



The layer of soil beneath our feet is one of the most valuable resources on this planet. From the food we eat, to the clothes we wear, our existence is inextricably linked to the fate of our soils.

The formation of soil

Soil is a complex and fragile medium, an amalgamation of water, air, minerals and organic matter. About half of the volume of any soil consists of pore spaces containing varying proportions of air and water, while the other half is principally the mineral component, comprised of weathered parent bedrock and deposited minerals.

Organic matter is a relatively small part, encompassing plant and animal material both living and dead, yet its influence is vast. It is crucial to the soil's fertility, resilience and structure. As the energy source for the soil's microbes it is the basis of the soil food web.

Soil fauna

Soils are home to a startlingly diverse collection of organisms, from earthworms to bacteria, fungi to mites and protozoa to springtails. All play a role in the breakdown (decomposition) of organic matter.

Soil biological diversity is estimated to be twice that of the tropical rainforest canopies, yet while we recognise that soils teem with life, our understanding of this underground metropolis remains erratic. In every m² of pasture land at a study site in Western Australia, scientists have calculated that there are 800 million protozoa, 900 000 nematodes and 130 000 mites ⁽¹⁾, while a teaspoon of soil can contain between 100 million and 1 billion bacteria ⁽²⁾. Yet only recently have we begun to understand that soil biodiversity influences how ecosystems function.

Decomposition

Organic matter decomposition is a biological process. Soil organisms use organic matter as a source of carbon, nitrogen and nutrients, releasing CO₂ in the process ⁽³⁾. If you could remove the soil fauna, the soil's nutrient and carbon cycles would come to an abrupt halt.

When new organic matter enters the soil, it's rapidly colonised by enzyme-secreting fungi and bacteria (microbes). These are soon joined by a succession of soil organisms such as protozoa, nematodes, mites and springtails that slowly consume the decaying material, its associated bacteria and fungi, or one another (as detritivores, microbial grazers and predators), and add to the organic matter through their own faecal pellets and remains.

The mixing and shredding action of soil organisms helps to increase the surface area of organic matter, opening up the substrate to microbial action, and inoculating bacteria and fungi into new areas. In turn, microbes help to improve soil structure through the formation of soil aggregates; clusters of soil particles held together by fungal hyphae, roots and bacterial excretions. These soil aggregates vary from 2 thousandths of a mm across, up to 2 mm, and the soil pores between them are essential for storing water, air, microorganisms, nutrients and organic matter.

'Active' and 'Passive' Soil Carbon

Soil contains a vast reservoir of carbon, over twice as much as is in the atmosphere ⁽⁴⁾. The quantity of a soil's organic carbon depends on the rate of addition of 'new' organic matter, and the rate of its turnover (decomposition). However the speed at which different organic carbon fractions decompose is variable, and scientists often refer to organic carbon as 'passive' or 'active'.

'Passive' carbon consists of highly complex and chemically stable carbon compounds that resist further decomposition ⁽³⁾, or which are physically protected from decomposition by their inclusion within soil aggregates. This 'passive' carbon, made up of protected humus and charcoal components, forms the soil's long-term carbon store ⁽¹⁾ and takes tens to hundreds of years to turnover.

By contrast, the newly added organic matter forms the 'active' or 'labile' carbon pool that is easily decomposed and rapidly used by soil microorganisms, so it has a swift turnover of just 2-3 years.

During decomposition, organic matter is converted into different, often simpler organic compounds, and available nutrients. For example, a protein molecule may undergo several changes to simpler organic molecules, before carbon is converted to carbon dioxide, nitrogen to ammonium, phosphorus to phosphate and sulphur to sulphate ⁽¹⁾. Fractions such as sugars and proteins tend to be broken down rapidly, while slower components include cellulose, lignin and phenols.

These, along with physically protected organic compounds, are relatively resistant to decomposition and sit somewhere in between the two extremes of active and passive, taking decades rather than years or centuries to break down.

It is the 'active' carbon that influences both the activity and number of soil fauna, and hence the fertility (nutrient turnover) of the soil ⁽³⁾. During decomposition about half of the carbon is mineralized and released as CO₂ ⁽⁴⁾. Only once nutrients are mineralised can they be made use of by plants ⁽¹⁾. Any excess nutrients, surplus to microorganism requirements are released and plants and other soil organisms subsequently compete for a share. Since microbes are superior competitors for nitrogen, plants can sometimes lose out, especially if the organic matter has a high proportion of carbon to nitrogen.

Effects of environmental variables

Microorganisms make excellent soil health indicators precisely because the soil is both their place of residence (in the pores between particles) and grocery store ⁽⁵⁾. Monitoring the biological component is one way of assessing a soil's ecological quality, and may provide an early warning of land degradation ^(1,6) with a reduction in soil biota reducing a soil's capacity to accomplish fundamental ecosystem services ^(7,8). For example heavy grazing of pasture in Western Australia is accompanied by substantial reductions in mite abundance and species richness ⁽⁹⁾, yet the physical and chemical components are currently far better understood than the biological.

Most soil fauna inhabit the soil's top 5 cm, making them vulnerable to changes in the environment, whether climatic or physical. Erosion can be particularly devastating, removing the majority of a soil's organic matter, which takes years to replace, while tillage can break up soil aggregates, exposing previously protected organic material to microorganisms, while at the same time aerating the soil and favouring increased microbial activity. Variations in temperature, moisture and pH all influence soil fauna activity, and consequently the turnover of organic matter.

Moist, warm and well-aerated soils generally favour rapid breakdown of organic material ⁽³⁾. If a soil dries out, most of the soil fauna must migrate, form a resistant stage (e.g. cyst) or perish, relying as they do on water absorption through their integument.

Soil carbon and climate change

The fate of the soil's carbon reservoir during anticipated global climate change and rising atmospheric CO₂ is of growing interest to scientists ^(10,11). Atmospheric CO₂ concentrations have already risen by 30% since the pre-Industrial era ⁽¹²⁾. At present the effect of elevated atmospheric CO₂, increased N deposition, and increased temperature on soil organisms and soil carbon stores is unknown.

There are concerns that an increase in air temperature could speed the release of yet more CO₂ back into the atmosphere. For example, most studies of the Arctic tundra estimate that it will switch from being a carbon sink to a carbon source, causing a positive feedback to atmospheric CO₂ ⁽¹²⁾. The Australian Government recently funded major projects on soil carbon related to climate change. The intention is to improve our understanding of how to measure soil carbon, to find effective ways of storing carbon in the soil and to understand how carbon in soil varies with land management ⁽¹³⁾.

Carbon is important for soil quality, agricultural productivity and maintaining the stability of landscapes. It's suggested that carefully managed soils could act as valuable long-term carbon sinks, with research looking at locking up rapidly decomposing carbon into more durable passive forms, referred to as carbon sequestration ⁽¹⁴⁾.

The ancient highly weather landscapes of Western Australia means that many soils are sandy and naturally infertile, with small amounts of organic matter. These soils have the potential to act as carbon sinks if properly managed.

Although the effects of global warming on soil organisms are largely unknown, two numerous and important soil fauna groups, mites and springtails, are currently being studied in a variety of locations, where scientists look at changes in abundance and diversity when subject to environmental change ⁽¹⁵⁾. Their dominance, sensitivity to changes in the soil environment and key roles in nutrient cycling, makes them ideal study organisms.

Importantly, as mites and springtails are implicated in the direct transfer of carbon from roots and the transformation of organic matter in soil, the ratio of mites to springtails is expected to change with the types of plants grown and the form of carbon in the soil. A monitoring program offers the chance to assess the consequence of change on this subterranean world.

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