

Chapter 2

New World Atlas of Desertification and Issues of Carbon Sequestration, Organic Carbon Stocks, Nutrient Depletion and Implications for Food Security

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Abstract Soils are both sinks and sources of C with great potential to mitigate climate change. Global estimates indicate that they contain between 1,206 Pg of soil organic carbon (SOC) to 1-m depth to more than 1,550 Pg C, which is twice the amount of C present in the atmosphere. Nevertheless the overall the C stocks could reach as much as five times that of the atmosphere considering that many soils are much deeper than 1 m. Instead, emissions from land use change are estimated to make up to 20 % of atmospheric CO₂ through loss of biomass and SOM. Notwithstanding these critical outcomes, soil's impact in climate change scenarios is generally not well understood and the UNFCCC after CoP 21 in Paris started to increase attention to the potential for soil C sequestration thanks to the French “4 pour 1000” initiative. We argue that SLM can increase productivity particularly by improving water use efficiency, optimizing nutrient cycles and their supply for crop production, enhancing vegetation cover, and improving food security level. Healthy soils produce healthy food, support healthy living, and promote a healthy environment.

Keywords Desertification · Atlas · Carbon sequestration · Global carbon · Sustainable land management

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2.1 Overview of the World Atlas of Desertification

A novel *World Atlas of Desertification* (WAD) is being compiled under the coordination of the Joint Research Centre (JRC) of the European Commission in partnership with the United Nations Environment Program (UNEP). The novel WAD will be available as both a published reference atlas and an online digital information portal. It builds upon recent scientific progress by taking a pragmatic and robust approach to the use of current concepts to assess and map land degradation and desertification. The updated WAD provides a foundation for improved mitigation strategies regarding global issues of food security, resource base efficiency, climate change, sustainable development and poverty reduction.

An entire chapter within the novel WAD is devoted to soil issues. Issues are organized in an ecosystem-based approach that identifies soil function and provides a detailed background. Additional attention is devoted to global soil resource availability and its capacity to feed a growing population that is expected to reach over 9 billion by 2050. The global average of per capita agricultural land decreased from 0.39 ha per person in 1960 to 0.21 ha in 2007 and continues to decline. Worldwide crop cultivation is practiced on 1.6 billion ha, but the distribution of arable land is extremely uneven. China and India account for more than 35 % of the total global population, and both have exploited most of their available land and water resources for agriculture. Similar situations exist throughout the Mediterranean and particularly in North Africa and the Middle East where only 5 % of the land is suitable for agriculture (Zdruli 2012).

2.2 Importance of Soils for Carbon Sequestration

Soils are both carbon sinks and sources. Global estimates indicate that soil up to 1 m depth contains between 1,206 Pg of soil organic carbon (SOC) (Hiederer/Köchy 2011) and more than 1,550 Pg C (Lal 2004; Baveye/Jacobson 2007), which is about twice the amount of atmospheric carbon (800 Pg). The total carbon soil stock could actually be up to five times that of the atmosphere because many soils are present at depths greater than 1 m. In particular, soils such as Mollisols (Soil Taxonomy) or Chernozems (WRB) are extremely important for storing organic carbon and providing food and fiber. Although soils cover only 3 % of global land area, they produce more than 40 % of the global food and over 90 % of these soils are used for cereal production (Eswaran et al. 2003). Soils must be considered as both national and international assets and be protected from any form of degradation.

The annual flux of carbon dioxide (CO₂) between the soil and atmosphere is estimated to be six times the amount derived from fossil fuels (GSP 2011). The amount of carbon stored in soil is about 300 times the amount released annually from burning fossil fuels. Emissions from land-use changes are estimated to contribute 20 % of atmospheric CO₂ as a result the loss of biomass and SOM (Smith

et al. 2007). Land use intensification has significant effects on the stability of soil ecosystems. These effects may assist in the prediction and modelling of climate change responses, especially when the peculiar effects of soil biota are also considered (de Vries et al. 2013).

Although drylands store much less SOC per hectare than humid regions, the vast surface area they cover globally (nearly 40 % of land cover) makes them an important global carbon sink (Lal 2009). The potential for SOC storage per hectare in dryland soils may be comparable to that in soils of the humid areas. Large dryland soil 'sink capacity' is created when high amounts of SOC are lost through degradation, which soils in humid regions may not experience (Farage et al. 2007).

Large quantities of carbon are stored in waterlogged and permafrost soils. Permafrost soils could potentially emit potent greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_2O) if the permafrost layer is affected by thawing or if wetlands are desiccated. These worst case scenarios could cause climate change to increase rapidly because the GHG CH_4 is 18–25 times more potent than CO_2 . Despite these critical outcomes, the impact of soil in various climate change scenarios is generally not well understood. The United Nations Framework Convention on Climate Change process has paid little attention to the potential for soil C sequestration.

2.3 Soil Organic Matter and Soil Quality

Soil quality is the capacity of a soil to perform ecosystem functions and provide ecosystem services. Soil quality depends on key determinants (Lal 2012). SOM is a key constituent in this context that heavily impacts soil quality through positive effects on physical, chemical, and biological properties of the soil. Depletion of SOM initiates a downward spiral of cascading adverse effects. Conversion from a natural to an agroecosystem (cropland and grazing land) and the attendant changes in water and energy budgets at the ecosystem level cause severe and rapid SOM depletion and negative impacts on physical soil quality. SOM depletion reduces aggregation and has adverse effects on soil structure and tilth in addition to GHG emissions into the atmosphere (Fig. 2.2).

Decreased soil structure leads to densification, water infiltrability reduction, increased erosion susceptibility and decreased availability of green water for plant growth. Disrupted elemental cycling and reduced availability of plant nutrients decrease the efficiency of inherent and applied resources as well as agronomic productivity. The downward spiral initiated by SOM depletion adversely affects farm income. Similarly, SOM decline below the threshold level adversely impacts soil chemical, biological and ecological processes that lead to a range of degradation processes. These processes include alteration of soil reactions; elemental imbalances of deficiency and toxicity, salinization and sodication; and reduction in activity and species diversity of soil fauna, flora and microbial biomass carbon (MBC). Severe SOM depletion causes impacts such as the breakdown of



Fig. 2.1 A fertile Chernozem from Hungary. *Source* E. Micheli who granted permission to use this photo

community wellbeing, civil structure and political instability that ultimately lead to societal collapse (Diamond 2006) (Fig. 2.1).

SOC comprises 50–60 % (average 58 %) of the global SOM stock in addition to providing a source of nutrients (macro and micro) and other elements. Thus, the SOC stock is among the principal terrestrial carbon stocks. These stocks vary among biomes or eco-regions because of differences in climate, soil type, physiography, vegetation, and land use (Fig. 2.3). The pedologic (soil originated) soil carbon pool comprises the two distinct, yet related, components of soil inorganic carbon (SIC) and SOC stocks. The pedologic pool to 3 m depth is estimated at 4,000 Pg, i.e. ~ 5 times the atmospheric pool (800 Pg) and 6.45 times the biotic stock (620 Pg). The pedologic carbon stock influences carbon cycling and heavily impacts radiative forcing and soil albedo through close interaction with biotic and climatic stocks and changes in the soil-related flux of GHGs (Rubio 2007). The magnitude of the flux of GHGs from soil to atmosphere depends on land use, soil/animals/vegetation management and the antecedent SOC pool.

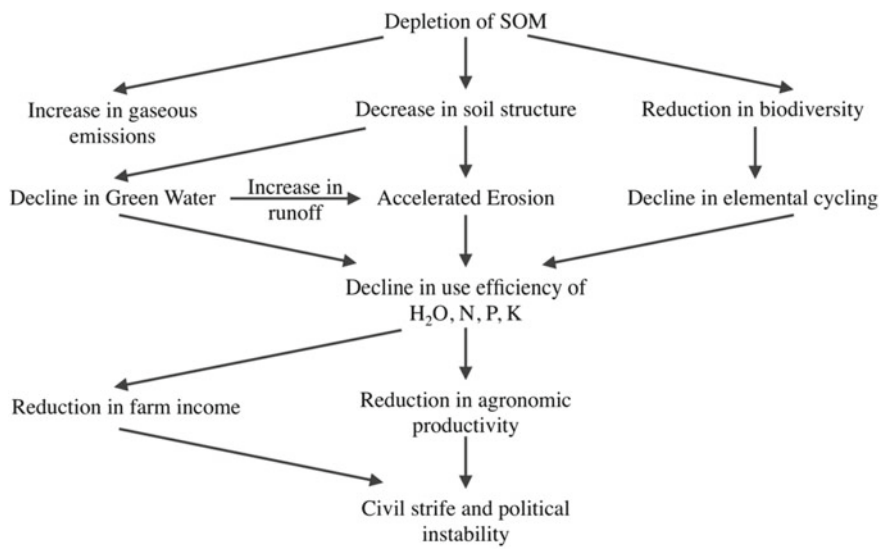


Fig. 2.2 Impact of the soil organic matter depletion on ecosystem functions and services. *Source* The authors

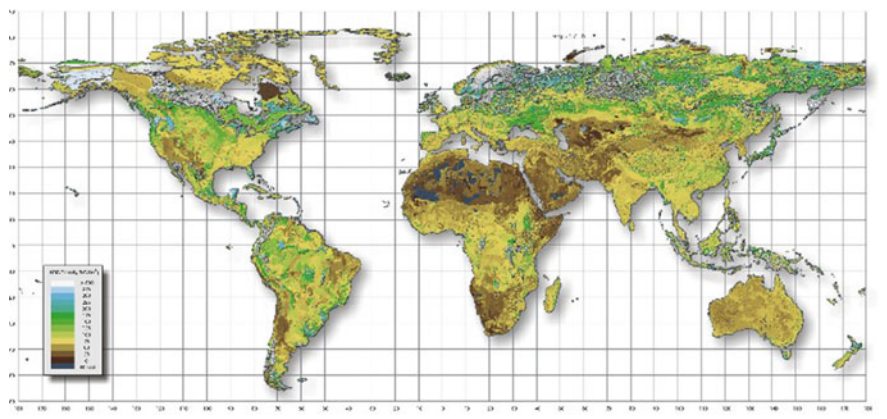


Fig. 2.3 Estimates of global soil organic carbon density from amended harmonized world soil database (Mg C ha⁻¹). *Source* Hiederer/Köchy (2011)

2.4 Land-Use/Cover Change and the Impact on SOC Stocks

Conversion from natural ecosystems to agroecosystems leads to decreased SOC stock (Lal 2004; Zdruli et al. 2014). The magnitude and rate of decline are generally higher in tropical soils than in temperate regions. Drastic perturbations caused by

land-use conversion and soil/crop/animal management heavily impact soil physical, chemical, biological and ecological properties and processes (Fig. 2.2). Pedological and ecological processes impacted include alterations in hydrothermal regime, energy budget, biochemical transportation, rhizospheric processes, microclimate and the rate of SOM decomposition and turnover. The overall impact is decreased net primary productivity (NPP), net ecosystem productivity (NEP) and net biome productivity (NBP). The threshold level of SOC concentration in the root zone is 1.1–2.0 % (temperate soils higher than tropical soils). Drastic reduction in the SOC concentration magnitude has a negative feedback which exacerbates the rate and magnitude of SOC stock depletion.

A wide range of factors determine the SOC stock depletion. There are economic, political, societal, cultural and human dimensions in addition to the biophysical factors. Reduced input of biomass carbon causes decreased SOC stock in agro-ecosystem soils. A negative ecosystem carbon budget reduces soil biodiversity, disrupts aggregation, degrades soil structure, exacerbates soil erosion hazards, decreases green water supply, increases risk of drought stress, disrupts elemental cycling and reduces soil fertility (Fig. 2.4).

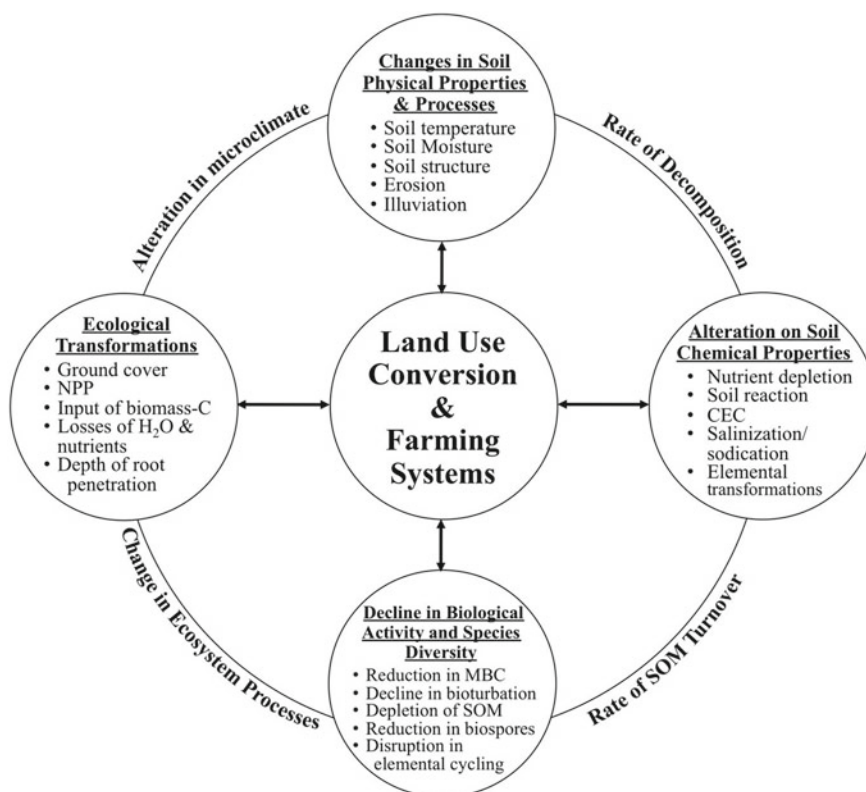


Fig. 2.4 Effects of land use conversion and farming systems on soil properties, processes, and ecosystem functions. *Source* The authors

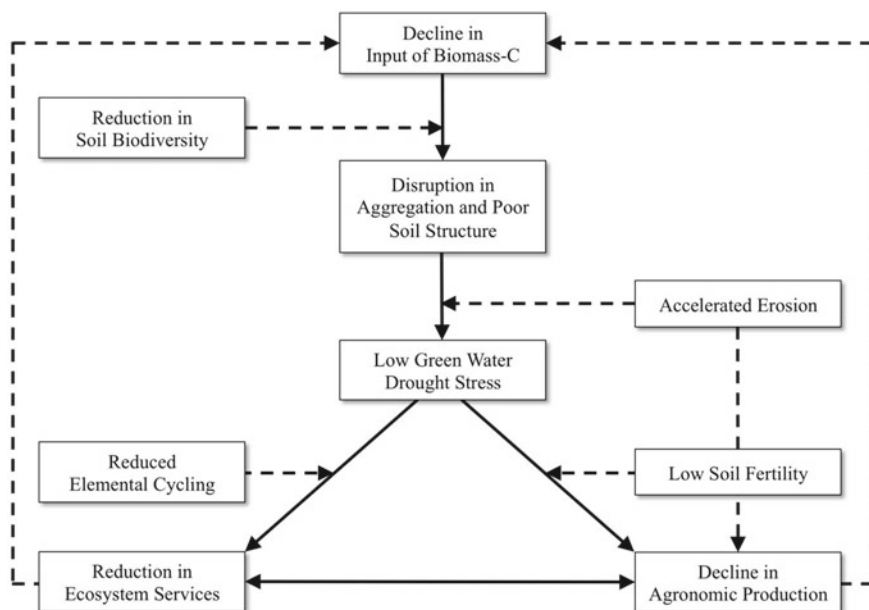


Fig. 2.5 Factors affecting soil organic carbon pool depletion in agroecosystems. *Source* The authors

Negative feedback to the SOC pool is the net effect of decreased agronomic production and reduced ecosystem services (Fig. 2.5). Accelerated soil erosion adversely affects the on-site SOC stock. Despite the limited amount of research on the fate of carbon transported by erosional processes on a watershed scale, erosion has been found to severely deplete the soil SOC stock of erosion-prone ecosystems (Lal 2003, 2004; Lal et al. 2004). Decreasing trends in SOC stock can be reversed by adopting best management practices (BMPs) that also have a low carbon footprint. The most important among a wide range of generic BMPs are no-till farming, cover cropping, integrated nutrient management, agroforestry systems and complex/diverse farming systems.

2.5 Global SOC Estimates

Although the issue of soil carbon sequestration is still a highly debated and complex topic, the general consensus is that increasing soil carbon stocks could be a highly cost effective (Grace et al. 2011) and environmentally suitable mitigation technique (Mermut 2010). Global and continental estimates of SOC stocks were made (Batjes 1996) and a close link between these stocks and potential CO₂ emissions from soil under different scenarios of land-use/cover and climatic change conditions were

developed (IPCC 2006). A few global estimates are presented as spatial data. Based on the complete dataset derived from the Harmonized World Soil Database (HWSD) version 1.2, Hiederer/Köchy (2011) estimated global SOC stocks separately for depths 0–30 cm (topsoil) and 30–100 cm (subsoil) or shallower depending on effective soil depth. The study found that the Earth's topsoil contains 574 Pg C and the subsoil 632 Pg C, which totals 1,206 Pg C for 1 m depth. These estimates largely depend on availability and quality of soil data and especially bulk density values that are often missing. Other uncertainties are derived from the various relationships between SOC and bulk density in mineral and organic soils and numerous other factors (Schrumpf et al. 2011).

2.6 Soil Nutrient Mining

The cycling of nutrients in ecosystems is closely related to the flow of energy (Gliessman 2007) and biomass transformation from biotic to abiotic components and vice versa via processes referred to as the *biogeochemical* cycles. The main cycles recognized are carbon, oxygen and nitrogen, while the atmosphere serves as the primary abiotic reservoir (Pidwirny 2006). Less mobile elements such as phosphorus, sulfur, potassium, calcium and most trace elements have local cycles and the soil remains their main abiotic reservoir. These nutrients are taken up by plant roots, stored for a period of time in biomass and eventually returned to the soil by soil decomposers within the same ecosystem. The soil ecosystem may collapse with severe consequences to food security and other ecosystem services when the nutrient balance in the soil is disturbed by high losses from harvest, land-use changes, leaching and erosion (Jones et al. 2013).

Soil nutrient depletion has severe economic impacts at the global scale; however, in Sub-Saharan Africa (SSA), they are more pronounced than anywhere else. Studies conducted since the mid-1980s (Stoorvogel et al. 1993) calculated nutrient balances for 38 countries in SSA and estimated annual soil fertility depletion rates of 22 kg N, 3 kg P and 15 kg K ha⁻¹ or the annual equivalent of 4 billion USD worth of fertilizer (Gilbert 2012). In Zimbabwe, soil erosion resulted in an annual loss of nitrogen and phosphorus totaling 1.5 billion USD (Eswaran et al. 2001) and 17.8 million tons of soil nutrients were lost from arable land annually due to land degradation. In South Asia, annual economic losses were estimated at 600 million USD for nutrient losses caused by erosion and 1,200 million USD due to soil fertility depletion (Stocking 1986; UNEP 1994). Furthermore, the Costa Rican Ministry of Environment showed that reduced soil fertility and soil erosion caused a 7.7 % drop in national agricultural Gross Domestic Product from 1970 to 1989 (Thatcher 2012). Additionally, the US annual harvest of major crops removes about 7.8 Tg of nitrogen (excluding the N₂-fixing crops alfalfa [*Medicago sativa* L.], soybean [*Glycine max* (L.) Merr.] and peanut [*Arachis hypogaea* L.]); 2.3 Tg of phosphorus; and 6.7 Tg of potassium with removals increasing by roughly 1 % year⁻¹ (IPNI 2010).

Nutrient depletion of soils combined with accelerated erosion and reduced fallow periods have direct consequences on crop productivity, food production, food security and human livelihood. Options for remediation and mitigation of soil nutrient mining include both the use of chemical fertilizers (IFPRI 2011) and green manure application through the expansion of nitrogen-fixing crops and trees or mixing organic waste with the soil. Organic farming has additional benefits. For example, the use of manures supports the development of microbial communities that are more complex than those from the use of synthetic fertilizers (Sradnick et al. 2013). However, these methods are complementary because neither of them alone solves the problem of soil fertility depletion. Many farmers in inland regions of Africa pay twice as much for fertilizers compared with European or US farmers due to high transportation costs. Data show that 40–60 % of the food produced in the US and UK is a result of fertilizer use (Stewart et al. 2005). One of the reasons for low yields recorded across SSA is that fertilizer use amount has remained constant at around 9 kg ha⁻¹ of cultivated land over the past 40 years. In comparison, the use of inorganic fertilizers in Asia has increased to 96 kg ha⁻¹ (Gilbert 2012). Increased population pressure in SSA and throughout Africa stresses the importance of the population–agriculture–environment nexus that remains severely unsustainable for much of the continent (Drechsel et al. 2001).

2.7 Sustainable Land Management Is the Answer for Carbon Sequestration and Food Security

Sustainable land management (SLM) can increase productivity by improving water use efficiency, optimizing nutrient cycling and supply for crop production, enhancing vegetation cover and improving food security. Healthy soils produce healthy food, support healthy living and promote a healthy environment.

Despite the possibility that economic benefits of some agricultural practices by carbon sequestration potential may be questionable in the long run, the World Overview of Conservation Approaches and Technologies (WOCAT) initiative has shown (WOCAT 2007) that SLM has the potential to increase yields by 30–170 %, increase water use efficiency by up to 100 % and increase SOC concentration by 1 % in degraded and up to 2–3 % in non-degraded soils (Lam et al. 2013). The most common SLM techniques include soil and water management (terracing, contour planting, living barriers, low tillage, mulches, cover crops including biological N-fixing (BNF) legumes that add a large quantity of N in just one season, grazing corridors and water harvesting) and soil fertility management (manure, compost, biochar,¹ biomass transfer, agro- forestry, N-fixing trees like [*Faidherbia albida* L.] and integrated overall soil management). Furthermore, approaches like EverGreen agriculture as a form of more intensive farming that integrates trees with

¹See at: <http://www.biochar-international.org>.

annual crops to sustain green cover on the land throughout the year and ‘climate-smart agriculture’ that includes techniques such as mulching, inter-cropping, no-till farming, improved grazing and better water management demonstrate their efficiency through increased income and environmental benefits that reduce greenhouse gas emissions and enhance food security (WBI 2012).

Additionally, conservation agriculture (no-till, bed-and-furrow technologies, residue management, cover cropping, rotations, etc.), especially in the drylands, shows promise because it provides a low-cost entry point for long-term sustainability. Conservation agriculture is based on the ‘no-till’ approach that aims to reduce the impact of farming on the environment and on the farmland itself. It is characterized by three principles: (i) minimum mechanical soil disturbance, (ii) permanent organic soil cover and (iii) diversification of crop species grown in sequences and/or associations and rotations.

The worldwide conservation farming area was estimated to be around 105 million ha in 2008 (FAO 2009) and increased to about 125 million in 2012; however, almost half the increase occurred in Latin America (Friedrich et al. 2012). No-till is practiced on about 70 % of arable cropland in countries like Brazil, Argentina, Paraguay, Uruguay, Australia and New Zealand, while in the US that figure is only 25 % of the cropland (Kruger 2012). The next most promising result of conservation agriculture is erosion control in addition to increasing and sustaining yields.

Conservation tillage (Amato et al. 2013) also requires less energy and labor. Thus, it reduces costs and environmental impacts, increases SOC concentration and improves soil tilth and fertility. Overall SOM content increase is important because it is considered the ‘elixir of life’ for soil. However, this technique relies heavily on herbicide use for weed control and may cause resistant weeds to develop, as in the case of cotton [*Gossypium hirsutum* L.] Fertilizers will continue to play an important role in increasing crop production, especially in less developed countries, but they must be carefully applied on the basis of soil characteristics and crop nutrient requirements.

2.8 Conclusion

The SLM strategies offer tremendous opportunities and benefits, especially for drylands:

- Reverse negative trends in resource-based degradation and declining agricultural productivity,
- Contribute to mitigation and adaptation to climate change and other environmental threats,
- Improve local livelihoods by reducing poverty and improving food security,
- Preserve and enhance ecosystem services and functionality, and
- Provide important environmental benefits at local, regional and global levels.

However, issues of SLM, soil quality (Bone et al. 2012) and holistic adaptive land management (Herrick et al. 2012) require a profound recognition of local conditions as there are no universal ‘ready-to-use recipes’ for every location on earth. Each approach must be tailored and adopted locally.

The UNCCD also promotes the *zero-net land degradation* by 2030 initiative (UNCCD 2012) based on the principle that for each degraded hectare of land, another one must be restored or rehabilitated to build a land-degradation neutral world (Stringer 2012). Another example is the African great green wall for the Sahara and the Sahel; this represents a concrete example of Africa’s contribution to the achievement of neutral land degradation.

Is it possible to defeat soil degradation and increase the capacity of soils to sequester carbon? Despite numerous positive and well documented examples worldwide this question remains critical unless immediate action is taken and the necessary policy and implementation frameworks for SLM are enacted through a holistic approach. Societies may need to prepare for the possibility that this conquest might take quite a long time to fully accomplish unless these requirements are met.

References

- Amato, G.; Ruisi, P.; Frenda, A.S.; et al., 2013: “Long-Term Tillage and Crop Sequence Effects on Wheat Yield and Quality”, in: *Agronomy Journal*, 105: 1317–1327.
- Baveye, P.C.; Jacobson, A.R., 2007: “Soil Science Education and the ‘Age of Money’: Reflections and Concerns for the Near Future”, in: *Water, Air, and Soil Pollution*, 187: 1–4.
- Batjes, N.H., 1996: “Total Carbon and Nitrogen in the Soils of the World”, in: *European Journal of Soil Science*, 47,2: 151–163; at: doi:[10.1111/j.1365-2389.1996.tb01386.x](https://doi.org/10.1111/j.1365-2389.1996.tb01386.x).
- Bone, J.; Barraclough, D.; Eggleton; et al., 2012: “Prioritising Soil Quality Assessment Through the Screening of Sites: The Use of Publicly Collected Data”, in: *Land Degradation and Development*, 23,3: 252–266.
- de Vries, F.T.; Thébault, E.; Liiri, M., 2013: “Soil Food Web Properties Explain Ecosystem Services Across European Land Use Systems”, in: *Proceedings of the National Academy of Sciences*; at: doi:[10.1073/pnas.1305198110](https://doi.org/10.1073/pnas.1305198110).
- Diamond, J., 2006: *Collapse: How Societies Chose to Fail or Succeed* (New York: Viking Press).
- Drechsel, P.; Kunze, D.; de Vries, F.P., 2001: “Soil Nutrient Depletion and Population Growth in Sub Saharan Africa: A Malthusian Nexus. Population and Environment”, in: *A Journal of Interdisciplinary Studies*, 22,4: 411–423.
- Eswaran, H.; Lal, R.; Reich, P.F., 2001: “Land Degradation: An Overview”, in: Bridges, E.M.; Hannam, I.D.; Oldeman, L.R.; Pening de Vries, F.W.T.; Scherr, S.J.; Sompatpanit, S. (Eds.): *Responses to Land Degradation*. Proceedings of the 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Thailand (New Delhi: Oxford University Press).
- Eswaran, H.; Beinroth, F.H.; Reich, P.F., 2003: “A Global Assessment of Land Quality”, in: Wiebe K. (Ed.): *Land Quality, Agricultural Productivity, and Food Security: Biophysical Processes and Economic Choices at Local, Regional, and Global Levels* (Cheltenham: Edward Elgar Publishing): 111–132.
- FAO, 2009: *Agriculture: Achieving Sustainable Gains in Agriculture*. Fact Sheet of FAO Programme (Rome: FAO); at: <http://www.fao.org/about/en/>.

- Farage, P.K.; Ardo, J.; Olsson, L.; et al., 2007: "The Potential for Soil Carbon Sequestration in Three Tropical Dryland Farming Systems of Africa and Latin America: A Modelling Approach", in: *Soil & Tillage Research*, 94: 457–472.
- Friedrich, T.; Derpsch, R.; Kassam, A., 2012: "Overview of the Global Spread of Conservation Agriculture", in: *Field Action Science*, 6: 1–17.
- Gilbert, N., 2012: "Dirt Poor: The Key to Tackling Hunger in Africa is Enriching Its Soil", in: *Nature*, 483: 525–527.
- Gliessman, S.R., 2007: *Agroecology: The Ecology of Sustainable Food Systems*, 2nd ed. (London: CRC).
- GSP, 2011: *Towards the Establishment of the Global Soil Partnership—Terms of Reference Working Document* (Rome: FAO).
- Grace, P.R.; Antle, J.; Aggarwal, P.K.; et al., 2011: "Soil Carbon Sequestration and Associated Economic Costs for Farming Systems of the Indo-Gangetic Plain: A Meta-Analysis", in: *Agriculture, Ecosystems and Environment*, 146: 137–146.
- Herrick, J.E.; Duniway, M.C.; Pyke, D.A.; et al., 2012: "A Holistic Strategy for Adaptive Land Management", in: *Journal of Soil and Water Conservation*, 67,4: 105A–113A.
- Hiederer, R.; Köchy, K., 2011: *Global Soil Organic Carbon Estimates and the Harmonized World Soil Database*. EUR 25225 (Luxembourg: Publications Office of the European Union).
- IFPRI, 2011: *Global Food Policy Report* (Washington DC: International Food Policy Research Institute); at: doi:[10.2499/9780896295476](https://doi.org/10.2499/9780896295476).
- IPCC [Egglestone, S.; Buemdia, L.; Miwa, K.; Ngara, T.; Tanabe, K. (Eds.)], 2006: *Guidelines for National Greenhouse Gas Inventories* (Hayama, Japan: IPCC/OECD/IEA/IGES).
- IPNI, 2010: *A Preliminary Nutrient Use Geographic Information System (NuGIS) for the US*. Publ. 30-3270 (Norcross, GA: International Plant Nutrition Institute).
- Kruger, S.H., 2012: "Conservation Crusader: Paraguayan Rolf Derpsch Helped Expand No-till Across Globe", in: *Corn and Soybean Digest*; at: <http://cornandsoybeandigest.com/conservation/conservation-crusader-paraguayan-rolf-derpsch-helped-expand-no-till-across-globe> (20 January 2014).
- Jones, D.L.; Cross, P.; Withers, P.J.A.; et al., 2013: "Nutrient Stripping: The Global Disparity Between Food Security and Soil Nutrient Stocks", in: *Journal of Applied Ecology*; at: doi:[10.1111/1365-2664.12089](https://doi.org/10.1111/1365-2664.12089).
- Lal, R., 2003: "Soil Erosion and the Global Carbon Budget", in: *Environment International*, 29: 437–450.
- Lal, R., 2004: "Soil Carbon Sequestration Impacts on Global Climate Change and Food Security", in: *Science*, 304: 1623–1627.
- Lal, R.; Griffin, M.; Apt, J.; et al., 2004: "Managing Soil Carbon", in: *Science*, 304: 393.
- Lal, R., 2009: "Sequestering Carbon in the Soils of Arid Ecosystems", in: *Land Degradation & Development*, 20: 441–454.
- Lal, R., 2012: "Soils and Ecosystem Services", in: Lal, R.; Lorenz, K.; Huttel, R.F.; Schneider, B. U.; Von Braun, J. (Eds.): *Ecosystem Services and Carbon Sequestration in the Biosphere* (Dordrecht: Springer): 11–38.
- Lam, S.K.; Chen, D.; Mosier, A.R.; et al., 2013: "The Potential for Carbon Sequestration in Australian Agricultural Soils is Technically and Economically Limited", in: *Nature Science Report*, 3: 2179.
- Mermut, A.R., 2010: "Global Warming, Carbon Balance and Land and Water Management", in: Zdruli, P.; Pagliai, M.; Kapur, S.; Faz Cano, A. (Eds.): *Land Degradation and Desertification: Assessment, Mitigation and Remediation* (Berlin: Springer): 67–77.
- Pidwirny, M., 2006: *Introduction to the Ecosystem Concept. Fundamentals of Physical Geography*; at: <http://www.physicalgeography.net/fundamentals/9j.html>.
- Rubio, J.L., 2007: "Desertificación y Cambio Climático" [Desertification and Climate Change], in: *Ambienta*, 70: 26–27.
- Schrumpf, M.; Schulze, E.D.; Kaiser, K.; et al., 2011: "How Accurately Can Soil Organic Carbon Stock Changes Be Quantified by Soil Inventories?", in: *Biogeosciences*, 8: 1193–1212.

- Smith, P.; Martino, D.; Cai, Z.; et al., 2007: "Agriculture", in: Metz, B.; Davidson, O.R.; Bosch, P. R.; Dave, R.; Meyer, L.A. (Eds.): *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press).
- Sradnick, A.; Murugan, R.; Oltmanns, M.; et al., 2013: "Changes in Functional Diversity of the Soil Microbial Community in a Heterogeneous Sandy Soil After Long-Term Fertilization with Cattle Manure and Mineral Fertilizer", in: *Applied Soil Ecology*, 63: 23–28.
- Stewart, W.M.; Dibb, D.W.; Johnston, A.E.; et al., 2005: "The Contribution of Commercial Fertiliser Nutrients to Food Production", in: *Agronomy Journal*, 97: 1–6.
- Stocking, M., 1986: *The Cost of Soil Erosion in Zimbabwe in Terms of the Loss of Three Major Nutrients*. Consultant's Working Paper No. 3 (Rome: FAO Land and Water Division, Soil Conservation Programme).
- Stoorvogel, J.J.; Smaling, E.M.A.; Jansen, B.J., 1993: "Calculating Soil Nutrient Balances in Africa at Different Scales. I. Supra-national Scale", in: *Fertilizer Research*, 35: 227–235.
- Stringer, L., 2012: *Global Land and Soil Degradation: Challenges to Soil*. Technical Paper. *Global Soil Week, Berlin 19–22 November 2012. University of Leeds, UK*.
- Thatcher, M., 2012: "Costa Rican Farmers Beat Climate Change by Protecting Soil", at: <http://www.insidecostarica.com/dailynews/2012/april/09/costarica12040904.htm>.
- UNCCD, 2012: "Zero Net Land Degradation". UNCCD Secretariat Policy Brief May 2012. Bonn, Germany; at: <http://www.unccd.int/en/resources/publication/Pages/default.aspx>.
- UNEP, 1994: "Land Degradation in South Asia: Its Severity, Causes and Effects upon the People", INDP/UNEP/FAO. World Soil Resources Report 78 (Rome: FAO).
- WBI, 2012: *Climate-Smart Agriculture: Helping the World Produce More Food* (Washington, DC: World Bank); at: <http://lnkd.in/9JcyfC>.
- WOCAT, 2007: "Where the Land Is Greener: Case Studies and Analysis of SWC Worldwide", in: Liniger, H.P.; Critchley, W. (Eds.) (Berne: CTA—University of Berne).
- Zdruli, P., 2012: "Land Resources of the Mediterranean: Status, Pressures, Trends and Impacts on Regional Future Development", in: *Land Degradation & Development*, 25,4: 373–384.
- Zdruli, P.; Calabrese, J.; Ladisa, G.; et al., 2014: "Impacts of Land Cover Change on Soil Quality of Manmade Soils Cultivated with Table Grapes in the Apulia Region of South-Eastern Italy", in: *Catena*, 121: 13–21.

Carbon Management, Technologies, and Trends in
Mediterranean Ecosystems

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