Soil Carbon & Organic Matter

FACT SHEET 6

Soil carbon is a key indicator of soil health. While it is not a plant nutrient, carbon is present in every living organism and is a dominant component of organic matter. Organic carbon is present in many different forms in the soil involved in all aspects of soil fertility and health.

From sun to soil

The process of building soil carbon starts with the process of photosynthesis. Essentially the conversion of sunlight energy, water and CO_2 into a range of plant materials which are ultimately delivered to the soil. The resulting carbon compounds contained in plant shoot material which are not harvested mechanically or by livestock are returned to the soil as leaf litter.

Figure 1: Green plants capture sunlight energy via photosynthesis and convert CO_2 into carbon compounds which are ultimately returned to the soil.

The greatest source of soil carbon though is from the products of photosynthesis that are exported to roots and released into the soil. Around half of the carbon fixed by photosynthesis in shoots is exported to roots.

Soil is the largest land sink of carbon

Sources of soil carbon

The most important source of carbon is in the form of **root exudates,** substances released from the plant root into the soil system. Roots exude a vast range of organic compounds primarily sugars, amino acids and organic acids in addition to proteins hormones and enzymes. Carbon released from plant roots in this form is essential to stimulate biological activity and nutrient cycling. Note that by definition, all organic compounds contain carbon. Roots also secrete mucilage, polysaccharide compounds which enhance soil structure.

Plant material as both roots and shoots contribute the largest amount of carbon entering the soil. Root cells which are sloughed off as well as senesced (dead) roots provide a source of energy for soil biota. Above ground plant parts, depending on environmental and management factors, generally contribute a relatively small proportion of the total soil carbon pool. On average leaf material contains 42% carbon and roots around 58%. It's not until it's at least partly decomposed that plant material is considered at contributing to the soil carbon pool.

Humus is the stable end product of decomposition of organic matter (plant and animal) by soil microbes.

Microbial biomass is potentially a significant contributor to soil carbon depending on the biological health and activity in soil. It has been reported to contribute up to 5% of total soil organic carbon under conventional management. Microbial biomass carbon will be influenced by environmental factors, land use, management and a range of soil characteristics.

More information on soil microbial biomass is provided in Factsheet 7 of this series.

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Charcoal, burnt organic material in various states of oxidation is another source of soil carbon.

Soil amendments for example, biochar products may have carbon content of between 60 to 80%.

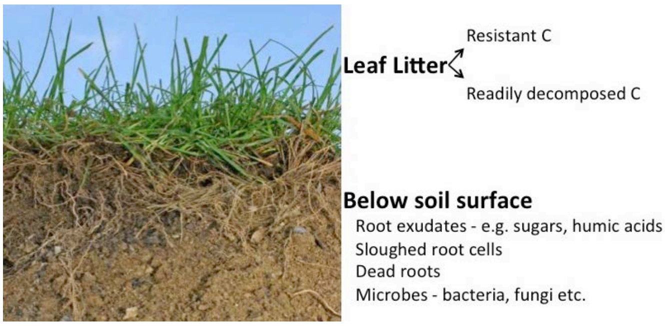

Figure 2: Sources of soil carbon.

Carbon in organic matter

There is often confusion around the distinction between soil organic matter (SOM) and soil organic carbon (SOC). On average SOM consists of about 57% carbon and this is the figure conventionally used to convert soil carbon % to soil organic matter %.

Soil organic matter consists of about 57% carbon

*To convert soil carbon % to soil organic matter % **multiply SOC** x 1.75.*

*Alternatively, to convert soil organic matter % to soil carbon % **divide SOM** by 1.75*

While carbon is the primary component, soil organic matter also contains hydrogen and oxygen and is an important source of nutrients; nitrogen, phosphorus, sulphur and trace elements. The negative charge associated with organic matter improves the capacity of the soil to hold nutrients by improving the cation exchange capacity of the soil. It improves soil structure, porosity and soil water infiltration rate.

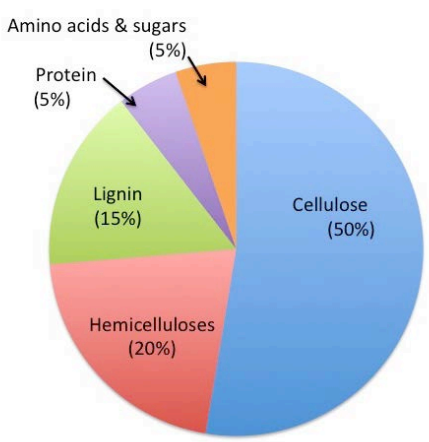

Figure 3: The main forms of organic carbon entering the soil from plant residues. (Source: Killham 1994)

Forms of soil carbon & decomposition

Plant residues contribute the largest fraction of soil carbon entering the soil. When entering the soil there is an initial flush of biological activity stimulating decomposition and then a slower rate of breakdown. This is because some compounds within the plant residue break down faster than others and some compounds are more resistant to microbial attack.

Cellulose represents more than half of the carbon in plant residues in most situations and depending on its form (as leaf or woody material) is most readily decomposed. Hemicelluloses are generally relatively more resistant to microbial breakdown and lignin is the most resistant component of plant residues entering the soil carbon pool. The relative amounts of each generally found in soil are provided in figure 3.

The form of plant residue carbon entering the soil will influence the rate of decomposition and turnover of soil carbon. Other factors such as soil biological activity, temperature and soil moisture will also affect turnover rates of soil carbon. Given similar environmental conditions the rate of decomposition of green leaves will be higher than that of dry leaves and stem material which will be higher than leaf litter and woody material.

Labile and non-labile carbon

Carbon compounds that are readily decomposed by soil microbes are termed labile carbon. The simple sugars and other carbon compounds present in root exudates and predated microbes can be assimilated by plants and other soil microorganisms in timeframes from minutes to hours. Carbon in this form is referred to as 'active'. This is the most important form for active carbon cycling. Where it's present in more complex carbon compounds, fresh plant residues, other forms of microbial or animal biomass the rate of breakdown may be in the order of days, weeks or months. These are all considered to be labile, readily available and utilised, forms of carbon.

Where the carbon is chemically or physically protected and resistant to microbial attack it is termed non-labile carbon. For example, lignin in plant stems may take up to a year to decay. Within woody material, depending on particle size, the physical protection afforded may extend the period required for decomposition to decades.

Turnover of soil carbon

The turnover of carbon in productive environments is rapid. As the productivity, as indicated by growth of plant material, and net primary production of carbon decreases the soil organic carbon pool increases. This indicates a decreasing rate of soil carbon turnover in less productive environments. However, those soils have a high capacity for storage of soil carbon.

Table 1: Typical distribution of carbon in different environments

Environment	Net primary production of C (t/ha/year)	Soil organic carbon pool (t/ha)
Rainforests	11	80
Temperate forests	6	100
Grasslands	3	150
Desert	0.05	1

Grassland soils store more soil carbon than other ecosystems

Carbon sequestration

Another term associated with the form of carbon is sequestration. Carbon sequestration is defined as the process of the removal and storage of carbon from the atmosphere (as CO2) in sinks such as vegetation (including grasses, forbs and trees) or soils through physical or biological processes such as photosynthesis.

Forests and trees are often considered as key contributors to carbon sequestration however, grasslands and soils are also important carbon sinks. The process of microbial decomposition produces CO2 and CO2 production is commonly used as a measure of biological activity. By increasing biological activity soil health and plant production is enhanced, increasing the capacity to store a greater amount of carbon in plant biomass and more importantly the soil.

Humus

The end product of organic matter turnover is humus, a relatively stable (non labile) component of the carbon pool which may be physically or chemically protected.

Humus enhances the structural stability of soil, increases nutrient holding and cation exchange capacity, nutrient availability and water holding capacity. Humus acts like a sponge in soil. An increase of just 1% humus in topsoil can result in a four-fold increase in water holding capacity.

Figure 4: The dark crumb structure of humus in topsoil.

The dead and decomposing remains of plants and plant roots, soil organisms and micro-organisms and larger soil animals such as worms and beetles all contribute to the soils organic matter fraction. These are all ultimately products of photosynthesis, either directly or indirectly. Once this material has fully broken down and is stable in the soil it is classed as humus.

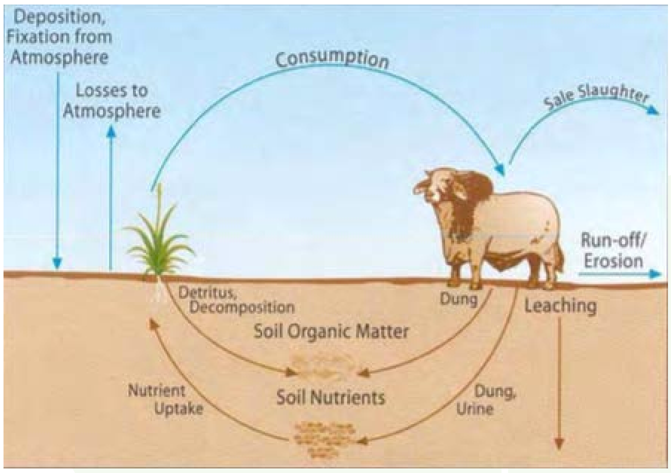

Figure 5: Carbon cycling in grazed grasslands.

Increasing carbon in grasslands

Increasing soil carbon in grasslands starts with photosysnthesis. The conversion of sunlight energy into plant material. The rate of photosynthesis can be increased in the following ways.

1. Increased plant density. The area of photosynthetic material i.e. green leaf, may be increased by increasing the density of plants per unit area of the soil surface.

2. Increasing plant species diversity. A higher diversity of plant species with different growth cycles will ensure an increased presence of green, actively growing plants for a greater period throughout the year.

3. Maintain optimal residual herbage mass. A minimum of 5 cm of green leaf should be retained on individual plants to increase potential growth post grazing and minimise any potential reduction of the root system.

4. Improved plant growth and vigour. Healthy plants will have larger root systems and produce more growth and leaf area for a longer period throughout the year, capturing more sunlight energy.

5. Increase water use efficiency. Rainfall is critical for optimal plant growth and more open porous soil will hold more water for plant uptake enhancing plant growth.

A feature of perennial grasses is that the dry weight of above ground leaf material is approximately equal to the biomass of the dry weight of roots. On average leaf material contains 42% carbon and plant roots contain 58% carbon so the total plant biomass will be 50% carbon.

Since plant roots and below ground processes are the largest contributors to the soil organic carbon pool management to enhance soil conditions will result in increases to soil carbon and organic matter.

Photo: Christine Jones

Figure 6: The biomass of perennial grass roots is equal to the biomass of above ground herbage.

Any action that increases the growth of perennial grasses will increase root production and therefore the potential to increase soil organic carbon.

This is the sixth of a series of 12 Factsheets which cover a range of topics detailing the critical elements for soil health and a range of soil processes. They are designed to help you achieve effective soil function and increase productivity.

More Information

This factsheet has been prepared by Judi Earl
Agricultural Information & Monitoring Services
Email: judi@aimsag.com.au Phone: 0409 151 969

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