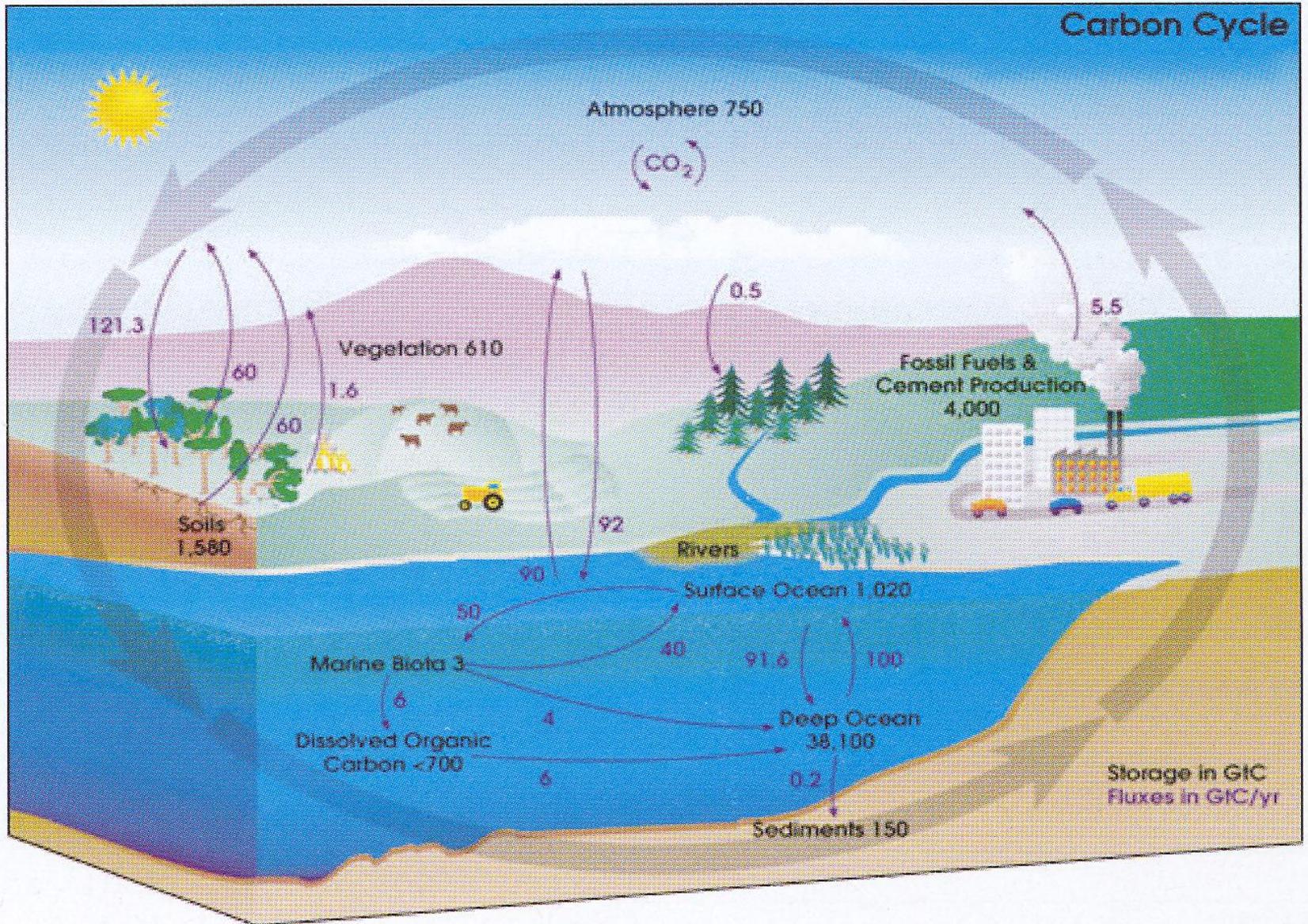
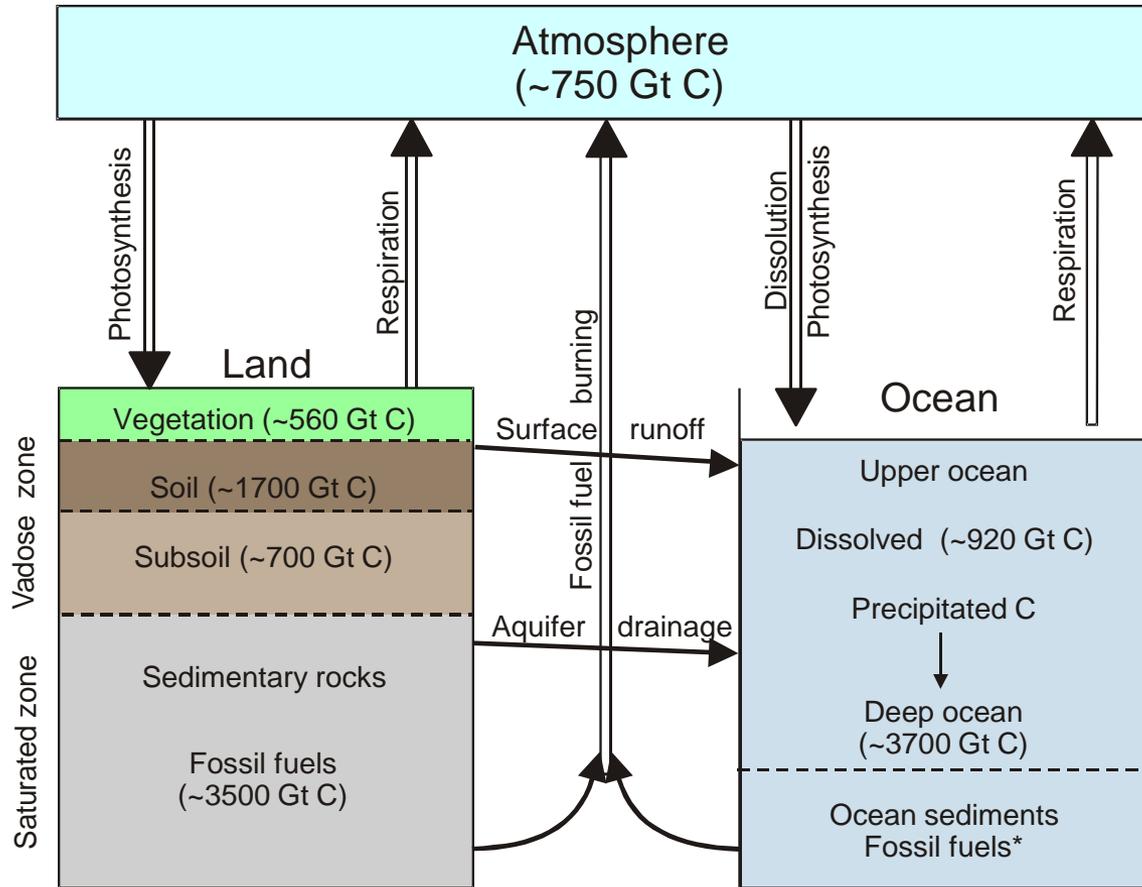


The Role of Soils in Climate Change

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Major carbon pools and fluxes of the global carbon balance





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

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.

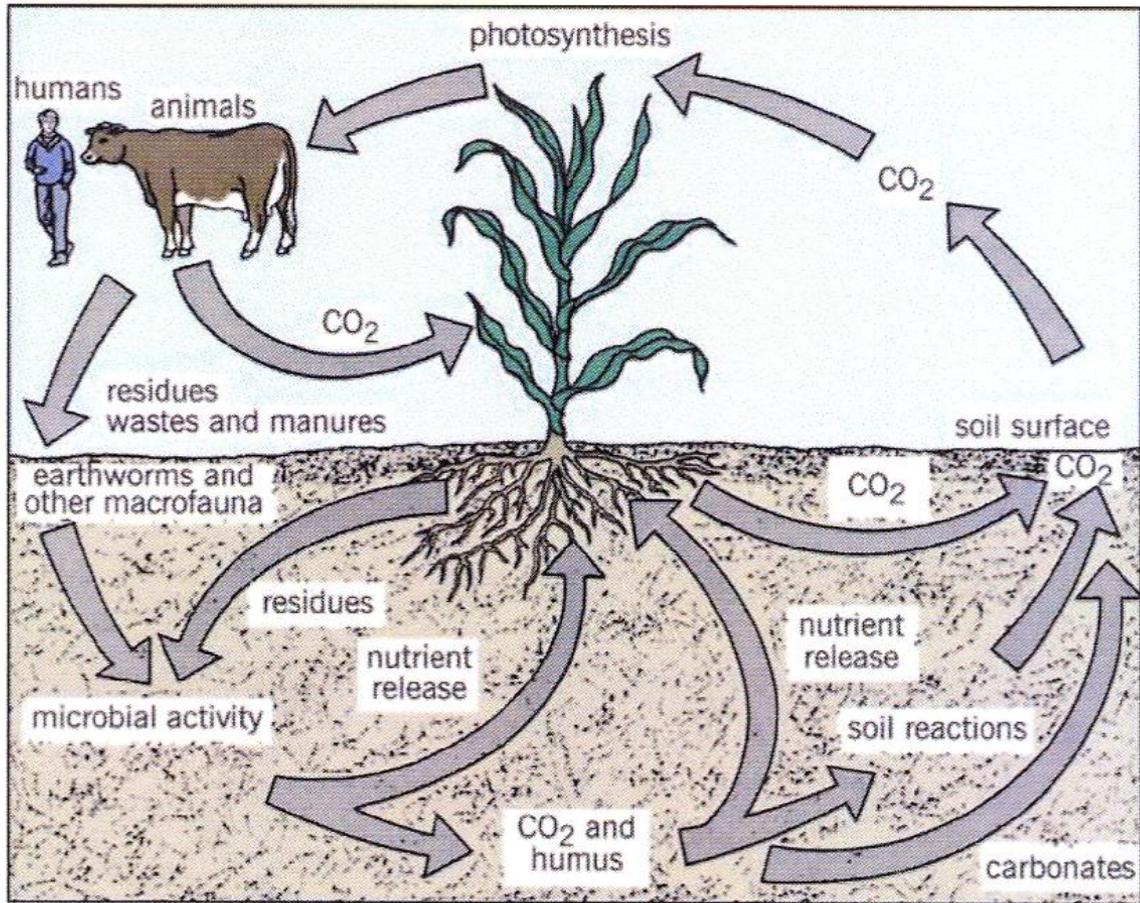
They contain ~ 1700 Gt C to a depth of 1 meter, and 2400 Gt to a depth of 2 meters.

About 560 Gt is contained in terrestrial biota (plants and animals).

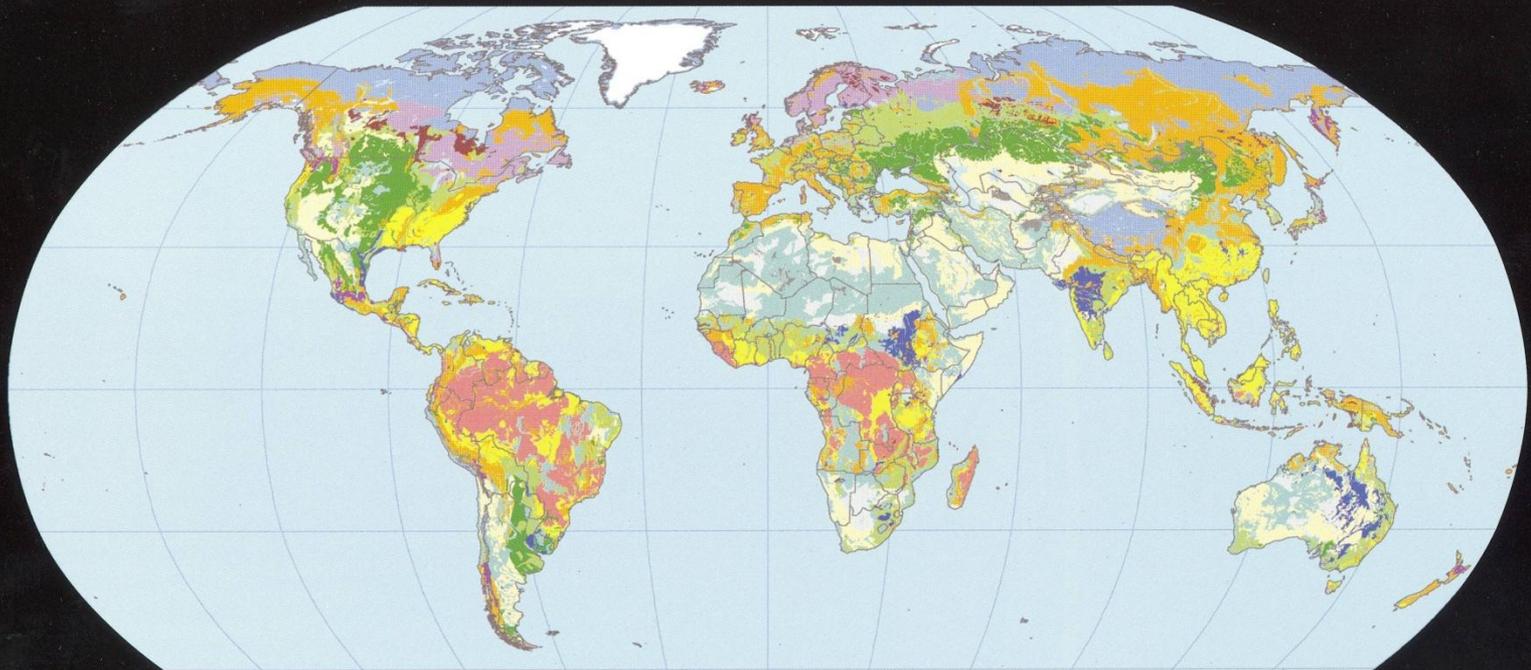
In contrast, the amount of carbon in the atmosphere is estimated to total 750 Gt.

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.



Global Soil Regions



Soil Orders

 Alfisols	 Entisols	 Inceptisols	 Spodosols	 Rocky Land
 Andisols	 Gelisols	 Mollisols	 Ultisols	 Shifting Sand
 Aridisols	 Histosols	 Oxisols	 Vertisols	 Ice/Glacier

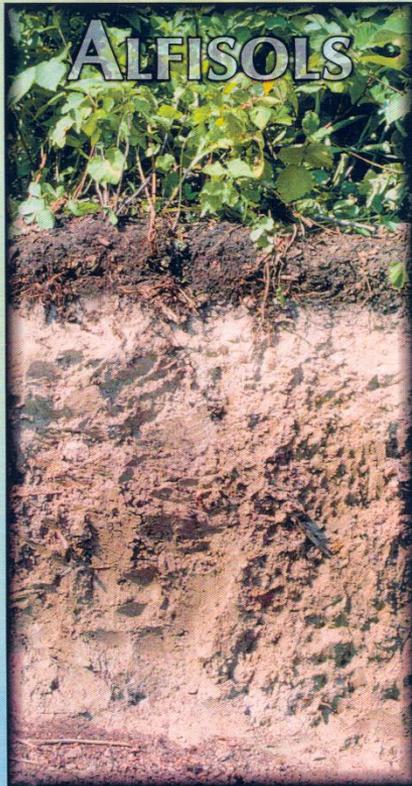
Table A.1 Estimated mass of carbon in the world's soils
(excluding glacier-covered areas)

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

<u>SOIL ORDERS</u>	<u>ORGANIC C (Gt)</u>
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
<u>TOTALS</u>	1,699.6

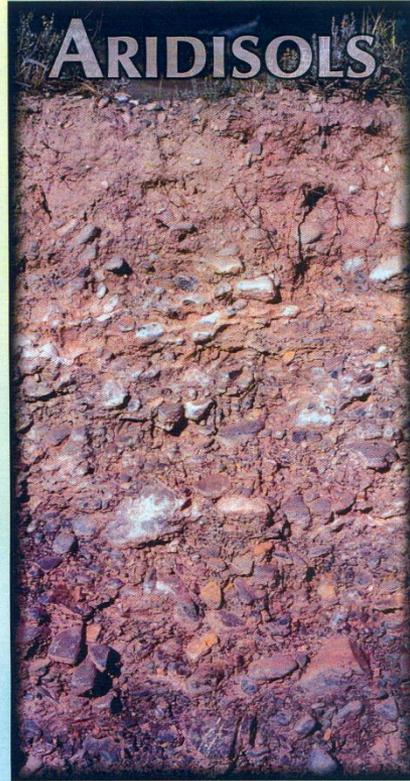


ALFISOLS

Alfisols are in semiarid to moist areas.

These soils result from weathering processes that leach clay minerals and other constituents out of the surface layer and into the subsoil, where they can hold and supply moisture and nutrients to plants. They formed primarily under forest or mixed vegetative cover and are productive for most crops.

ALFISOLS MAKE UP ABOUT 10% OF THE WORLD'S ICE-FREE LAND SURFACE.

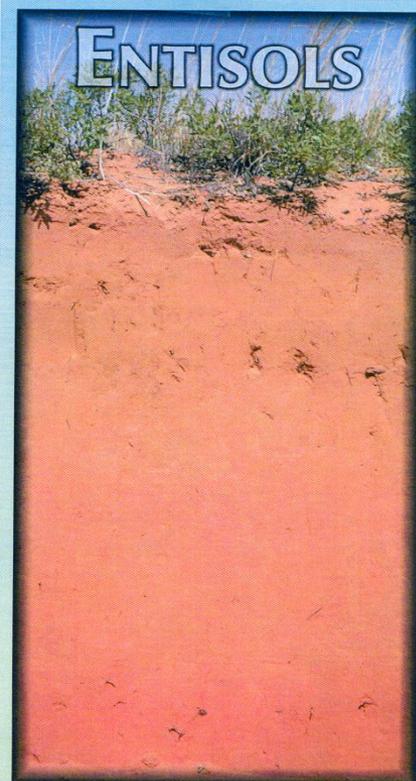


ARIDISOLS

Aridisols are soils that are too dry for the growth of mesophytic plants. The lack of moisture greatly restricts the intensity of weathering processes and limits most soil development processes to the upper part of the soils. Aridisols often accumulate gypsum, salt, calcium carbonate, and other materials that are easily leached from soils in more humid environments.

Aridisols are common in the deserts of the world.

ARIDISOLS MAKE UP ABOUT 12% OF THE WORLD'S ICE-FREE LAND SURFACE.

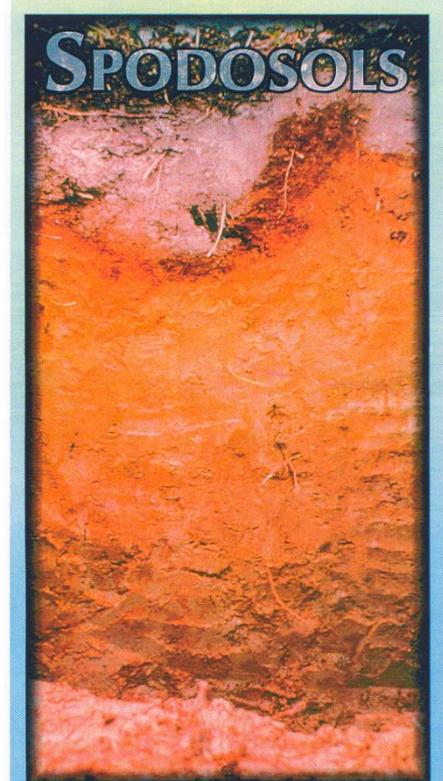


ENTISOLS

Entisols are soils that show little or no evidence of pedogenic horizon development.

Entisols occur in areas of recently deposited parent materials or in areas where erosion or deposition rates are faster than the rate of soil development; such as dunes, steep slopes, and flood plains. They occur in many environments.

ENTISOLS MAKE UP ABOUT 16% OF THE WORLD'S ICE-FREE LAND SURFACE.

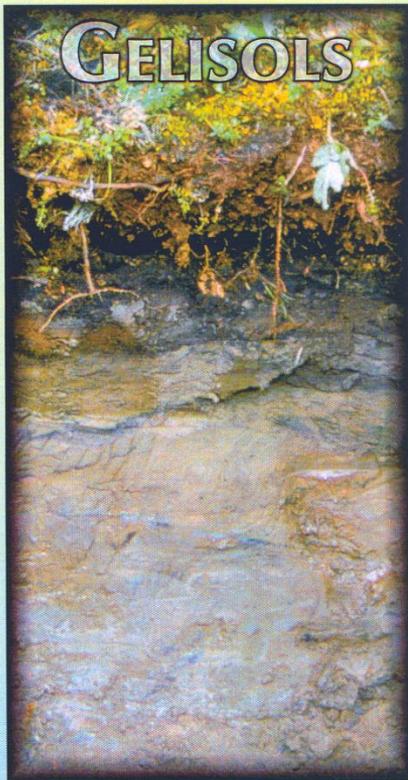


SPODOSOLS

Spodosols formed from weathering processes that strip organic matter combined with aluminum (with or without iron) from the surface layer and deposit them in the subsoil. In undisturbed areas, a gray eluvial horizon that has the color of uncoated quartz overlies a reddish brown or black subsoil.

Spodosols commonly occur in areas of coarse-textured deposits under coniferous forests of humid regions. They tend to be acid and infertile.

SPODOSOLS MAKE UP ABOUT 4% OF THE WORLD'S ICE-FREE LAND SURFACE.

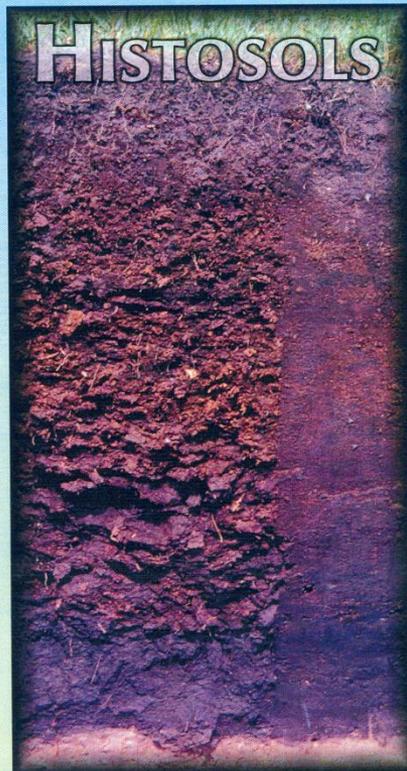


GELISOLS

Gelisols are soils that have permafrost near the soil surface and/or have evidence of cryoturbation (frost churning) and/or ice segregation.

Gelisols are common in the higher latitudes or at high elevations.

GELISOLS MAKE UP ABOUT 9% OF THE WORLD'S ICE-FREE LAND SURFACE.



HISTOSOLS

Histosols have a high content of organic matter and no permafrost. Most are saturated year round, but a few are freely drained. Histosols are commonly called bogs, moors, peats, or mucks.

Histosols form in decomposed plant remains that accumulate in water, forest litter, or moss faster than they decay. If these soils are drained and exposed to air, microbial decomposition is accelerated and the soils may subside dramatically.

HISTOSOLS MAKE UP ABOUT 1% OF THE WORLD'S ICE-FREE LAND SURFACE.

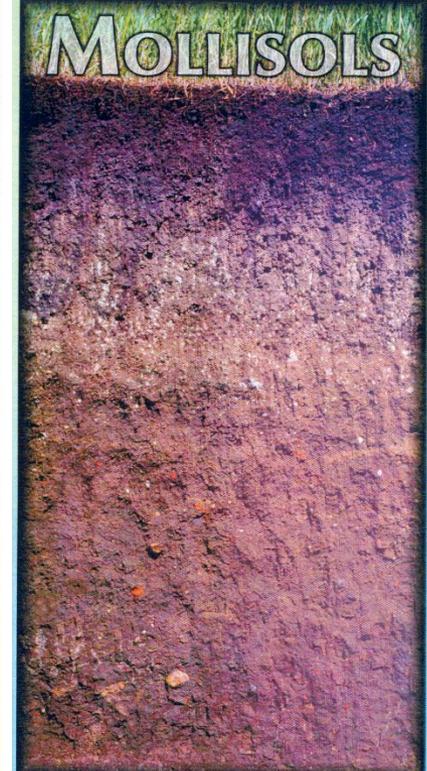


INCEPTISOLS

Inceptisols are soils of semiarid to humid environments that generally exhibit only moderate degrees of soil weathering and development.

Inceptisols have a wide range in characteristics and occur in a wide variety of climates.

INCEPTISOLS MAKE UP ABOUT 17% OF THE WORLD'S ICE-FREE LAND SURFACE.



MOLLISOLS

Mollisols are soils that have a dark colored surface horizon relatively high in content of organic matter. The soils are base rich throughout and therefore are quite fertile.

Mollisols characteristically form under grass in climates that have a moderate to pronounced seasonal moisture deficit. They are extensive soils on the steppes of Europe, Asia, North America, and South America.

MOLLISOLS MAKE UP ABOUT 7% OF THE WORLD'S ICE-FREE LAND SURFACE.

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 undergoes aerobic decomposition and releases large fluxes of carbon dioxide.

Human Management of Soils

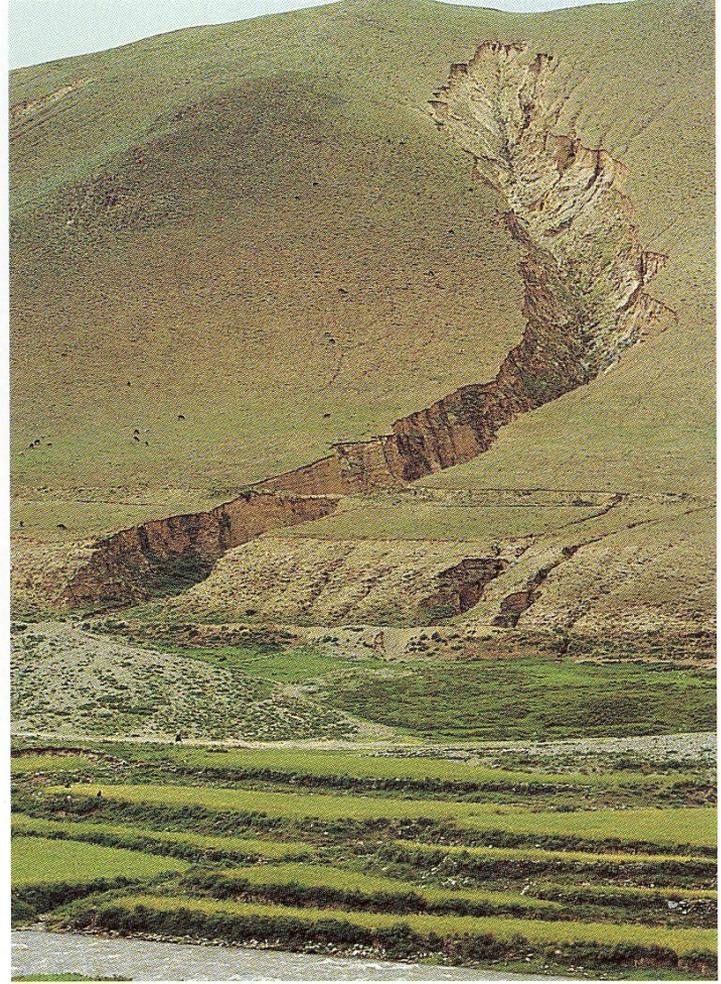
Soil carbon balance is influenced by human management, including the clearing or restoration of natural vegetation and the modes of land use.

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 CO₂, their present carbon deficits offer an opportunity to absorb CO₂ 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.

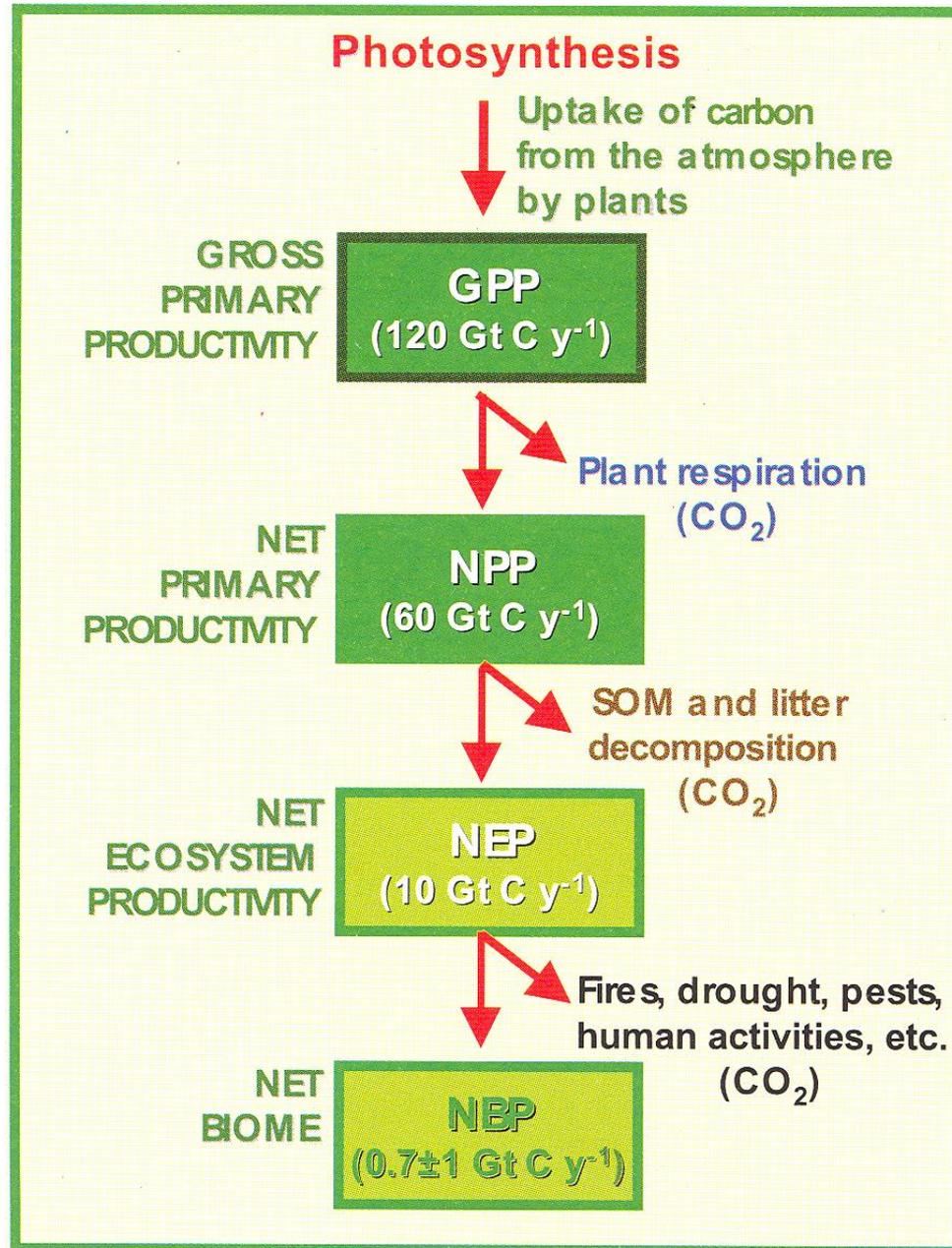
Reversing that depletion via carbon sequestration can induce a benign cycle of productivity gain. Enrichment of the topsoil with organic matter makes it less prone to compaction, crust formation, and erosion.

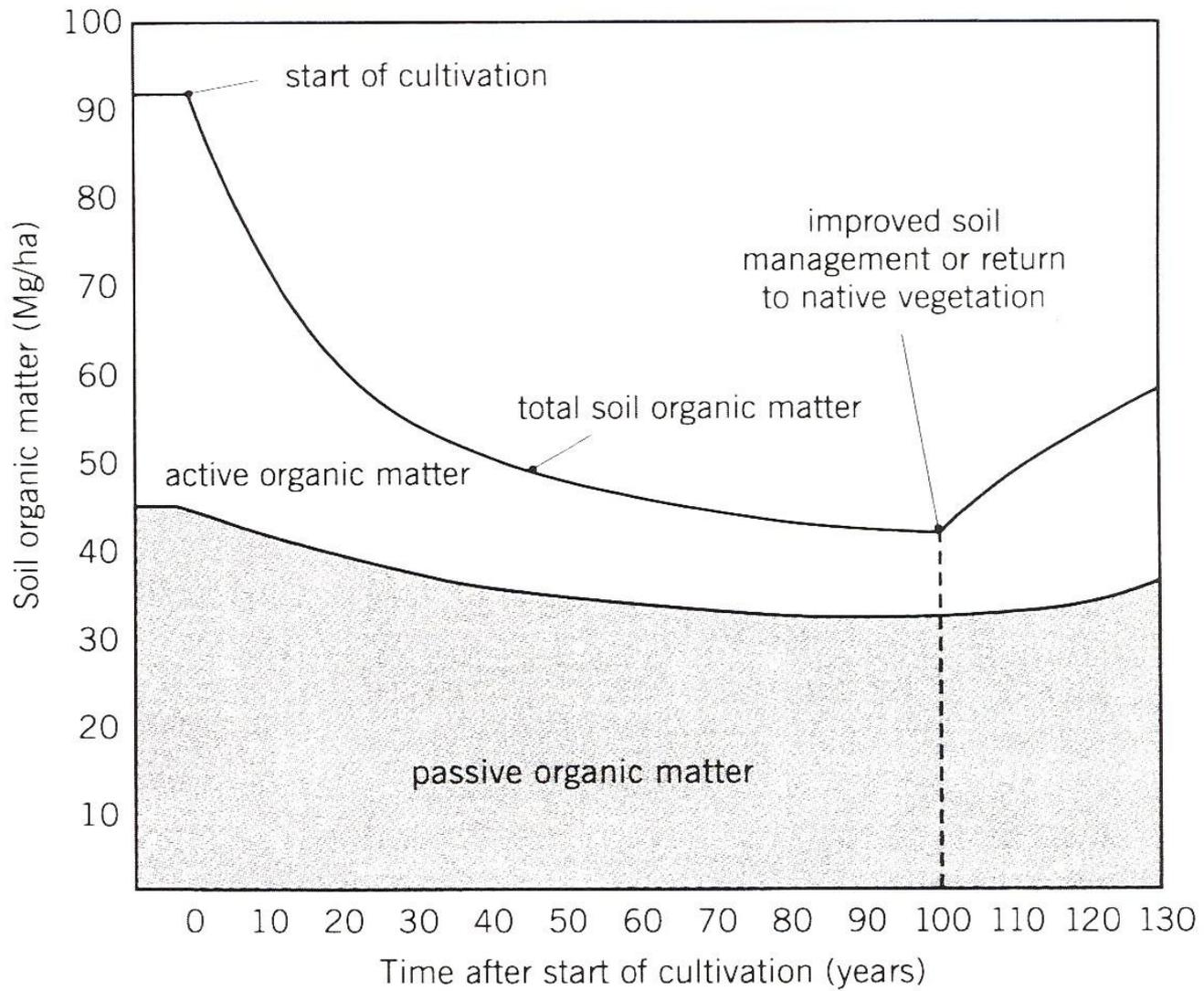
Potential C sequestration in agricultural soils is estimated to total 600 and 900 megatons per year over several decades.

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 leaving the soil bare.

Soil Carbon Sequestration: Rationale

- Quadruple synergy - Soil carbon sequestration removes CO₂ 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 and the MDGs.

- The UN Framework Convention for Climate Change (UNFCCC) - aims to reduce CO₂ 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.

- The Millennium Development Goals seek to end poverty and empower smallholders.

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.

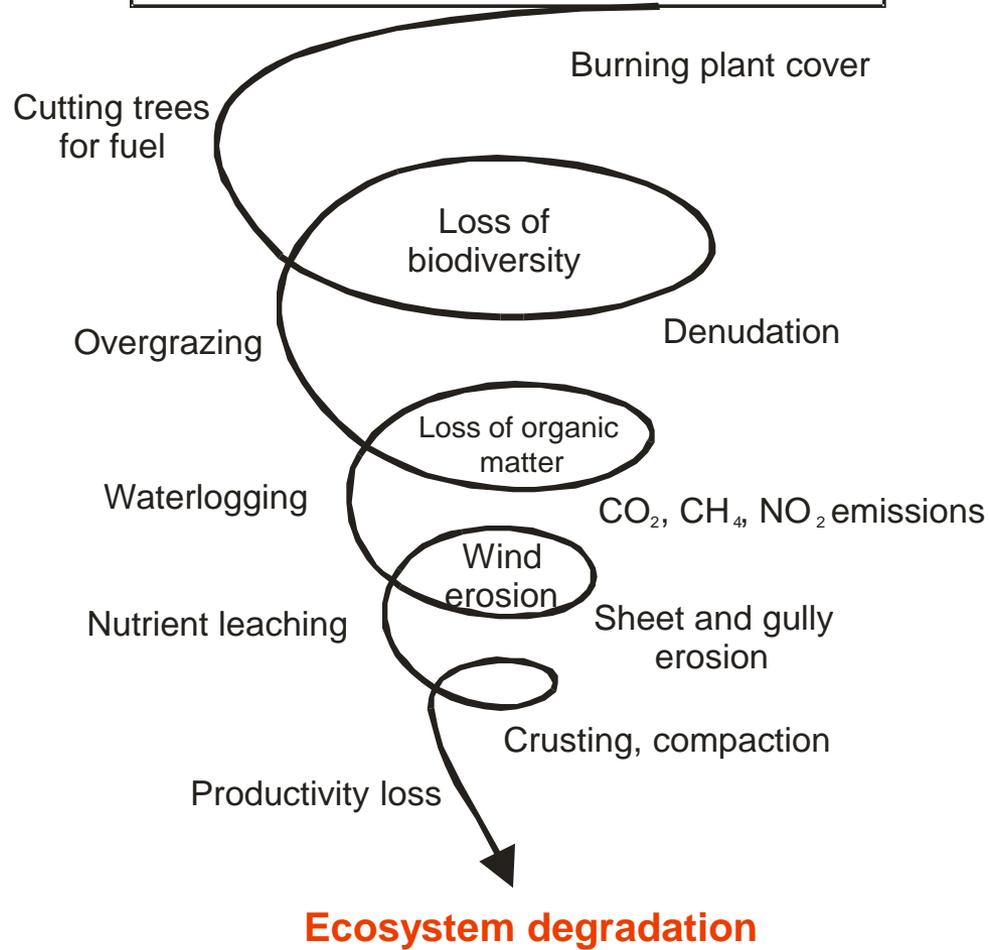
Soil Carbon Sequestration: Current situation

- Although CDM does not currently support soil carbon sequestration projects, emerging markets in Canada and the United States are supporting offset trading from soil carbon sequestration.
 - In Canada, farm groups such as the Saskatchewan Soil Conservation Association (SSCA) encourage farmers to adopt no-till practices in return for carbon offset credits.
 - In the USA, the Pacific Northwest Direct Seed Association offers soil carbon credits generated from no-till management to an energy company.
 - The Chicago Climate Exchange (CCX) (www.chicagoclimatex.com/) allows GHG offsets from no-tillage and conversion of cropland to grasslands to be traded by voluntary action through a market trading mechanism.

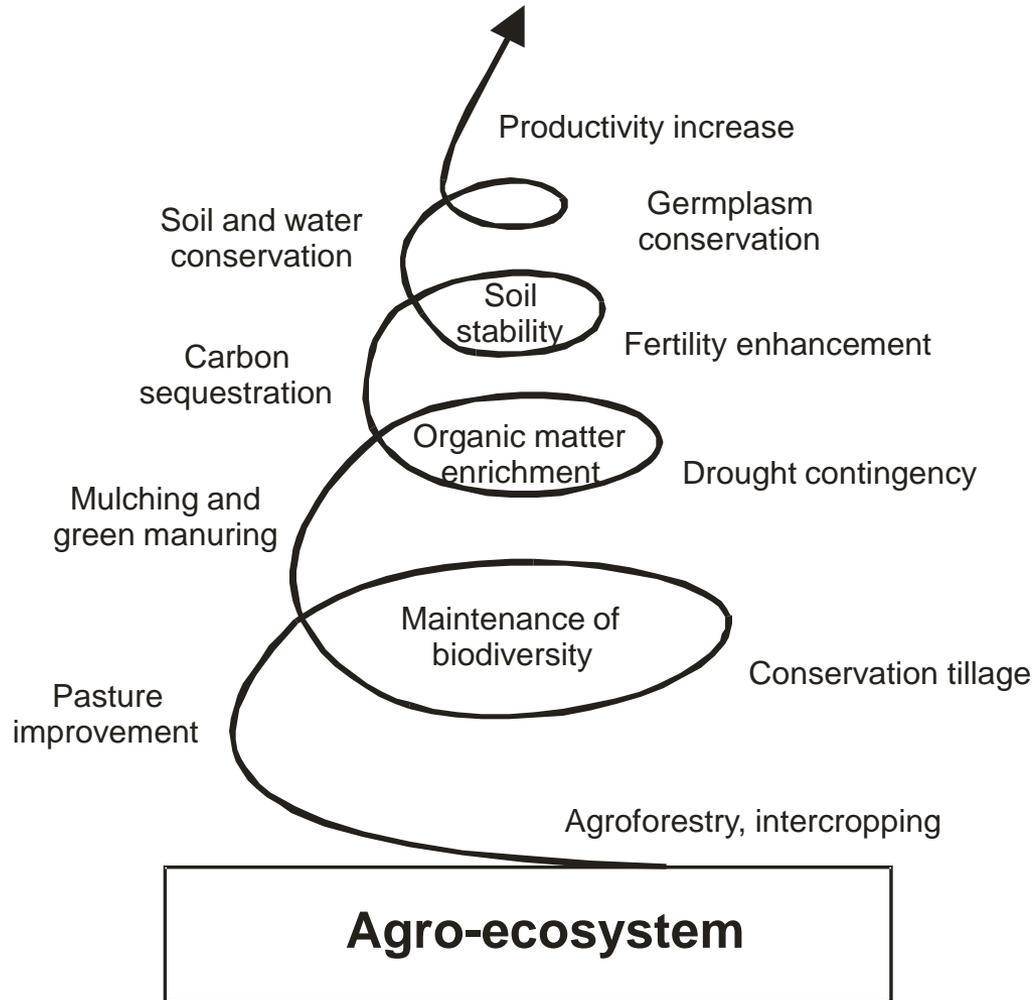
Soil Carbon Sequestration: Recommendation

- Obtain UNFCCC approval for soil carbon sequestration projects to mitigate GHG.
- Implement Programs
- Continuing research to enhance success and remove barriers.

Agro-ecosystem



Sustainable production



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.