Total Organic Carbon

Total organic carbon (TOC) is the carbon (C) stored in soil organic matter (SOM). Organic carbon (OC) enters the soil through the decomposition of plant and animal residues, root exudates, living and dead microorganisms, and soil biota. SOM is the organic fraction of soil exclusive of non-decomposed plant and animal residues. Nevertheless, most analytical methods do not distinguish between decomposed and non-decomposed residues. SOM is a heterogeneous, dynamic substance that varies in particle size, C content, decomposition rate, and turnover time.

Soil organic carbon (SOC) is the main source of energy for soil microorganisms. The ease and speed with which SOC becomes available is related to the SOM fraction in which it resides. In this respect, SOC can be partitioned into fractions based on the size and breakdown rates of the SOM in which it is contained (table 1). The first three fractions are part of the active pool of SOM. Carbon sources in this pool are relatively easy to break down.

SOM contains approximately 58% C; therefore, a factor of 1.72 can be used to convert OC to SOM. There is more inorganic C than TOC in calcareous soils. TOC is expressed as percent C per 100 g of soil.

Factors Affecting

Inherent - Soil texture, climate, and time all affect SOC accumulation. Soils rich in clay protect SOM from decomposition by stabilizing substances that bind to clay surfaces. Aggregation, enabled by the presence of clay, also protects SOM from microbial mineralization. Extractable aluminum and allophanes (present in volcanic soils) can form stable compounds with SOM that resist microbial decomposition. Warm temperatures decrease SOC content by increasing decomposition rates, while high mean annual precipitation increases accumulation by stimulating the production of plant biomass and associated SOC. With time, the breakdown of SOM produces humus-carbon, which resists decomposition by microorganisms.

Carbon loss via soil erosion results in SOC variations along the slope gradient. Level topography tends to have much more SOC than other slope classes. Both elevation and topographic gradients to some extent control local climate, vegetation distribution and soil properties, as well as associated biogeochemical processes, including SOC dynamics. Microclimate cooling with elevation may favor SOC accumulation. An analysis of factors affecting C in the conterminous United States concluded that the effects of land use, topography (elevation and slope), and mean annual precipitation on SOC are more obvious than that of mean annual temperature. However, when other variables are highly restricted, there is clearly a decline in SOC with increasing temperature.

Dynamic - Depending upon the rate of C mineralization, the amount and stage of decomposition of plant residues and organic amendments added to soil controls accrual of SOC. Turnover times for various organic materials shows that humus-carbon mineralizes slowly and thus accumulates in the soil, whereas microbial biomass C may disappear relatively quickly (table 1). Soil aggregates of different sizes and stability are possible sites for physical protection of SOM from decomposition and C

Table 1. Size and breakdown rates of various soil organic matter fractions.

Soil Organic Matter Fraction	Particle Size (mm)	Turnover Time (years)	Description
plant residues	≥ 2.0	< 5	recognizable plant shoots and roots
particulate organic matter	0.06 – 2.0	< 100	partially decomposed plant material, hyphae, seeds, etc
soil microbial biomass	variable	< 3	living pool of soil organic matter, particularly bacteria and fungi
humus	≤ 0.0053	< 100 – 5000	ultimate stage of decomposition, dominated by stable compounds

mineralization. Soil disturbance and destruction of aggregates may be the major factor responsible for increasing exposure of SOM physically protected in aggregates to biodegradation.

Crop residues incorporated in or left on the soil surface reduce erosion and SOC losses in sediment. Liming to increase the pH of acidic soil increases microbial activity, organic matter decomposition, and CO_2 release. Diversity of the soil microbial population also affects SOC. For example, while soil bacteria aggressively participate in C loss by mineralization, some fungi, such as mycorrhizae, are believed to slow the decay of SOM by aggregating it with clay and minerals. SOM and SOC are more resistant inside aggregates than in free form. Soil depth affects the distribution of SOC. Thus, plowed deep soils tend to accumulate SOC in layers beneath the disturbed top soils because of restricted mineralization rates.

Relationship to Soil Function

SOC is one of the most important constituents of the soil due to its capacity to affect plant growth as both a source of energy and a trigger for nutrient availability through mineralization. SOC fractions in the active pool, previously described, are the main source of energy and nutrients for soil microorganisms. Humus participates in aggregate stability, and nutrient and water holding capacity.

OC compounds, such as polysaccharides (sugars) bind mineral particles together into microaggregates. Glomalin, a SOM substance that may account for 20% of soil carbon, glues aggregates together and stabilizes soil structure making soil resistant to erosion, but porous enough to allow air, water and plant roots to move through the soil. Organic acids (e.g., oxalic acid), commonly released from decomposing organic residues and manures, prevents phosphorus fixation by clay minerals and improve its plant availability, especially in subtropical and tropical soils. An increase in SOM, and therefore total C, leads to greater biological diversity in the soil, thus increasing biological control of plant diseases and pests. Data also reveals that interaction between dissolved OC released from manure with pesticides may increase or decrease pesticide movement through soil into groundwater.

Problems with Poor Carbon Levels

A direct effect of poor SOC is reduced microbial biomass, activity, and nutrient mineralization due to a shortage of energy sources. In non-calcareous soils, aggregate stability, infiltration, drainage, and airflow are reduced. Scarce SOC results in less diversity in soil biota with a risk of the food chain equilibrium being disrupted, which can cause disturbance in the soil environment (e.g., plant pest and disease increase, accumulation of toxic substances).

Improving Carbon Levels

Compiled data shows that farming practices have resulted in the loss of an estimated 4.4×10^9 tons of C from soils of the United States, most of which is OC. To compensate for these losses, practices such as no-till may increase SOC (figure 1). Other practices that increase SOC include continuous application of manure and compost, and use of summer and/or winter cover crops. Burning, harvesting, or otherwise removing residues decreases SOC.

Measuring Total Organic Carbon

Presently, no methods exist to measure TOC in the field. Attempts have been made to develop color charts that match color to TOC content, but the correlation is better within soil landscapes and only for limited soils. Near infrared spectroscopy has been attempted to measure C directly in the field, but it is expensive. Numerous laboratory methods are available.

References:

Edwards JH, CW Wood, DL Thurlow, and ME Ruf. 1999. Tillage and crop rotation effects on fertility status of a Hapludalf soil. Soil Sci. Soc. Am. J. 56:1577-1582.

Sikora LJ and DE Stott. 1996. Soil Organic Carbon and Nitrogen. In: Doran JW, Jones AJ, editors. Methods for assessing soil quality. Madison, WI. p 157-167.

Time needed: Laboratory methods are variable.

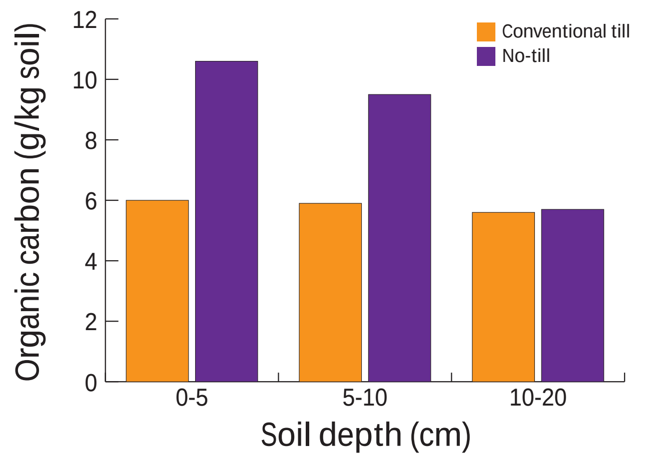

Figure 1. Effect of 10 years of conventional till and no-till on OC (calculated from SOM data in Edwards et al., 1999).