MANAGING SOILS FOR ECOSYSTEM SERVICES*

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MANAGEMENTUL SOLURILOR PENTRU SERVICII ECOSISTEMICE

Rezumat. Solurile sunt o sursă de numeroase bunuri şi servicii ecosistemice, relevante pentru bunăstarea oamenilor şi conservarea resurselor naturale, printre acestea numărându-se reciclarea şi transformarea elementelor, păstrarea şi reînnoirea resurselor de apă proaspătă, a biodiversităţii, moderarea schimbărilor climatice prin emisia şi folosirea compuşilor de carbon şi azot, denaturarea şi filtrarea poluanţilor, păstrarea istoriei planetare şi umane; asigurarea cu hrană şi habitat a oamenilor şi altor organisme. Aceste bunuri şi servicii depind de calitatea solului şi procesele de susţinere a vieţii. Printre determinanţii calităţii solului sunt: conţinutul de substanţă organică (după carbon) şi argilă, mineralele predominante în argilă, activitatea şi diversitatea speciilor faunei şi florei din sol, inclusiv a masei microbiene după carbon, profunzimea solului şi accesibilitatea rezervelor de apă şi nutrienţi în sol, capacitatea de restabilire a proprietăţilor pedosferice şi proceselor din sol sub influenţa perturbărilor antropice şi naturale.

Solul, ca rezervor principal de carbon organic şi anorganic, poate servi ca sursă de acumulare a gazelor cu efect de seră, iar prin respectarea unui sistem raţional de management şi folosire a terenurilor, poate fi folosit ca un mijloc de acumulare a dioxidului de carbon din atmosferă. Odată cu creşterea populaţiei, folosirea judicioasă a resurselor de sol devine primordială pentru asigurarea unei dezvoltări durabile.

Cuvinte-cheie: schimbarea climei, management durabil, sechestrarea carbonului, emisii de gaze, securitatea alimentară şi nutriţională.

Introduction

Ecosystem services refer to multitude of resources and benefits that are supplied by natural and managed ecosystems and their principal components such as the pedosphere or soil [Constanza et al., 1997; Leslie, 2011]. Ecosystem services involve a framework for structures and synthesizing processes that create numerous goods and services of interests/relevance to human wellbeing and nature conservancy [Daily, 1997]. There are two schools of thoughts regarding the management of natural resources: i) earth's resources are for human exploitation and use and should be used to the fullest extent, ii) humans must minimize the use of resources and preserve natural ecosystems. The concept of ecosystem services is a compromise between these two opposite views, and proposes the use of ecosystem goods and services for both human wellbeing and nature conservancy.

There also exists a difference between natural capital and ecosystem services. For example, soil organic carbon (SOC) pool, and its recycling and restoration is a natural capital. Sustainable management of SOC pool provides numerous ecosystem services such as food security, water quality and renewability, climate change adaptation and mitigation, food and habitat for biodiversity etc.

Soils have numerous ecosystem functions and services [Lal, 2013]. Thus, the objective of this article is to describe the importance of soil resource base and of soil quality in provisioning of numerous ecosystem services both for human wellbeing and nature conservancy. Specific examples of ecosystem functions and services are outlined in Table 1.

Table 1

Ecosystem functions and services provided by soil resources

Ecosystem Functions		Ecosystem Services	
1.	**Elemental Cycling**: C, N, S, P	1.	**Provisioning**: food, feed, fiber, fuel, minerals
2.	**Net Gross Productivity**: NGP, NPP, NEP, NBP	2.	**Regulating**: climate, water, nutrients, biodiversity, gene pool
3.	**Weathering**: rate of new soil formation	3.	**Cultural**: aesthetical, recreational, scenic, spiritual
4.	**Nature Conservancy**: Habitat for flora and fauna	4.	**Archive**: planetary and human history

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Some examples of soil-generated ecosystem services are briefly outlined below:

1. Soil Carbon Storage and Sequestration: Some soils have a large carbon (C) sink capacity. Examples of soil that store a large amount of SOC are Chernozems, Mollisols, Histosols, Cryosols, Andosols, etc. Chernozems of Eastern Europe have a high SOC storage and sequestration capacity [Dokuchaev, 1883/1967]. Adoption of complex rotations involving cover crops and use of organic amendments can increase SOC pool and enhance productivity of Chernozems[Boincean,2010]. In addition, soils of arid and semi-arid climates also contain soil inorganic C (SIC) of primary (lithogenic) or secondary (pedogenic) carbonates. Total amount of SOC and SIC pools in world soils to 3-m depth is estimated at 4200 Gt. In comparison, C pool is about 620 Gt in forests and vegetation, and 800 Gt in the atmosphere. The atmospheric C pool is increasing at the rate of ~4.3 GtC/yr because of fossil fuel combustion and cement production. The soil C pool, or the pedospheric pool, is strongly linked with biotic atmospheric, oceanic, and lithogenic pools through inter-connectivity between these pools. The soil C pool is linked with other pools through inter-connectivity between lithospheric, pedospheric, climatic, biotic and hydrospheric processes.

Conversion of natural to managed ecosystems depletes SOC pool through accelerated erosion, mineralization and leaching. Strong depletion of SOC pool to below the threshold level adversely impacts soil functions by constraining numerous pedospheric processes. The threshold level is generally higher for soils of temperate (1.5-2.0%) than those of the tropics (1.0-1.5%).

The SOC sink capacity, the magnitude of soil organic matter (SOM) that can be stored in a soil solum (profile) with a long mean residence time (MRT), depends on a range of endogenous and exogenous factors. Important among endogenous factors are clay and silt contents, clay mineralogy, surface area and cation/anion exchange capacity, soil depth, water and nutrient retention capacity etc. Principal exogenous factors are mean annual temperature, mean annual precipitation, latitude/longitude, slope aspect and landscape position, natural vegetation, land use and management.

The SOC sequestration potential depends on the historic land use and vulnerability to soil degradation processes (e.g., accelerated erosion by water and wind). A severe soil and ecosystem degradation is among important impacts of population growth [Ehrlich and Holdren, 1971; Holdren and Ehrich, 1974]. The SOC sequestration can be realized through adoption of a restorative land use, and conversion to conservation agriculture (CA) in conjunction with complex crop rotations based on cover cropping and use of integrated nutrient management (INM) [Lal, 2004]. The rate of SOC sequestration is higher for soils of cool and humid climates than that for warm and dry regions, clayey or finer than sandy or coarse-textured, and for those containing 2:1 expanding-lattice rather than 1:1 or fixed-lattice clay minerals. Rates of soil C sequestration range from 100 to 1000 kg/ha/yr for SOC and 1 to 5 kg/ha/yr for SIC. Technical potential of soil C sequestration (GtC/yr) is 0.4-1.2 for croplands, 0.3-0.5 for grazing lands, 0.3-0.7 for salt-affected soils, and 0.2-0.7 for restoration of degraded/desertified soils. Total sink capacity of soil-based sinks is 50-100 GtC compared with 200-300 GtC for permanent forests [Lal, 2010].

2. Climate Change Moderation: Soils affect and are affected by the climate, and the latter is an active factor of soil formation [Jenny, 1941]. Soils moderate climate through heat exchange (specific heat capacity, and thermal conductivity), and gaseous exchange (CO_2, CH_4, N_2O) with the atmosphere.

These processes are strongly affected by concentration of SOC (and SIC), activity and species diversity of soil biota and the pedospheric processes affected by them (e.g., respiration, nitrification/denitrification, methanogenesis). Soils also moderate climate through soil water retention (high heat capacity) and albedo (reflection of radiation into space). Soil C sequestration over the geologic time scale is affected by weathering of alumino-silicates by which carbonates are transformed from land into the ocean. A coupled cycling of C with that of H_2O, N, P and S play an important role in provisioning of several ecosystem services including moderation of climate, and renewability of water.

3. Water Renewal and Purification: Soil is one of the largest reservoirs of fresh water. With 30% porosity of retention pores, one hectare of soil to 1-m depth (bulk density of 1.325 Mg/m^3) has a water storage capacity of 3000 L. With intense biotic activity (arable land containing 5 Mg/ha of live biomass, and millions of microorganisms in a spoonful of healthy soil), soil is a bioreactor capable of denaturing and transforming pollutants of natural and anthropogenic toxins. Soils containing high contents of SOC and inorganic (clay) colloids with large surface area and charge density (negative and positive charge) have a high capacity to absorb/

adsorb pollutants and filter these from water infiltrating into the ground water or an aquifer. Additional water demand of 40% by 2030 can be met by improving the "green water" supply through management of soil-water resources. Because of its capacity to purify natural water, soil is also termed as a "biogeomembrane".

***4. Biodiversity*:** Soil is the biggest reservoir of the gene pool, and is a vast seed bank. It is teeming with life of both primary and secondary consumers. The antibiotic "Streptomycin" was derived from soil. Thus, soil can be appropriately defined as an "organic-carbon mediated realm in which solid, liquid, gas and biology all interact from a scale of nanomatter to landscape and global scale" (Fig. 1). A spade of rich garden soil may harbor more species than the entire Amazon nurtures above ground. A teaspoon of a healthy soil may contain 100 million to 1 billion of diverse organisms (e.g., bacteria, fungi, protozoa, springtail, nematodes, spiders, mites, earthworms, millipede, centipede, ant, termites and large burrowing animals). However, soil biodiversity is adversely affected by monoculture and inappropriate management [Power, 2010]. Croplands are also a major source of greenhouse gases [Searchinger et al., 2008; Tilman et al., 2009].

5. Food and Nutritional Security: Soil is the principal medium for food production. Both the amount and nutritional quality of the food produced depend on soil quality. Indeed, there exists a strong link between quality of soil, environment, plant, animal and human. Healthy soils create healthy environment, grow healthy plants, maintain healthy animals, and support healthy human population. There is a tradeoff between SOC stock and food prpduction[West et al., 2010]. There are presently about 842 million food-insecure people globally, mostly in South Asia and sub-Saharan Africa (SSA). However, 2 billion people suffer from micronutrient deficiency. It is the concentration of SOC in the surface layer that retains and supplies essential micronutrients (e.g., Fe, Mo, Zn, I, Cu, Se). The global food demand would double over the period 1990-2030, and increase by 70% between 2010 and 2050. In some countries of SSA, food production may have to be tripled or quadrupled. In Asia and Africa, plant-derived food requirements may increase by a factor of 2.5 to 7 in some countries. Thus, there is a strong need to identify agricultural systems which increase production and also store C in soil and ecosystems.

Whereas meeting the increase in food demand is a challenge, it also indicates a bright future for agriculture. There is an additional food demand by 2050 of grains by 1 billion ton/yr, and meat by 200 million ton/yr. It is precisely in this context that the importance of restoring quality of soils of agro-ecosystems cannot be over emphasized. Bridging the vast yield gap, difference in research plot yield and that for on-farm or national crop yield, necessitates improvement in soil quality and restoration of SOC concentration to above the threshold level. In comparison with the average cereal yield of 3.27 ton/yr in 2005, yield will have to be increased to 3.60 ton/yr by 2025, and 4.30 ton/yr by 2050 if the dietary preferences do not change. With the rapid change in dietary preference towards animal-based diet, however, global average cereal yield must be increased from 3.27 ton/yr in 2005 to 4.40 ton/yr by 2025 and 6.0 ton/yr by 2050. Similarly, the total cereal production (million ton) must be increased from 2240 in 2005 to 2780 by 2025 and 3255 by 2050 with similar dietary preferences compared

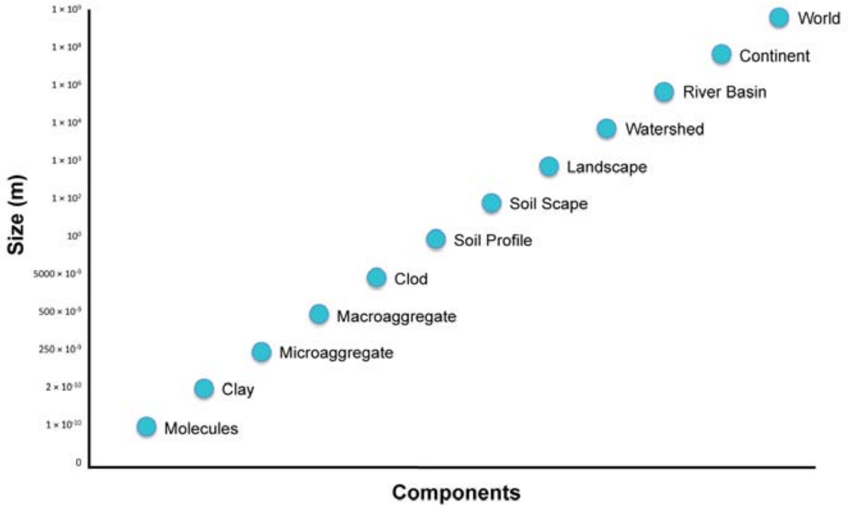

Figure 1. Scaling issue in carbon sequestration from molecular to global scale

with 3629 by 2025 and 3255 by 2050 with changing dietary preferences. Improvements in soil quality by restoration of SOC concentration in the root zone is also essential to enhance the use efficiency of fertilizer and water, and recycle/reuse essential but finite resources.

Soil Organic Carbon as an Indicator of Climate Change

The projected climate change is a major global issue of the 21st Century. Among numerous indicators of climate change, and especially of soil's/ecosystem's resilience to changing and uncertain climate, alterations in SOC concentration and pool can serve as an important indicator. Some notable merits of using SOC as an indicator of climate change are listed in Table 2.

Table 2

Merits of using SOC concentration and pool as an indicator of climate change

1. It is a familiar property
2. It can be measured directly and indirectly
3. It can be measured in four dimensions (length, width, depth, time)
4. It lends itself to repeated measurements over the same time
5. It is linked to ecosystem goods and services
6. It is a key factor of soil formation/renewal and functions
7. It is a strong determinant of soil quality
8. It has a memory and is important to understanding planetary history
9. It has well defined chemical, physical, biological and mineralogical properties
10. It can be used in conjunction/synergism with other indicators
11. The degree of uncertainty can be quantified and predicted
12. It has predictable pathways across the landscape and over time
13. It is an important archive of paleoclimate and environment
14. It is a reservoir of gene pool

Soil and Sustainable Intensification

Sustainable intensification of soil resources already appropriated to agroecosystems and other crucial land uses is essential to nature conservancy and human wellbeing. The strategy is to produce more food and other commodities from less land, water, fertilizers and pesticides, energy and gaseous emission. In addition to ever decreasing arable land area (because of competing uses for urbanization, recreation, industrialization, nature conservancy etc.), there is also a decreasing supply of fresh and renewable water resources. Thus, sustainable intensification of agroecosystems also involves judicious use of water by: i) using precision irrigation based on variable rate, ii) matching irrigation to crop needs at specific growth/phenological stages, iii) using deficit irrigation based on partial root drying or nature conservancy, iv) replacing flood irrigation by micro-irrigation, v) increasing water productivity by improving soil quality, and vi) strengthening nutrient cycling through integrated nutrient management and biological nitrogen fixation and mycorrhizal inoculation.

Disease Suppressive Soils

Soils of good biological quality, with an optimal concentration of SOC and high biotic activity of micro/meso/macro organisms, are disease-suppressive soils. The strategy is to use organic amendments (animal and green manure, compost, partially decomposed peat etc.) to manage beneficial micro-organisms in the rhizosphere. Disease-suppressive soils are those in which development of plant diseases is minimal even in the presence of virulent pathogens and a susceptible host. In this context, there are two types of disease suppression: i) general suppression related to the total amount of microbial activity, and ii) specific suppression through enhancement of specific microorganisms or a group of microorganisms. Needless to say that creation of disease-suppressive soils is essential to reducing use of pesticides and other environmental pollutants.

2015 International Year of Soils

The 68th U.N. General Assembly (A/RES/68/232) declared 2015 the "International Year of Soils" (IYS). Among numerous objectives of IYS are the following:

- To create full awareness of civil society and decision makers about the fundamental roles of soils for human well being,
- To advance full recognition of the prominent contributions of soils to food security, climate change, adaptation and mitigation, essential ecosystem services, poverty alleviation and sustainable development, and
- To promote effective policies and actions for the sustainable management and protection of soil resources.

The International Union of Soil Science (IUSS) in collaboration with other organizations is celebrating IYS with numerous activities to signify the importance of soils to human and societal well being and nature conservancy.

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