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Soil protection and reduction of greenhouse gas emissions

How can a healthy soil contribute to climate change mitigation?

BACKGROUND

The link between soil and climate

Climate change poses a threat to global agriculture, with the African continent particularly vulnerable. Since 1961, climate change has reduced agricultural productivity in Africa by 34 per cent. Projections warn that up to 80 million additional people could be affected by hunger[1]. Already today, 40 per cent of the world's land area is considered degraded[2]. At the same time, agricultural activities contribute considerably to the degradation of ecological and agricultural systems.

Soils play a key role in food security and climate change. After the oceans, soils are the Earth's second largest carbon sink – they store more CO_2 than the atmosphere and all forests combined. But only healthy soils have this capacity. When they are degraded, they lose both their fertility and their storage capacity.

Soil protection and rehabilitation practices (SPR) increase the carbon content of soils and agroforestry systems, improve soil health and increase productivity. However, implementing SPR measures for climate change requires a transformation of agricultural and food systems.

[1] IPCC (2022): Special Report "Climate Change and Land"
[2] UNCCD (2022): Global Land Outlook 2

THE GLOBAL PROGRAMMES ProSoil AND Soil Matters IN BRIEF

As part of Germany's Special Initiative "Transformation of Agricultural and Food Systems", the Global Programme "Soil Protection and Rehabilitation for Food Security" (ProSoil) supports and advises smallholder farmers in Ethiopia, Benin, Burkina Faso, India, Kenya, Madagascar and Tunisia on agro-ecological and climate-smart agricultural practices with a focus on sustainable land management. Stakeholders from the scientific community, civil society and the private sector are actively involved in the activities, in addition to the relevant government agencies in each country. Since the launch of ProSoil in 2014, soil degradation has been reversed on more than 981,000 hectares of land. This has resulted in an average yield increase of 44 percent, directly benefiting the livelihoods of more than 2.6 million people. More than 65 percent of the farmers reached are women. Through climate-smart soil management solutions, the carbon footprint has been reduced by around 1.74 million tonnes of carbon dioxide, as healthy soils are an important carbon sink. The Global Programme "Soil Matters - Innovations for Soil Health and Agroecology", launched in 2025, builds on the results of ProSoil and aims to develop and promote agroecological innovations in partnership with the private sector to scale up impact and support agricultural transformation processes. Soil Matters is active in Tunisia, India, Kenya, Ethiopia, Madagascar and Cameroon. Both Global Programmes, ProSoil and Soil Matters, are commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) and co-funded by the European Union (EU) and the Gates Foundation.

Why is the topic important?

Smallholders play a particularly important role in agriculture: 60 per cent of the word's food is produced by smallholder farmers in low- to middle-income countries. They typically farm less than 1-2 hectares of land. In regions of high poverty and limited resources, soil protection and restoration are crucial – both for securing livelihoods and for climate protection. Measures such as integrated soil fertility management, erosion control and conservation agriculture (e.g. direct seeding, mulching, composting) help to maintain or restore soil functions in the long term. These measures not only increase productivity, but also make a cost-effective contribution to reducing greenhouse gas emissions if compared with other technologies (e.g. direct air carbon capture). An annual mitigation potential of 922 Mega tonnes CO_2eq per year is achievable at less than 100 US$ per tonne of CO_2eq per year by increasing soil organic carbon in croplands[3]. This corresponds to ca. 1,7% of global greenhouse gas emissions (without emissions from land use and land use change and forestry).
At the same time, poorly managed soils are vulnerable to carbon losses, for example through erosion, intensive tillage or land use change. Agroforestry, the integration of trees into agricultural systems, is of key importance here. Since carbon is stored in the biomass of trees for longer than in the soil, agroforestry systems offer particularly stable potential for CO_2 sequestration.

Biochar, a form of charcoal produced by heating organic biomass in a low-oxygen environment, can also provide a permanent carbon sink, but biochar production should be limited to organic waste that would otherwise be burnt.

In addition to carbon removal, SPR practices improve soil health, water infiltration and biodiversity[4]. This increases the resilience of agricultural systems to extreme climatic events such as drought or erratic rainfall. Many of these practices also promote crop and income diversification, further contributing to the resilience of rural communities and to food and nutrition security.

[3] Sutton, William R., Alexander Lotsch, and Ashesh Prasann. 2024. Recipe for a Livable Planet: Achieving Net Zero Emissions in the Agrifood System. Agriculture and Food Series. Washington, DC: World Bank. doi:10.1596/978-1-4648-2093-9.
[4] ProSoil (2024):" Soil Protection and climate change adaptation: How can a healthy soil help combat the impacts of climate change?" *Link*

Healthy soils and their role as carbon sinks are increasingly being recognised in international climate policy. Some countries have included measures to promote soil carbon in their national climate protection plans (NDCs)[5]. It has been estimated that, soils could absorb between 2 and 4 per cent of human-made emissions, assuming that governments around the world agree on a global effort to gradually change land use practices to turn agricultural soils into carbon sinks[6].

Smallholder farmers in developing countries can also contribute to carbon sequestration. Depending on the practice, average sequestration rates range from 0.1 and 1 tonne of CO_2eq per hectare per year[7]. Methods such as reduced tillage or the use of legumes as catch crops enable sequestration rates of 0.2-0.5 tonnes of CO_2eq per hectare per year[8]. Soil sample measurements in Western Kenya showed that integrated soil fertility management practices[9] promoted by ProSoil sequester about 0.44 tons of CO_2eq per hectare per year, while soil conservation techniques[10] promoted by ProSoil can achieve up to 3.38 tonnes of CO_2eq[11]. In comparison agroforestry systems in the project region in Western Kenya sequester between 2-4 tonnes of CO_2eq per hectare per year. The modelled values for soil carbon sequestration (excluding forest biomass) for the ProSoil intervention areas are between 0.076 and 0.49 tonnes of CO_2eq per hectare per year, depending on the location. Climatic conditions play an important role: biomass accumulation is higher in humid regions than in arid areas without irrigation systems. As soil sampling is expensive and time consuming, these values are based on modelled crop yield surveys, using conservative assumptions to avoid overestimating the climate impact. Reporting of mitigation impacts includes the deduction of a 20 per cent non-permanence risk buffer to account for the risk of loss of sequestered carbon due to land use change.

Table 1: Modelled emission factors for soil carbon sequestration in the ProSoil project regions)

	Ethiopia (Afar)	West-Kenya	India	Mada-gascar	Tunisia	Burkina Faso	Benin
Average t CO_2/ha/year 2022-2024	0,076	0,495	0,241	0,192	0,481	0,267	0,383

[5] Badabate et Al. (2023): Improving the Nationally Determined Contribution (NDC) of the Republic of Benin: Challenges, needs for support and opportunities for future engagements *Link*

[6] Sommer, R. and D. Bossio (2014), 'Dynamics and climate change mitigation potential of soil organic carbon sequestration'.

[7] Smith, P. et al. (2008), 'Greenhouse gas mitigation in agriculture'

[8] Minasny, B. et al. (2017), 'Soil carbon 4 per mille'

[9] ISFM practices: soil analyses, liming of acidic soils, use of compost and manure, mineral fertilizer where needed, bio-pesticides

[10] conservation techniques practices: continuous minimum mechanical soil disturbance, Permanent organic soil cover, Diversification of crop species grown in sequences and/or associations

[11] Wehinger, T. and Lutta, A. (2024) The economics of soil organic carbon: Multi-benefits from sustainable land management for smallholders in Western Kenya. A case for the Economics of Land Degradation Initiative.

Challenges: Barriers for effective climate mitigation through soil protection and rehabilitation

Despite its many benefits, smallholder adoption of SPR is limited by a lack of economic incentives and supportive policy frameworks, technical skills, access to finance and access to technology. Public and private investment in climate-smart agriculture is low and often does not sufficiently support local extension systems. These extension systems are an important element in reaching smallholder farmers. Other barriers include inadequate market access and unclear land rights, which discourage investment by the private sector or by smallholder farmers themselves. Prevailing incentive schemes, such as mineral fertiliser subsidies, often promote only short-term yield increases rather than longer-term soil health targets.

Although SPR is gaining attention in climate policy, more long-term policy planning is needed to integrate soil health into national or local agricultural, climate and development plans. Regulatory oversight and practical implementation of public policies that tap the greenhouse gas mitigation potential of smallholder agriculture also depend on the establishment of robust monitoring systems.

Agriculture with cover crops, © GIZ

How to overcome these challenges?

ProSoil supports smallholder farmers in increasing their yields through the promotion of climate-smart farming practices. Higher yields are the main incentive for farmers to adopt sustainable SPR methods in the long term. Measures such as conservation agriculture, agroforestry systems, soil and water conservation, the use of organic fertilisers from manure or urban waste and biochar all help to improve productivity and meet climate targets. The project strengthens local agricultural advisory systems and promotes business models that improve access to markets for crops and agroecological inputs by expanding local supply and value chains for, for example, organic fertiliser and appropriate equipment. ProSoil also works at the policy level: For example, the programme supports the Ethiopian government in establishing a national soil information system, and is supporting the creation of an enabling policy environment for soil health in Kenya. It also facilitates access to climate finance, for example through the voluntary carbon market in Western Kenya (see box below). In India, a cooperation with the National Bank for Agriculture and Rural Development (NABARD) scales up a system for producing fertilizer from urban organic waste for smallholder agriculture. This addresses urban organic waste management and the shortage of organic fertiliser by transforming urban waste into high quality organic fertiliser for smallholder farmers. ProSoil is also working together with research institutions to expand the knowledge base for climate-smart soil rehabilitation measures, including studies on the use of biochar in India and Benin[12].

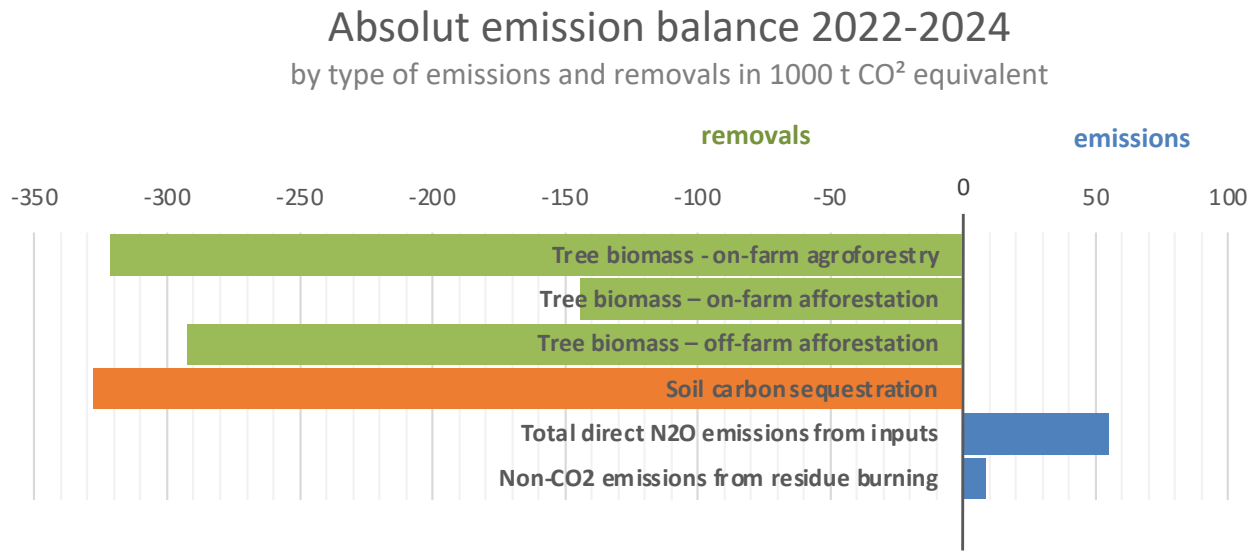
12 ProSoil (2023): Greenhouse gas emissions from Terra Preta substrates in India. ***Link***; ProSoil (2023): Émissions de gaz à effet de serre des substrats de Terra Preta au Bénin ***Link***

As direct measurement of soil carbon on agricultural land is complex and costly, ProSoil relies on model-based emission factors. The soil carbon monitoring system is based on modelling biomass inputs from crop residues using crop yield surveys. Standardised emission factors from the FAO EX-ACT tool[13] are used for agroforestry and afforestation activities. The modelling takes into account relevant sources, sinks and returns of greenhouse gases, including methane and nitrous oxide emissions from fertilisation. The programme follows the principle of applying conservative carbon accounting assumptions to realistically and reliably reflect its climate impact.

Outcomes

- Climate-smart soil management solutions introduced by ProSoil have contributed to reducing CO_2eq emissions by around 1.74 million tonnes between 2020 and 2024[14].
- The measures implemented by ProSoil saved or sequestered around 725,000 tonnes of CO_2eq in 2024 – equivalent to the annual emissions of around 67,000 Europeans[15].
- The total reduction achieved in the ProSoil project regions between 2022 and 2024 shows that a large part of the reduction is achieved through the establishment of agroforestry biomass, while soil carbon sequestration contributes 35 per cent (see figure 1).
- In Madagascar, studies show that improved pasture fodder crops can increase soil carbon content by more than 50 per cent per hectare compared to traditional crops.
- In India, working with the National Bank for Agriculture and Rural Development (NABARD), the use of urban organic waste for fertiliser production has been scaled, helping reduce methane emissions.
- Together with research partners, ProSoil is expanding the evidence base for climate smart SPR, including the use of biochar in India and Benin. In northern Benin, the use of biochar (mainly from otherwise unused maize cobs) increased cotton yields by 74 per cent, while sequestering carbon in soils[16].
- In western Kenya, maize yields tripled while fertiliser costs were eliminated through SPR measures in a climate-smart way: up to 3,5 tonnes of CO_2eq per hectare and year can be mitigated.

Figure 1: Emission balance ProSoil



13 Environmental eXternalities ACcounting Tool ***Link***

14 This corresponds to the clearing of approximately 8,700 hectares of tropical rainforest, based on a pure carbon loss of 200 t C/ha.

15 eurostat (2025): "EU greenhouse gas footprint: 10.7 tonnes per capita ***Link***

16 ProSoil (2023): Greenhouse gas emissions from Terra Preta substrates in India. ***Link***; ProSoil (2023): Émissions de gaz à effet de serre des substrats de Terra Preta au Bénin ***Link***

Example from the Field
Turning Carbon into Opportunity: How Kenya's Project is Reviving Soil and Supporting Farmers

In Kenya, long-term financing for sustainable land management (SLM) has been successfully tested through a carbon offset project. In western Kenya, smallholder farmers face land degradation, food insecurity and limited agricultural support. The carbon project in ProSoil areas channels revenues from the voluntary carbon market into 20-year, semi-annual SLM advisory contracts for 60,000 to 100,000 farmers, coordinated by a local non-profit organisation. The initiative increases yields by about 30 per cent by promoting agroecological practices, sequesters approximately 3.5 tonnes of CO_2eq per hectare per year in soils and agroforests, restores soil carbon content and strengthens climate resilience.

The project demonstrates how private carbon finance can be used as a sustainable financing mechanism for agricultural extension, which is the main entry point for supporting smallholder farmers. However, establishing an effective implementation structure for such projects remains a challenge due to the high transaction costs of bringing together large numbers of smallholder farmers and the limited upfront funding available for project development.

The evolving legal and regulatory framework in Kenya also poses uncertainty for the long-term planning of carbon projects. While fluctuating voluntary carbon prices make income projections difficult, the growing global demand for nature-based solutions offers encouraging long-term potential.

More information: ***Link***

Misiko Stephen Musamali and Nakhungu Rose Musamali using maize stovers to shed ready compost manure at their farm in Namilama B Village, Chwele Kabuchai ward, Kabuchai Subcounty, Bungoma county, © GIZ

Key Messages

- **Soil protection is an important strategy for mitigating climate change, but it is not an alternative to climate protection measures in other sectors**. Modelling the climate protection impact of soil protection measures in seven partner countries for the period 2020 to 2024 shows that implementing conservation agriculture and agro-forestry on 982,000 hectares can sequester a total of 725.841 t CO_2eq per year. Taking into account that the gradually increasing area under soil protection, a total 1.74 million tons of CO_2eq at has been sequestered between 2020 and 2024 (at least, as some countries could not provide data for 2020 and 2021). Given that 746 million tonnes of CO_2eq were emitted in Germany in 2022 according to the German Federal Environment Agency, this shows that soil protection is not a substitute for mitigation measures in other sectors.
- To provide smallholder farmers with access to climate finance and to compensate them for their climate performance, **innovations in cost-effective monitoring systems and soil information systems** are needed that reliably assess the mitigation performance. Currently, recognized monitoring approaches for soil carbon are either too imprecise (based on emission factors only) or too expensive (soil sampling) to allow large numbers of smallholders to access carbon markets.
- **Compensation schemes for mitigation effects achieved by smallholders through sustainable SPR measures**, including organic fertiliser in subsidy schemes, can provide an incentive for smallholders to increase climate impacts on large scale.
- **Carbon projects in smallholder agriculture require high initial investment** in the set up of extension services and monitoring systems. These projects can only be realized if the farming practices promoted result in an **economic benefit for the farmers**.

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