FOOD FORWARD NDCs

Sequestering carbon in soil and enhancing soil health in crop systems

Overview

After oceans, soils are the second largest active carbon sink, with 1,500 billion tonnes of carbon found in soil organic matter worldwide. Soils are the most complex and biodiverse ecosystem in the world. Their water and carbon storage are essential for soil fertility, releasing nutrients for plant growth, and supporting the structural and biological health of the soil.

Soil organic carbon represents 25% of the full potential of natural climate solutions. However, soil health and biodiversity below ground has been largely neglected by the industrial agricultural revolution of the last century. Unsustainable land management practices that degrade soils have led to not only greenhouse gas (GHG) emissions but also a reduction in soils' ability to sequester carbon and support agricultural productivity. Between 20-40% of the global land area is degraded or degrading to varying extents and degrees, negatively affecting over 3.2 billion people. Therefore, restoring soil health is crucial for enhancing productivity of food landscapes, and it can play a significant role in climate change mitigation.

Soil health refers the ability of the soil to sustain the productivity, diversity and environmental services of terrestrial ecosystems. Healthy soil ensures (site-specific) high productivity and environmental health leading to improved ecosystem services. Soil health maintains the whole ecosystem and is associated with building soil organic carbon and reducing greenhouse gas emissions. The main GHGs are carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4).

Soil health depends on the physical, chemical and biological properties or composition of the soil, which are all interconnected. Soil health is the prerequisite for sustainable crop production. Understanding and improving these properties will result in improving the productive capacity of soil, along with boosting crop yield and quality. Therefore, safeguarding soil health and its productive capacity can help improve food security and nutrition outcomes.

Concrete measures to implement

Natural biological processes in healthy soils enable carbon sequestration and soil fertility. Farming practices that support soil health need to be customized or adapted to local conditions. However, some overarching strategies are used in nearly all climate zones, soil conditions or crop systems:

- Minimizing soil disturbance (e.g., no- or minimum tillage) through direct seed and/or fertilizer placement, which involves growing crops with minimum soil disturbance during and since the harvest of the previous crop. It can be used with all annual and perennial crops and vegetables. Direct planting can be done manually (e.g. jab planters) or mechanically (e.g. animal or tractor-drawn no-till drills) while avoiding compaction of soil. Minimizing disturbance protects against the loss of soil carbon through erosion and rapid breakdown of organic matter in the soil.
- Maintaining permanent soil cover with mulch, live mulch or crop residues. Mulch is any organic material (such as decaying leaves, bark or compost) spread over soil and crops to enrich and insulate the soil. Live mulch is a crop used in intercropping for the purposes of providing soil cover. Crop residues or live cover protect the soil from direct impact of erosive raindrops; conserve the soil by reducing evaporation and suppressed weed growth. Cover crops provide temporary or permanent vegetative cover to control erosion, reduce nutrient runoff and leaching, suppress weed growth, improve soil fertility, and increase biological diversity. Farmers can also customize cover crop mixes and management practices to meet their specific goals. Maintaining soil cover protects against erosion by wind and water and lower surface temperatures reduce the rate of decomposition of organic matter and hence, emissions of CO_2. Organic mulches are a source of carbon added to the soil and stimulate activity of meso- and microorganisms.
- Using organic fertilizer which increases organic matter with natural inputs while reducing or eliminating synthetic fertilizer inputs. Common organic

inputs include compost, animal manure and bedding, bone meal and blood meal, seaweed and algae, and green manure crops, especially legumes. Rotating livestock in fallowed fields is an additional method for manure-based fertilization. **Adaptive nutrient management** is important during a transition to improve soil health and establish a new equilibrium but relies on cropping systems and the availability of natural inputs. Organic fertilisers are a source of organic carbon for building soil carbon directly and indirectly by supporting stronger plant growth.

- Applying **biochar** in soil, if suited to the appropriate conditions, can assist carbon sequestration, improve soil quality, and bolster productivity and crop production.
- Integrated Soil Fertility Management (ISFM) following the 4Rs (Right Source of nutrients, at the Right Rate, at the Right Time and in the Right Place) of nutrient stewardship to optimize resource use. ISFM is a set of soil fertility management practices that require the use of fertilizer, organic inputs and improved germplasm, combined with knowledge on how to adapt these practices to local conditions. The approach aims to maximize agronomic use efficiency of the applied nutrients, improve crop productivity and eventually phase out the use of synthetic fertilizers. Especially in areas with poor soils, IFSM can help to steadily build up soil fertility, as more productive crops potentially increase organic carbon inputs to the soil from roots and plant litter over time.
- Maximizing plant species diversification involves cultivating a variety of crops that belong to the same or different species in each area through varied crop sequences and associations. **Breeding crop plants with deeper and bushy root ecosystems** could simultaneously improve both the soil structure and its levels of steady-state carbon, retention of water and nutrients, and plant yields.
- Crop rotation involves growing a series of crops in the same area in sequence, for example, alternating cereals (maize and wheat) with legumes (for example, beans). Along with cover crops, nitrogen-fixing cash crops (primarily legumes, such as peas or beans) can provide an additional source of soil nitrogen. Although most research examining the benefits of crop rotations focuses on soil fertility, research also confirms that increasing crop diversity through multispecies rotations produces a corresponding increase in soil species richness, which together with stronger plant growth with different rooting depths, can increase the amount of carbon stored in the soil.

- Erosion control: Minimize the potential for erosion through conservation systems that protect crop fields from wind and water runoff through terracing, windbreaks and contour buffer stripes, considering local topography (i.e. steep slopes are vulnerable to erosion by water, flat open areas are vulnerable to erosion by wind). Erosion can result in net loss of organic and inorganic carbon from soil.

The above practices are often integrated in larger systems that include other practices which have the potential to increase soil carbon sequestration and soil fertility and health:

- Integrated manure management: This includes the optimal handling of livestock manure involving its collection, storage, treatment and application. See *Sustainable livestock management*.
- Integrated crop-livestock system: This includes, for example, rotating livestock grazing and crop or graze livestock on cover crops. For more information see *Integrated crop-livestock management*.
- Agroforestry (the interaction of agriculture and trees, including the agricultural use of trees): This involves the planting of trees or shrubs in or around farmland or pastureland. Agroforestry on degraded lands increases soil organic carbon, improves soil nutrient availability and fertility, enhances soil microbial dynamics, and reduces soil erosion. Implementation of agroforestry systems should rely on a sophisticated design in order to avoid competition of trees and crops and ensure synergies between different species. For more information see *Implementing agroforestry systems*.
- Reducing land-use change and conversion of natural ecosystems for food production: For more details on measures to address direct and underlying drivers of ecosystem conversion, see *Reducing land-use change and conversion of natural ecosystems for food production*.

Enabling governance measures

The OECD provides examples of governance measures, based on examples implemented across the globe:

- Secure land tenure rights: Land managers and farmers are more likely to invest in soil management measures if their land rights are sufficient and secure. Security of tenure can be improved by land registration and titling, but other measures may be more effective depending on the context. Such measures should be equitable and gender-responsive to prevent unequal land access and enable women to be effective stewards of the environment.

- Full and effective participation from, and inclusion of, local communities and stakeholders ensures their free, prior, and informed consent (FPIC) in existing government plans and programmes, as well as evaluating economic, social and environmental trade-offs during programme design.
- Agricultural advisory services and sustainable inputs can provide land users with the necessary information and inputs to implement sustainable agricultural practices for soil health.
- Scaling market-based instruments (e.g., pricing CO_2 emissions with a carbon tax or Emission Trading Systems and rewarding net soil carbon sequestration with carbon price-based payment).
- Reduce and remove large-scale agricultural subsidies that create perverse incentives to overproduce or move towards monocultures, both of which can degrade soil health.
- Reinforcing or establishing regulations that increase the use of practices that enhance soil organic carbon and prevent the loss of organic soils, which can increase soil carbon stocks (e.g. in the United States, the Farm Bill requires farmers to comply with specific provisions to access U.S. Department of Agriculture (USDA) program benefits. These provisions include, for example, the **Highly Erodible Land Conservation program**, which enforces soil conservation practices on farmlands).
- Scaling government certification schemes (e.g., CARBOCERT in Spain established methodologies to measure net soil carbon sequestration on farmlands that can be certified and provides farmers the opportunity to access government subsidies to support the adoption of soil carbon storage practices).

Tools and MRV systems to monitor progress

FAO's Soil Carbon Monitoring

Using survey and modelling

Link: https://www.fao.org/3/i2793e/i2793e.pdf

FAO EX-Ante Carbon-balance Tool

Soil Organic Carbon MRV Sourcebook for Agricultural Landscapes

From the World Bank

Link: https://documents1.worldbank.org/curated/en/948041625049766862/pdf/Soil-Organic-Carbon-MRV-Sourcebook-for-Agricultural-Landscapes.pdf

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EO4CarbonFarming MRV Tool

From the ESA

Link: https://business.esa.int/projects/eo4carbonfarming

FAO's Tool for Agroecology Performance Evaluation

Indicators for assessing soil health

Link: https://www.fao.org/3/ca7407en/ca7407en.pdf

Verra Methodology for Improved Agricultural Land Management (VM0042)

VM0042 quantifies the greenhouse gas emission reductions and soil organic carbon removals that result from improved agricultural land management (ALM) practices. ALM includes such practices as water management; biomass residue management; improvements in fertilizer use; reduced tillage; grazing practices; and practices for cash and cover crop planting and harvesting.

Link: https://verra.org/methodologies/vm0042-methodology-for-improved-agricultural-land-management-v2-0/

Carbon Benefits Tool

Link: https://cbp.nrel.colostate.edu/

Land Degradation Surveillance Framework for assessing soil health, land degradation and vegetation diversity

Link: https://www.cifor-icraf.org/knowledge/publication/25533

4p1000 Initiative

A global Initiative that facilitates concrete actions around land and soil management, encouraging a transition to regenerative, productive, and resilient agriculture that benefits farmers and herders.

Link: https://4p1000.org/?lang=en

FAO Global Soil Partnership

A global mechanism to place soils into the Global Agenda and promote sustainable soil management. The Partnership works to improve soil governance and guarantee productive soils for food security, climate change adaptation and mitigation, and sustainable development.

Link: https://www.fao.org/global-soil-partnership/en/

Climate change mitigation benefits

- Enhanced soil carbon management has huge emissions mitigation potential: FAO estimates its global technical mitigation potential at 1.9

(0.4–6.8) $GtCO_2$ per year. At the farm level, soil organic carbon sequestration in croplands ranges between 0.11 and 1.92 tons carbon per hectare per year.

  - It should be noted, however, that carbon content does not increase infinitely, and reaches a saturation level after which it no longer increases further. It can also be re-released, if practices are not maintained or if triggered by climactic changes.

- Reduced agricultural emissions: Avoided emissions by preventing, for example, the release of CO_2 due to soil disturbance and through best-practice nitrogen emissions management.

Other environmental benefits

- Benefits for the climate: in addition to their impacts on the global carbon cycle, and as a source or sink for CH_4 and N_2O, soils can exert other physical effects on climate through alteration of albedo and their influence on regional water cycles.

  - Soils are also important in regional water cycles which may in turn impact evapotranspiration rates and sensible heat fluxes, with potential implications for the local climate.

- Benefits for water: increased water retention in the soil and more fertile soils from better management can reduce the need for irrigation and could reduce fertilizer needs. It can reduce GHG emissions generated by the pumping of irrigation water, direct emissions if less mineral fertilizer is applied to the soils, as well as emissions embedded in fertilizer production.

  - Improvement of water quality.
  - Contribution to the restoration of the water cycle.

- Cleaner air due to the reduction of synthetic fertilizer use (reducing the formation of fine particulate matter).
- Reducing fuel use and hence energy consumption in the long term.
- Conservation and increase of (soil) biodiversity.

Adaptation benefits

- Improvements in soil productivity due to:
    - Organic matter increase.
    - In-soil water conservation.
    - Improvements in soil structure and rooting zone.
- No-till and reduced-tillage cropping systems (using no-till seed drills and planters) provide good protection against soil erosion, reduce compaction, reduce disruption to fungal hyphae and improve habitat for wildlife and beneficial insects (e.g. ground cover provided by thatch and crop residue).
- Increasing soil biodiversity (by increasing soil organic matter) and hence nutrient availability in the soil.
- Increased crop yield and decreased amount of fertilizer use per hectare over the long-term.
- Enhanced resilience to climate-related water stress.
- See further relevant information in *Implementing integrated crop-livestock systems*, *Implementing agroforestry practices*, *Improved management of grasslands*, and *Implementing nature positive food production practices*.

Other sustainable development benefits

Soil health is critical to achieving the Sustainable Development Goals. Several SDGs are directly impacted by soil properties and processes and their sustainable management, including SDGs 2, 3, 6, 13, 15 and 17. Several SDG 15 targets related to mitigating land and soil degradation also have synergies with the Convention on Biological Diversity. Additionally, several SDGs are indirectly affected by soil quality and its management including SDGs 1, 5, 6, 8, 10, and 16. For example:

- SDG 1 (No poverty) & SDG 2 (Zero hunger): Regions faced with endemic poverty are also those where most of the population is dependent on agriculture. Therefore, sustainable soil management and improved agriculture are key factors for bolstering food security. Smallholder farmers operate on about 12% of the world's arable land and are an integral part of the global food system. More than 500 million smallholder farms across the globe are managed by poor populations, who often rely on their farms for subsistence.

- SDG 3 (Good health and well-being): Healthy soils increase nutrient availability in soil. It filters water that flows through it, as well as acting as a sponge to retain water and mitigating waterborne diseases.
- SDG 5 (Gender equality): Water security is a gendered issue as women and girls are disproportionately responsible for water collection.
- SDG 12 (Responsible consumption and production): Healthy soil increases productivity on farms, bringing in greater income to families and increasing their livelihood opportunities beyond the farm.
- SDG 14 (Life under water) & SDG 15 (Life on land): Soil biodiversity is key to sustainable agriculture and human well-being, as healthy soil is home to two-thirds of the world's biodiversity. There are more organisms in a tablespoon of healthy soil than there are people on earth. Soil also plays a critical role in watershed management by mitigating waterborne diseases as well as organic and inorganic contaminants.

Main implementation challenges and potential negative externalities and trade-offs

- High initial investment costs associated with machinery, and labour costs, depending on the choice of management practices.
- Lack of funding (e.g. organizational credit) can hinder development and farmers' capacity building activities.
- Inconsistent organizational policies and lack of organizational facilities to service farmers.
- Difficulties maintaining crop residue on farms (e.g. leading to outbreaks of pests). In other cases, crop residues are a source of income for farmers or used for livestock feed or as fuel or building material and are hence removed from the fields.
- Potential **yield reductions** in colder regions, impacting farmers' incomes, mostly during a transition period.
- **Nitrogen (N) immobilization** if materials with a high carbon-to-nitrogen ratio are incorporated; this increases biological activity, which causes a greater demand for N.

- Decreased albedo as soil organic matter content increases the absorbance of the soil.
- Increased nitrogen leaching from organic matter rich soil which can impact water quality.
- Increased weeding and herbicides use in no-till systems.
- See further relevant information in ***Implementing integrated crop-livestock management***, ***Implementing agroforestry systems***, ***Improved management of grassland***, and ***Implementing nature positive food production practices***.

Measures to minimize challenges and address potential negative externalities and trade-offs

- It is important to be aware that a **change of soil management practices** and the resulting increase of soil organic carbon does not necessarily lead to carbon sequestration (and hence negative emissions). In soils which are in a state of continuous carbon loss, a build-up of carbon can result in a reduction in carbon losses and hence needs to be accounted for differently.
- Mainstreaming sustainable soil management practices into relevant ministries and local and regional institutions and ensuring they are equipped with the necessary resources – including trained and motivated extension workers – to provide farmers with effective assistance.
- Increasing measures to reduce knowledge barriers to soil carbon sequestration practices, such as government advisory services and investments in Research & Development, including the co-design of practices with the farmers in living labs.
- Providing credit to farmers to buy equipment and inputs through banks and credit agencies at reasonable interest rates.
- Offering financial (affordable lines of credit) and practical support for the measurement of net soil carbon sequestration and other abatement practices to farmers wishing to participate in carbon credit schemes or offset markets to encourage investments. **Guidelines** for agricultural carbon offset projects are provided by the G7 CompensACTION Initiative.
- Reducing tariffs on imported conservation agriculture equipment to encourage and promote their availability. Over time, producing this

equipment locally will boost availability, customize the equipment for local needs, create jobs and cut costs.

- Scaling support for capacity building at all levels.
- Design and implementation of crop rotations according to the various objectives, for instance: food and fodder production, residue production, pest and weed control, nutrient uptake or biological subsurface mixing/cultivation.
- Use of appropriate/improved seeds for high yields as well as high residue production of above-ground and below-ground parts, based on soil and climate conditions.
- Applications of biochar can enhance the carbon sequestration capacity of soil.
- Scaling subsidies and other incentives to compensate for yield reductions (e.g. access to premium sustainable markets).
- Inform consumers to make sure that the demand side is ready to adapt their consumption behaviour.
- See further relevant information in *Implementing integrated crop-livestock management*, *Implementing agroforestry systems*, *Improved management of grassland*, and *Implementing nature positive food production practices*.

Implementation costs

- Costs of carbon sequestration in soil in croplands and grasslands range from less than USD 20 per ton to USD 100 per ton, as estimated in the IPCC report.

Intervention in practice

- GIZ ProSoil: From 2014 to 2027, GIZ and the German Federal Ministry for Economic Cooperation and Development (BMZ) are implementing a program to conserve and rehabilitate soil, enhancing food security and sustainable land use in six African countries and India. ProSoil aids its partners in the widespread implementation of climate-smart agroecological practices, offering farmers training and guidance on reducing soil erosion and enhancing and maintaining soil fertility. Upon completion, the project will conserve or rehabilitate 816,000 hectares of soil, bolster resilience against drought, increase crop yields, and contribute to income and food security.

- CGIAR's Research Program on Maize shows that conservation agriculture reduces farmer vulnerability to climate risks throughout southern Africa. Farmer adoption of conservation agriculture practices covers more than 627,000 hectares in Malawi, Zambia and Zimbabwe, with yield benefits of 30% to 50% (up to 140%) under drought conditions. The results have enriched the discussions on climate-smart agriculture and associated policies in southern Africa.
- The SIMLESA project, funded by the Australian Centre for International Agricultural Research (ACIAR) has significantly increased food crop yields, up to 38%, as well as incomes, while maintaining soil health in the countries where it has been implemented (Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania and Uganda).

References

1. Abagandura, G. O., Şentürklü, S., Singh, N., Kumar, S., Landblom, D. G., & Ringwall, K. (2019). Impacts of crop rotational diversity and grazing under integrated crop-livestock system on soil surface greenhouse gas fluxes. *PLoS ONE*, *14*(5). Retrieved February 6, 2024, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6530893/
2. Al-Kaisi, M. M., & Yin, X. (2005). Tillage and Crop Residue Effects on Soil Carbon and Carbon Dioxide Emission in Corn–Soybean Rotations. *Journal of Environmental Quality*, *34*(2), 437–445
3. Ataei, P., Sadighi, H., Aenis, T., Chizari, M., & Abbasi, E. (2021). Challenges of Applying Conservation Agriculture in Iran: An Overview on Experts and Farmers' Perspectives. *Air, Soil and Water Research*, *14*, 1178622120980022
4. Bhan, S., & Behera, U. K. (2014). Conservation agriculture in India – Problems, prospects, and policy issues. *International Soil and Water Conservation Research*, *2*(4), 1–12
5. Calvo, F. (n.d.). How Farm Policies Can Help Protect Our Soils. *International Institute for Sustainable Development*. Retrieved February 7, 2024, from https://www.iisd.org/articles/analysis/farm-policies-protect-soils
6. Carvalho, J. L. N., Raucci, G. S., Frazão, L. A., Cerri, C. E. P., Bernoux, M., & Cerri, C. C. (2014). Crop-pasture rotation: A strategy to reduce soil greenhouse gas emissions in the Brazilian Cerrado. *Agriculture, Ecosystems & Environment*, *183*, 167–175

7. Climate Smart Agriculture Sourcebook. (n.d.). Retrieved February 6, 2024, from https://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b7-soil/chapter-b7-3/en/
8. Conservation agriculture reduces climate risks throughout Southern Africa. (n.d.). *CGIAR*. Retrieved February 7, 2024, from https://www.cgiar.org/annual-report/performance-report-2020/conservation-agriculture-reduces-climate-risks-throughout-southern-africa/
9. Dickinson, D., Balduccio, L., Buysse, J., Ronsse, F., Huylenbroeck, G. van, & Prins, W. (2015). Cost-benefit analysis of using biochar to improve cereals agriculture. *GCB Bioenergy*, *7*(4), 850–864
10. European Union DG-ENV. (2011). *SOIL: the hidden part of the climate cycle*. Retrieved from https://climate.ec.europa.eu/system/files/2016-11/soil_and_climate_en.pdf
11. FAO. (2019). *TAPE Tool for Agroecology Performance Evaluation 2019 – Process of development and guidelines for application.* Retrieved from https://www.fao.org/3/ca7407en/ca7407en.pdf
12. FAO. (2021). *Climate change mitigation options in agrifood systems: Summary of the Working Group III contribution to the Intergovernmental Panel on Climate Change Sixth Assessment Report (AR6)*. Retrieved from https://www.fao.org/documents/card/en/c/cc4943en
13. FAO. (n.d.). Benefits of Conservation Agriculture (CA). Retrieved February 7, 2024, from https://www.fao.org/conservation-agriculture/impact/benefits-of-ca/en/
14. Goswami, S. B., Mondal, R., & Mandi, S. K. (2020). Crop residue management options in rice–rice system: a review. *Archives of Agronomy and Soil Science*. Retrieved February 7, 2024, from https://www.tandfonline.com/doi/abs/10.1080/03650340.2019.1661994
15. Henderson, B., Lankoski, J., Flynn, E., Sykes, A., Payen, F., & MacLeod, M. (2022). Soil carbon sequestration by agriculture: Policy options. Retrieved February 7, 2024, from https://www.oecd-ilibrary.org/agriculture-and-food/soil-carbon-sequestration-by-agriculture_63ef3841-en;jsessionid=CC7AnzMq1vfeipkJ25cuITmXLEII5ueAZGloo1-d.ip-10-240-5-171
16. Kell, D. B. (2011). Breeding crop plants with deep roots: their role in sustainable carbon, nutrient, and water sequestration. *Annals of Botany*, *108*(3), 407
17. Lal, R., Monger, C., Nave, L., & Smith, P. (2021). The role of soil in regulation of climate. *Philosophical Transactions of the Royal Society B*. Retrieved February 8, 2024, from https://royalsocietypublishing.org/doi/10.1098/rstb.2021.0084
18. Rumpel, C., Henry, B. K., Chenu, C., & Amiraslani, F. (2022). Benefits and trade-offs of soil organic carbon sequestration

19. Soil+ the SDGs: the answer lies beneath our feet. (n.d.). *Coalition of Action for Soil Health*. Retrieved February 8, 2024, from https://www.coalitionforsoilhealth.org/news/soil-the-sdgs-the-answer-lies-beneath-our-feet

20. Sun, W., Canadell, J. G., Yu, L., Yu, L., Zhang, W., Smith, P., et al. (2020). Climate drives global soil carbon sequestration and crop yield changes under conservation agriculture. *Global Change Biology*, *26*(6), 3325–3335

21. Thierfelder, C., Bunderson, W., & Mupangwa, W. (2015). Evidence and Lessons Learned from Long-Term On-Farm Research on Conservation Agriculture Systems in Communities in Malawi and Zimbabwe. *Environments*, *2*, 317–337

22. Turmel, M.-S., Speratti, A., Baudron, F., Verhulst, N., & Govaerts, B. (2015). Crop residue management and soil health: A systems analysis. *Biomass Use Trade-Offs in Cereal Cropping Systems: Lessons and Implications from the Developing World*, *134*, 6–16

23. Wageningen Centre for Development Innovation, Wageningen University & Research. (2021). *Food-system interventions with climate change and nutrition co-benefits: A literature review*. Retrieved from https://www.ifad.org/documents/38714170/43188972/wageningen_foodsystems 8e20-ea3d-a7ab-77328ddf6adb?t=1622789088577