil Data.
- Experience gained through the development of the GlobalSoilMap initiative and pilot studies in more than 10 countries.

Stage 1: Updated Harmonized World Soil Database (HWSD)

A collaboration led by the FAO[12] produced the HWSD several years ago at a resolution of approximately 1km. It is now widely used by the climate-change and other modeling communities. FAO has plans to update the product with the support of interested GSP Partners. The HWSD represents the soil with two layers down to a depth of 1m. The product provides a comprehensive set of soil attributes. The original HWSD did not incorporate data from several large countries and instead relied on interpretations of the FAO Soil Map of the World together with data provided by the European Commission, IIASA, ISRIC and the Chinese Academy of Sciences. The update aims to include data from the countries that have not contributed so far. While the HWSD has been an invaluable first step in providing gridded data globally, it is constrained by the following:

- The two-layer soil model (topsoil, subsoil) is inadequate for many studies that involve simulation of the water balance, plant growth, greenhouse gases, susceptibility to mass movement, etc.
- Restricting soil data to 1 m is problematic, especially for hydrological and ecological studies where the dynamics of water, carbon, nutrients and solutes need to be considered to a much greater depth especially in more strongly weathered landscapes and when perennial vegetation is involved. Other applications need to know the depth of the soil (e.g. landslide prediction, landscape hydrology).
- The grid resolution of 1 km is useful for synoptic studies and sufficient for global-level presentations. However, the characterization of soil profiles and soil polygons, which form the HWSD data base, is inadequate and the product is not sufficiently reliable for many applications. There are no statistical estimates of uncertainty. Many applications now require soil data at resolutions that match digital elevation models and remotely sensed imagery (typically 100m or finer).

The ITPS recommended in July 2013 that the current Harmonized World Soil Database should be updated and used as the de facto standard soil grid for the world until better products are

[11] www.fao.org/3/a-i3161e.pdf

[12] www.fao.org/nr/land/soils/harmonized-world-soil-database/en/

released. Since then, the ISRIC 1-km grid has been released (see below)[13] and comparisons between the products are now needed to determine whether the original recommendation is worth pursuing. Some countries are also releasing fine-resolution grid products (see below) that bring into doubt the value of revising the HWSD for their specific jurisdiction. These matters need to be resolved during implementation planning for Pillar Four.

Background to the development of a finer-resolution global grid (Stage 2)

In 2008, work began on the design and planning for a soil grid of the world at fine resolution (100 m) and this became known as GlobalSoilMap.[14] The intent was to integrate the best available data from local and national sources and deliver the information online as part of the Global Earth Observing System of Systems. The format and resolution was to be compatible with other fundamental data sets on terrestrial systems (i.e. vegetation, land cover, terrain, remote sensing).

GlobalSoilMap was catalyzed through an initial investment from the Bill and Melinda Gates Foundation. Their focus was Africa but they also established an international consortium with responsibility for the global effort. The technical and logistical complexity of the project has been substantial but good progress has been made during the initial research phase of the project. Achievements to date include:

- preparation of comprehensive and scientifically innovative technical specifications
- completion of proof-of-concept studies (USA, Nigeria, South Korea, Denmark, Australia)
- international collaboration and enthusiasm to produce the operational system.

The product has a flexible method for estimating and extracting soil data for any depth or depth-integral. A variety of digital soil mapping methods is used to provide estimates of soil properties and these depend on local data availability. Estimates of uncertainty are also provided.

The resolution of 100 m was selected because it matched the resolution of another key global data set – the SRTM digital elevation model. It is also at the coarsest resolution for resolving hill slopes in many landscapes – the scale at which a large amount of soil variation occurs. This resolution provides better support at local scales where most decisions are made. It should be noted that some countries are working at finer resolutions (e.g. 50 m) and then supplying grid estimates at the 100-m resolution in accordance with the Technical Specifications.

There is widespread agreement on the Technical Specifications of GlobalSoilMap but the slower than expected rate of progress has created difficulties. An important issue has been the limited availability of funds for global coordination and delivery.

[13] www.isric.org/content/new-version-soilgrids1km-and-soilinfo-app-released

[14] Arrouays et al. (2014). GlobalSoilMap: towards a fine-resolution global soil map. Advances in Agronomy, 125, 93-134.

A solution to this problem was proposed by ISRIC (a member-institution of GlobalSoilMap Consortium and secretariat for the venture). Their proposal ("Soil1kGrid") was to follow the GlobalSoilMap Technical Specifications but with two key differences. First, the grid would be produced at a 1-km resolution. More significantly, it would be centrally produced using environmental covariates (mostly at 1-km resolution) and soil profile data held by ISRIC in Wageningen. Soil1kGrid approach has now been implemented[15] and it is a new and interesting approach, but some issues need to be taken into consideration:

- The soil profile data held by ISRIC are substantially less than those held by soil information institutions around the world. Transfer of the latter to ISRIC would be a large and complex task.
- Centralized production of the global grid, as opposed to a compilation of national or regionally generated grids, can lead to inconsistencies between the global grid and national products, especially for countries that produce their own grids using data that are not available to ISRIC.

As noted earlier, finding a practical, pragmatic and short-term solution to the supply of globally gridded products needs to be resolved during the implementation planning for Pillar Four and it will most likely require a combination of approaches.

Stage 2: Fine-resolution global grid of soil properties by 2015 (Version 0)

The approach recommended by the ITPS requires the people and systems outlined in Section 4. It cannot be achieved using voluntary procedures and in-kind resourcing.

The proposed Stage 2 involves an acceleration of existing national efforts to produce the fine-resolution grid according to the Technical Specifications of GlobalSoilMap. The GSP regional partnerships would facilitate this process.

- Approximately one-third of countries are expected to be able to produce initial products through their national soil information institutions with the assistance of the GSP.
- The second third of countries typically have significant quantities of legacy data but lack the institutions and technical capacity necessary for product delivery by 2015. These countries would have an interim product generated for their country through the regional partnerships and facilitated by the Working Group for Pillar Four. This interim product would be updated in Version 1 of the global grid in 2018 using new technical capacity within the country built through the GSP training programs.
- The final third of countries have limited legacy data and face major challenges including very low income, conflict or a lack of institutional capacity. The fine-resolution grid for these countries will be generated through the regional partnerships and the Working Group for Pillar Four. The grid for these countries will not be updated until new soil data become available, most likely after 2018.

[15] http://www.isric.org/content/new-version-soilgrids1km-and-soilinfo-app-released

Stage 3: Update of the fine-resolution global grid of soil properties by 2018 (Version 1)

As indicated above, this version of the grid would be released when the global soil information system becomes fully operational in 2018. The key advance with this stage is a doubling of the number of countries providing their own grid data (either through their own institutions or through the regional arrangements) compared to 2015.

In summary, the ITPS recommended that the global soil grid should be produced using a staged approach with short- and medium-term delivery dates including Version 0 on World Soils Day in the International Year of Soils (2015) and Version 1 on World Soils Day in 2018, coinciding with the establishment of the fully operational Global Soil Information System.

Global Soil Polygons and Supporting Classification

There is reasonable agreement on the design of hierarchical polygon systems at the national and global level. Some would argue that polygon-based are outdated and need to be replaced by grid-based systems. However, polygons and grids are complementary and both are needed for the following reasons.

- Many decisions on land use and management require the delineation of areas with sharp boundaries either for legal or practical reasons
- Soils are natural bodies of material and in some landscapes they are best delineated using polygons because this accurately depicts physical reality (e.g. distinct sedimentary bodies such as alluvial terraces)
- There is educational value in being able to identify landscape units with distinctive patterns that reflect landscape evolution and pedogenesis
- Stratification of landscapes into zones with a similar evolutionary history is also valuable for digital soil mapping because the relationships between environmental covariates and soil properties are often conditional on this history – the polygons can be used as a nominal environmental covariate.
- Based on the experience with the coarse 1.5 M global soil map of FAO, a very broad community of stakeholders (including other GSP pillars) require a revised and improved global soil map.[16]

The *de facto* global standard for soil polygons is provided by SOTER (notionally at a cartographic scale of 1:1 500 000). The coverage provided by SOTER-compliant databases is incomplete. While the urgency for completing the SOTER coverage is not as immediate as for the gridded soil data, there are good reasons for completing the global coverage. The key tasks are as follows.

- Prepare specifications for an electronic SOTER (eSOTER) product based on those for SOTER with particular emphasis on specifying the taxonomic requirements (e.g.

[16] See, for example, Omuto C, Nachtergaele F, Vargas Rojas R (2013). State of the art report on global and regional soil information: Where are we? Where to go? Global Soil Partnership Technical Report, Food and Agriculture Organization of the United Nations, Rome.

consider addition of the proposed Universal Soil Classification) and terrain characterization (where digital elevation models can now be used).

- Progressively deliver eSOTER data via a web services and ensure compatibility with SoilML
- Negotiate a timeline for completion with the key parties.

The consistent polygon coverage would replace the FAO/UNESCO Soil Map of the World. However, there are several important issues to consider:

- The completion of SOTER may draw resources away from the effort to produce the global soil grid. However, it is likely that different groups of partners would become involved.
- Most applications for polygon data are at the national or sub-national level. Therefore, SOTER requires very clear specifications and coordination.
- Based on rates of progress to date, it may be difficult to achieve the momentum necessary to complete the product.

The ITPS recommended replacement of the FAO/UNESCO Soil Map of the World by completing the SOTER coverage for the world by incorporating the missing coverage from North America, Oceania and Europe using revised technical specifications. Achieving this will depend on the availability of resources to support the work in each country.

Soil profile and point data

There are strong reasons for developing a global data base of soil profiles. The widespread use of the WISE[17] database has demonstrated the value of such a system. However, maintaining and updating large soil profile databases is expensive, particularly when the data come from multiple sources.

To be useful, soil profile data nearly always need to be geo-referenced but this can raise sensitive issues relating to privacy and intellectual property. In some countries, precisely geo-referenced soil data collected on private land infringe national legislation on privacy if delivered to public services without prior consent of the land owner. Any such issues need to be resolved before such data are included into the global soil information system.

The ITPS recommended that development of a world soil profile data base should proceed with two tiers. The first tier would consist of a diverse and open archive for all kinds of field-based data collections. The second tier would be much smaller and harmonized with quality assurance and representativeness being its hallmark. In both tiers, soil information agencies would need to be encouraged to provide data as freely available web services. Provision via web services (based on an agreed specification for data exchange such as SoilML) would allow the compilation of a single database for particular studies if required. A global soil profile archive could serve as a soil

[17] Batjes, N.H. (2008). ISRIC-WISE harmonized global soil profile dataset (version 3.1). Report 2008/02, ISRIC –World Soil Information, Wageningen.

profile reference and conversion library, with analyses by multiple methods being available for all samples.

Tier 1: Comprehensive soil profile and analytical database

The ITPS recommended compilation of this large soil profile and analytical database for the world without the stringent requirement for a minimum data set (apart from geo-referencing and metadata) or representativeness.

This Tier-1 Database would hold a continuously growing archive of soil profile descriptions and analyses from around the world. Nomenclatures and analytical methods would not be harmonized as long as each data set is accompanied by sufficient meta-information so that quality checks can be undertaken. Data would be supplied either by using a global data collection tool (such as ISRIC'S soilprofiles.org), which extends the former WISE data base, or by setting up web feature services following agreed specifications for digital data exchange.

The number of soil profiles in this database is likely to exceed 100 000 and could be much greater than 10^7 if soil testing data (e.g. from commercial soil testing companies) are included.

Tier 2: World reference-soil profile dataset

The ITPS also recommended the development of a world reference-soil database containing harmonized soil profiles This Tier-2 dataset would be a subset of the Tier-1 soil profile collection and it would have specific requirements on the quality and documentation of soil profile data. It would require harmonized and quality-assured morphological, physical and chemical data that are globally representative of:

- geographic regions
- major soil types
- ecologically, agriculturally or scientifically significant soils

The precise criteria for selecting representative soils need to be defined along with the necessary technical specifications. Strong preference should be given to soil profiles with associated archived specimens to enable further measurement and analysis (e.g. to support the development of standard spectral libraries for proximal sensing). The number of soil profiles in this database is unlikely to exceed 20 000.

6. Monitoring and forecasting

As noted earlier, detecting and forecasting soil change with time is technically more demanding than mapping, but the information is needed for monitoring and verification purposes in relation of a number of multilateral environmental agreements. In most parts of the world, scientists draw their evidence for inferences about soil change from a variety of sources including:

- long-term monitoring sites (from simple plots through to complex field experiments)
- simulation modeling

- proxies (e.g. monitoring changes in land management rather than soil variables directly, or comparing paired-sites where space is substituted for time)
- narratives (e.g. historical accounts of soil condition).

Only a few countries have national monitoring systems with the capability to detect soil change with time. The technical design and logistical considerations of these national systems are well known.[18] However, securing long-term institutional commitment is particularly difficult partly because the return on investment for existing systems is poorly documented.

For countries lacking soil monitoring, it seems efficient to resample existing representative and well-described soil profiles (i.e. Tier 2). The ITPS recommended that all GSP member countries should be encouraged to implement national monitoring systems with the capacity to detect soil change with time.

Before committing to a global system for monitoring and forecasting soil condition, a better understanding is required of the return on investment from these various sources of evidence. An initial task is to undertake a feasibility study to identify the most worthwhile components. Some aspects that need to be considered include the following.

- Determine how the existing FAO statistical system (FAO Stat) can be expanded through the development of SoilStat (i.e. analogous to Aquastat). Variables to be assessed for an augmented system should include the drivers of soil change: for example; land management practices, agricultural inputs (e.g. fertilizer, lime, energy costs, tillage), loss of high-quality agricultural land.
- Investigate opportunities for coordinating and harmonizing existing soil monitoring programs (e.g. including the Long-Term Ecological Research network, national systems, and the emerging soil carbon monitoring systems) through the adoption of common measurement protocols and integrating temporal remote sensing.
- Evaluate the merit of preparing guidelines for the design and maintenance of local, national and international soil monitoring networks.
- Assess whether new monitoring networks are needed in high-priority regions where soil change is suspected to be occurring or likely to occur (e.g. permafrost regions, important food producing districts, landscapes where agricultural intensification is occurring).
- Study available concepts about soil condition indicators (e.g. Huber et al. 2008[19])

The ITPS recommended that a feasibility study is needed to identify investment priorities and design options for establishing a global system for monitoring and forecasting soil condition, and more specifically, the study needs to explore how this can link to the FAO statistical system

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[18] See for example: McKenzie NJ (2008). Monitoring soil and land condition. In 'Guidelines for surveying soil and land resources.' Australian Soil and Land Survey Handbook Volume 2. (Eds McKenzie NJ, Grundy MJ, Webster R, Ringrose-Voase AJ) (CSIRO Publishing: Melbourne).

[19] Huber et al. (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.

through the establishment of SoilStat. This study could form part of the implementation planning process.

7. Analysis and synthesis functions

Regular reporting on the status and trends in soil condition at the global scale serves several functions. The reports will identify the rate and extent of soil-change and the likely consequences for society, including soil productivity and sustainability. The regular reporting will also bring an operational discipline to the management of soil information. Systems for collecting and analyzing data can be progressively improved and a body of knowledge will be developed over several cycles of reporting.

The central focus for the ITPS is preparation of definitive and regular reports on the status of the world's soils. The first report will be published on World Soils Day at the end of the of the International Year of Soils in 2015. Due to the short timeframe, the first report will establish the benchmark condition of soils using peer-reviewed scientific publications – it will set the framework for future reports and outline priorities for investigation and monitoring. A key task will be to ensure the global soil information system meets the short and long-term needs of these status reports on the world's soils. The global reporting mechanism on soils would also contribute directly to other global assessment activities, most notably:

- Assessment of the Land Degradation Neutral World target agreed at the Rio+20 conference
- General reporting by the Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Science-Policy Interface of the UNCCD
- Regular assessments by the FAO such as updates to the State of Land and Water

  Resources.

8. Governance

The design and management of the global soil information system requires a governance structure and associated management systems. The ITPS is an appropriate body for providing strategic oversight. However, it will not be in a position to deal directly with many of the technical and management aspects of the global soil information system.

The ITPS Plenary Assembly agreed that the Working Group for Pillar Four could perform this more operational function, however, clear rules and procedures for the operation of the Working Group need to be developed during implementation planning.

The ITPS recommended that a charter of ethics needs to be developed for the global soil information system. This could serve as a common credo to guide all organizations and individuals involved with the global soil information system. This affirmation of values and principles aimed to summarize the intent and responsibilities of all institutional matters relating to Pillar Four (e.g. legal, administrative, codes of conduct for individuals and organizations). The ITPS also recommended that the proposed charter of ethics would need to specifically address intellectual property because of its importance to the success of the global soil information system. While supportive of the intent, the Plenary Assembly considered this would be a large and difficult activity. It was agreed that some aspects relating to intellectual property, privacy and terms of use could be dealt with through existing institutional arrangements (see Recommendation 3 above).

9. Implementation

In developing this Plan of Action, the GSP Plenary Assembly has taken into account the guidance and recommendations provided by the ITPS and partners of the GSP. The Plan of Action provides a clear strategic framework and the next step is to proceed to detailed implementation planning in accord with the Rules of Procedures for the Global Soil Partnership. During this process, the GSP Secretariat will provide regular reports on progress to the GSP Plenary Assembly.

To provide context for this process, the ITPS estimated that the total global investment needs to be in the order of $40 to 50 million for the period 2013 to 2018. This is made up of new funds and in-kind support from national soil information institutions. This is necessary to support the people and systems outlined in Section 4.