Soil Biodiversity, Functions, Ecosystem Services and the International Sustainable Development Agenda

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Abstract

The paper focuses on soil biodiversity within agro-ecosystems. Soil biodiversity underpins a multitude of ecosystem functions and processes which deliver benefits to people (ecosystem services). These ecosystem services are essential both to sustain food production and manage the impacts of agro-ecosystems beyond farming and are, therefore, at the heart of achieving sustainable intensification of agriculture. Restoring soil ecosystem services offers considerable opportunity to address the current alarming state and trend in degradation of agricultural soils world-wide. Attention is drawn to the current international policy framework, with examples of the main multi-lateral environment agreements (the Conventions on Desertification, Climate Change and Biodiversity) and the outcomes of the recent Rio+20 Conference. Terminology differs significantly between these, but sustaining or restoring soil functions and health can be clearly identified as a cross-cutting approach to achieve the various stated objectives. A number of other forums, processes and institutions are providing a similar message. Whilst there is room for improved coherence among these agreements and approaches etc., and options for more specific frameworks to strengthen attention to soils, one immediate priority is to identify ways and means to support and enhance implementation of existing agreements and frameworks.

1.1 Overview

Biodiversity underpins ecosystem processes, which in turn deliver benefits to people (ecosystem services) and therefore for human well-being (e.g. as *per* The Millennium Ecosystem Assessment 2005). Soils underpin the functioning of terrestrial ecosystems and therefore most of the services they deliver. This paper focusses on soils in agro-ecosystems because farming is the dominant use of land, soil biodiversity is a key determinant of land productivity and farming currently faces significant sustainability challenges. Improved management of soil biodiversity in agro-ecosystems offers solutions for sustainable farming and food security, whilst simultaneously increasing carbon storage, improving water cycling and reducing off-farm pollution. This forges very strong multi-level and multi-sectoral links between soil biodiversity and the global sustainable development agenda, including between multi-lateral environment agreements and in particular relating to biodiversity, desertification and climate change.

Section 2 of this paper briefly outlines how biodiversity underpins soil functions and processes which in turn deliver ecosystem services. Relationships are complex and most of our knowledge is based on practical experience of trying to manage the outcome of these functions and processes (that is, soil health and services). Section 3 gives a brief overview of the recent global trend in soils in agriculture concluding that current farming practice, overall at the global and regional scales, continues to essentially degrade land and soil ecosystem services. Losses in ecosystem services required for crop production have been partly compensated by applying more external inputs, but simultaneously increased farming footprints on the broader ecosystem. Concerns regarding resource depletion, an off-farm inpacts, now prompt us to seek new development models that shift efforts towards more sustainable intensification. Section 4 presents some examples of the progress being achieved, in particular by farmers and their support organisations, by changing management to reinstate soil ecosystem services required by both farmers and beyond farming.

Section 5 draws attention to the global sustainable development agenda, with emphasis on biodiversity, ecosystems and the environment within this dialogue. This landscape reflects considerable recognition of the relevant challenges and significant opportunities for soil biodiversity to address them; although terminology varies considerably between different interest groups. Section 6 identifies the key need for strengthened implementation of efforts in response to existing policies. This suggests that a priority topic for discussion at *Global Soil Week* might be the identification of socio-political and economic constraints to up-scaling and mainstreaming workable biodiversity based solutions, and ways and means to overcome them, by building better and more effective partnerships.

1.2 Soil biodiversity, functions, and ecosystem services

The biological functions of soils are complex and underpin a number of often inter-related bio-physical processes which deliver a multitude of ecosystem services. A somewhat simplified overview of this is provided in Table 1.

Table 1: Examples of organisms, functional groups, ecosystem processes in soils (modified from Wall 2004), and ecosystem services derived from soils (based on Millennium Ecosystem Assessment 2005). Relationships are complex and services are usually based on combinations of processes, and services can also be inter-dependent. These, and other, services underpin broader aspects of human well-being such as food security, water security and reduced risks from natural disasters.

Organisms	*Functional groups*	*Ecosystem process*	*Ecosystem services*
Vertebrates (lizards, beavers); invertebrates (crustaceans, molluscs in sediments; ants, termites in soils; earthworms)	Bioturbators, ecosystem engineers	Soil and sediment alteration and structure, laterally and to greater depths, redistribute organic matter and microbes	*Supporting services:* Soil formation Nutrient Cycling *Regulating services:* Climate regulation Disease and pest regulation Water regulation (water availability, including
Plant roots, algae, diatoms	Primary producers	Create biomass, stabilize soils and sediments	

Decapods, millipedes	Shredders	Fragment, rip, and tear organic matter, providing smaller pieces for decay by organisms	regulating extremes – drought and flood) Detoxification Pollination *Provisioning services:* Food Freshwater Fuel Fibre Biochemicals Genetic resources *Cultural services:* Spiritual, recreational, symbolic etc. values of landscapes
Bacteria and Fungi	Decomposers	Recycle nutrients, increase nutrient availability for primary production	
Symbiotic (e.g *Rhizobium)* and asymbiotic (e.g. *Azobacter, Cyanobacter*)	Nitrogen fixers	Biologically fix atmospheric N_2	
Methanogenic bacteria, denitrifying bacteria	Trace-gas producers	Transfer of C, N_2, N_2O, CH_4 denitrification	
Roots, soil organisms	CO_2 producers	Respiration, emission of CO_2	

Some of the key functions of biodiversity and processes in soil ecosystems are, in practice, primarily about regulating the three major bio-geochemical cycles on earth: nutrient, carbon and water cycling. These functions, and the services they support, are essential for sustaining the three natural resource related challenges that dominate current discussion regarding sustainable development and human well-being: put simply - food, energy and water security. These three cycles are also inter-dependent, particularly in soils (examples are provided later). Additional important functions of soils include regulating pests and diseases and supporting pollinators; both are important ecosystem services for farming and in the case of pest regulation also contribute to reducing off-farm impacts (reducing chemical pollution).

The nature of the covering on top of the soil, in particular the presence or absence of living plants (e.g., “cover crops”) or organic matter (e.g., stubble, stover or mulch), and therefore the extent of exposed soil, is also a key determinant of how the ecosystem services provided by soils are influenced. Whilst plant roots are often considered as part of “soil biodiversity”, any consideration of soils as ecosystems must include the above ground biological components, whether rooted or not (examples are provided later).

The influence of soils on nutrients, carbon and water is substantial locally, regionally and globally, and in places probably exerts the major influence. Approximately 62% of the water falling on land is either stored within or evaporated from the soil and plants covering it (Hartmann 1994). Of the freshwater which is stored on land, 74% is retained in glaciers, 25% is stored in the vadose and saturated zones of the soil, leaving less than 1% as accessible surface water (Bockheim and Gennadiyev 2010). These figures clearly indicate the importance of soil water for the Earth's land–water–energy balance and feedbacks as the climate warms (Koster *et al*. 2004; Huntington 2006). Soil cover controls the flux of energy and water by interacting with components of the atmosphere, hydrosphere, biosphere and pedosphere (Lal 2009). Soil organic carbon is itself composed of, or derived from, biodiversity and promotes soil biological activities and processes, resulting in more bacterial waste products, organic gels, fungal hyphae (polysaccharides), and worm secretions and casts (Wuest *et al*. 2005), which in turn improve aggregate stability, porosity and nutrient cycling, including retention by soils and thereby water quality. World soils collectively comprise the third largest global Carbon pool (2000 Pg of organic C and 750 Pg of inorganic C to a depth of one metre). This total is 3.2 times the atmospheric pool (720 Pg) and 4.1 times the biotic pool (560 Pg) (Lal 2004).

There is incomplete scientific understanding of the intricate relationship between biodiversity, functions, processes and ecosystem services in soils. It is currently difficult to answer questions regarding what levels and elements of biodiversity are required to sustain particular functions. We do know that diversity matters; for example, Ernst *et al*. (2009) found that soil water infiltration and flow was positively affected by the combined activity of ecologically different earthworm species, and, in turn, earthworm population densities depend on land cover (Blanco-Canqui and Lal 2007). Fortunately, we know more about land management and its practical impacts on soil ecosystems and ecosystem services. Practitioners tend to use more easily understood concepts such as soil “quality” and “health”: soil quality being the capacity of a specific kind of soil to function, within natural or managed ecosystems boundaries, to sustain plant and animal production, maintain or enhance water and air quality, and support human health and habitation; soil health includes the ecological attributes of the soil, which have implications beyond its quality or capacity to produce a particular crop (FAO 2002). These attributes are chiefly those associated with the soil biota: its diversity, its food web structure, its activity and the range of functions it performs. Soil biodiversity *per se* may not be a soil property that is critical for the production of a given crop, but it is a property that may be vital for the continued capacity of the soil to support that crop (FAO 2002).

1.3 Anthropogenic drivers of degradation of soil biodiversity and ecosystem services

According to Millennium Ecosystem Assessment (2005), some two-thirds of our ecosystems are degrading, some in the process of severe degradation. The Global Assessment of Human-Induced Soil Degradation showed that already by the 1980’s, most of the world’s agricultural land had been degraded to some degree, and degradation had reached alarming proportions for half the land area (Oldeman *et al*. 1991). Severe degradation of cropland is most extensive in Africa, with 65% of cropland areas affected, compared with 51% in Latin America and 38% in Asia (CA 2007). More recently, only some 10% of the global agricultural land is considered to be under improving condition, with the rest suffering from some degree of continuing degradation, and with 70% being characterized as being moderately to highly degraded (FAO 2011). Given the multi-dimensional nature of soil ecosystems, land degradation is not a binary concept, but a matter of degree along the different dimensions, with functional consequences. Most of the key dimensions of this degradation involve water (usually water scarcity, but also in places water logging), nutrients (both depletion in and run-off from soils), chemical impacts and loss of organic carbon.

There exists a strong relationship between agronomic production and the soil organic carbon (SOC) pool, especially in low-input agriculture (Lal 2009), including a good correlation between SOC, soil structural stability and plant-available water (Mrabet 2008; Abid and Lal 2009; So *et al*., 2009; Imhoff *et al*. 2010). That is, a strong relationship between water and carbon regulation ecosystem services provided by soils. Despite this knowledge, current agricultural land use continues to contribute to the decline of the SOC pool in vast regions of intensive crop production (Cole *et al*. 1993). Most agricultural soils have lost 25 to 75% of their original carbon pool, and severely degraded soils have lost 70 to 90% of the antecedent pool (Bockheim and Gennadiyev 2010).

Accelerated on-farm soil erosion and nutrient depletion undermines farm productivity and sustainability and increases downstream sedimentation, a major reason of investments in water and irrigation infrastructure losing capacity faster than planned, and degrades water quality. Globally, agriculture is the main contributor to both point and non-point-source water pollution, especially from nitrogen (WWAP 2012). The European Nitrogen Assessment report from 2011 shows the annual economic cost in Europe from inefficient Nitrogen use to be 70 to 320 billion Euros (Sutton *et al*. 2011). This loss of nutrient regulation services provided by soils is resulting in severe impacts on estuaries and marine ecosystems: for example, the increasing occurrence and severity of "dead-zones", due to eutrophication, in marine systems (WWAP 2012). In addition to impacts of nutrients (fertilizers), the use of other chemicals, especially pesticides, is degrading soil biodiversity and the ecosystem services it supports, including interfering with carbon storage, water retention, nutrient cycling and pest and disease regulation (Giller *et. al*. 1997).

Tillage agriculture, which pulverises and exposes soils and destroys soil life and health, that has been promoted in the US after World War One as soon as 'tractorization' became possible, and since the end of World War Two generally in the North and continues to be promoted in the South, is generally unable to harness soil ecosystem services adequately and has high negative externalities (Kassam *et al*. 2009; FAO 2011). The result of tillage as a predominant agricultural land use practice, in combination with exposed or uncovered soil surfaces, excessive chemical use and reduced organic input, has been to reduce SOC, soil aggregate structure and soil biodiversity, leading to severe degradation and finally to desertification, as can be observed in agro-ecosystems in most parts of the world (Oldemen *et al*. 1991; Montgomery 2007; CA 2007; FAO 2011). Nutrient depletion and chemical degradation of soil are primary causes of decreasing global crop yields, and cereal crop yields have been decreasing since the mid-80s (or mid-90s depending on how one calculates this). In irrigated areas, secondary salinization and water logging threaten past productivity gains (CA 2007).

The removal of land cover, cover crops or crop residues through burning or for fodder and biofuel purposes, is also a major threat to soil productivity, environmental quality, and overall sustainable development (Blanco-Canqui and Lal 2009; Hakala *et al*. 2009; Lal 2009). Besides giving physical protection to the surface soil layer and having an impact on infiltration and evaporation, land vegetation cover and organic residues enhance the build-up of soil organic matter and soil biodiversity activity which contribute to improving soil porosity, soil particle aggregation, soil moisture storage, and deep water infiltration (Wuest *et al*. 2005; Ben-Hur and Lado 2008; Lal 2009).

These anthropogenic drivers combine to generate interdependent affects on soil biodiversity, soil functions and therefore the delivery of essential ecosystem services derived from agro-ecosystems, including degrading the services farming itself requires. The situation regarding water security is made even worse in arid and semi-arid areas where tillage farming combines with negative annual water balances, short and variable rainy seasons, and increasing soil salinity to degrade soil systems more rapidly.

These trends in lost ecosystem services have global implications. For example: they suggest food supply is increasingly insecure, with all the potential ramifications for everybody of such a situation. Water loss from soils, in dry and sub-humid areas, is the direct cause of desertification (by definition). Although 78% of currently degrading land is in non-dryland areas, over 45 per cent of Africa is affected by desertification, 55 per cent of this area is at high or very high risk of further degradation and 2/3rds of Africa's arable land could be lost by 2025 if this trend continues, land degradation directly affects 1.5 billion people globally and 74% of the poor are directly affected by land degradation (UNCCD Secretariat 2011). By 2030, about half of the world population will be living in areas of high water stress (OECD 2008), agriculture already accounts for 70% of global water withdrawals and is under increasing competition with other water uses (WWAP 2012), meanwhile water is already the major constraint to increased agricultural output (CA 2007).

1.4 Reversing degradation: restoring ecosystem services and achieving sustained increases in agricultural productivity, reducing off-farm impacts and responding to climate change

Fortunately, there are solutions to reverse the above trends, and in particular by restoring the benefits of biodiversity. There are some examples where "biodiversity" can be used as a direct intervention in the production system aimed to alter the abundance or activity of specific groups of organisms through inoculation and/or direct manipulation of soil biota; for example, inoculation with soil beneficial organisms, such as nitrogen-fixing bacteria, Mycorrhiza and earthworms, has been shown to enhance plant nutrient uptake, increase heavy metal tolerance, improve soil structure and porosity and reduce pest damage (FAO 2002). But the most obvious solution, with the greatest large-scale application, is to enable soil ecosystems to auto-restore by managing and the reversing the drivers of soil degradation. Because soils underpin numerous ecosystems services, and in particular regarding water, carbon and nutrient cycling, and these are largely mutually reinforcing, soil restoration offers solutions to simultaneously achieve multiple outcomes including sustainable increases in agricultural production, more positive off-farm impacts and effective responses to climate change (both mitigation via carbon storage and adaptation particularly improved water management).

Today it is more widely recognized that minimal soil disturbance improves biodiversity outcomes including aggregate stability, water cycling and SOC accumulation and stabilization (Bescansa *et al*. 2006; da Veiga *et al*. 2008; Fernandez-Ugalde *et al*. 2009;). A very clear and direct relationship between improved farming practices, SOC content, and available water content was reported by Fernández-Ugalde *et al*. (2009). Soil cover also has a decisive positive effect on soil water dynamics and contributes to enhanced crop water productivity as well as nutrient and SOC management (Naudin *et al*. 2003; Dabney *et al*. 2004; Wuest 2007; Mulumba and Lal 2008a; Jordan *et al*. 2010; Liu *et al*. 2011). The time lag for run-off generation is also greater when crop residue is left on the soil surface (Jordan *et al*. 2010) and this can also assist in flood regulation downstream. Similar benefits are achieved through vegetated cover (Leys *et al*. 2010). Soils with cover crops or mulched with crop residues can also reduce maximum soil temperature and lower its amplitude (Trevisan *et al*. 2002; Fabrizzi *et al*. 2005; da Silva *et al*. 2006; Zhang *et al*. 2009), due to their higher solar reflectivity and lower thermal conductivity (Hillel 1980; Shinners *et al*. 1994). Other ecosystem services enhanced by maintained cover crops, or retaining crop residues, such as off-setting CO_2 emissions and maintaining the overall soil quality or facilitating weed management and hence reducing the use of herbicides, need to be factored into considerations regarding options. The adaptation of agriculture to climate change (Batisti and Naylor 2009) through restoration of soil quality by improving the quantity and quality of the SOC pool, and hence water retention, represents a major opportunity (Lal 2004).

Opportunities are not limited to rainfed farming systems. Water-saving technologies such as growing aerobic rice (Bouman *et al*. 2007) or using the System of Rice Intensification (SRI) methods (Kassam *et al*. 2011; Uphoff *et al*. 2012) also represent major opportunities for sustainable management of soils, water and other agricultural inputs in irrigated systems.

The modern successor of no-till farming, generally known as “Conservation Agriculture”, involves the simultaneous application of four practical ecosystem-based principles centred on locally-formulated practices: limited soil disturbance; maintaining a continuous soil cover of organic mulch and/or plants (main crops and cover crops including legumes); cultivation of diverse plant species; and good crop, nutrient, weed and water management. All contribute to enhance system resilience. Conservation agriculture is now practised worldwide on an estimated 125 million ha: mainly in North and South America, and in Australia, but uptake is increasing in Kazakhstan, Ukraine, Russia and China, and is gaining traction elsewhere in Asia (including on the Indo-Gangetic Plains), and in Europe and Africa where two-thirds of the area is under small-holder production (Friedrich, Derpsch and Kassam 2012). Conservation Agriculture has become the flagship of an alternative agricultural paradigm for intensifying crop production that not only improves and sustains agricultural productivity but also delivers important ecosystem services beyond farming systems (Kassam *et al*. 2009, 2011; FAO 2011). For example, the promotion of conservation agriculture in the Itaipu watershed, in the Paraná basin in Brazil, has enabled the reduction of soil erosion and the delivery of clean water to the Itaipu dam to generate hydro-electric power for Brazil, Argentina and Paraguay (Mello and van Raij 2006; ITAIPU 2011). Not only did this improve farmer livelihoods, it extended the life expectancy of the dam five-fold (a considerable benefit considering the investment cost and economic importance of the dam – and likely far outstripping the local economic benefits for farming directly). Gomez *et al*. (2011) report that Conservation Agriculture reduced erosion up to 97.4%, when compared to conventional tillage, in vineyards and olive groves France, Spain and Portugal, as well as delivering improvements in SOC and nutrient availability for crops. The System of Rice Intensification (SRI) is an alternate way of producing irrigated or rainfed flooded rice that includes better attention to restoring the functions of soils by keeping the soil just moist but not continuously flooded, thereby promoting aerobic conditions for soil biodiversity. SRI is reported to increase yields by 25–75 per cent, reduce water requirement by 40-50 per cent, reduce seed needs by 80 to 90 per cent, the use of fertilizer by some 50 per cent and lower cost of production by 20 per cent. SRI changes in the management of crops, soil, water and nutrients have now been demonstrated across some 50 countries by 4-5 million resource-limited small-scale farmers on some 5 million hectares, by using locally-available resources as productively as possible (Barison and Uphoff 2011). Such examples of how restoring soil health, that is, managing biodiversity, and the functions and services it underpins, not only deliver on-farm benefits but also wider public benefits including reduced run-off of nutrients and chemicals, reduced erosion, improved surface water management and hence improved water security downstream.

Experience shows that it is possible to achieve win-win outcomes (sustainable intensification, enhanced off-farm benefits and responding to climate change) through soil restoration interventions. These mutually supporting outcomes are illustrated further in the next section with regards to addressing multiple international agreements and policies on the environment and sustainable development.

1.5 The relevance of soil ecosystem services to the international policy landscape and the sustainable development agenda

1.5.1 Key forums

A number of international agreements and conventions serve as important forums for integrating soil biological management into environmental and sustainable development policies and agendas. They also highlight the importance of fostering partnerships among the broad range of stakeholders concerned as a means to address more effectively the challenges identified.

The recent set of global international environmental conventions has been developed on the basis of the “Agenda 21 Plan of Action” that was adopted at the UN Conference on Environment and Development in Rio in 1992. This “Earth Summit” called for countries to incorporate environmental considerations into their development plans and build national strategies for sustainable development. Three key environment conventions arose from this summit: on biodiversity, desertification and climate change (see further below). At a special session of the UN General Assembly in 1997 (“Rio plus five”), countries agreed to have national strategies in place by 2002. A “Rio plus ten” summit took place in Johannesburg in 2002 to assess progress achieved and agree on a plan of implementation. Subsequent national strategies for sustainable development provide useful opportunities for addressing issues of soil biodiversity management and conservation as part of an integrated approach; although most do not explicitly use either “soils” or “biodiversity” terminology.

The UN Convention to Combat Desertification (UNCCD) aims to address land degradation and drought in dryland areas, with the expressed aim of improving living conditions for people. The text of this Convention binds signatory governments to promote long-term integrated strategies to improve the productivity of land, rehabilitate degraded areas, and conserve and manage land and water resources in a sustainable fashion, in particular at community level. National Action Programmes to address land degradation have been drawn up by a large number of countries through a consultative process, and form a basis for donor support. Soil biological management, including the conservation and sustainable use of soil biodiversity and ecosystem services, is a core component of action to combat desertification; although, again, rarely articulated as such. A set of impact indicators for the UNCCD have been proposed which link the objectives of improved living conditions for affected people, improved ecosystem condition and the generation of global benefits to be delivered by the convention (UNCCD 2011). All of these objectives and indicators, to varying degrees, are influenced by soil biodiversity and functions. Indicators which are more directly related to soil ecosystem services include: water availability per capita, aridity index, level of land degradation (including salinization, water and wind erosion), plant and animal biodiversity, carbon stocks above and below ground, land under sustainable land management, and land cover status (UNCCD 2011).

The UN Framework Convention on Climate Change (UNFCCC) aims to achieve stabilisation of greenhouse gas (GHG) concentrations in the atmosphere within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. Its Kyoto Protocol aims to reduce GHG emissions. There are strong links between climate change and soil management with regards both mitigation and adaptation. The storage of carbon in, or loss from, soils is obviously relevant to managing greenhouse gas balances and therefore mitigating climate change. At the global level, the mining, manufacture and transport of mineral fertilisers are also major sources of GHG emissions. Food production itself, at the farm level and not including processing and transportation, is estimated to account for some 10% of global energy use (FAO 2012) and, therefore, fertilizer use efficiency is a major factor determining GHG emissions also from energy inputs in agriculture. The climate change induced shifts in ecosystems, which in turn affect human well-being, are largely triggered by impacts on the water cycle (IPCC 2008). Given limits on, and competition for, surface water, climate change adaptation opportunities in farming therefore largely centre on sustaining or restoring water regulation services provided by soils. Improved soil management is also an important response option for reducing climate change induced water risks downstream (e.g., regulating flooding).

Soil biodiversity was identified as an area requiring particular attention under the programme of work on agricultural biodiversity of the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) as early as its third meeting in 1996 (decision III/11). Special attention was paid to the role of soil and below-ground biodiversity in supporting agricultural production systems, especially, at that time, with regards to nutrient cycling. A series of case-studies was undertaken, in a range of environments and production systems, and in each region. Recognising a critical gap in knowledge, Parties were encouraged to conduct case studies on symbiotic soil micro-organisms in agriculture and subsequently on soil biota in general. The CBD's Subsidiary Body on Scientific, Technical and Technological Advice considered soil biodiversity as a critical, yet much neglected, component of biological diversity in agro-ecosystems, particularly in 2005 based on the report of an international workshop (FAO 2003). Consequently, the eighth meeting of the COP in 2006 adopted the *International Initiative for the Conservation and Sustainable Use of Soil Biodiversity* as a framework for action (Table 2).

Table 2: Some key objectives and activities of the CBD International Initiative for the Conservation and Sustainable Use of Soil Biodiversity (decision VIII/23, part B) (http://www.cbd.int/decision/cop/?id=11037).

Objectives	**Core Activities**
Sharing of knowledge and information and awareness-raising	- Compile, synthesize, and evaluate case studies - Identify research gaps, work to facilitate new knowledge acquisition and dissemination - Create and strengthen networking arrangements with a focus on supporting local initiatives on the ground - Enhance public awareness, education and knowledge - Develop information systems and databases
Capacity-building for the development and transfer of knowledge of soil biodiversity and ecosystem management into land use and soil management practices	- Evaluate capacity-building needs - Develop, apply and adapt indicators and tools for assessment and monitoring

	- Promote adaptive management approaches - Mobilize targeted participatory research and development - Identify and develop datasets on soil biodiversity at national level that are important for agriculture
Strengthening collaboration among actors and institutions and mainstreaming soil biodiversity and biological management into agricultural and land management and rehabilitation programmes	- Mainstream soil biodiversity and ecosystem management in agricultural and land management programmes and policies - Develop partnerships and collaborative activities for development and implementation - Promote the participation of indigenous and local communities - Promote collaboration with respect to soil erosion and water management

The *Strategic Plan for Biodiversity* (2011-2020) was adopted at the tenth meeting of the COP to the CBD in 2010 (decision X/2) and is the overarching framework on biodiversity, not only for the biodiversity-related conventions, but for the entire United Nations system (http://www.cbd.int/sp/). It is accompanied by 20 "Aichi Biodiversity Targets" representing time bound actions to achieve implementation of the Strategic Plan as a contribution to sustainable development. Soil functions and biodiversity are relevant to most of the targets but in particular directly to targets: 7 (by 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity), 8 (by 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity), 14 (by 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable) and 15 (by 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification). The eleventh meeting of the COP of the CBD, Hyderabad, India, October 2012, agreed a number of decision relevant to soils including regarding the monitoring framework, and indicators for, the Aichi Biodiversity Targets, and in particular highlighted the importance of ecosystem restoration recognising that this can contribute to climate change mitigation and adaptation, socio-economic development and food security.

At the United Nations Conference on Sustainable Development 2012 ("Rio + 20") governments assessed progress, and made further commitments, as a follow up to the original Earth Summit in 1992. The outcome of the conference[1] made explicit reference to "soils" only with respect to desertification, but "land" and its management are referred to more prominently. For example: paragraph 205 recognized the economic and social significance of good land management, including soil, particularly its contribution to economic growth, biodiversity, sustainable agriculture and food security, eradicating poverty, the empowerment of women, addressing climate change and improving water availability; paragraph 206 recognized the need for urgent action to reverse land degradation; paragraph 207 noted the importance of restoring degraded

[1] "The future we want", document A/CONF.216/L.1

lands, improving soil quality and improving water management, in order to contribute to sustainable development and poverty eradication and, in this regard, encouraged and recognized the importance of partnerships and initiatives for the safeguarding of land resources; paragraph 208 stressed the importance of the further development and implementation of scientifically based, sound and socially inclusive methods and indicators for monitoring and assessing the extent of desertification, land degradation and drought, as well as the importance of efforts under way to promote scientific research and strengthen the scientific base of activities to address desertification and drought; paragraph 110 resolved to increase sustainable agricultural production and productivity globally, including through strengthening international cooperation, particularly for developing countries, by increasing public and private investment in sustainable agriculture, land management and rural development; paragraph 111 reaffirmed the necessity to promote, enhance and support more sustainable agriculture that improves food security, eradicates hunger and that is economically viable, while conserving land, water, plant and animal genetic resources, biodiversity and ecosystems and enhancing resilience to climate change and natural disasters. Regarding pollution, paragraph 124 stressed the need to adopt measures to significantly reduce water pollution, and paragraph 163 noted with concern that the health of oceans and marine biodiversity are negatively affected by nitrogen-based compounds, from a number of land-based sources, including land run-off.

Although terminology differs significantly between these various agreements and forums, strong and mutually reinforcing linkages and potential synergies exist between them, via the common thread of soil ecosystem services.

1.5.2 Emerging broader consensus on key natural resource issues and the role of soil ecosystem services as a solution

Rockstrom *et al*. (2009) proposed a new approach to global sustainability in which they identified planetary boundaries (with parameters) within which they expect that humanity can operate safely: climate change; biogeochemical nitrogen and phosphorous cycles; freshwater use; land system change; rate of biodiversity loss; ocean acidification; and stratospheric ozone. Sustaining and restoring soil functions, processes and ecosystem services, particularly within agricultural landscapes, is a major means to move towards safely operating within the first five boundaries simultaneously (climate, nutrients, water, land, biodiversity), and arguably, due to CO_2 reductions achieved if climate boundaries are not exceeded, also to the sixth (ocean acidification).

Because of the importance of food security, and the increasingly recognised external impacts of farming, agriculture related issues are high on the national and international policy agenda. Food, energy and water security already dominate the current sustainable development debate with regards to natural resource use. There is also increasing attention to the interrelationships between the three topics in dialogues such as the “food, water and energy nexus” (e.g. Hoff 2011).

There has been a shift in policies and approaches in recent years away from managing agriculture independently as a sector primarily relying on external inputs (land, water, chemicals) towards viewing agriculture within a broader ecosystem and landscape setting. In particular, there is increasing recognition of the role of ecosystem services in supporting agriculture: for example, paragraph 111 of the outcomes of the aforementioned “Rio + 20” summit recognizes the need to maintain natural ecological processes that support food production systems; paragraph 122, interestingly, involves a significant paradigm shift regarding how development interests view water management by recognizing the key role that ecosystems play in maintaining water quantity and quality and supporting actions to protect and sustainably manage these ecosystems (previously ecosystems had, largely, been seen as victims of water management not solutions to its challenges).

An emerging consensus on the need to sustainably intensify agricultural production, largely because the alternative is no longer a viable option and has significant implications for increased biodiversity loss, has prompted a shift towards improved ecosystem management as a logical approach. For example, "*Save and Grow*" is a cornerstone of FAO's approach to food production and represents a paradigm shift towards the sustainable intensification of smallholder crop production (www.fao.org/ag/save-and-grow/). Some relevant elements of the strategy include:

(i) Crop production intensification will be built on farming systems that offer a range of productivity, socio-economic and environmental benefits to producers and to society at large;
(ii) Agriculture must, literally, return to its roots by rediscovering the importance of healthy soil, drawing on natural sources of plant nutrition, and using mineral fertilizer wisely; and
(iii) Sustainable intensification requires smarter, precision technologies for irrigation and farming practices that use ecosystem approaches to conserve water.

Soil biodiversity and ecosystem services are at the heart of such approaches. The outcome has been better recognition, by agriculture and environment interests, of opportunities for mutually reinforcing activities that meet common objectives. For example, as illustrated in our own institutional case by ever strengthening cooperation between the CBD and the FAO, among others.

The Comprehensive Assessment of Water Management in Agriculture (CA 2007) made a significant contribution to a strengthened science base, and increased awareness, of the challenges and solutions at the water and food interface. Whilst recognising the opportunities to improve irrigation efficiency, importantly the assessment concluded that the greatest potential increases in yields are in rainfed areas: but with the caveat that only if leaders decide to do so will better water and land management in these areas reduce poverty and increase productivity. Given the limited opportunities for managing rainfall itself (although managing evapo-transpiration from land cover is an exception), restoring or sustaining the water related ecosystem services provided by soils (and land cover) within agricultural landscapes is a large, if not the main, element of a sustainable strategy for improving yields in rain-fed areas.

Sustainable management of the natural resource base supporting agriculture is one of the three major strategic objectives of the Consultative Group on International Agriculture Research (CGIAR). The CGIAR Research Programme on Water, Land and Ecosystems (http://www.iwmi.cgiar.org/CRP5/) combines the resources of 14 CGIAR centres and numerous external partners to provide an integrated approach to natural resource management research, and to the delivery of its outputs. The programme focuses on the three critical issues of water scarcity, land degradation and ecosystem services, as well as the CGIAR System Level Outcome of sustainable natural resource management. It will also make substantial contributions to the

System Level Outcomes on food security, poverty alleviation and health and nutrition. The current topic is effectively already embedded as the major component of this research approach.

These examples, among others, illustrate increasing recognition of the importance of ecosystem services to achieving sustainable agriculture. All of the above examples centre on sustaining and/or restoring the functionality of soils in agricultural landscapes. The extent to which such recognition and approaches are mainstreamed into policies in practice is, however, more difficult to assess. Too many examples of "business as usual" approaches can still be found. But the current direction of the above forums for agricultural development is to make cultivation less, rather than more, dependent on external inputs, given their adverse effects on soil and water quality, and particularly on the soil biota, whose contribution to agricultural productivity is only beginning to be scientifically understood (Chi *et al*., 2005; Rodriguez *et al*., 2009; Uphoff *et al*., 2012).

1.6 Key areas for attention at Global Soil Week

Significant openings exist for the management of soil biodiversity and ecosystem services to address clearly identified global sustainability goals and across broad agendas. Promoting biodiversity (and its role in ecosystem services) as a solution to addressing sustainable development challenges increases resonance with interests beyond the immediate specialist field. Experience shows that effective partnerships are critical for success. Partnership is the cornerstone of the CBD Soil Biodiversity Initiative (Table 2) as well as to success of the examples of progress in section 1.4 (above). This topic involves many stakeholders, probably key amongst these are farmers, and their support networks, who's land management practice is central and, therefore, incentives for behavioural change among farmers are critical.

Whilst the policy landscape, overall, is conducive to the integration of soil biodiversity based solutions, it can be fragmented. There are opportunities to align interests more explicitly around common goals and restoring soil ecosystem services is a much more cross-cutting means to achieve them than might currently be realised. There are also potential opportunities for strengthened frameworks for soils within or complementary to existing international agreements.

We conclude, however, that the key immediate issue is implementation of existing policies under their various inter-related frameworks. A priority is, therefore, to better identify the social, political and economic constraints to implementation and ways and means to address these. To start discussion, some inter-related questions to be addressed might include:

Is the evidence base for restoring soil ecosystem services sound?

If sound, why then is uptake of identifiable solutions not more widespread?

What are the key drivers of unsustainable practice, can they be reversed, and how?

Economics is paramount – what are the important economic incentives and disincentives in play? Can they be realigned, and how?

Food, energy and water security interests dominate. Are environment and development interests properly aligned?

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