Food and Agriculture Organization of the United Nations

GLOBAL SOIL PARTNERSHIP

Plan of Action for Pillar Three of the Global Soil Partnership

Adopted by the GSP Plenary Assembly

Promote targeted soil research and development focusing on identified gaps, priorities and synergies with related productive, environmental and social development actions

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PLAN OF ACTION

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Acronyms

AgMIP	Agriculture Model Intercomparison and Improvement Project
ARIs	Advanced Research Institutions
CGIAR	Consortium of International Agricultural Research Centers
FACCE-JPI	Joint Programming Initiative on Agriculture, Food Security and Climate Change
FAO	Food and Agriculture Organization of the United Nations
GSBI	Global Soil Biodiversity Initiative
GSP	Global Soil Partnership
ICT	Information and communications technology (tools)
IFAD	International Fund for Agricultural Development
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ITPS	Intergovernmental Technical Panel on Soils
IASS	Institute for Advanced Sustainability Studies
IUSS	International Union of Soil Sciences
NARS	National Agricultural Research System
NRC	National Research Council (United States)
RSC	Royal Society of Chemistry (United Kingdom)
RSP	Regional Soil Partnership
R&D	Research and Development
SDG	Sustainable Development Goals
SWSR	Status of the World's Soil Resources report
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
WBGU	German Advisory Council on Global Change (Germany)

Glossary[1,2]

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.*

Food Security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food.[3]

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.[4]

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.

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 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

[1] The Glossary from the State of the World's Soil Resources should be used here.
[2] Five definitions are marked with (*), indicating that changes have been suggested by the Working Group of Pillar 3 and provided in Annex I for consideration of the ITPS, in case a term has not been included in the SWSR-2015.
[3] FAO. 2009. The State of Food Insecurity in the World 2009. Food and Agriculture Organization of the United Nations.
[4] Vanlauwe, B. 2013. Integrated Soil Fertility Management – a concept that could boost soil productivity. Rural 21. 3:34-37.

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).

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).[5]

Soil Degradation is defined as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. Degraded soils have a health status such, that they do not provide the normal goods and services of the particular soil in its ecosystem.[6]

Soil Erosion is the most visible effect of soil degradation, and refers to absolute soil losses in terms of topsoil and nutrients. Soil erosion is a natural process in mountainous areas, but is often made much worse by poor land management practices.

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).[7]

Soil Restoration is defined as any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state. In time, ecological processes and functions will match the original conditions.

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.[8]

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 Soil Management refers to the definition for sustainable soil management developed in the World Soil Charter.

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[5] The working group that prepared the Plan of Action of Pillar 3 used in the text the term soil contamination/pollution, knowing that there might be different definitions or even uses of these terms which couldn't be sorted out.

[6] http://www.fao.org/soils-portal/soil-degradation-restoration/en/

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

Executive Summary

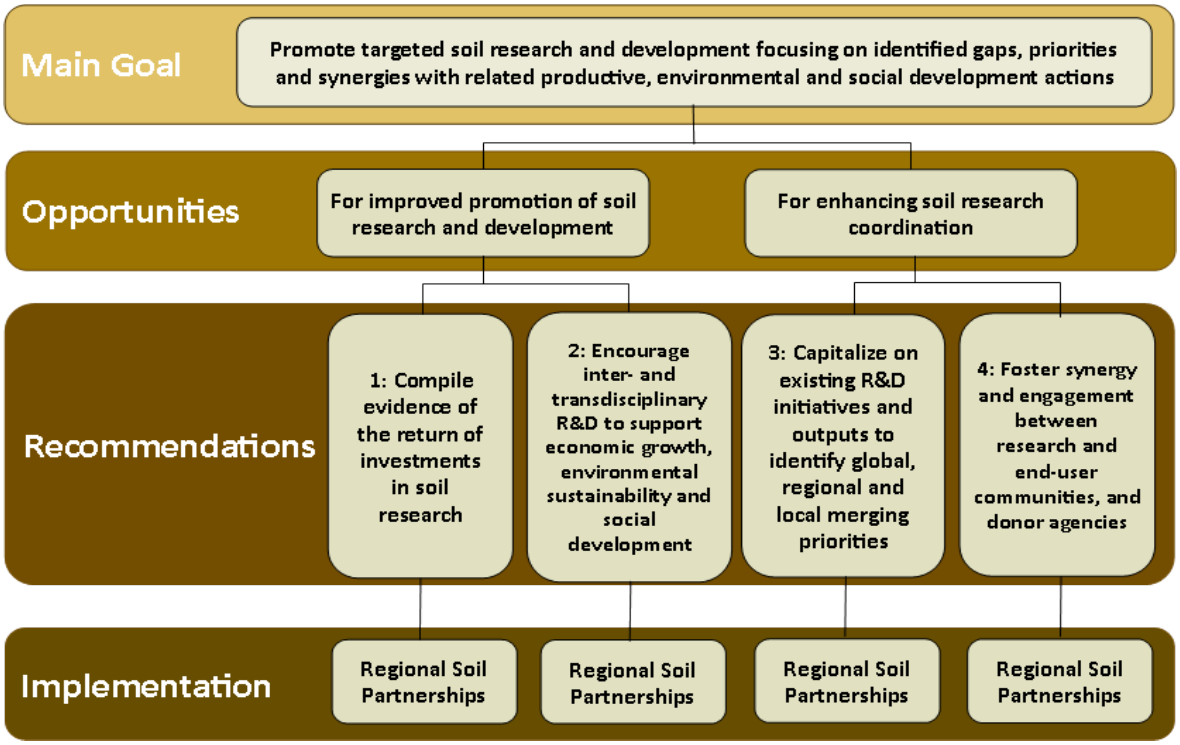
Soils are a prime basis of life for people, animals, plants and macro- and microorganisms. Soils provide important contributions to ecosystem functioning and services due to their substance-converting, buffering and filtering capacities, which are relevant for nutrient, water and carbon cycles. From an anthropological perspective, soils support agriculture, forestry, urban development, recreation and other important economic, environmental and social factors. A key mandate of the Global Soil Partnership (GSP) is to emphasize, in all relevant venues, the essential role of soils for humankind, including the development and implementation of a global strategy for soils research and development (R&D) to enhance the ability of soils to make important contributions to ecosystem services.

A relevant example of the potential role of the GSP on soils R&D comes from agriculture. Since the 1960s, agricultural R&D has been focused primarily on plant breeding and the use of agrochemicals, rather than on soils. A remarkable example is the Green Revolution that led to a global increase in food production, although in some cases it also resulted in soil degradation as a negative impact over time of unsustainable intensification of agriculture. As a consequence, soils R&D in general should help to better understand: (i) soil processes and how they contribute to soil functions, (ii) how we can efficiently manage (protect and enhance) soils so that they can continue to fulfil these functions, including the rehabilitation of degraded soils, and (iii) how we better understand the geographic distributions of soil functioning and the trajectories of future changes in these functions. For this purpose, the soils research community should be strengthened with improved access to research results, facilities, logistics, and to resources needed for boosting innovative soil research. In addition, to ensure changes in attitude and practice at end-user level, scientists and decision makers developing new soils R&D programs need: (i) to understand the factors that will affect the uptake and impacts of improved technologies by end-users and therefore, to develop suitable options for their promotion; and (ii) to identify and address main change agents within the political, economic, environmental and demographic sectors for effectively closing the gap between research and technology adoption. To this end, lessons learnt from previous and current agricultural research and implementation efforts should be intensively documented and incorporated in future R&D strategies.

The Plan of Action for Pillar 3 stresses the enhancement of strategic collaboration within the global soils R&D community, with a main facilitating role of the GSP; provides pertinent background considerations on potential contribution of R&D to global economic growth, environmental sustainability and social development; and proposes a framework for implementation of concrete action plans and programmes. The present document addresses global issues, while not specifying thematic and geographic priorities. In fact, the definition of R&D priorities is to be done at regional level via the Regional Soil Partnerships (RSPs). Since many of the required actions will be carried out by these RSPs, the recommendations are of broad nature, and should guide implementation in accordance with regional and national contexts and priorities.

The main expected outcome under this pillar is the engagement of all potential actors to develop R&D strategies, invest resources and execute complementary actions towards agreed objectives,bearing in mind all R&D possible dimensions (i.e., close gaps in knowledge, generate or improve technologies to solve problems, and support human development).

The following framework is suggested for the development and implementation of the Plan of Action of Pillar 3 of the GSP. Four recommendations were developed to address the two identified opportunities and are to be implemented through the Regional Soil Partnerships:



Summary of recommendations for implementation of the GSP Pillar 3 Plan of Action:

The Plan of Action for Pillar 3 includes four main recommendations to enhance interactions between the scientific community engaged in conducting basic and applicable R&D on soils, and end-user communities including decision makers, in order to boost impact through adaptation and dissemination of the knowledge and technologies developed:

Recommendation 1: Compile for all partners evidence of the return of investment in soil research, stressing the importance of soil functions (e.g., economic cost of soil degradation and the value of its rehabilitation) for the provision of services by ecosystems and in reaching the UN Sustainable Development Goals.

Recommendation 2: Encourage inter- and transdisciplinary research and development to support the five pillars to enhance the development of appropriate sustainable soil management practices and systems, the applicable use of soil information, the harmonization of methods and determination of best indicators, and the dissemination of research results beyond the scientific community, to globally support economic growth, environmental sustainability and social development.

Recommendation 3: Capitalize on existing R&D research initiatives and outputs through meta-analysis and synthesis reviews for all partners, to identify global, regional and local emerging priorities.

Recommendation 4: Foster synergy and engagement between research and end-user communities, and donor agencies, to facilitate active collaboration in a joint-learning approach that can be effective in broadening the research focus and enhancing its impact

1. Introduction

The Global Soil Partnership (GSP) was formally endorsed 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, fiber, 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:

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. Harmonisation 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, strictly following the Guidelines for the development of Plans of Action of the GSP Pillars as presented in the Rules of Procedure.

This document presents a Plan of Action for Pillar 3. It provides:

- a rationale for soil research and development (R&D) activities in the context of the GSP;
- a justification of soils R&D, from the economic, environmental and social perspectives;
- a set of potential recommendations, for the design of a strategic global research system;
- suggested initial options for implementation of the recommendations;
- some highlighted external factors that could jeopardize its successful implementation.

Pillar 3 of the GSP implies improved cooperation between soil related disciplines, and the imperative to build bridges between the soil R&D and end-user communities. This can be done by enhancing the global scientific knowledge base, arranging more coherent soil related R&D activities, improving the applicability of soils research, and providing new avenues for future well integrated and better targeted R&D programs.

The formulation process for this Plan of Action was initiated at a special meeting held during the 2nd Global Soil Week (Berlin, October 2013), with an open invitation to scientists to form part of a dedicated Working Group. A workshop was subsequently convened in Jordan (December 2013), with the main objective of preparing a draft document through members of the newly formed Working Group. During 2014, the Working Group (a total of 29 members in the mailing list, cf. Appendix II) prepared (via email) and submitted two drafts to the GSP Secretariat. The first draft was considered by the second working session of the Intergovernmental Technical Panel on Soils (ITPS) at FAO Headquarters in Rome (April 7-11, 2014) and major observations and recommendations were made by members of the Panel. Based on these inputs, including an agreed general framework, the second draft was submitted for review by the ITPS members attending the 20th World Congress of Soils Science held in Jeju, Korea (June 8-13, 2014). The ITPS members welcomed the improvements, and agreed on appointing a sub-group of three expert members of the Working Group (Bernd Bussian, Olegario Muñiz and Charles Rice) to develop a further draft to be submitted to the GSP Secretariat in December 2014. The subsequent third draft version of the Plan of Action was shared with the full Working Group for review between December 2014 and January 2015. In 2015, the draft Plan was received by the ITPS on two occasions, one to benefit from the advice of two external reviewers (Johan Bouma and Rattan Lal) and the other for final adjustment. The resulting final draft Plan of Action for Pillar 3 was endorsed during the third working session of the ITPS, held at Potsdam (April 13-17, 2015), prior to submission to the Plenary Assembly of the GSP in June 2015. The final draft was endorsed during this Plenary Assembly with the assumption that comments provided during this session and via email would be incorporated. All these inputs have been addressed to produce this final Plan of Action for Pillar 3.

Finally, for a better understanding of this Plan of Action, the following key points are highlighted regarding specific considerations and the general context in which the document was developed:

- It had to include a definition for Soils R&D, developed from a GSP perspective;
- It had to define the specific role of Pillar 3 within a broad Soils R&D community;
- It had to consider Soils R&D with a focus broader that only agriculture;
- It didn't have to provide a comprehensive overview of past and ongoing Soils R&D efforts since this would form part of its implementation;
- It didn't have to defined research priorities, since this has to be done by the Regional Soil Partnerships as they should be region specific and liable to change over time; and
- It only had to include (as potential topics) recommendations on specific Soils R&D priorities identified by the other pillars and the Status of the World's Soil Resources 2015[9] (SWSR-2015) report.

Relevance of Pillar 3 within the soils research & development community

In general terms, Research & Development can be defined as a set of systematic activities that combine both basic and applied research, with the objective of either developing new knowledge and goods, or improving existing knowledge and goods. However, both the *research* and *development* dimensions must be adequately considered in a balanced manner.

There are notable differences in soils R&D between developed and developing countries, which mostly relate to funding availability, capacities and main goals. These differences may have positive implications in terms of respective comparative advantages and complementarities that should facilitate intelligence work to identify and prioritize research gaps, and boost engagement and collaboration. Based on their research background, and particularly on the complementary dimensions of ***development*** that are addressed by researchers in developed (e.g., understanding nutrient cycles) and developing (e.g., practical solutions to low fertility) countries. For purposes

[9] For a complete description of these threats please refer to the SWSR-2015.

of the GSP, it is proposed to define soils R&D as the **set of systematic activities that can strategically combine both basic and applied research, with the intention of generating knowledge that can lead to the development and adoption of new or improved technologies and through them, to support development agendas**.

Knowledge and technologies required to cope with today's global challenges demand innovative, integrated and feasible solutions. Enhancing strategic collaboration between advanced research institutions (ARIs) such as universities and institutions from developed countries and the CGIAR system, and national agricultural research systems (NARS), in the context of food production requirements, should be key focus of Pillar 3 of the GSP. Complementarily, Pillar 3 should include a leading role to obtain recognition from all relevant stakeholders of the contributions of soil science to society (e.g. by communicating R&D outputs more widely). Main goals of its implementation are the identification of strategic gaps, priorities and synergies (e.g. by supporting inventories of R&D products), assistance in the formulation and implementation of an international soil R&D agenda including joint research programmes, and the coordination of actions to strengthen global soil R&D efforts (e.g. by enabling access to facilities and training, and/or logistics, or by providing strategic information to the donor community for coordinated support to soils R&D).

2. Opportunities for improved promotion of soil research and development

2.1 Opportunity 1: Relevance of soils research and development in today's society

Soil is a fundamental natural resource that facilitates essential processes which sustain human, animal and environmental well-being. It represents a critical component for life on earth (Figure 1), as it supports the production of food, feed, fuel and fiber; ensures sufficient supplies of clean water; acts as a buffer against extreme climatic events (soil is the largest terrestrial store of carbon), and supports the richest biodiversity on earth. By 2050 the global population may exceed 9 billion (United Nations, 2008). Population pressure increases demand for food, water and energy, resulting in a range of compelling needs confronting humanity in the coming decades. These needs provide an opportunity for soil scientists, in collaboration with other research communities, to more efficiently address knowledge gaps, integrate research questions and cope with threats to soil resources towards developing sustainable solutions to guarantee a continual provision of soil mediated ecosystem services.

Addressing these priorities requires a clear definition of sustainable soil management in different eco-regions and land uses, appreciation of the economic, environmental and social consequences of unsustainable management, and comprehensive analyses of the value of investing in soil protection and rehabilitation. This may hopefully lead to improved capacities in the soils R&D community to predict impacts (e.g. through the development of soil models) and to generate technological solutions or adaptation actions to protect and enhance soil functioning, based on identified and prioritized gaps in knowledge and technologies.

A pending task for the soils R&D community is to clearly demonstrate the crucial role of soils for society, i.e. to link the seven functions of soils (see Glossary) with services provided by ecosystems, and in relation to the UN Sustainable Development Goals (http://www.un.org/millenniumgoals), particularly to "end hunger, improve nutrition and promote sustainable agriculture" (Goal 2); "ensure availability and sustainable use of water and sanitation for all" (Goal 6); "tackle climate change and its impacts" (Goal 13); "protect and promote sustainable use of terrestrial ecosystems, halt desertification, land degradation and biodiversity loss" (Goal 15) and "strengthen the means of implementation of global partnerships for sustainable development"(Goal 17).

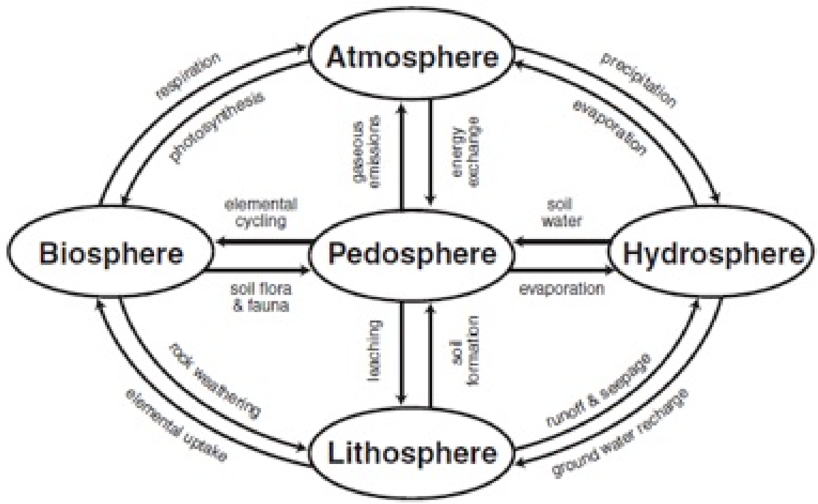


Figure 1: Interactive role and functions of the Pedosphere (the layer of the Earth composed of soil and subject to soil formation processes) within environmental processes (Lal *et al.*, 1997).

Recommendation 1: Compile for all partners evidence of the return of investment in soil research, stressing the importance of soil functions (e.g., economic cost of soil degradation and the value of its rehabilitation) for the provision of services by ecosystems and in reaching the UN Sustainable Development Goals.

Any programming of new soil R&D activities, or activities aiming to strengthen the outputs and availability of results from existing research, can build on existing reference material from large soil-oriented national or continental-wide (e.g. Europe) research programmes. To improve the availability of this material, a joint information sharing effort is needed. In addition, in the short term research priorities can be stated more clearly, partially based on **knowledge gaps, research questions** and **threats to soils resources** recently proposed by different sources as priorities within the soils R&D community. The regional soil partnerships should prioritize the knowledge gaps, research questions and threats listed below and add additional priorities unique to that region in order to develop appropriate actions for implementation:

a. Knowledge gaps

In accordance with the "Soil Thematic Strategy" of the commission of the European Communities (European Commission, 2012), the following priority areas for soil research are critical "*to close the gaps in knowledge"* and *"strengthen the foundation for policies*":

- Processes underlying soil functions (e.g. soil's role in global CO_2 accounting, the protection of biodiversity and the hydrologic cycle).
- Spatial and temporal changes in soil processes.
- Ecological, economic and social drivers of soil threats.
- Factors influencing soil related ecosystem services.
- Operational procedures and technologies for soil protection and restoration.

- Soil biodiversity as an environmental service.
- Soil as part of our natural and cultural heritage to be properly preserved.

b. Research questions

Considering the inter- and transdisciplinary and multifunctional nature of soils, key research questions identified by a number of scientists (e.g., Janzen *et al.*, 2011) in relationship with ecosystem services include:

- Food (Security): How can we increase food production by 60-70% to feed 9 billion people without impacting the environment?
- Water: How can we manage soils to contribute to the sustainable use of water resources and enhance water quality?
- Nutrients: How do we enhance nutrient use efficiency, nutrient cycling and nutrient balance, through soil management while producing quality food, feed, fiber and fuel?
- Energy: How can we produce biomass for biofuels without degrading soils and other natural resources they support?
- Climate buffering: How can we manage soils to provide resilience to increased climate variability and regulate climate through reduced greenhouse gas emission while maximizing soil C sequestration?
- Biodiversity: How can we improve the understanding, management and conservation of soil biodiversity to enhance ecosystem services?
- Recycling (wastes): How can we improve the use of soils as biogeochemical reactors, thereby remediating / avoiding contamination and maintaining soil productivity?
- Global equity: How do we balance global needs with local solutions?

Addressing these questions also implies to understand trade-offs between them (e.g. the role of soil biodiversity not only in nutrient cycling but also in soil structure maintenance and its effect on water cycling).

c. Soil threats

Recently, several national research councils and advisory boards have published strategic papers to bring the frontiers and challenges of soil science research to the attention of funding institutions (e.g., NRC, RSC, WBGU). All reports agree that the state of soils is deteriorating and that there is urgent need to improve soil health. The most significant threats to soils around the world have been identified in the SWSR-2015[10] to be formally issued at the end of 2015 - and they are the following (in order of priority at global level):

1. Erosion
2. Organic carbon change
3. Nutrient imbalance
4. Salinization and sodification
5. Sealing and capping
6. Loss of soil biodiversity
7. Contamination
8. Acidification
9. Compaction
10. Waterlogging

[10] For a complete description of these threats please refer to the SWSR-2015.

The degree of severity, geographic extent and interaction between these threats are diverse and very complex. Therefore, the prioritization of research activities to target defined threats and hence to serve specific gaps in the developmental cycle is urgently needed.

In general, it is necessary to emphasise how soils R&D could help to better understand soil processes and how they contribute to soil functions, how to efficiently manage (protect and enhance) soils so that they can continue fulfilling these functions (including the rehabilitation of degraded soils), and how to better understand the geographic distributions of soil functioning and the trajectories of future changes in these functions. Complementarily, to ensure changes in attitude and practice at end-user level (from farmers to urban communities, from farming cooperatives to big business, etc.), scientists and decision makers need: (i) to understand the factors that will affect the uptake and impacts of improved technologies by end-users and therefore, to develop suitable options for their promotion; and (ii) to identify and address main change agents within the political, economic, environmental and demographic sectors for effectively closing the gap between research and technology adoption. To this end, research outputs including lessons learnt from previous and current agricultural research and implementation efforts should be intensively documented and incorporated in future R&D strategies.

2.2 Opportunity 2: The interdisciplinary nature of soils

Soil science is intrinsically inter-disciplinary as it involves pedology, geology, biology, chemistry, physics, mathematics, statistics, and social sciences, among others. Soil research should therefore be streamlined to enhance development impacts and human well-being, while enabling sustainable soil protection and use. This requires interaction between multiple actors, including the private sector with complex and interrelated missions and functions (e.g., Engel, 1997), and mechanisms and extended networks to stimulate this interaction (e.g., individual projects embedded in a larger e-infrastructure for an effective sharing of approaches and results). Innovative approaches are needed, supported by enough resources to emphasize joint-learning experiences through real connection between stakeholders and the implementation of research results in practice, which is the ultimate proof of relevance of R&D (e.g., Bouma *et al.*, 2011). Proper monitoring and evaluation (M&E) approaches are needed to enhance the capacity to learn from past experiences and understand the extent to which research R&D affect livelihoods (e.g., Alene *et al.*, 2007) and ecosystem services, including the support to global biodiversity (e.g., Janzen *et al.*, 2011). Developing strategies to enhance economic growth, environmental sustainability and social development based on tailored soils R&D is therefore important to ensure accountability, maintain credibility and improve governance and decision-making processes. Questions related to future societal trends will challenge soil research in a particular manner.

a. Economic growth

Soil is a natural asset with both direct and indirect economic value and should be managed and protected accordingly. Soil degradation impacts both the average and variance of yield, as well as all factors involved in agricultural production and productivity. Such impacts translate into economic costs in terms of loss of income (or consumption) or increased income (or consumption) risk, increased costs of production and increased costs of soil rehabilitation/remediation. Several studies conducted to quantify these costs under varying circumstances indicated that they could be substantial. Furthermore, the degradation of natural capital assets may result in external (off-site) costs at different scales (watershed, regional or global) and in many cases the costs may be borne by future generations.

Although off-site costs can be substantial, they do not enter into the decision-making process of farmers and stakeholders along the value chain, since reliable estimates are scarce and decisions on natural capital use are generally only based on the impacts on-farm (e.g., Lipper, 2001). This needs to be changed, based on efforts to express the financial value of soil-related ecosystem services which have been quite successful and convincing to non-soil scientists (e.g., Dominati *et al.*, 2014)

There are no simple solutions, but it is clear that a concerted and collaborative approach to global soil research is required. In order to ensure a positive impact of soil R&D activities, research strategies should be adapted to environmental and geopolitical conditions to ensure best-fit solutions to development priorities, including consideration of the economic value of soil conservation and economic benefits of healthy soils.

b. Environmental sustainability

Different activities such as mining and agriculture, and more recently urbanization, affect soil health and the ecosystems services they support. In the case of mining, the major environmental impact is the result of physical damage to landscapes and the discharge of harmful solid, liquid and gaseous wastes to terrestrial and aquatic ecosystems. These contaminants cause soil erosion, deterioration of soil biology and biodiversity, negatively impact soil fertility, and may acidify soils and water. Contaminants may remain in the soil, and potentially enter the food chain or the water supply, for periods ranging from hundreds to thousands of years

In the case of agriculture, adequate crop production is becoming increasingly difficult in some regions, partially because of the loss of soil fertility and declining nutrient use efficiency. Sustainable intensification of agriculture to increase productivity needs significant external inputs, particularly (usually expensive) nitrogen and phosphorus fertilizers, contributing to nutrient imbalances. This makes research into ways of closing nutrient budgets and seeking alternative sources of nutrients important. Research should also address the detrimental consequences of application of excess fertilizers and amendments (e.g. untreated wastewater rich in nutrients and pathogens), including emission of greenhouse gases, accumulation of contaminants in soils, and soil resistance to antibiotics that affect human health.

Another agricultural practice representing a threat to ecosystems and human health is the inadequate use of pesticides. Knowledge on the global distribution and pathways of pesticides in soils is insufficient, as no international monitoring/screening programmes exist. Applying the concept of planetary boundaries (Rockström *et al.*, 2009), pesticides in soils pose a major threat to the environment as they may disrupt critical functions and processes. Critical thresholds of pesticides in soil have not been defined for single pesticides or mixtures. Their fate in different soils under field conditions may differ from those predicted in the registration procedure, and long-term effects can be expected since soils are slower to respond than aquatic ecosystems. There is a strong need for a global screening strategy, aiming at a holistic database on pesticide application and soil pollution, including new approaches for efficient and environmentally friendly plant protection measures.

Regarding urbanization, historically human populations have tended to settle on fertile soils with easy access to water sources. However, the rapid growth of cities and associated infrastructure (e.g. industry) is increasingly generating conflicts, particularly in regions where soils suitable for food production or the generation of other ecosystem services are scarce.

Therefore, better soil management, integrated soil fertility, pest and water management, and more discriminate land use planning, are of the utmost importance to ensure long-term sustainable land management and crop production. The challenge is to find innovative and effective strategies to improve the management of external nutrient inputs and water, and optimize their use efficiency and productivity at farm level to improve both yield and quality without adversely affecting the environment. Novel approaches and technologies should be pursued, with the aim to decrease negative impacts on soil and the environment and to provide better product quality and benefits to human health. In this context, further sustainable intensification of agriculture is desirable for farms at all scales, to tailor soil management (particularly application of agrochemicals) to local differences within agro-ecosystems. In this way the use of natural resources and its associated cost could be reduced..

c. Social development

Research & Development and dissemination of adequate technologies are particularly relevant for regions with high demographic growth rates and low levels of agricultural productivity. In these areas, the challenges are to lift the poorer rural families out of poverty and hunger; to ensure livelihoods and rural employment by increasing crop production through ecologically efficient practices of agriculture; and to pursue economic, environmental and social sustainability. Anthropological and cultural aspects, including safeguarding ancestral knowledge on soil and land management, have to be taken into account in addition to technological and economic factors.

There is also need for high-level policy measures and pertinent research activities to improve interactions between the urban and rural sectors. The waste stream is an obvious example. Cropping and agricultural models serving the needs of nearby urban regions (and *vice versa*) may create more equitable and sustainable rural environments, including adequate transportation and access to basic services. In many nations of Africa, the provision of minimal services should contribute to lift populations out of poverty and help to slow the population growth, as it was possible to do in a number of other locations.

Understanding the role of soils in urban areas and in urban/rural integration is a basic condition for successful urban planning and land and soil management. Earning from successful cases of urban agriculture in some Latin American countries may be pursued.

Recommendation 2: Encourage inter- and transdisciplinary research and development to support the five pillars to enhance the development of appropriate sustainable soil management practices and systems, the applicable use of soil information, the harmonization of methods and determination of best indicators, and the dissemination of research results beyond the scientific community, to globally support economic growth, environmental sustainability and social development.

Implementation of this recommendation follows closely the research questions addressed by the five pillars of the GSP (Annex III), which incorporate the traditionally conflicting concepts of economic growth and sustainable development. Studies increasingly show that the rational use of natural resources can be economically and socially attractive, but more of such analyses are needed as suggested in Annex III.

While this plan of action necessarily takes a global perspective, maximum attention must be paid to context specific conditions (climate, pedology, land use and different cropping systems). To improve soil quality, health and functions, approaches and technologies adapted to different situations have to be widely adopted

3. Opportunities to enhance soil research coordination

It is clear that the soil research community should strive to work together and in close collaboration with other disciplines to plan and execute effective R&D initiatives. Pillar 3 puts a special accent on consolidated actions towards implementing a functional soil R&D system. In this regard, soil science should engage with other disciplines and highlight the broad functionality of soils. As a consequence, R&D and end-user communities could interact in a way that soils are seen from a perspective of quality and ability to serve a wide range of basic functions and to overcome the perception that soil is important to agriculture alone. Such a multi-functional research and development system requires a region-based approach, as a general rule, coupled with equal opportunities for soil researchers and soil users, since soil properties and soil resources are always regionally distributed. Thus, region-based implementation paves the way to better forecasting of research and innovation trends and market opportunities.

In most areas, soil scientists are organized in national and regional soil science societies under the overall purview of the International Union of Soil Science (IUSS). Alongside these science-oriented societies, many soil specialists from the applied sector are organized in a variety of groups active in different fields like nature conservation or farmers' associations. Also, an increasing number of *ad hoc* soil conferences and symposia are being organized. A region-based approach, *via* the RSPs established in the framework of the GSP, would facilitate the involvement of relevant communities in the implementation of agreed initiatives.

3.1 Opportunity 3: Gaps, priorities, synergies with related productive, environmental and social development actions

In an era in which technology and knowledge derived from evidence provided from research should underpin sound policy and practices, the main limitations confronted by the research and development communities are twofold: a) incomplete representation of the role of soils in providing a range of ecosystem services, and b) in many regions, a lack of adequate funding for integrated systems involving research and development actors. However, several research communities have recently experienced that good information utilized in the right context can lead to considerable funding. There is a need, therefore, to present convincing case studies (covering representative sites at worldwide level but suitably highlighted at regional level) showing the prominent role that soils can play in providing a range of ecosystem services. In a nutshell, only good information can help to efficiently target and design R&D efforts (e.g. covering required timeframes and levels of investment, how they generate multiple benefits, etc.) at global and regional scales.

Recommendation 3: Capitalize on existing R&D research initiatives and outputs through meta-analysis and synthesis reviews for all partners, to identify global, regional and local emerging priorities.

Information, processes and events with potential to support this recommendation may include:

- The SWSR-2015 report issued under the aegis of the ITPS and the GSP, which provides a global overview of the state and trend of soil resources and can be used as an initial source of information on gaps in knowledge and priorities for research.
- Inventories by the RSPs to complement the work done for the SWSR-2015, including past (15-20 years) and on-going initiatives, to identify regional knowledge gaps and define specific research priorities.
- General analyses and realistic recommendations on R&D strategies (e.g. regional work based on eco-zones) and special efforts (e.g. modelling for a particular eco-zone) feeding on the information provided by the SWSR-2015, the inventory analyses provided by the RSPs, and the inputs provided under other GSP pillars (Annex III).
- Design and execution of participatory actions to identify R&D priorities through the RSPs and other mechanisms of engagement with local partners undertaken at different levels and scales.
- Use of opportunities provided by the World Congress of Soil Science, Global Soil Week, regional and national congresses and workshops on soil science and other relevant venues, to obtain information about trends and needs of R&D activities. This could include sponsorship of dedicated sessions to support the intelligence work and/or address specific research gaps.
- A Global Soil Portal (along the lines of the successful European Soil Portal and other national scale portals) to assemble and disseminate important soil data and soil research information, including ongoing projects and links to project findings.
- Interaction with the private sector (i.e. agribusiness in general - end retailers, logistics companies & supply chains - as well as other business activities which impact soils) to strategically involve it in a close partnership since (with some exceptions) they drive innovation and hence impact on a significant amount of on-the-ground farming practices, also bearing in mind that public-private partnerships are being encouraged by donors.
- The collection and exchange of information among eco-regions with similar contexts (biophysical, socioeconomic and/or institutional dimensions) as knowledge, technologies and experiences shall be suitably adapted by the R&D community and accepted/adopted by the end-users.
- An initial (and brief) study of the baseline structure of the soil R&D community including main existing networks and initiatives, like research bodies of United Nations conventions, the IUSS (e.g. working groups on International Actions for the Sustainable Use of Soils, Land Degradation, and Global Soil Change), those linked to the SDGs, and other large programmes and initiatives.

3.2 Opportunity 4: Coordination to strengthen global soil R&D activities

Pillar 3 must take account of the shift in focus from a classical agricultural perspective to a more multi-disciplinary approach, including ecosystem benefits related questions, such as climate change, land-use change, food security, environmental protection, biodiversity conservation and energy production. In addition, the widespread introduction of modern information and communication technology (ICT) is drastically changing processes of information generation and dissemination. This implies further progress in terms of inter and trans-disciplinary research collaboration, including with the information society and social sciences.

Work under Pillar 3 of the GSP should inspire researchers to seek multi-disciplinary collaboration both within and outside soil science, improve the quality and applicability of research, provide new avenues for future R&D programmes, draw the attention of funding bodies, and design soil science research so as to address pressing societal, agricultural, and environmental challenges. This includes other sciences (e.g. computer information specialists, sociologists and economists to understand how research will be accepted and implemented), policy experts, and emerging professionals in the view to meet societal needs. Opportunities should be assessed for a broader community of researchers to be part of global and regional partnerships, including agronomists, experts on pasture/rangeland management, geomorphologists, hydrologists, water resource managers, ecologists, agro-climatologists, economists and rural sociologists, foresters, geologists, etc.

Given its mandate, the GSP should in effect encourage innovative inter- and trans-disciplinary research, and facilitate contacts with the donor community to generate adequate funding of R&D initiatives.

Recommendation 4: Foster synergy and engagement between research and end-user communities, and donor agencies, to facilitate active collaboration in a joint-learning approach that can be effective in broadening the research focus and enhancing its impact.

This effort must be of an ongoing nature and therefore, may require financial support to (e.g.) enable visits from leaders of identified initiatives and programs, approach potential donors, and/or participate in meetings that will facilitate these actions.

Supportive activities may include from different perspectives:

- Proactive contacts with international and regional existing R&D initiatives dealing with current global challenges, to foster strong synergies leading to higher potential impacts. E.g. NARES and regional research systems, centers and research programs of the Consultative Group on International Agricultural Research (CGIAR); the Global Research Alliance on Agricultural Greenhouse Gases and the associated scientific programs (e.g. the AgMIP, the FACCE-JPI, the Belmont Forum); the Science-Policy Interface of the FAO, GSBI, IPBES, IPCC, IUSS, IFAD, UNCCD, IAEA; World Health Organization, European Union Horizon 2020 research programme; and sources of soil data (e.g., ISRIC).
- Work with Pillar 2 to increase funding opportunities through donors, including Gates Foundation; African Development Bank; Future Earth, initiatives in land restoration/rehabilitation, etc.
- A database of scientists interested in the work of the GSP and willing to assist at global and regional scales, including basic information and interests of the researcher.
- Following successful examples, social media could facilitate the creation of research and development communities at global and regional scales (i.e. using Facebook, Twitter, LinkedIn, ResearchGates, wikispaces, blogs, and other recognized web-based platforms).
- Global and regional workshops and writeshops with participants from a wide range of stakeholders (demand side) and researchers (supply side) for preparation of sound initiatives,

either responding to calls for proposals or as initiatives of the GSP that meet national, regional and global needs.

- Inter- and trans-disciplinary collaboration with the four other pillars of the GSP to ensure that important information (e.g. data on soil fertility status, crop performance, yield gaps, etc.) will be effectively collected, organized and available to strengthen targeted research and technology dissemination.
- Regularly updated databases sharing innovative research approaches used by soil practitioners.
- Crosslinking innovative R&D and emerging issues by soil scientists to UN activities on chemicals production, use and disposal (namely Stockholm, Rotterdam and Basle convention and the Strategic Approach to International Chemicals Management).
- Particular attention to public private partnerships, given the potential role of the private sector in supporting actions towards increasing access to inputs and input use efficiency, and in reducing emissions from agriculture.

4. Implementation

The framework proposed for Pillar 3 of the GSP is relatively simple (Figure 2), and includes the key factors that should be considered to potentiate the soil R&D community and to enhance its relationship with end-user communities. It should be open-ended, since it may need eventually to consider new actions and actors for implementation. Continuous fluxes of information will be needed to support decision making to guide specific actions at global and regional scales.

Implementation of the Plan of Action will nevertheless require active collective action to consolidate accurate information, and to design and execute global and regional initiatives. In that regard, the GSP may need to validate and regularly revise this Plan of Action (so far developed by the soil community) by involving other relevant communities and end-users expected to actively participate in its realization. Successful implementation on the ground will require active and operative RSPs including stakeholders with an ample range of capacities, and participation by professionals from advanced (research and academy) institutions.

Considering current global challenges, implementation could start with three concrete actions, which are:

- For Recommendation 2: the identification of key factors causing soil degradation (e.g. as result of agricultural, industrial and residential use), with geographic and eco-regional differentiations. On the basis of such a comprehensive analysis, corrective actions can be suggested. It is worthwhile to keep in mind that much experience has been gained in combatting soil degradation (examples in WOCAT, 2007). In some cases the problem is not so much lack of technical information but lack of implementation of measures due to socio-economic reasons. In other cases there are huge gaps that require urgent attention, like the extent (area and intensity) of land degradation.
- For Recommendation 2: the preparation of overviews of: (i) efforts to monitor soil conditions all over the world, considering physical and chemical variables (including pollution/contamination) - under the leadership of Pillar 4[11]; and (ii) approaches and results

[11] Pillar 4 - Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines.

on soil rehabilitation/restoration with geographic and eco-regional differentiations – under the leadership of Pillar 1[12]. Much is being done already and comprehensive overviews are needed as they are essential to arrive at meaningful sharing of experiences, as well as generating new initiatives with a more efficient use of resources.

- For Recommendation 3: establishment of international (GSP) and regional (RSP) expert groups to collect and analyze current global/regional research efforts and their (potential) impact on sustainable development. On the basis of this and of regional R&D priorities, new initiatives can be conceptualized for research topics and/or approaches that fill gaps in our current knowledge and show the way to effectively generate and disseminate (in coordination with other pillars of the GSP) such knowledge.

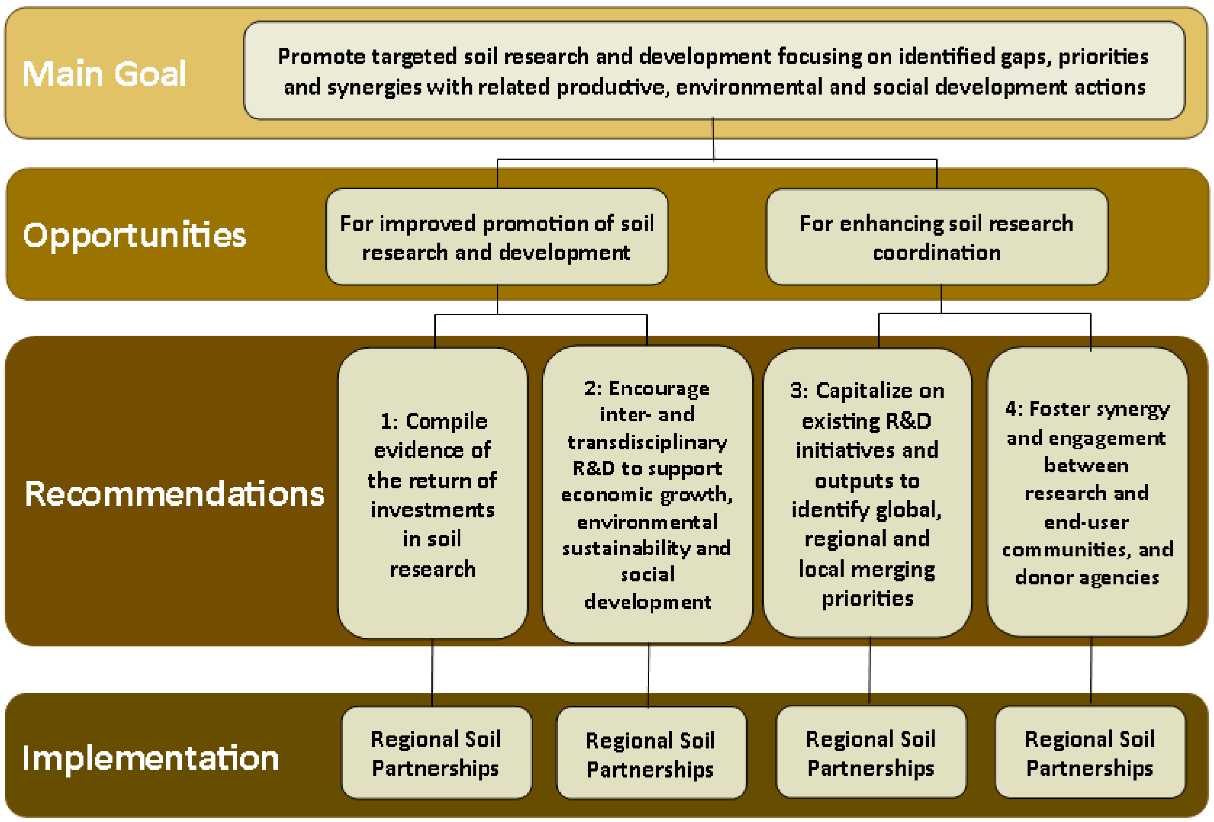


Figure 2: Framework for development and implementation of the Plan of Action of Pillar 3 of the GSP. Four recommendations to address two identified opportunities, to be implemented through the Regional Soil Partnerships.

http://www.fao.org/globalsoilpartnership/the-5-pillars-of-action/4-information-and-data/en/

[12] Pillar 1 - Promote sustainable management of soil resources for soil protection, conservation and sustainable productivity. http://www.fao.org/globalsoilpartnership/the-5-pillars-of-action/1-soil-management/en/

Whilst execution of actions with global impact (e.g. development of a global soil portal) will mostly depend on the GSP Secretariat, implementation at regional scale will involve participatory (starting with all countries involved) preparation of pathways and timelines (e.g. to develop, apply and analyse surveys to identify research priorities). Regional Soil Partnerships will require backstopping from the GSP as they will be the main actors that support implementation at regional scales.

Global and regional indicators will have to be determined to evaluate implementation, performance and usefulness of the Plan at global, regional and local scales. They may include:

- Outputs from workshops/writeshops
- Number of developed initiatives and prepared proposals
- Individuals trained (and corresponding demographics)
- Technologies adapted/developed
- Number of experts that were consulted/responded to requests from the GSP and RSPs
- Type and amount of outreach efforts (e.g., videos, publications)
- Impact on sustainable development

5. Risk management: external factors

Implementation of the Plan of Action for Pillar 3 may face a number of external challenges, which will have to be addressed at different levels by providing sound evidence on the crucial importance of soils to sustainable development. Only successful case studies can convince stakeholders and policy makers of the significance of soils R&D. The following external factors may affect the successful implementation of Pillar 3 at global and national levels:

Global/regional scale:

- Conflicting priorities of the donor community.
- Insufficient support/openness from the R&D community.
- Lack of response in global consultations.
- Intellectual property issues (on data collected and concepts, knowledge, and technologies developed).
- Lack of agreement in prioritization of R&D needs.
- Lack of agreement in the scope of interventions (e.g. land management vs. soil management – semantics vs. actions on the ground?).
- Scope of R&D: only knowledge generation and technology development or also adaptation of already developed technologies?
- Responses (formulation of priorities, velocity of reaction, etc.) may be different depending on level of development within the regions.
- Willingness/capacities of regions to support implementation of global initiatives (e.g., servers to store databases from R&D activities).

National scale:

- Conflicting national priorities on R&D.
- Lack of legislation (e.g. for conservation of soil resources, indigenous practices, etc.) supported or implemented by governments to aid in prioritising the need for soil R&D.
- Disagreements in focus of R&D activities.

- Lack of adequate capacity (staff, laboratories, infrastructure).
- Personal security related issues.
- Willingness/capacities of countries to support implementation of regional initiatives (e.g., servers to store databases from R&D activities).

6. References

Alene, A.D., V.M. Manyong, S. Abele, and D. Sanogo (editors). 2007. Assessing the impact of agricultural research on rural livelihoods: achievements, gaps, and options. Scientific papers presented during the twenty-sixth conference of the International Assoociation of Agricultural Economists, 12–18 August 2006, Brisbane, Australia. IITA, Ibadan, Nigeria. 80 pp.

Barrios, E. 2007. Soil biota, ecosystem services and land productivity. Ecological economics, 64: 269-285.

Bouma, J., A.C.van Altvorst, R.Eweg, P.J.A.M.Smeets and H.C.van Latesteijn. 2011. The role of knowledge when studying innovation and the associated wicked sustainability problems in agriculture. Advances in Agronomy 113:285-314.

Dominati E, Mackay A, Green S and Patterson M 2014: A soil-change based methodology for the quantification and valuation of ecosystem services from agro-ecosystems: A case study of pastural agriculture in New Zealand. Ecol. Econ.100, 119-129.

Engel, P. 1997. The social organization of innovation. Amsterdam: Royal Tropical Institute.

European Commission. 2012. Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: The implementation of the Soil Thematic Strategy and ongoing activities. Brussels, COM 2012/46 final. http://eusoils.jrc.ec.europa.eu/library/jrc_soil/policy/DGENV/COM(2012)46_EN.pdf

European Union. 2013. Regulation no 1291/2013 establishing Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020) and repealing Decision No 1982/2006/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:347:0104:0173:EN:PDF

Janzen, H.H., P.E. Fixen, A.J. Franzluebbers, J. Hattey, R.C. Izaurralde, Q.M. Ketterings, D.A. Lobb, W.H. Schlesinger. 2011. Global Prospects Rooted in Soil Science. Soil Sci. Soc. Am. J. 75:1-8.

Lal, R., J. M. Kimble, and R. F. Follett. 1997. Pedospheric processes and the carbon cycle. Pp. 1-8 in Soil Processes and the Carbon Cycle, R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, eds. Boca Raton, FL: CRC Press

Lipper, L. 2001. Dirt Poor: Poverty, Farmers and soil resource investment and socio-economic aspects of soil degradation. Economic and Social Development Paper 149. FAO: Rome, pp. 1-3.

MEA. 2005. Millenium Ecosystem Assessment: Ecosystems and human well-being: Biodiversity synthesis. Washington, D.C., World Resources Institute.

Montanarella, L. and G. Tóth. 2007. Desertification in Europe. European Commission Joint Research Centre Institute for Environment and Sustainability. TP 280I-21020 Ispra (VA), Italy. http://eusoils.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/Conf/Desertification_Europe.pdf

Meinzen-Dick R, Adato M, Haddad L, Hazell P. 2004. Science and Poverty. An Interdisciplinary Assessment of the Impact of Agricultural Research. International Food Policy Research Institute. Washington, DC.

National Research Council. 2004. Valuing Ecosystem Services: Toward Better Environmental Decision-Making. Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems. 290 p. ISBN: 978-0-309-09318-7

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, III, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley. 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14(2): 32.

United Nations, Department of Economic and Social Affairs, Population Division. 2013. World Population Prospects: The 2012 Revision, Highlights and Advance Tables. Working Paper No. ESA/P/WP.228.

WOCAT (World Overview of Conservation Approaches and Technologies). 2007. Where the Land is Greener. In: Liniger H, Critchley W, (Ed). Case studies and analysis of soil and water conservation initiatives worldwide. Bern. Switserland.

Annex I: Proposed additions to the Glossary

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.

Bioturbation in soils refers to the reworking of soil and sediments by macrofauna, animals or plants and may include displacing soil by plant roots, digging by burrowing animals (such as termites, earthworms, or rodents), pushing sediment aside (such as in animal tracks), or eating and excreting sediment, as earthworms do.

Climate Smart Agriculture refers to agriculture that sustainably increases productivity, improves resilience (adaptation) and reduces greenhouse gas emissions (mitigation), contributing to the achievement of national food security and development goals.

Conservation agriculture (CA) aims to achieve sustainable and profitable agriculture and subsequently to improve farmers' livelihoods through the application of the three principles: minimal soil disturbance, permanent soil cover and crop rotations. It is a way to combine profitable agricultural production with environmental concerns and sustainability and it has been proven to work in a variety of agro-ecological zones and farming systems.

Interdisciplinary research consists of different scientific disciplines that cooperate in working together on a given problem and involves coordination of activities and methodologies[13].

Multidisciplinary research consists of different scientific disciplines working rather independently on a given problem[15].

Nutrient imbalance refers to an excess or a lack of nutrients (mainly nitrogen, phosphorus and potassium) in the soil as a consequence of (bad) land use and management. It may result in soil contamination when nutrients are in excess and in loss of inherent fertility when nutrients are mined[14].

Soil biodiversity refers to the diversity in soil life, from genes to communities, and the ecological complexes of which they are part, that is from soil micro-habitats to landscapes.

Soil health is "the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health."[15]

Soil rehabilitation is used to refer to the re-establishment of soil ecosystem functions after these have been affected or impaired by land degradation. In time, activities may fall short of fully restoring the biotic community to its pre-degradation state.

Sustainable Intensification of Agriculture refers to environmentally sustainable increase of food production or yields on existing farmland (i.e., without the cultivation of additional land).

Sustainable Soil Management: Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity.[16]

Transdisciplinary research is a new form of learning and problem solving involving cooperation between different parts of society and science in order to meet complex challenges of society. Transdisciplinarity research starts from tangible, real-world problems. Solutions are devised in collaboration with multiple stakeholders[15].

Water productivity may be defined as unit of biomass produced per unit of water applied.

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[13] Source: Johan Bouma.

[14] SWSR-2015.

[15] FAO. 2008. An international technical workshop Investing in sustainable crop intensification The case for improving soil health. Integrated Crop Management Vol.6-2008. FAO, Rome: 22-24 July 2008.

[16] World Soil Charter, 2014

Annex II: Pillar 3 mailing list (December 2012 – February 2015).

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Annex III: Research questions and themes raised within the GSP (Plans of Action for GSP pillars 1, 2, 4 and 5; the Status of the World's Soil Resources report, and external reviewers) to be considered for the implementation of Pillar 3.

Pillar 1: Sustainable Soil Management

- **Technical challenges:** Technology knowledge development to optimally use the available technologies, for improving and maintaining vegetation cover, protecting soil from water run-off, quality seed-bed preparation, pest and weed control (including responsible use of phytosanitary treatments), field transport operations for fertilizer spreading and crop harvesting, maintaining soil organic matter, and improving of sustainable soil management practices as a whole.
- **Sustainable soil management:** Research on soil structure and texture, soil organic matter, soil tilth, soil cover, soil biota, soil functions and productivity, chemical fertilizers and pesticides, cropping systems, crop rotation, organic manures and fertilizers, and phytosanitary treatments and microbial inoculants.
- **Economic challenges:** Overcome low economic efficiency of agriculture due to cost of inputs, lack of versatility, adaptability of tools and technologies in different regions, management conditions, instability of crop production, and poor ability of the soil to perform ecosystem functions.
- **Costs and Benefits from Sustainable Soil Management Practices:** Analysis of cost-benefit scenarios in terms of implementing sustainable soil management technologies and approaches to determine the cost effectiveness of local innovations and modern scientific advances. Promotion of sustainable soil management at land user and policy levels, assessing the costs of inaction versus the costs and benefits of sustainable soil management. Gaps include knowledge, skills and technology transfer to various stakeholders.
- **Policy changes:** Scientific facts and recommendations to appropriate policy platforms, to support allocation of resources to reverse soil degradation, protect soils and enhance its ecosystem functions. National level policies need to focus on protecting agriculturally productive and potentially agriculturally productive soils for agricultural use, to increase sustainable soil management, to improve and maintain the functions of soils in non-agricultural land uses, to combat desertification, and finally to provide a global and legal framework to achieve land and soil degradation neutrality, and minimize the loss of fertile soil.

Pillar 2: Investment, Technical cooperation, policy, education, awareness and extension

- **Investment:** Research programmes that provide rapid, accessible and integrated scientific information and advice for key policy areas, particularly in relation to the consequences of environmental or climate change and the development of indicators and tools to monitor soil quality and threats to soils.
- **Technical cooperation:** include research institutions, such as the CGIAR (Consortium of International Agricultural Research Centers) with its international institutes and centres (CIAT, CIMMYT, IITA, ICRISAT, IRRI, etc.) and other partners on issues related to training and international cooperation involving the soil-related themes;

  Recommendation 6: Scientific and technical cooperation should be promoted and strengthened between partners of the Regional Soil Partnerships and through -South and North-South cooperation schemes (links to Pillars 1 and 3).

- **Public awareness rising:** Funding and performance targets mean that greater emphasis is placed on high- level research and peer reviewed publications than on outreach activities, often only carried out by motivated 'volunteers'. As a result, soil scientists have evolved to communicate soil through a complex language, dominated by a technical vocabulary that is incomprehensible to almost everyone outside the soil science community. Outreach activities should be structured in a way that ensures active participation and discovery by participants in order to assist them in understanding the links between soil, its functions and cause-effect relationships in its use and misuse.
- **Education:** Soil science education should follow with actual research priorities as for instance the impacts of climate change on soils and food security. A soil education programme is needed for capacity building, strengthening capacity to attaining an adequate skills base, trained to collect the necessity data and interpret the results for decision makers.

  Encourage funding organisms to reward education and outreach aspects within research programmes and proposals.
- **Awareness:** Research outputs should increasingly be judged on both their scientific integrity and their relevance and societal impact. In addition to the production of scientific papers and reports, new ways of communicating the importance of soil and soil science to diverse groups from national and international politicians to primary-age school students, must be found at national scales.
- **Extension:** Education and participatory training of soil extension services staff at all levels in a way that research outcomes can be made available for users in various forms.

Pillar 4: Soil data and information

- **Opportunities created by technical advances:** 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.

Pillar 5: Harmonization of methods, measurements and indicators

- **Soil quality observation and analytical design:** develop new soil assessment and monitoring techniques including innovative analytical techniques for field and laboratory applications to assess indicators for soil functioning and ecosystem services; this includes remote sensing and sensor techniques for broad applications in rural agriculture.
- **Cross-referencing, validation and integration of large data sets**: utilize new developments in information technology, geographic information systems, statistics and modeling for the harmonization and exploratory processing of large data bases including interactive web-based communication of soil data.
- **Indicator development:** develop an indicator system for soil monitoring which is closely rooted in practical soil management, and which considers regional frame conditions.

Status of the World's Soil Resources

- Sustainable intensification – how can we get the benefits from intensification while minimizing the environmental costs that are currently associated with the intensification?
- How can we manage for resilient soil and related ecosystem services while continuing to maximize efficiency? To what extent can you have both?

- What is the extent of degraded lands? There are currently no sound estimates. What portion of degraded lands can be attributed to intensification?
- What can we learn from management practices used in intensification areas to help restore degraded lands? Are there any options that can integrate best management practice for sustainable intensification? What are the short- and long-term tradeoffs of resource use and sustainability? What are the environmental costs and economic benefits of land use intensification?
- Policy relevance should be developed with balancing the interests among the multi-stakeholders of farmers, consumers and government.
- How do changes in harvest frequency and crop rotation affect soil resilience? How much change is needed to restore degraded lands?
- A global synthesis or inter-correlation could be an option for international study for characterizing the soil changes with continuous intensification, especially with greenhouse production.

Compatibility in the use of natural resources with economic and social goals:

- Rational use of natural resources and external inputs.
- Reduction of soil contamination and emission of toxic substances.
- Options for soil fertility conservation (e.g., conservation agriculture, integrated nutrient and soil fertility management, etc.).
- Biodiversity conservation.
- Increased knowledge of soil health: properties, composition of the soil biological community and complex plant-soil-microbial interactions to enhance decomposition of soil organic matter, nutrient use efficiency, bioturbation, and disease and pest control.
- Increased understanding of methodologies for the restoration of soil functions.
- Understanding the linkages between soil (class, heath, management, etc.) and quality/quantity of water resources.
- Whenever possible the standardization of indicators and metrics, or their adaptation to local conditions, and M&E protocols for assessment and monitoring of soil health, aimed at communicating sustainability performance to different stakeholders.
- Best combinations of biological, physical and chemical (lowest dose and frequency of pesticides with the least negative side effects) methods for integrated pest management.
- Metrics for determination of potentially agriculturally productive soils within geographic areas and eco-regions.
- Trade-offs and cost/benefit analyses, including the financial value of soil-related ecosystem services, the value of science and of actions towards rehabilitation of degraded soils.
- Metrics of the impact of inputs (mainly pesticides) on soil quality and health, at global scale.