Biology of soil

There is no such thing as humus and your compost has little to offer! An agroecologist offers a radically different understanding of what lies beneath.

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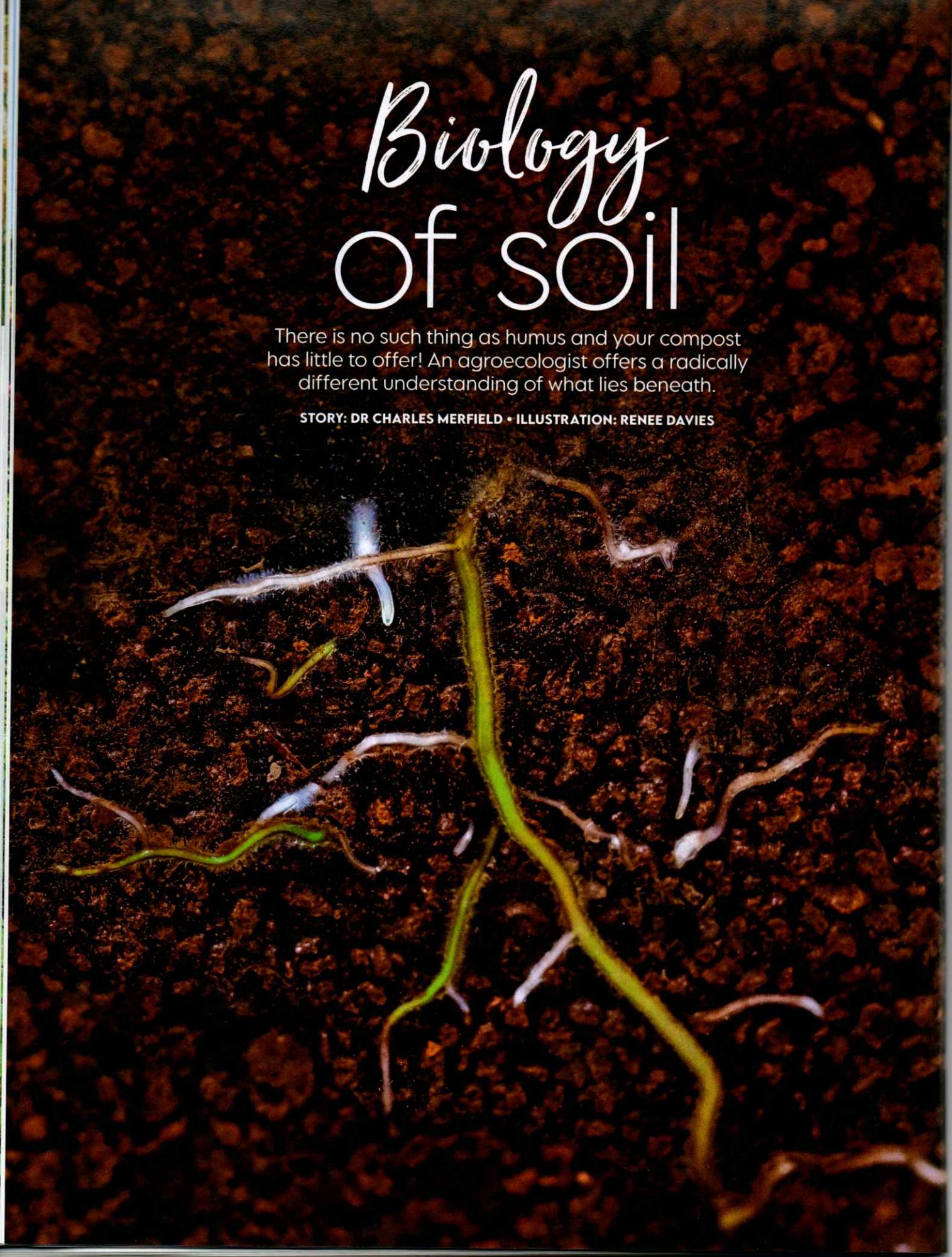

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The science of soil biology and organic matter has undergone a revolution – a paradigm change – over the last two decades. This has turned much old thinking on its head. Indeed, biological soil science was quite limited until new tools such as genetics from medicine and 3D imaging from physics came along in the 1990s, creating totally new ways to study soil.

Old assumptions about soil

What we used to think is that soil biology was driven by dead organic matter inputs such as leaf litter, compost and manure. These are initially broken down by organisms such as worms and springtails before microbes such as fungi and bacteria finished the decomposition process by mineralising the organic matter into inorganic forms – ammonium and phosphate, for example. The mineral forms are then taken up by plants turning them back into organic forms, completing the cycle of life.

It was thought that simple and thus small organic compounds – sugars, proteins, fats and oils – were broken down quickly, in a matter of days to weeks. We thought more complex materials – polymers such as cellulose – took weeks to years to break down, and that the toughest plant matter, lignin (wood), was transformed into humus – recalcitrant organic matter that is resistant to further decay – and took centuries, even millennia to finally decompose. Humus was often viewed as some kind of wonder material that was the foundation on which soil health was built.

New knowledge about soil

We now know that the main driver of soil biology and organic matter formation are plant root exudates – not dead organic matter.

Root exudates are simple soluble organic compounds such as sugars, proteins and oils. Plants push these out of their roots to feed a vast diversity and density of microbes that live directly around the roots, an area called the rhizosphere.

The microbes return this favour by helping the plant get nutrients and water, as well as protecting it from pests and pathogens.

Different plant species produce different exudates that support different microbes. Individual plants can even change the type of exudate to favour particular microbes when they need their specific help; for example, favouring mycorrhizal fungi that can get water that plants can't reach when the soil is dry.

Between 10% and 40% of the photosynthates plants make from sunlight, such as sugar, are turned into root exudates to feed these plant friendly microbes.

Depending on the type and size of plants, hundreds of grams, even kilograms of exudates per square meter per year can be produced.

Cycle of underground life

The microbes that consume the exudates are themselves eaten by bigger organisms such as amoeba and nematodes,

PHOTO: ADOBESTOCK

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which are then eaten by even larger organisms such as mites and worms. When these larger organisms die, they are then consumed by bacteria and fungal decomposers thus completing the soil's biological cycle.

An often underappreciated part of the soil food web are viruses, particularly viruses that attack bacteria, called bacteriophages. When a bacteria is killed by a virus, it explodes showering new viruses and the bacterial cell contents into the soil. This contrasts with the likes of a bacteria eaten by an amoeba, as the whole bacteria is subsumed into the inside of the amoeba.

It is these tiniest particles of organic matter that are the most important form of organic matter. They find their way into minute cracks and crevices inside the mineral soil particles, particularly inside clay. Once inside the mineral particles, the organic matter is protected from further decay as the spaces they are in are so tiny that even the smallest organisms – bacteria – cannot reach them.

This form of organic matter is called mineral associated organic matter – MAOM. The organic matter that results from the breakdown of the likes of leaves and compost is now called particulate organic matter – POM.

MAOM, POM and humus

MAOM makes up 80% of the organic matter in soil; POM is just 20%. It is also MAOM that persists for centuries to millennia; POM is fully mineralised in a few months to years, or decades at most, even tough woody material. The biggest surprise of all is that humus does not exist!

When scientists directly study soil using the new tools such as CT scans (similar to the ones in hospitals), they cannot find humus. It is now considered to be an artefact of the chemical extraction methods used before the 1990s.

Indeed, the idea of humus as these large complex organic molecules that are resistant to decay does not really make sense. Large pieces of organic material, like a leaf, are broken down and down into smaller and smaller bits, first by the likes of worms, then by microbes, finally being broken down into their inorganic constituents. How in this process of breaking down do these large recalcitrant molecules get formed? What is it about their molecular structure that makes them resistant to further decay? These questions cannot be answered as the questions themselves are wrong because humus does not exist.

This is quite the shock to many, particularly those in organic agriculture and gardening as their view of soil health has been predicated on humus, with compost being the ideal soil "food". However, compost mostly becomes POM so is quickly mineralised. So, while compost and other organic residues such as leaves are beneficial, it is plant root exudates that really drive soil health, as they directly feed the microbes in the rhizosphere which are the basis of the rest of the soil ecosystem.

So to maximise soil health, you need to maximise root exudates by maximising the diversity and biomass of living plants. Those in regenerative agriculture call this the liquid carbon pathway, a catchy but technically inaccurate term for plants capturing energy from sunlight, turning that into photosynthates such as sugars, proteins and oils, and pushing them out of their roots as exudates.

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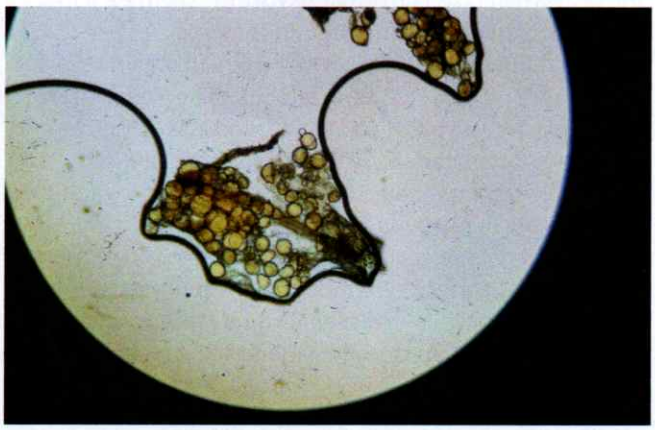
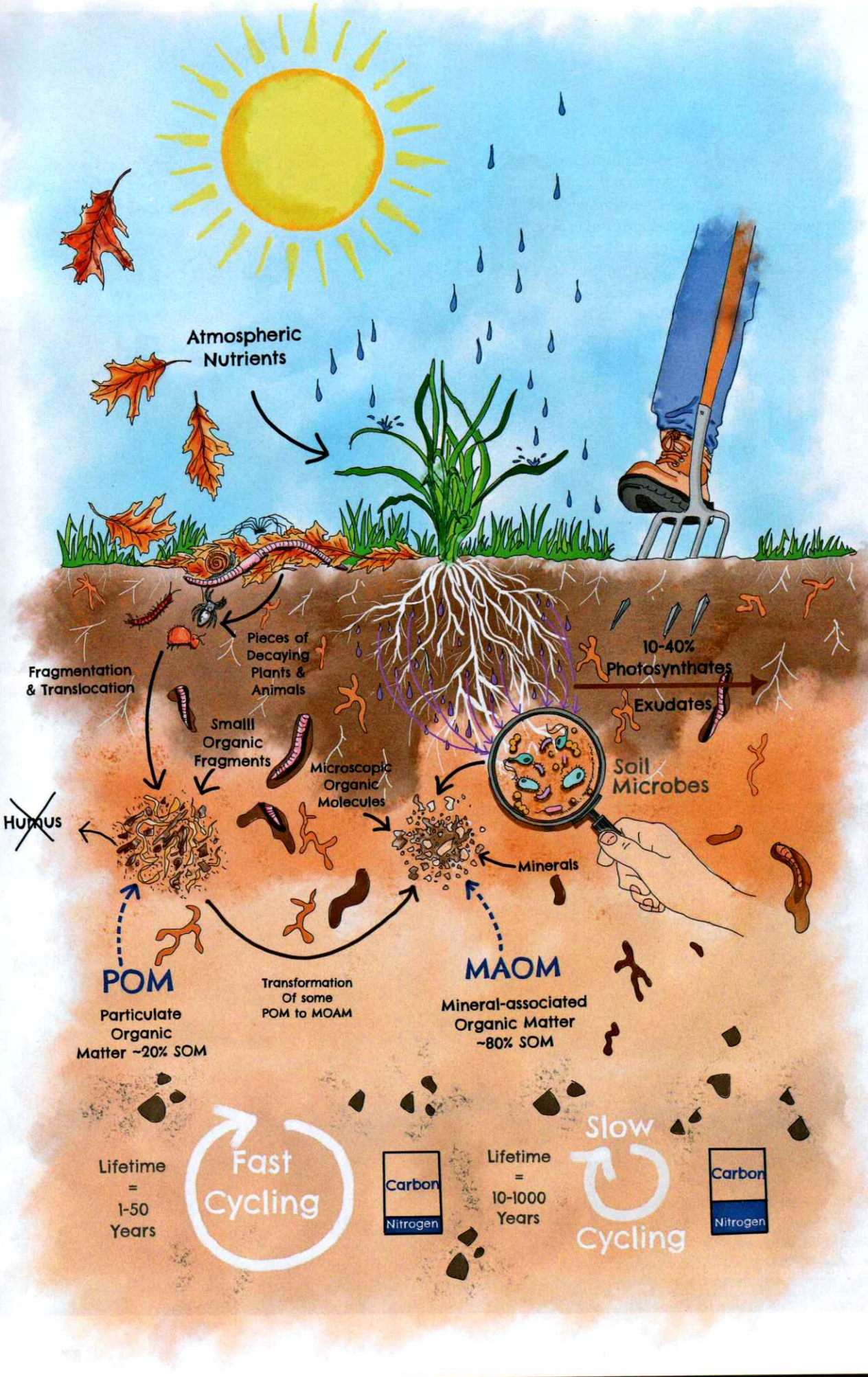


Left: Soil fungi and micro-organisms in a soil and compost sample; Microscopic image of inactive root lamina colonised by spores of arbuscular mycorrhizal fungi.

Dr Charles Merfield says that new tools have created new ways of studying soil and radically turned our understanding of it on its head.

PHOTO: KAI SCHWOERER/STUFF


Atmospheric Nutrients
Pieces of Decaying Plants & Animals
Fragmentation & Translocation
10-40% Photosynthates
Exudates
Small Organic Fragments
Microscopic Organic Molecules
Soil Microbes
Humus
Minerals
POM
Particulate Organic Matter ~20% SOM
Transformation Of some POM to MOAM
MAOM
Mineral-associated Organic Matter ~80% SOM
Lifetime = 1-50 Years
Fast Cycling
Carbon
Nitrogen
Lifetime = 10-1000 Years
Slow Cycling
Carbon
Nitrogen

These simple, soluble organic compounds that we used to think were mineralised in days to weeks are now the foundation of soil biology and health!

A different way of thinking

We are used to thinking of plants as taking up water and mineral nutrients from the soil via their roots and using those to build their foliage. However, like all living things (including animals), plants are mostly made of carbon, hydrogen and oxygen. To be exact, plants are 45% carbon, 45% oxygen and 6% hydrogen. The chemical elements nitrogen, phosphorous, potassium that we typically think of as plant nutrients or fertilisers only make up 4% of the dry weight of plants.

All of the carbon in a plant comes from carbon dioxide in the atmosphere. Plants don't take up carbon via their roots. Much of the oxygen and hydrogen also come from the atmosphere, oxygen directly and along with hydrogen from the splitting of water during photosynthesis. That water comes from the sky as rain.

There is an adage in soil science: we are all temporally not soil, ashes to ashes and all that. Except it's incorrect. We are all temporally not sky – that is, the atmosphere, as we are mostly made of the nutrients carbon, oxygen and hydrogen that plants get from the atmosphere.

Plants take the energy from sunlight, combine it with the atmospheric nutrients and a pinch of soil nutrients, and use that to build both their foliage and roots, pushing up to 40% out through their roots as exudates to feed and power soil biology. So the traditional view of plants is upside down. They take up most of their nutrients by weight from the atmosphere, along with energy from sunlight and push that into the ground!

This new scientific understanding means most of the energy flowing through the soil ecosystem comes directly from plant root exudates, with only a small amount from dead organic matter, which also originates from plants.

There is another axiom in regenerative agriculture: living roots year round, meaning it is a diversity of plant species, having lots of leaves capturing sunlight, producing lots of photosynthates thereby producing lots of root exudates, that drives soil biology and MAOM formation. Thus the old idea that we "feed" soil by the likes of mulching and applying compost is mostly wrong.

Soil without a covering of living plants is a dying soil, as its biology is missing most of its real "food", that is its main source of nutrients and energy: root exudates. So if you can see your soil, even if it is mulched, that soil is not as healthy as it could be. Papatūānuku should always be cloaked by green leaves, capturing the energy from sunlight and carbon from the atmosphere to produce root exudates to feed the living soil. ■