Soil Organic Matter

"Soil organic matter is a substance and a process. It is a mixture of materials – plant and animal remains and products of decay processes that have been going on for months or years."

F. E. Broadbent

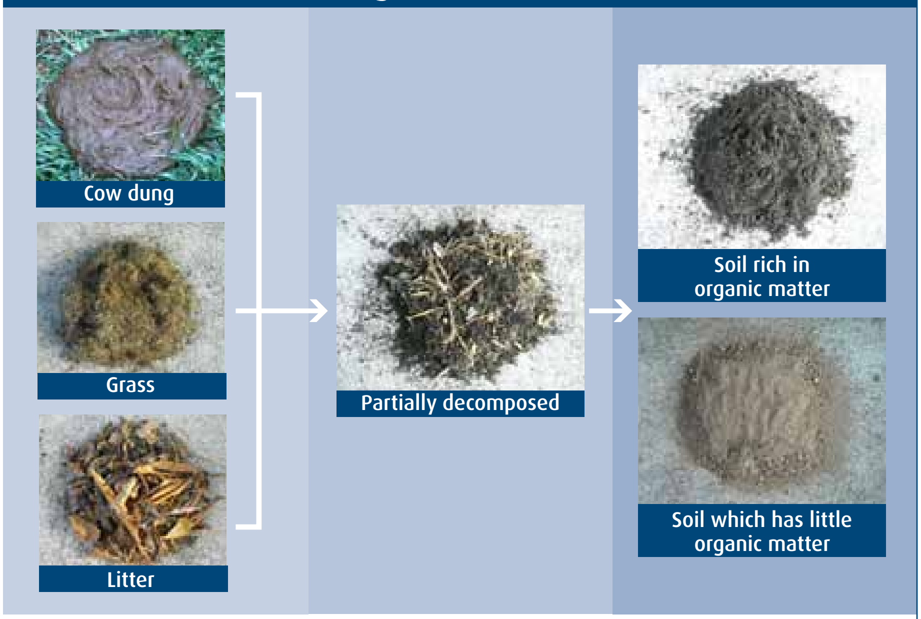
Introduction

The biggest difference between soil and rock is the presence of organic matter and the associated biological activity that takes place in the former. Soil organic matter is at the heart of healthy and productive soils. Although organic matter typically makes up a small percentage of most mineral soils (less than 10 percent by weight), it is very important because it positively influences or modifies the effects of almost all soil properties. Understanding the role of organic matter in maintaining a healthy soil is essential to ensure a high level of productivity and to minimise the negative environmental impacts of farming activities.

What is soil organic matter?

Soil organic matter is the fraction of the soil that includes: plant and animal residues at various stages of decomposition; plant roots; cells and tissues of soil organisms; and substances synthesised by the soil population. Fresh or undecomposed plant materials such as litter and straw and animal dung lying on the soil surface are not included in this definition although upon decomposition, these will eventually become part of the soil organic matter. Organic matter is largely made up of the elements carbon, hydrogen, oxygen, and nitrogen and also phosphorus and sulphur. It is expressed as a percentage of the soil mass less than 2 mm in diameter.

The formation of soil organic matter



Decomposition of plant residues and animal manure added to the soil produces organic matter that is beneficial to soil health and plant growth

Soil organic matter is a dynamic mixture that reflects the balance between additions of new organic matter and losses of organic matter already in the soil. Soil organic matter exists in various forms which differ in their biodegradability or resistance to decomposition. It is generally divided into three pools: active, intermediate or slow, and recalcitrant or resistant. The active pool includes microbial biomass and labile organic compounds that make up less than 5 percent of the soil organic carbon. The slow pool usually makes up 20 to 40 percent These three pools have different rates of turnover. The active pool ranges from months to years, the slow pool in decades, and the recalcitrant pool in hundreds to thousands of years.

The active and part of the intermediate pools are involved in nutrient supply and in the binding of small soil particles together to form larger structural units called aggregates. Aggregation is important for water infiltration, aeration and drainage, and reduces the soil's susceptibility to erosion. On the other hand, the recalcitrant pool or humus possesses a large quantity of negative charges and contributes largely to the nutrient-holding capacity (cation exchange capacity) of the soil. It also imparts a dark colour to topsoil.

Why soil organic matter matters?

Organic matter is critical for maintaining soil health. The level of organic matter is highest in the topsoil and, with few exceptions, declines dramatically with depth. New Zealand farmers regard the top 6 inches as their most productive soil. Topsoil is therefore a precious resource primarily due to the high level of organic matter and nutrients it contains relative to subsurface soil. Once depleted, organic matter takes many years to replace. With this in mind, adding plant and animal residues and minimising topsoil loss through erosion and other forms of soil disturbance should be an important goal of every land manager.

Organic matter serves several functions, the most important of which are as a soil conditioner and as a source of plant nutrients. Organic matter adds body to sandy soils and increases its moisture- and nutrient-holding capacity. It promotes granulation in clayey soils which helps in plant root penetration and entry of water and air into the soil. It makes cultivation easier, resulting in better seedbeds, and reduces surface crusting that can adversely affect the emergence of seedlings. The functions of soil organic matter are broadly categorised into biological, physical and chemical but they actually overlap and interact with each other.

Biological

Organic matter is a food and energy source for soil organisms and a source of plant nutrients. Organic matter decomposition is a microbiological process which releases inorganic forms of nutrients such as nitrogen (N) phosphorus (P) and sulphur (S) which slowly becomes available for plant use. The humus which develops as an intermediate product of this decomposition also acts as a store for nutrients. Soil organic carbon is generally highly correlated with total nitrogen. Therefore, the amount of N mineralisation (i.e. conversion of organic N compounds to ammonium-N) increases as soil organic carbon increases.

Organic matter provides active absorption sites for the deactivation of organic chemicals such as pesticides, particularly herbicides. Micro-organisms associated with soil organic matter may also rapidly decompose soil-applied organic chemicals.

Adding organic matter to the soil contributes a certain level

Topsoil is a precious resource primarily due to the high level of organic matter and nutrients it

of sequestration of carbon from the atmosphere. This is currently an active area of research by scientists concerned with increasing the carbon content of soils to mitigate the adverse effects of climate change and to potentially utilise it in emission trading schemes.

Physical

One of the major effects of organic matter is to improve soil structure. Plant roots, earthworms, bacteria, fungi and other micro-organisms release organic compounds which help bind soil particles together to produce stable aggregates. This improves aeration and increases permeability which in turn makes the soil less susceptible to erosion. Stable aggregates also resist compaction caused by ploughing, and vehicle and animal traffic.

Organic substances have been shown to hold up to five times their own weight of water. This contributes to improving the available water-holding capacity of soil, making growing plants less prone to short-term droughts.

The dark colour imparted by organic matter in the topsoil increases the absorption of solar radiation. This may facilitate soil warming in spring and consequently seed germination and plant growth.

Chemical

Organic matter possesses a high surface area and contains lots of negative charges. These negative charges contribute to the nutrient retention capacity of soils by attracting positively charged ions (cations) in soil such as calcium, magnesium, potassium, ammonium,etc. These would otherwise leach and get lost in the soil profile. It should be noted that negatively charged ions (anions) such as nitrate and sulphate are not held by the negative charges of organic matter and are therefore subject to leaching loss.

Organic matter acts as a chemical buffer by resisting rapid change in pH. On the positive side, this mechanism delays soil acidification particularly in soils subjected to long-term fertilisation by urea and ammonium-containing fertilisers. On the negative side, one may need to apply larger quantities of liming material in order to raise the pH of an already acidic soil to a desirable level.

Organic matter complexes cations, particularly micronutrient cations such as iron and zinc, through a process known as chelation. The formation of iron-organic complexes makes the insoluble iron more available for plant use.

How is soil organic matter measured?

In the laboratory, organic matter is actually measured as total carbon by high temperature combustion analysers which raise the soil sample to a temperature of about 1,300°C and the total carbon is measured as carbon dioxide. Total carbon is expressed as a percentage of the soil weight. The measurement includes both organic and inorganic (carbonates) carbon. However, since most New Zealand soils contain very little inorganic carbon, total carbon is a good measure of organic matter content. To obtain the percentage of organic matter, total carbon is multiplied by a conversion factor of 1.72. This assumes that organic matter is 58 percent carbon. In reality, the carbon content of organic matter varies and so it is better not to convert and just report the measured total carbon as is.

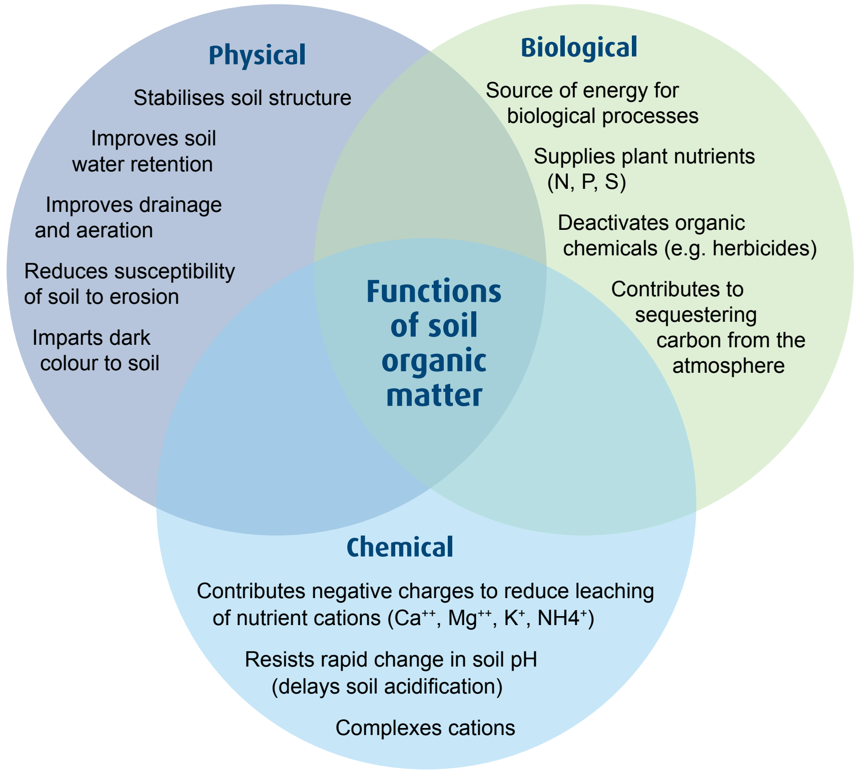
Ratings of total carbon for New Zealand soils are as follows:

Level	Total carbon (%)
Very low	Less than 2
Low	2-4
Medium	4-10
High	10-20
Very high	Above 20

Depending on soil type but regardless of land use, desirable provisional target values of total carbon for New Zealand mineral soils set by Landcare Research are: above 2 percent (Semi-arid, Pumice and Recent soils), above 3 percent (Allophanic soils), and above 2.5 percent (all other soils).

The quality of soil organic matter can be described by the so-called carbon to nitrogen (C/N) ratio which is the total carbon content (C) of the soil divided by its total nitrogen content (N). A C/N ratio of less than 10 means that organic matter is easily mineralised which releases soluble inorganic forms of N (ammonium and nitrate) into the soil. On the other hand, a C/N ratio greater than 10 means that organic matter is less easily mineralised. A high C/N ratio may indicate possible N deficiency but different land uses will vary in their expected responses. In pastures, the optimum C/N ratio ranges from 8 to 12.

Soil organic matter serves several functions



What factors influence organic matter levels in soils?

Soil organic matter represents the largest terrestrial carbon pool being almost three times that of plant and animal biomass. The amount of carbon stored in a soil is determined by a dynamic equilibrium between carbon additions from plant and animal biomass production and carbon losses by mineralisation or microbial respiration and removal by soil erosion processes through time.

If additions are greater than losses, soil organic matter accumulates. If additions are less than losses, soil organic matter becomes depleted. When the system is in balance and additions equal losses, the quantity of soil organic matter does not change appreciably over time. In general, any factor that affects soil microbial activity also affects breakdown of soil organic matter.

Temperature

Soil temperature influences the activity of soil micro-organisms decomposing organic matter. The optimum soil temperature range for bacterial activity is between 21 to 38°C, but some activity may occur at temperatures as low as 5°C, although at greatly reduced rates.

Oxygen

Most soil micro-organisms are aerobic and require oxygen and water for their respiration. When the soil is saturated with water or gets compacted, microbial respiration slows down significantly which then reduces the decomposition of soil organic matter. Partially or continuously saturated soil condition has protected organic (peat) soils from losing organic matter through oxidation.

Rainfall

Rainfall (or irrigation) influences soil moisture content which in turn determines plant growth and the resulting input of plant biomass into the soil. Rainfall also influences soil moisture content by affecting soil microbial activity. Organic matter decomposition is faster in moist soil than in dry soil. As the soil becomes wet or saturated, microbial activity declines, as does decomposition.

Soil reaction or pH

Under acidic soil conditions, bacterial activity which is responsible for most of the decomposition of organic matter is greatly reduced. However, the activity of soil fungi is less affected by low pH.

Management practices to raise or maintain soil organic matter levels

Raising or maintaining soil organic matter to desirable levels is crucial to sustainable land management as it retains nutrients for plant use, reduces the runoff rate and the hazard of erosion, and improves the physical condition of the soil. Broadly speaking, soil organic matter can be increased by increasing inputs of organic materials and/or decreasing losses. However, most organic matter added to the soil will rapidly decompose to carbon dioxide gas through the process of microbial respiration and will not become part of the soil organic matter. In general, only about 5 to 15 percent of applied carbon to soil eventually becomes soil organic carbon. Therefore, very large amounts of organic matter need to be added to soil to increase its organic carbon content in the long term. Periodic application of organic matter is required to maintain desirable levels. The key to organic matter management is to strike a balance between additions and losses so that a significant decline is avoided.

Most pastoral soils in New Zealand are generally considered to be rich in organic carbon (range: 3.5 percent to 15 percent by weight) so that large increases in productivity are not expected by adding more organic matter. However, recent research has shown that in intensive lowland livestock systems (e.g. dairying), soils have lost organic carbon by an average of 1 tonne carbon/ha/yr over the last 20-30 years while in hilly land soils, organic carbon levels have increased. This implies that retention or maintenance of soil organic matter level will be an important challenge on intensively used pastures.

Recommended practices for raising or maintaining soil organic matter are as follows:

Increasing inputs of organic materials	Reducing organic matter losses
Apply organic materials to soil Apply manure, farm dairy effluent and biosolids in pastures. Add plant residues, compost, green manures, prunings or mulch in arable and horticultural situations.	**Minimise soil erosion** Erosion removes organic matter contained in topsoil. Maintaining good vegetative or ground cover to protect soil from erosion will ensure that valuable topsoil and organic matter are conserved.
Increase pasture/crop growth Increase plant growth by optimising soil fertility and good grazing/crop management practices (e.g. irrigation) to maximise the capture of carbon from the atmosphere.	**Minimise soil degradation** Soil compaction by farm machinery and pugging by animal treading reduces plant productivity which reduces organic matter inputs to soil.
Retain crop residues All crop residues such as straw and maize stalks should be incorporated into the soil or left on the soil surface to decompose whenever possible.	**Reduce tillage operations** Because excessive tillage accelerates organic matter decomposition and makes soils susceptible to erosion, the adoption of zero or minimum tillage becomes important in reducing organic matter loss.
Grow cover crops Growing cover crops rather than leaving the land fallow over winter adds carbon to the soil. If grazed in situ, a significant proportion of crop carbon will be returned to the soil in manure.	**Avoid overgrazing** Overgrazing leads to reduction of pasture biomass and therefore productivity. Lower pasture biomass means low input of organic matter to the soil. Overgrazing also increases the area of bare ground making the surface soil more prone to erosion.
Include a pasture phase in arable cropping Grasses and legumes are regarded as soil builders because their root residues add active organic matter to the soils. They will help return the paddock to either long-term or short-term pasture depending on the degree of soil degradation.	**Manage decomposition rates** Encourage soil organisms (e.g. worms, beetles) to enhance the burial and incorporation of plant litter into soil aggregates to protect organic matter from loss by decomposition. Living shelterbelts with deep roots will capture and sequester carbon at deeper soil layers.

Additions and losses determine the level of soil organic matter

Additions

- Plant residues
- Manures
- Compost and vermicompost
- Biosolids

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Soil organic matter content

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Losses

- Mineralisation (microbial respiration)
- Soil erosion

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