

11.2 The Global Carbon Cycle

Definitions

Carbon pools: Bodies containing stocks of inorganic or organic forms of carbon.

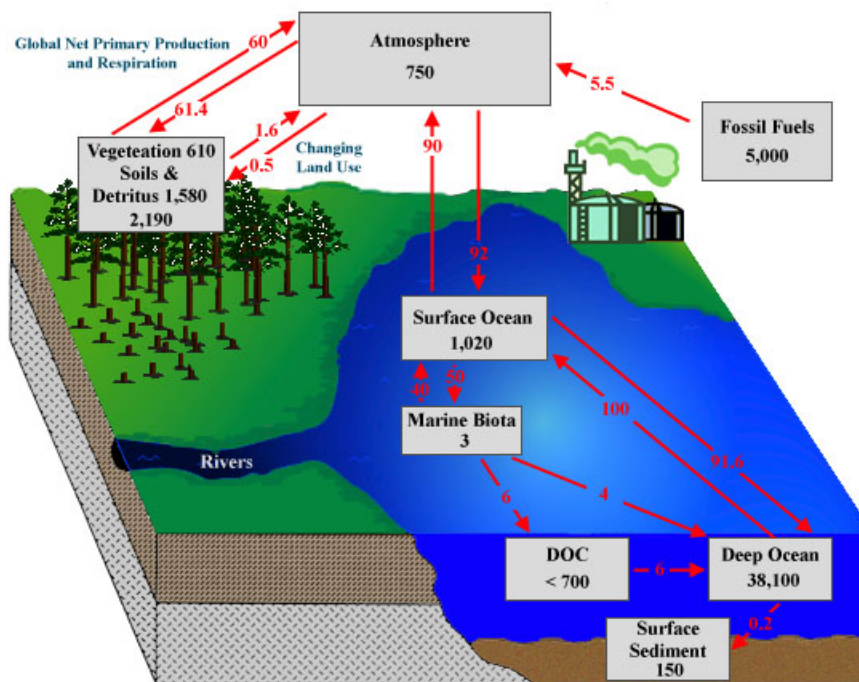
Flow: The movement of mass from one pool to another. Also called flux.

Metric ton: One metric ton is equal to 1,000 kg (1×10^3 Kg or 1×10^6 g).

Gigaton (Gt): One gigaton is equal to one billion tons (1×10^9 tons or 1×10^{15} g).

Petagram: A petagram is equal to 1×10^{15} g and is also equal to a gigaton.

Concepts



Source: Schimel, 1995
Adapted by: Craig Nickel

Figure 11.2. The global carbon cycle, showing the reservoirs (Gt C) and fluxes (Gt C y⁻¹) relevant to the anthropogenic perturbation as annual averages over the period 1980-1989 (Schimel, 1995). The component cycles are simplified and subject to considerable uncertainty. In addition, this figure represents average values. Reproduced with permission from Blackwell Science, Oxford.

The global C cycle contains the following pools: atmosphere (750 Gt C), vegetation (610 Gt C), soil and detritus (1,580 Gt C); fossil fuels (5,000 Gt C), organic C in oceans (1,020 Gt C), inorganic C in oceans (38,100 Gt C) and carbonate rocks (1×10^6 Gt C) (Fig. 11.2).

Carbon dioxide accounts for 50 to 60 percent of the increase in radiative forcing caused by gases contributing to global warming. Global soil respiration from plants, soil microbes and soil fauna contribute about 60 Gigatons (Gt) C yr⁻¹. Prior to 1960, this flux was almost balanced by photosynthesis. Therefore, the atmospheric CO₂ was almost in a steady state condition. Schimel (1995) has provided an overview of the global carbon cycle showing the annual fluxes and reservoirs (Fig. 11.2). Over the past 30 years, CO₂ emissions from fossil fuel burning and industrial sources have increased to about 5.5 Gt C yr⁻¹ (Schimel, 1995). Contribution from deforestation is estimated at about 1.6 Gt C yr⁻¹. These perturbations have resulted in an increase of CO₂ in the atmosphere. Consequently, the stabilization of atmospheric CO₂ has become a global concern. In order to stabilize the CO₂ concentration in the atmosphere, two approaches can be used: (1) decrease CO₂ emissions; or (2) sequester the carbon fixed through photosynthesis in terrestrial and aquatic ecosystems in the form of organic carbon.

Soil C Content

Soil matter content has been tabulated for major ecosystems around the world (Table 11.1). Mean organic matter content is the lowest in extreme desert, rock and ice and the highest in the tundra and alpine. Only 14% of the world terrestrial area is cultivated.

Table 11.1. Soil organic matter content in different ecosystems (Schlesinger, 1997).

Ecosystem Type	Mean soil organic matter (kg C/m²)	World area (ha x 10⁹)	Total world soil organic carbon (Gigatons)	Carbon storage in different ecosystems (%)
Tropical forest	10.4	24.5	255	17.5
Temperate forest	11.8	12	142	9.8
Boreal forest	14.9	12	179	12.2
Woodland & shrubland	6.9	8.5	59	4.0
Tropical savanna	3.7	15	56	3.8
Temperate grassland	19.2	9	173	11.9
Tundra and alpine	21.6	8	173	11.9
Desert scrub	5.6	18	101	6.9
Extreme desert, rock & ice	0.1	24	3	0.2
Cultivated	12.7	14	178	12.2
Swamp and marsh	68.6	2	137	9.4
Totals		147	1456	100

Out of the 1456 Gt of soil organic carbon, around 12% is in each of the following: cultivated soils, boreal forest, temperate grassland, and tundra and alpine. Tropical soils contain 17.5% of the world carbon due to large areas (Table 11.1). At present, there is a search for sinks of carbon dioxide accumulating in the atmosphere. Soil organic matter is a source, as well as a sink, for atmospheric carbon dioxide depending upon climate, land use and land management.

Applications

Table 11.2. Physical Properties of an Orthic Gray Luvisol sampled at shoulder position of a transect at a study site within Prince Albert National Park, Saskatchewan, Canada (Huang and Schoenau, 1996). Reproduced with permission from the Agricultural Institute of Canada and the authors.

Genetic Horizon	Depth (cm)	pH	CEC (cmol +ve/kg)	Clay (g/kg)	Bulk density (Mg/m ³)
L	10-8	6.5	112	-	0.07
F	8-5	6.7	108	-	0.09
H	5-0	6.7	80	-	1.50
Ae	0-11	6.5	8.7	93	1.47
Bt	11-26	6.5	17	245	1.56
Bmk	26-50	6.0	18	283	1.62
Ck	50-70	8.2	10	215	1.42
Ck	70-120	8.3	13	237	ND

Several insights can be gained by studying the information in Table 11.2. The bulk density of materials in the L layer is less than the H layer because undecomposed plant material has a greater porosity and size. As the plant materials are decomposed, the porosity and bulk density decreases.

Orthic Gray Luvisols develop in calcareous material and have forest vegetation. These soils have an eluvial and illuvial horizons. The translocation of clay particles and the leaching of carbonates leads to the formation of an acidic Ae horizon. In contrast, the parent material in the Ck horizon has pH 8.3, indicative of CaCO₃ in the parent material.

The LFH are organic layers while the Bt has a significant amount of clay and organic matter. The cation exchange capacity in the LFH is almost entirely due to the presence of organic matter. The pedon shows evidence of eluviation because the Ae horizon has 93 g clay/kg soil compared to 245 g clay/kg in the Bt horizon. The eluviation of clay takes place over the period of soil formation, which is approximately eight to ten thousand years in the Boreal region.

Table 11.3. Physical Properties of an Orthic Gray Luvisol sampled at shoulder position of a transect at a study site within Prince Albert National Park, Saskatchewan, Canada (Huang and Schoenau, 1996). Reproduced with permission from the Agricultural Institute of Canada and the authors.

Genetic Horizon	Depth (cm)	Total C (g/kg)	Inorganic C (g/kg)	Organic C (g/kg)	Organic C (kg/ha)
L	10-8	433	5.9	427	6200
F	8-5	391	0.4	391	10900
H	5-0	344	2.5	341	25900
Ae	0-11	10.5	2.9	7.7	12400
Bt	11-26	6.4	1.0	5.4	12700
Bmk	26-50	4.0	0.7	3.2	12600
Ck	50-70	17.5	15.4	2.1	5800
Ck	70-120	38.2	36.1	2.1	14800

Insights about inorganic and organic forms of carbon can be gained by studying the data from Table 11.3. The greatest concentration (g/kg) of organic C occurs in the organic layers (LFH) which are above the mineral soil. In the Canadian System of Soil Classification, organic horizons have greater than 17% (170 g/kg) of organic C. Soil organic matter decreases with depth in Gray Luvisols. In contrast, the inorganic C increases with depth. This soil has calcareous parent materials, therefore the inorganic carbon increases with depth. The contrast of trends of organic and inorganic forms of carbon is due to the process of soil formation.

11.3 Properties of Soil Organic Matter

Soil organic matter is a master variable and affects many soil properties and processes. Although these properties have been in different sections of this book, it is important to summarize the mechanisms that are directly related to soil organic matter content.

Soil organic matter consists of living or dead plant material, living organisms, products derived from microbial and faunal metabolism and stabilized complex organic material called humus. Humus forms strong and stable bonds with the mineral colloids (clays, iron and aluminum oxides) to form soil aggregates. Aggregation of soil affects the pore size distribution in soil and controls the flow of water and air into and out of soil. The formation of organo-mineral complexes and aggregation of soil are fundamental processes and are most intense in the upper part of the pedon. It is precisely these processes which lead to intense and intimate reactions between the biosphere and the lithosphere -- the interactions of organisms with the mineral fraction leading to the development of soil.

Soil organic matter has a cation and anion exchange capacity as well as reactive surfaces which can adsorb polar and non-polar organic molecules. Therefore, organic and inorganic materials that are added interact with soil organic matter. Thus, soil organic matter can attenuate organic and