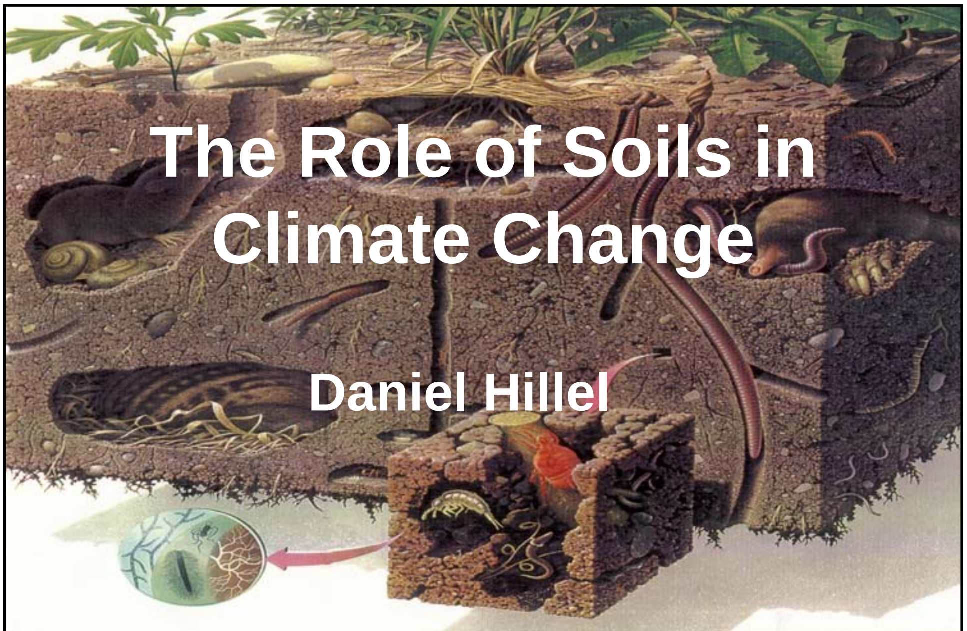
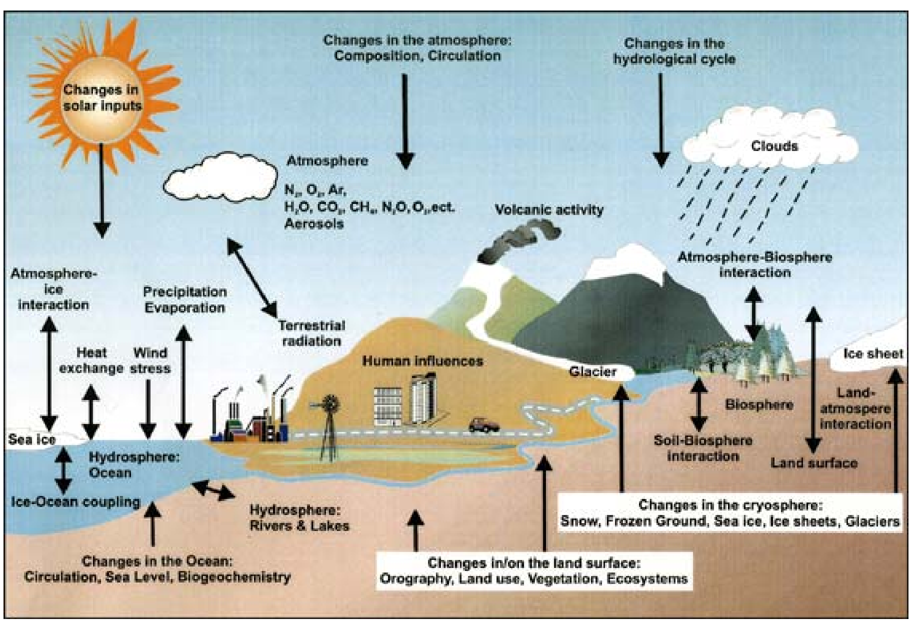
The Role of Soils in Climate Change

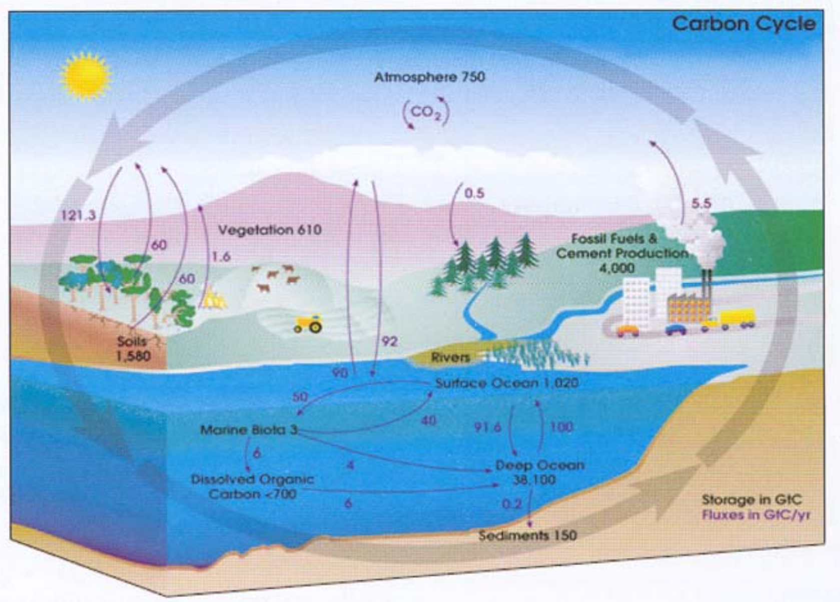
Daniel Hillel

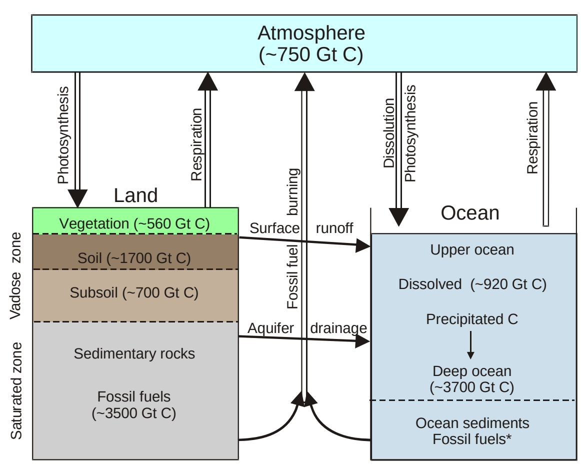


COLUMBIA UNIVERSITY
CENTER FOR CLIMATE SYSTEMS RESEARCH

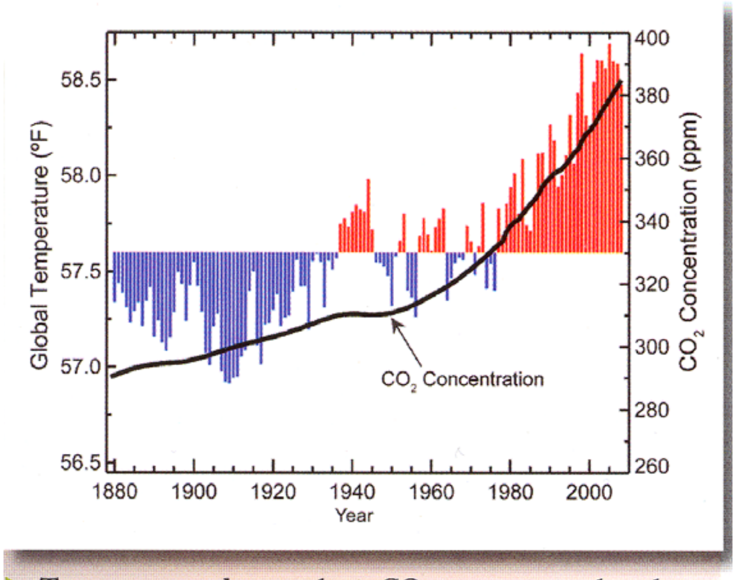


Major carbon pools and fluxes of the global carbon balance





Carbon exchange in the land-ocean-atmosphere continuum
(*Quantitative estimates vary widely)



Temperature and atmospheric CO_2 concentration have been steadily rising. *Image courtesy of Dr. Jerry Hatfield.*

Background

The earth's terrestrial ecosystem is a bio-thermodynamic machine driven by solar energy and involving the exchanges of water, oxygen, carbon, nitrogen, and other elements in the soil-biota-atmosphere continuum.

Green plants perform photosynthesis by absorbing atmospheric CO2 and reducing it to forms of organic carbon in combination with soil-derived water, while utilizing the energy of sunlight.

Roughly 50% of the carbon photosynthesized by plants is returned to the atmosphere as CO2 in the process of plant respiration. The rest is incorporated in leaves, stems, and roots.

Plant residues are deposited on or within the soil. There, organic compounds are ingested by a diverse community of aerobic and anaerobic organisms, including primary decomposers (bacteria and fungi), and secondary consumers (nematodes, insects, earthworms, rodents, etc.).

The ultimate product of organic matter decay in the soil is a relatively stable complex of compounds known collectively as humus.

Carbon Exchange in the Terrestrial Domain

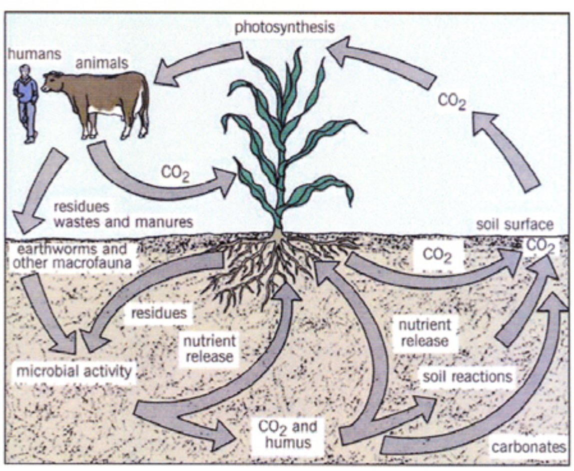
The world's soils are major absorbers, depositories, and transmitters of organic C.

They contain ~ 1700 Gt C to a depth of 1 meter, and 2400 Gt to a depth of 2 meters.
About 560 Gt is contained in terrestrial biota (plants and animals).

In contrast, the amount of carbon in the atmosphere is estimated to total 750 Gt.

The quantity of organic C in soils is spatially and temporally variable, depending on the balance of inputs versus outputs over time.

Organic carbon in soils typically constitutes less than 5% by mass, mainly in the upper 20 to 40 centimeters (the so-called "topsoil"). However, that content varies greatly, from 1% in arid-zone soils, called aridisols, to 30% or more in waterlogged organic soils such as histosols.



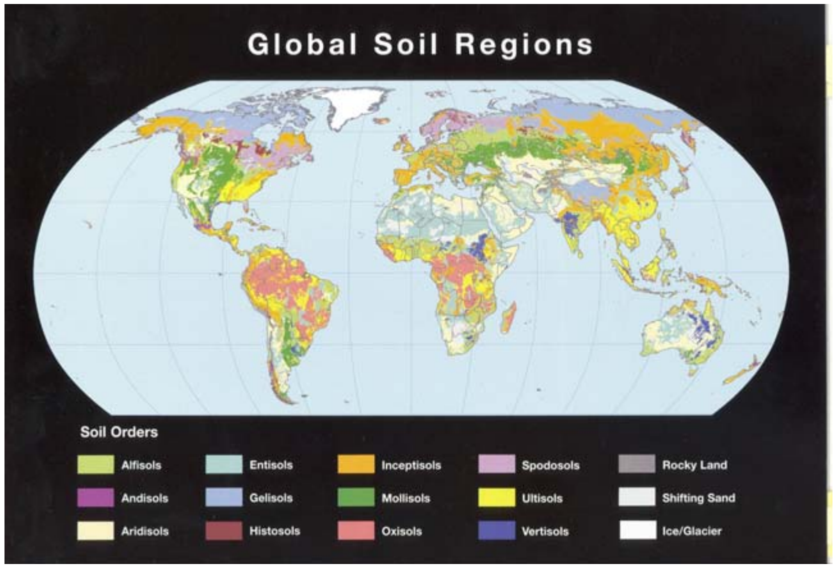


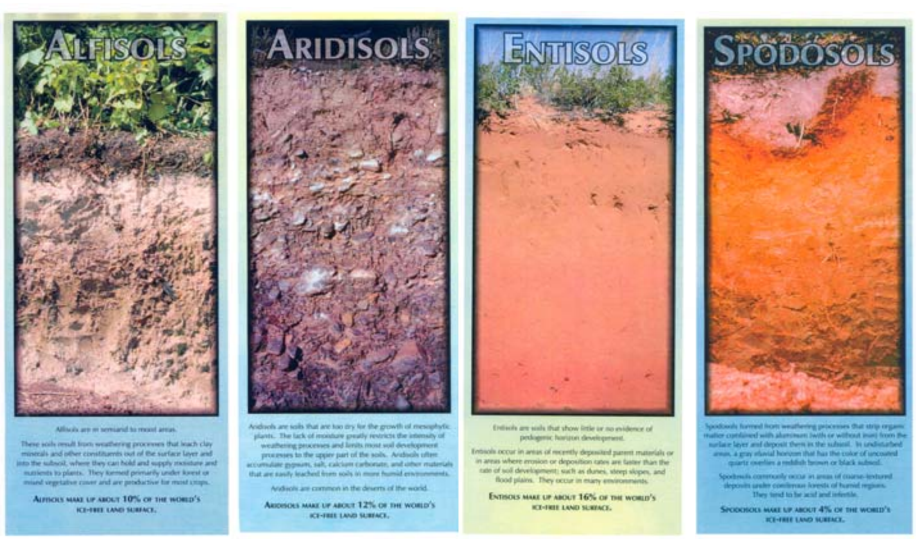
Table A.1 Estimated mass of carbon in the world's soils (excluding glacier-covered areas)

Soil orders	Area k.km2	Area %	Organic C t/ha	Organic C global Gt	Organic C % global	Inorganic C Gt
Alfisols	13,159	10.1	69	90.8	5.3	43
Andisols	975	0.8	306	29.8	1.8	0
Aridisols	15,464	11.8	35	54.1	3.2	456
Entisols	23,432	17.9	99	232.0	13.7	263
Gelisols	11,869	9.1	200	237.5	14.0	10
Histosols	1,526	1.2	2,045	312.1	18.4	0
Inceptisols	19,854	15.2	163	323.6	19.0	34
Mollisols	9,161	7.0	131	120.0	7.0	116
Oxisols	9,811	7.5	101	99.1	5.8	0
Spodosols	4,596	3.5	146	67.1	3.9	0
Ultisols	10,550	8.1	93	98.1	5.8	0
Vertisols	3,160	2.4	58	18.3	1.1	21
Other soils	7,110	5.4	24	17.1	1.0	5
TOTALS	130,667	100.0		1,699.6	100.0	948

Note: five soil orders (Entisols, Gelisols, Histosols, Inceptisols, and Mollisols) account for some 72% of all the organic carbon in the world's soils. Gelisols alone account for between 14% and 24.5% of the total. There is, however, a large measure of uncertainty in the data.

MASS OF CARBON IN THE WORLD'S SOILS

SOIL ORDERS	ORGANIC C (Gt)
Alfisols	90.8
Andisols	29.8
Aridisols	54.1
Entisols	232.0
Gelisols	237.5
Histosols	312.1
Inceptisols	323.6
Mollisols	120.0
Oxisols	99.1
Spodosols	67.1
Ultisols	98.1
Vertisols	18.3
Other soils	17.1
TOTALS	1,699.6



Climate Change Impacts on Different Soils

Soil formation involves the interaction of climate, topography, geology, biota, and time. These differ from region to region. Consequently, there are numerous soil types, differing in basic properties and potential responses to climate change.

Soils with a high content of carbonaceous matter, known as organic soils, typically form where prolonged saturation with water results in a deficiency of oxygen, which inhibits decomposition and promotes the accumulation of organic matter.

When converted to agricultural use, such soils are drained. Aeration accelerates decomposition and spurs the emission of CO2. Cultivated peat soils may lose as much as 20 tons C per hectare per year in tropical and subtropical climates, and roughly half that amount in temperate climates.

Of special concern are permafrost wetlands of cold regions (termed gelisols), abundant in Siberia, Canada, and Alaska. When subjected to warming, they thaw out and, while still saturated, emit methane. Later, when drained of excess water and aerated, peat undergo aerobic decomposition and releases large fluxes of carbon dioxide.

Human Management of Soils

Soil carbon balance is influenced by human management, including the clearing or restoration of natural vegetation and the modes of land use.

Cultivation spurs microbial decomposition of SOM while depriving it of replenishment, especially if the cropping program involves removal of plant matter and if the soil is kept bare seasonally.

Organic carbon is lost from soils both by oxidation and by erosion of topsoil. Some cultivated soils may, over time, lose as much as one-third to two-thirds of their original organic-matter content. Consequently, soils degrade in quality, fertility, structure.

Though agricultural soils acted in the past as significant sources of atmospheric CO_2, their present carbon deficits offer an opportunity to absorb CO_2 from the atmosphere and to store it as added organic matter in the future decades.

The historical loss of carbon in the world's agricultural soils is variously estimated to total 42 to 78 billion tons. Substantial restoration of that loss may be achieved by minimizing soil disturbance while optimizing nutrient and water supply to maximize plant production and residue retention.

Potential Sequestration of Carbon in Soils

Depletion of organic matter in soils initiates a vicious cycle of degradation, affecting food security and environmental quality.

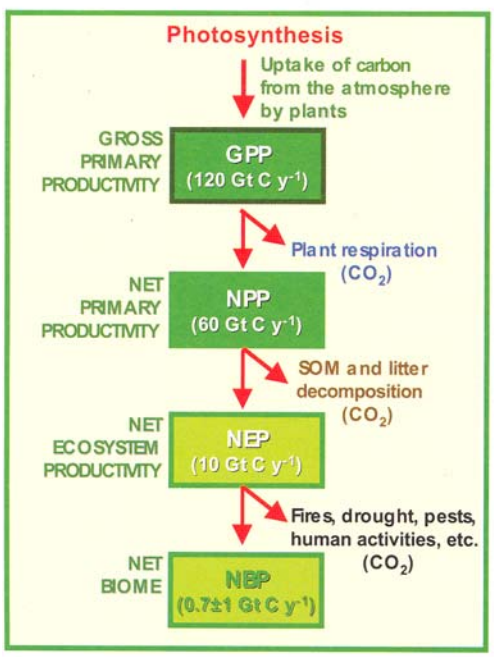
Reversing that depletion via carbon sequestration can induce a benign cycle of productivity gain. Enrichment of the topsoil with organic matter makes it less prone to compaction, crust formation, and erosion.

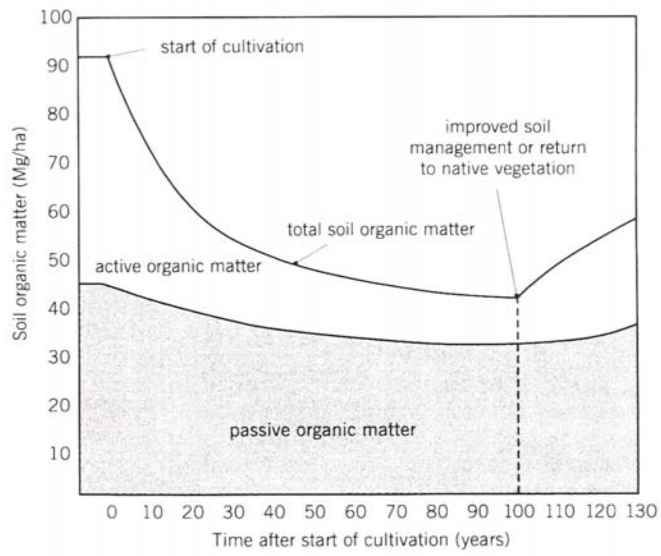
Potential C sequestration in agricultural soils is estimated to total 600 and 900 megatons per year over several decades.

The recommended practices include reforestation, agro-forestry, no-till farming to avoid mechanical disturbance of the soil, use of high-residue cover crops, shortening or elimination of fallow periods, augmentation of soil nutrients (by fertilizers, manures, composts, sludge), application of soil amendments (e.g., lime to neutralize acidity), improved grazing, soil and water conservation, and the production of energy crops to replace fossil fuels.

A necessary caveat: Soil and economic conditions differ greatly from one location to another and from one period to another. Therefore, there can be no simple universal prescriptions regarding practices to manage soils to help mitigate the greenhouse effect.

Terrestrial global carbon balance (simplified)





Practices to Help Mitigate Global Warming

The agricultural sector can help mitigate global warming in three main ways:
(1) reducing its own emissions by adopting such practices as no-till plantings;
(2) absorbing atmospheric CO2 by enhanced photosynthesis, storing C in the soil;
(3) producing renewable biofuels from biomass (convertible to ethanol/biodiesel).

Modern precision agriculture, recognizing heterogeneity of soils in the field, applies fertilizers and water preferentially where most needed, at precisely calibrated rates to maximize nutrient-use and water-use efficiency and to minimize losses.

Necessary caveats: (1) Some practices aimed at intensifying agricultural production entail increased use of mechanical or chemical energy: irrigation, fertilization, pest/weed control, transportation. (2) The potential sequestration of organic matter in soils is generally finite. SOC saturation (where absorption and emission rates are in dynamic equilibrium) may be attained in several decades.

Economic policies are needed to promote C-efficient practices. Schemes to reward carbon sequestration must be based on effective monitoring, since the gains achieved by such practices as conservation tillage, cover crops, and residue retention can be lost very rapidly by reversion to traditional tillage, residue removal or burning, and fallowing.

Soil Carbon Sequestration: Rationale

- Triple synergy - Soil carbon sequestration removes C02 from the atmosphere and stores carbon in the soil, increasing the soil organic contents. The increased nutrient level in the soil can improve biodiversity. Thus, soil carbon sequestration can contribute to fulfilling the objectives of the three UN conventions.

  - The UN Framework Convention for Climate Change (UNFCCC) - aims to reduce C02 from the atmosphere. Article 3.4 of the 1997 Kyoto Protocol identified agricultural soils and land use change categories as useful carbon sinks.

  - The UN Convention to Combat Desertification (UNCCD) - aims to reduce land degradation. Decision 3/COP.8 suggests "increase in carbon stocks (soil and plant biomass) in affected areas" as an indicator of sustainable land management, conservation of biodiversity and mitigation of climate change.

  - The UN Convention on Biodiversity (UNCBD) - aims to conserve biodiversity. Soil organic carbon is essential for agro-ecosystem function and can be increased through soil carbon sequestration.

Soil Carbon Sequestration: Challenges of Claiming Soil Carbon Credits

- Additionality: credits generated must be additional to any reduction in carbon that would have occurred under a "business as usual" scenario.
- Permanence: the length of time that carbon is sequestered and maintained in a sink (e.g. forest or agricultural soil).
- Duration: the length of the contract.
- Leakage: the problem of project activities inducing economic agents to take actions that would increase greenhouse gases emissions elsewhere.

Soil Carbon Sequestration: Current situation

- Operational Market for soil carbon sequestration projects:

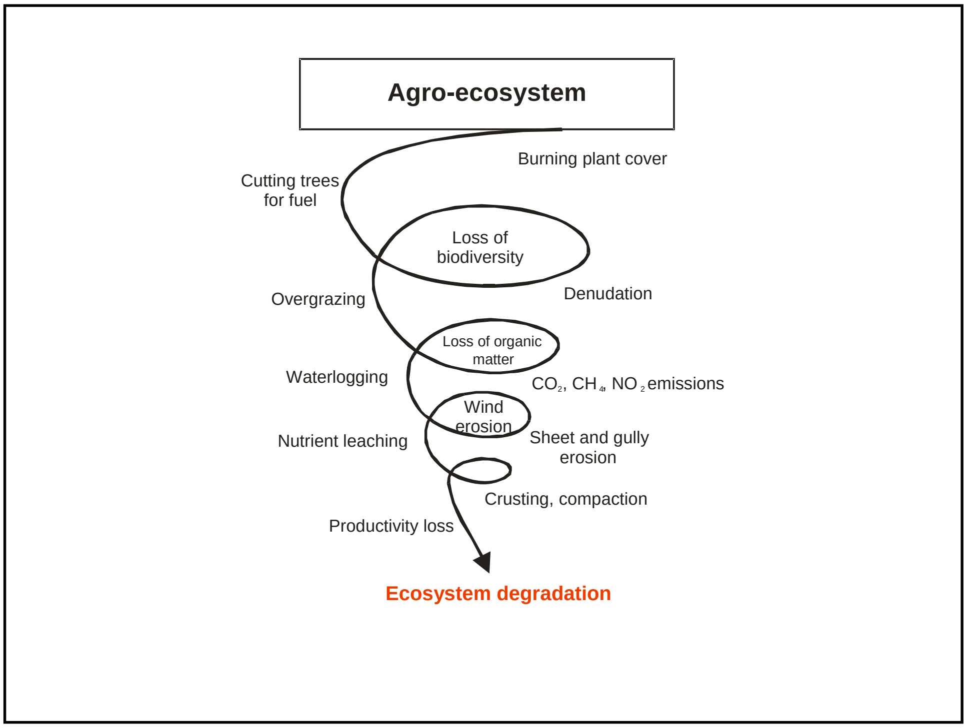
    - **Chicago Climate Exchange (CCX), Inc.** is North America's only legally binding rules-based greenhouse gas emissions allowance trading system.
        - Aggregators: an offset aggregator is a CCX-registered entity that serves as an administrative and trading representative on behalf of multiple individual participants. A list of Aggregators can be found on the CCX website.
        - Eligible projects include: continuous no-till and strip-till cropping in the US and Canada, grass planting, tree planting, and improved rangeland management.

- Pilot projects, research and development:

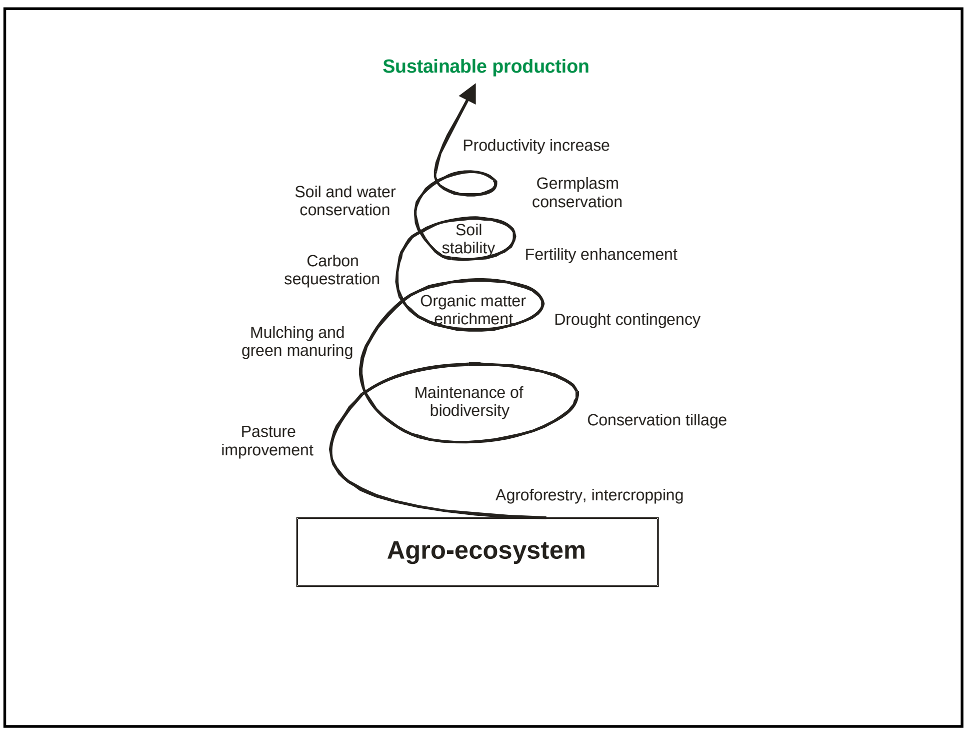
    - Nine African countries: Benin, Burkina Faso, Ghana, Mali, Namibia, Niger, Nigeria, Tanzania, and Tchad
    - Latin America: Brazil

Soil Carbon Sequestration: Recommendation

- Continuing research to remove the barriers.
- Obtain UNFCCC approval for soil carbon sequestration projects to mitigate GHG.



Agro-ecosystem
Burning plant cover
Cutting trees for fuel
Loss of biodiversity
Overgrazing
Denudation
Loss of organic matter
Waterlogging
CO_2, CH_4, NO_2 emissions
Wind erosion
Nutrient leaching
Sheet and gully erosion
Crusting, compaction
Productivity loss
Ecosystem degradation



Sustainable production
Productivity increase
Soil and water conservation
Germplasm conservation
Soil stability
Carbon sequestration
Fertility enhancement
Organic matter enrichment
Mulching and green manuring
Drought contingency
Maintenance of biodiversity
Conservation tillage
Pasture improvement
Agroforestry, intercropping
Agro-ecosystem

Conclusion

The world's soils are media within which dynamic biogeochemical processes take place, involving energy, water, oxygen, carbon, nitrogen, and other components that are in constant flux and interaction.

In the past exploitation of soils caused their degradation and contributed to global warming.

Managing soils to enhance carbon absorption from the atmosphere and its storage as soil organic matter is a technically and economically feasible option for attenuating global warming, and it can be environmentally beneficial in many other ways as well.