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The science behind 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

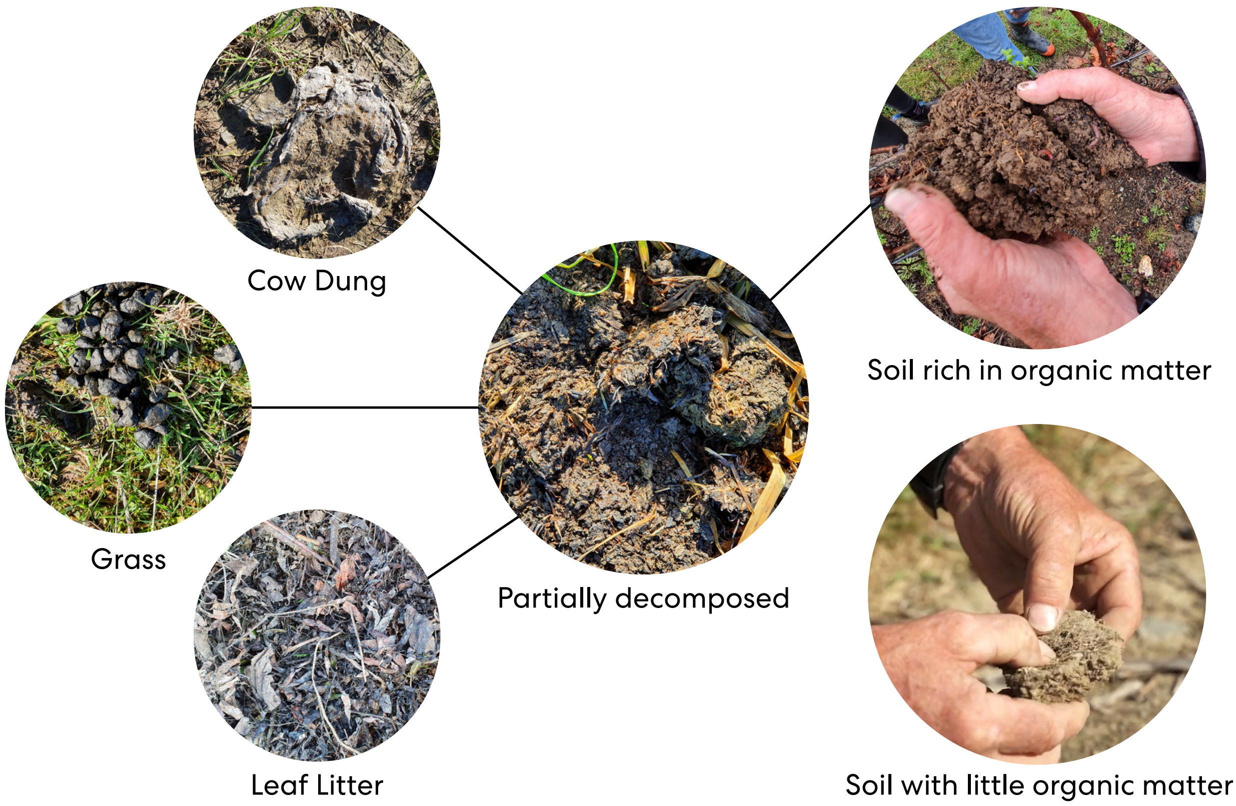
The biggest difference between soil and rock lies in the presence of organic matter and the associated biological processes that occur in soil. Soil organic matter is central to healthy and productive soils. Although organic matter usually constitutes a small portion of most mineral soils (typically less than 10% by weight), its significance arises from its ability to enhance or adjust nearly all soil characteristics. Understanding the role of organic matter in sustaining healthy soil is critical for achieving high productivity and reducing the adverse environmental effects of growing practices.

What is soil organic matter

Soil organic matter encompasses various components, such as plant and animal remains in different stages of decay, plant roots, the cells and tissues of soil organisms, and substances synthesized by the soil population. Fresh, undecomposed materials like litter, straw, and animal dung on the soil surface are excluded but eventually become part of soil organic matter as they break down. Organic matter primarily consists of carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur and is expressed as a percentage of the soil mass less than 2mm in diameter.

Soil organic matter is a dynamic blend, continually changing due to the addition and loss of organic materials. It comes in various forms, each differing in biodegradability or resistance to decomposition. They are typically categorised into three pools: the active pool, the intermediate or slow pool, and the recalcitrant or resistant pool. The active pool constitutes less than 5% of the soil's organic carbon and includes microbial biomass and labile organic compounds. The slow pool, making up 20% to 40%, has turnover times in the range of decades, while the recalcitrant pool takes hundreds of thousands of years to turn over.

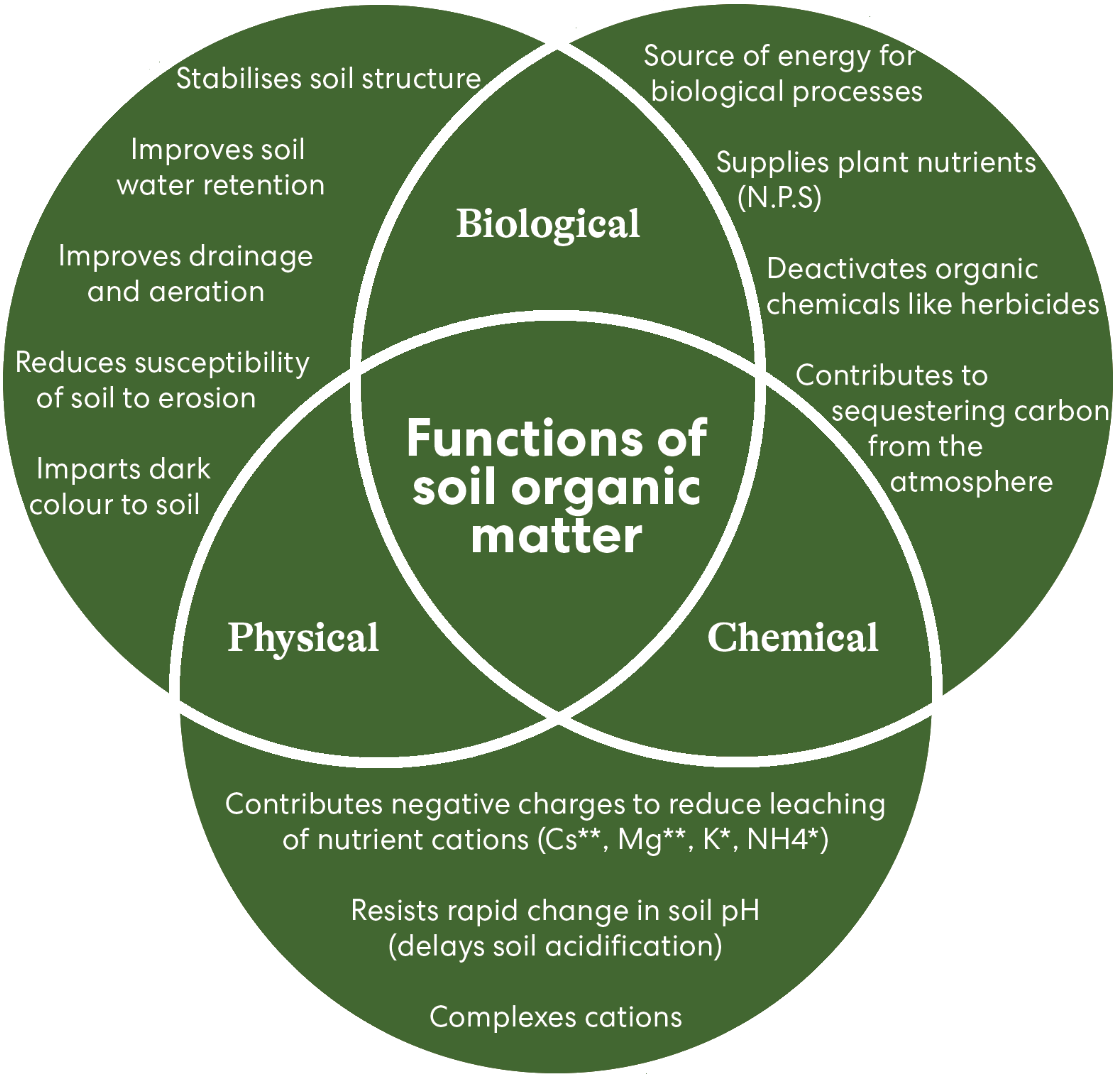
The active components within the intermediate pools play roles in nutrient supply and binding small soil particles into larger structural units called aggregates. These aggregates are vital for water infiltration, aeration, drainage, and erosion prevention. In contrast, the recalcitrant pool, or humus, contains numerous negative charges and significantly contributes to the soil's nutrient-holding capacity, known as cation exchange capacity. Additionally, humus gives topsoil its characteristic dark color.



Why organic matter matters

Organic matter plays a crucial role in maintaining soil health. It's most abundant in the topsoil, and, except for a few exceptions, declines significantly as you go deeper. Among New Zealand growers, the upper 6 inches of soil is considered the most productive. This is mainly due to its rich organic matter and nutrient content in comparison to the subsurface layers. Once this resource is depleted, it takes many years to regenerate. Given this, it's imperative for growers to focus on replenishing organic matter by incorporating plant and animal residues while minimizing topsoil loss through practices like erosion control and avoiding soil disturbance.

Organic matter has several key functions, primarily as a soil conditioner and a source of plant nutrients. It adds substance to sandy soils, enhancing their ability to retain moisture and nutrients. In clay soils, organic matter promotes granulation, aiding plant roots in penetration and facilitating the movement of water and air. It also eases cultivation, resulting in improved seedbeds and reduced surface crusting, which can affect the emergence of seedlings. Organic matter's roles can be broadly categorised into biological, physical, and chemical functions, but these categories often intertwine and interact with one another.



Functions of soil organic matter

Biological

Organic matter serves as a food and energy source for soil organisms and provides essential plant nutrients. The breakdown of organic matter is a microbiological process, releasing inorganic nutrients like nitrogen (N), phosphorus (P), and sulphur (S) over time, which are gradually made available for plant use. Humus, develops as an intermediate product during these decompositions, also acts as a nutrient reservoir. Notably, soil organic carbon and total nitrogen are often closely related. Consequently, higher soil organic carbon levels tend to increase the process of nitrogen mineralization, transforming organic N compounds into ammonium-N.

Organic matter plays another crucial role by offering active sites for absorbing and deactivating organic chemicals, particularly pesticides and herbicides. Soil microorganisms associated with organic matter can also effectively break down organic chemicals applied to the soil.

Additionally, the inclusion of organic matter in the soil contributes to the carbon sequestration process, capturing carbon from the atmosphere. This has become a significant area of research among scientists concerned with enhancing soil carbon content to counteract the adverse impacts of climate change and explore its potential in emission trading schemes.

Physical

One of the major effects of organic matter is to enhance soil structure. Plant roots, earthworms, bacteria, fungi, and other microorganisms release organic compounds, which work to bind soil particles together, creating stable aggregates. This, in turn, improves aeration and increases permeability, making the soil less vulnerable to erosion. These stable aggregates also resist compaction, even when subjected to plowing or the weight of vehicles and animals.

Furthermore, organic substances have the remarkable ability to retain up to five times their own weight in water. This significantly boosts the soil's water-holding capacity, reducing the susceptibility of plants to short-term droughts.

Moreover, the dark hue introduced by organic matter in the topsoil amplifies the absorption of solar radiation. This, in turn, promotes soil warming during spring, facilitating the germination of seeds and fostering plant growth.

Chemical

Organic matter, with its extensive surface area, is rich in negative charges. These negative charges contribute to soil nutrient retention by attracting positively charged ions (cations) like calcium, magnesium, potassium, and ammonium. This prevents these essential nutrients from leaching away through the soil, helping to make them available for plant use. It's important to note that negatively charged ions (anions), such as nitrate and sulfate, are not held by the negative charges or organic matter and can still leach, posing a risk of nutrient loss.

Additionally, organic matter acts as a pH buffer, helping to resist rapid changes in soil acidity. This buffering effect is particularly beneficial in soils that receive long-term fertilisation with urea and ammonium-containing fertilisers, slowing down the process of soil acidification. However, it's worth noting that in cases where soil pH needs adjustment, especially in already acidic soils, a larger quantity of liming material may be required to reach the desired pH level.

Moreover, organic matter plays a role in complexing cations, particularly micronutrient cations like iron and zinc, through a process known as chelation. This complex formation enhances the availability of typically insoluble iron for plant use, contributing to improved plant health and growth.

How soil organic matter is measured

In the lab, organic mater is measured by determining total carbon using high-temperature combustion analysers. These analysers heat the soil sample to around 1,300°C, measuring the total carbon as carbon dioxide.

Total carbon is expressed as a percentage of the soil's weight, and this measurement includes both organic and inorganic (carbonates) carbon. However, since most New Zealand soils contain minimal inorganic carbon, total carbon serves as a reliable indicator of organic content.

To calculate the percentage of organic matter, total carbon is multiplied by a conversion factor of 1.72. This assumes that organic matter consists of 58% carbon. In practice, the carbon content of organic matter can vary, so it's often more accurate to report the measured total carbon without conversion.

Ratings of total carbon for New Zealand soils

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, and irrespective of land use, there are recommended target values for total carbon in New Zealand mineral soils, established by Landcare Research:
- For semi-arid pumice and recent soils, the target is above 2%.
- For allophanic soils, it's above 3%.
- For all other soils, the target is above 2.5%.

We evaluate the quality of soil organic matter using the carbon-to-nitrogen (C/N) ratio. This ratio represents the total carbon (C) content of the soil divided by its total nitrogen (N) content.

A C/N ratio less than 10 indicates that organic matter is readily mineralized, releasing soluble inorganic forms of nitrogen (ammonium and nitrate) into the soil. Conversely, a C/N ratio greater than 10 suggests that organic matter is less easily mineralized. While a high C/N ratio might indicate potential nitrogen deficiency, the response can vary depending on different land uses. For pastures, the optimal C/N ratio typically falls within the range of 8 to 12.

Organic matter levels in soil

Soil organic matter stands as the largest carbon pool on land, nearly three times the size of plant and animal biomass. The amount of carbon stored in soil hinges on a dynamic equilibrium, with carbon inputs from plant and animal biomass creation weighed against carbon losses due to mineralization, microbial respiration, and removal through soil erosion processes.

When the rate of additions surpasses that of losses, soil organic matter accrues. Conversely, when additions lag behind losses, soil organic matter depletes. In a balanced system where additions and losses are in equilibrium, the amount of soil organic matter remains relatively stable over time. Broadly speaking, anything that influences soil microbial activity also impacts the decomposition of soil organic matter.

Temperature

Soil temperature plays a vital role in shaping the activity of soil microorganisms involved in the decomposition of organic matter. Bacterial activity thrives within the optimal soil temperature range of 21°C to 38°C, but it can still persist, albeit at significantly reduced rates, at temperatures as low as 5°C.

Oxygen

The majority of soil microorganisms are aerobic, meaning they rely on oxygen and water for their respiration. When the soil becomes waterlogged or densely compacted, microbial respiration markedly slows down, leading to a reduction in the breakdown of soil organic matter. In some cases, partially or continuously saturated soil conditions have shielded organic (peat) soils from losing organic matter through oxidation.

Rainfall

Rainfall and irrigation substantially impact soil moisture levels, which, in turn, govern plant growth and the quantity of plant biomass added to the soil. Moreover, rainfall affects soil moisture by modulating soil microbial activity. Organic matter decomposition occurs more swiftly in moist soil compared to dry soil. As the soil becomes wet or saturated, microbial activity decreases, along with the pace of decomposition.

Soil pH

The soil's acidity or pH level plays a crucial role. Under acidic soil conditions, bacterial activity, responsible for much of organic matter decomposition, diminishes significantly. However, soil fungi's activity is less affected by low pH levels.

Recommended practices

Maintaining or increasing soil organic matter is essential for sustainable land management. It serves several critical functions, including nutrient retention for plant use, the reduction of runoff and erosion risks, and the enhancement of soil structure. In essence, to boost soil organic matter, you can focus on increasing organic material inputs and minimizing losses. However, it's important to note that much of the organic matter added to the soil is swiftly decomposed into carbon dioxide through microbial respiration and doesn't become part of the soil's organic matter. Typically, only about 5% to 15% of the applied carbon eventually becomes soil organic carbon. Consequently, substantial amounts of organic matter are required to make a lasting impact on organic carbon content, necessitating periodic applications to maintain desired levels. Achieving the right balance between additions and losses is crucial to prevent significant declines in organic matter.

In New Zealand, most pastoral soils are generally regarded as having substantial organic carbon content, ranging from 3.5% to 15% by weight. As a result, adding more organic matter is not likely to yield substantial productivity increases. Nevertheless, recent research reveals that in intensive lowland livestock systems, like dairying, these soils have lost approximately 1 tonne of carbon per hectare per year over the past two to three decades, while hilly land soils have witnessed increases in organic carbon levels. This indicates that retaining or restoring soil organic matter levels will be a critical challenge, particularly in intensively managed pastures.

Increasing inputs of organic materials

Apply organic materials to soil
Apply manure, farm dairy effluent and bio solids in pastures. Add plant residues, compost, green manure, prunings or mulch in arable and horticulture situations.

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.

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.

Grow cover crops
Growing cover crops rather than leaving 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.

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.

Reducing organic matter losses

Minimise soil erosion
Erosion removes organic matter contained in topsoil. Maintaining good vegetation or ground cover to protect soil from erosion will ensure that valuable top soil and organic matter are conserved.

Minimise soil degradation
Soil compaction by farm machinery and pugging by animal treading reduces plant productivity which reduces organic matter inputs to soil.

Reduce tillage operations
Because excessive tillage accelerates organic matter decomposition and makes soil susceptible to erosion the adoption of zero or minimum tillage becomes important in reducing organic matter loss.

Avoid overgrazing
Overgrazing leads to reduction of pasture biomass and therefore productivity. Over grazing also increases the area of bare ground making the surface soil more prone to erosion.

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 shelter belts with deep roots will capture the sequester carbon at deeper soil layers.

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