Healthy soils

Healthy soil is alive

Soils supply essential nutrients, water, oxygen (air) and root support to plants.

Healthy soil is living soil. It contains many living organisms. It is deep, loose, and easy to dig and full of air and water. Healthy soil has *aggregates* or structures (that look like bread crumbs) that create air pockets allowing water to *infiltrate* or move deep into the soil. Healthy soils act as giant moisture holding sponges, which is very important in times of drought and flooding.

We are what we eat. Healthy soils lead to healthy plants and healthy people.

Healthy soils are naturally fertile and able to supply sufficient amounts of nutrients to plants. To do this the soil needs a continuous supply and build-up of organic matter. Soil health and it's fertility have a direct influence on the *nutrient* content of food crops.

THE SOIL CONNECTION

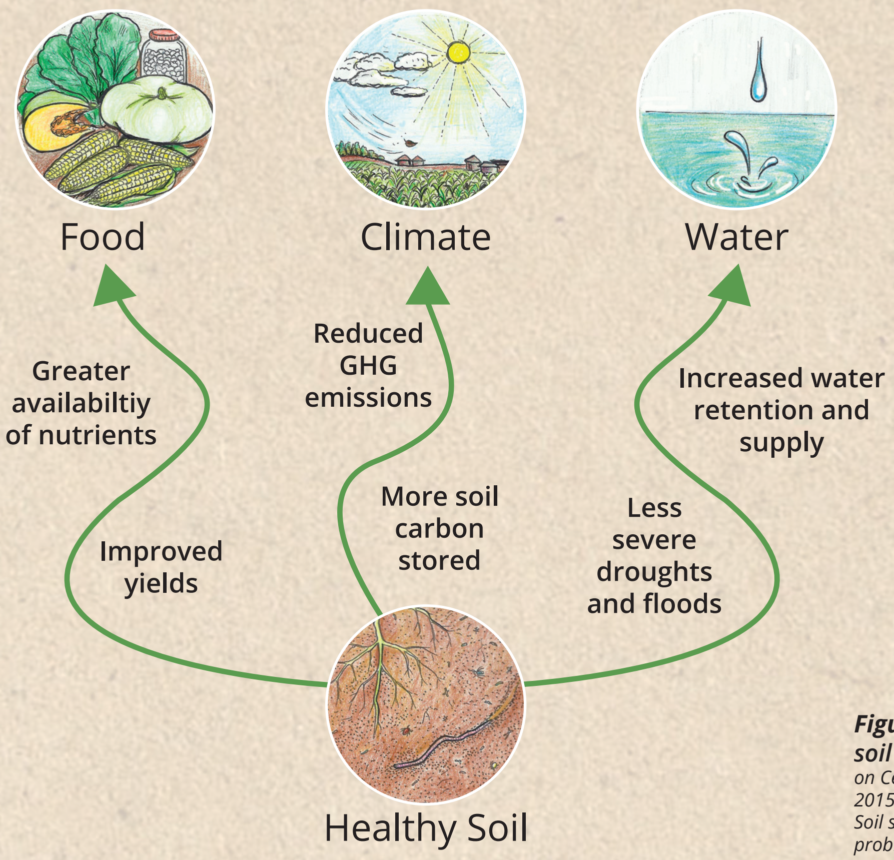


***Figure 1:* Healthy soil diagram** *(Based on Centre for Food safety 2015. Soil and Carbon; Soil solutions to climate problems)*

DICTIONARY:

GHG – greenhouse gas

Aggregate – a collection or composite of similar particles

Infiltrate – to move into or through something

Nutrient – components or parts of food that organisms use to survive and grow

Organism – a life form such as an animal, plant or micro-organism such as a bacterium or fungus

Carbon and Soil Organic Matter – the main building block of life and soil

A key element of all living things, carbon, is constantly cycling through nature as either a liquid a solid or a gas. Soil carbon is sometimes also called organic matter. Because carbon is the main building block of all organic molecules, the amount in a soil is strongly related to the total amount of all the organic matter – the living organisms plus fresh residues plus well decomposed residues.

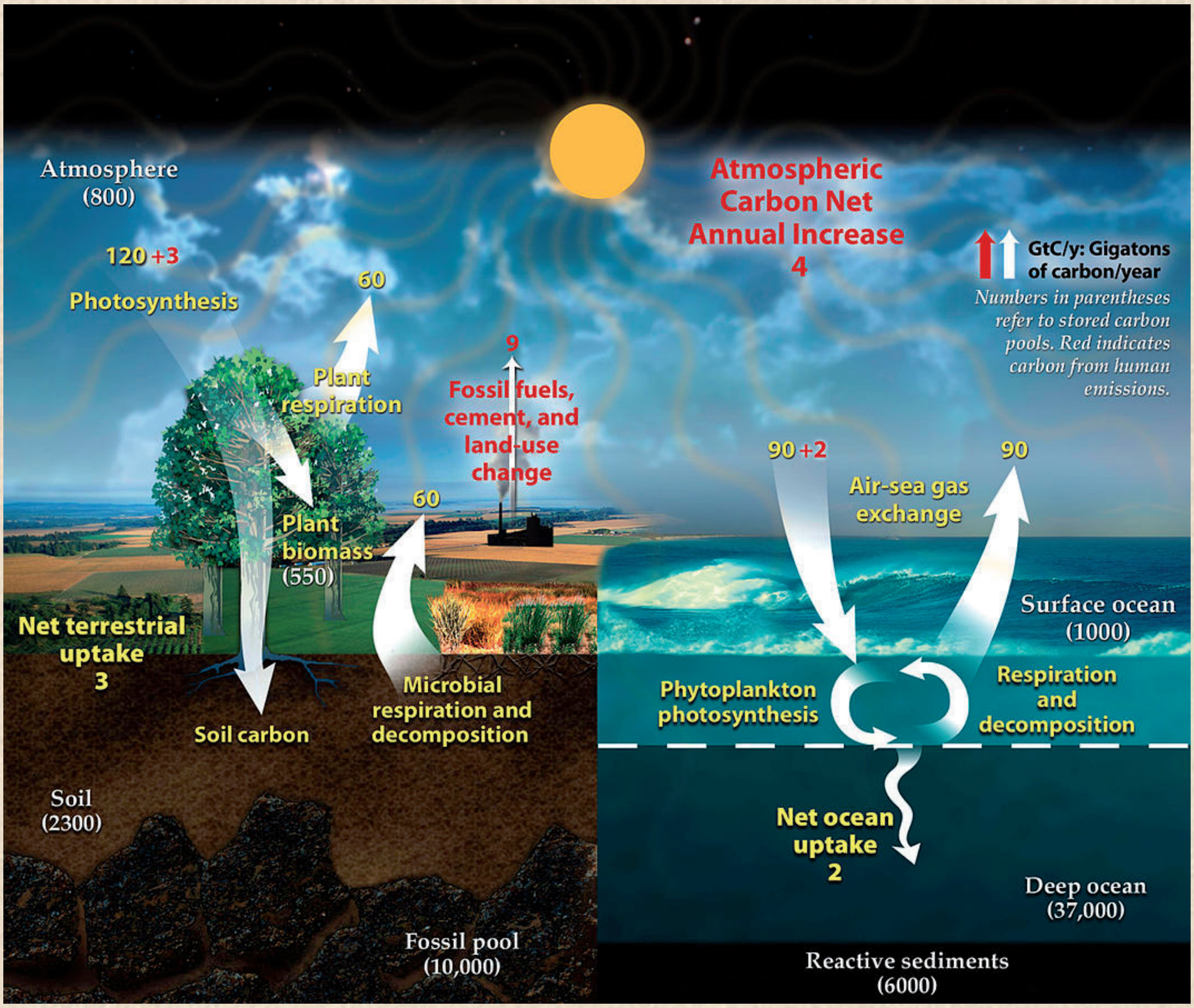


Figure 2: The Carbon cycle *(From: https://commons.wikimedia.org/wiki/File:Carbon_cycle.jpg#/media/File:Carbon_cycle.jpg)*

This diagram of the carbon cycle shows the movement of carbon between land, air and oceans in billions of tons of carbon per year. Yellow numbers are natural flows, red are human contributions and white numbers indicate stored carbon, usually in liquid or sold form.

An excess of carbon dioxide (CO_2) in the earth's atmosphere is warming the planet and increasing the size, number and intensity of extreme weather events. Some of this excess CO_2 is dissolving into the world's oceans causing them to become acidic.

More than 90% of the world's carbon is found in the deep ocean. On land, around 80% of carbon is in the soil.

Why soil organic matter is so important

Organic matter has an overwhelming effect on almost all soil properties, although it is generally present in relatively small amounts. A typical agricultural soil has 1% to 6% organic matter. It consists of three distinctly different parts – living organisms, fresh residues, and well decomposed residues. These three parts of soil organic matter have been described as the **living**, the **dead**, and the **very dead**.

SOM composition:

- Carbon = 42%,
- Oxygen = 42%,
- Hydrogen = 8%,
- Ash = 8%,
- Macronutrients (N, P, K, S, Ca, Mg),
- Micronutrients (Fe, Mn, B, Zn, Cu, Cl, Co, Mo, Ni)

Functions ascribed to SOM and interactions

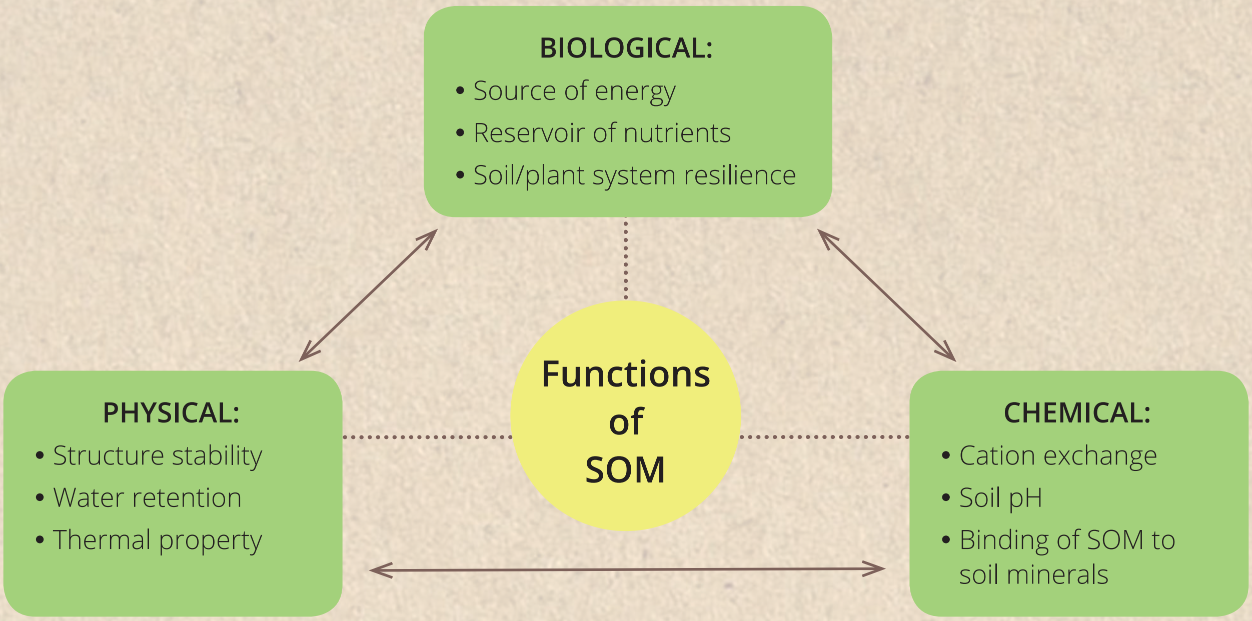


***Figure 3:** Functions of SOM*

The **living part** of soil organic matter includes a wide variety of *microorganisms*, such as bacteria, viruses, fungi, protozoa, and algae. It also includes plant roots, insects, earthworms, and larger animals, such as moles and rabbits, that spend some of their time in the soil. The living portion represents about 15% of the total soil organic matter.

These different types of organisms:

- Help to control insect pests, weeds and plant diseases
- Form beneficial *symbiotic relationships* with plant roots
- *Recycle* plant nutrients from soil organic matter and minerals back to roots and
- Improve soil structure.

DICTIONARY:

Resilience – the ability to cover from setbacks and stress
Water retention - water holding
Temperature regulation – controlling and adjusting of temperature; keeping temperature changes more even.
Thermal property - temperature regulation
Micro organisms – tiny bugs or creatures that are too small to see with the naked eye
Recycle - re-use - a process of changing wastes into new products
Symbiotic relationships – a cooperative mutually beneficial relationship

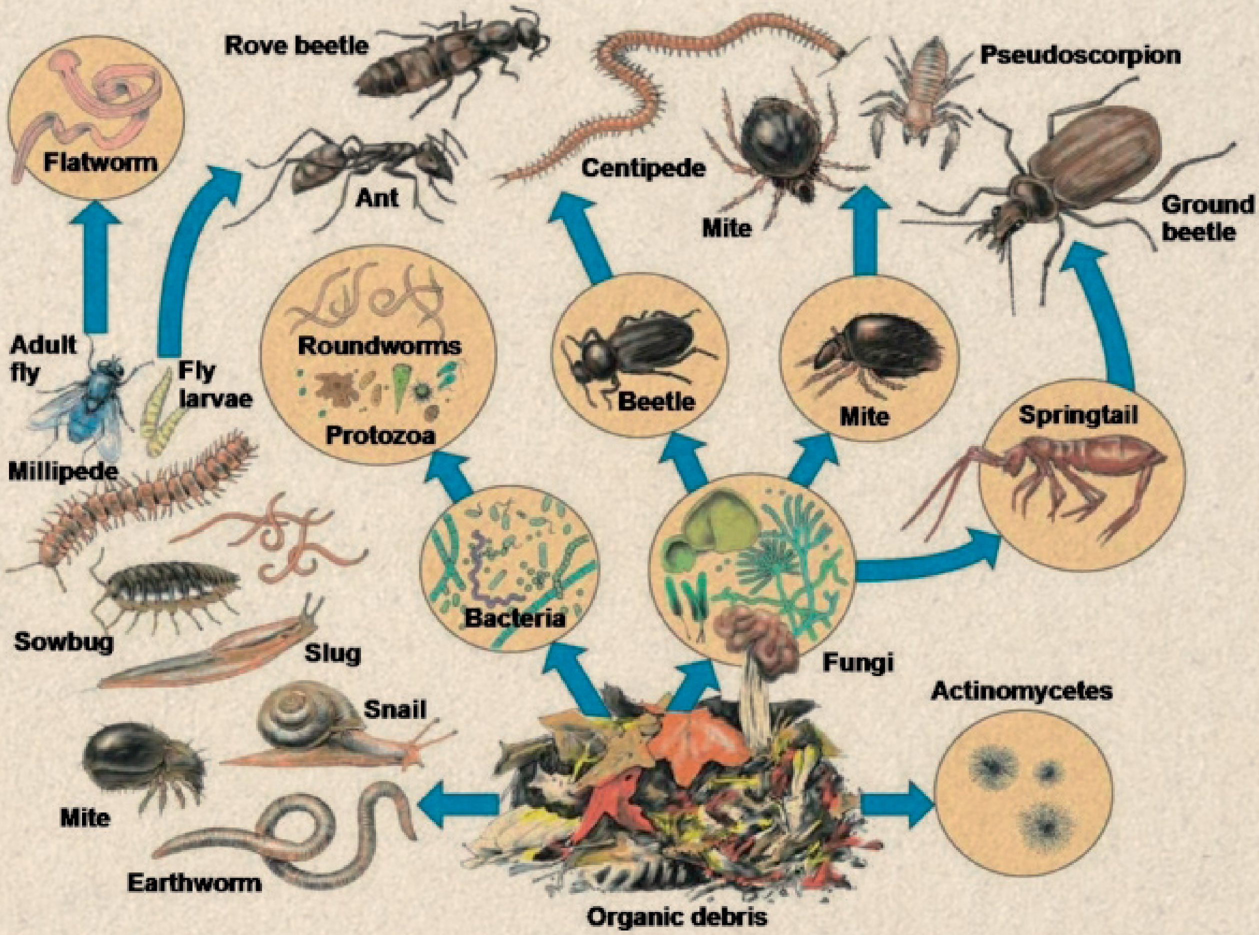


Figure 4: Micro-organisms and small living creatures in the soil *(From: Life in the Soil – www.wunderground.com)*

In a teaspoon of healthy soil there are more microbes than there are people on earth.

Microorganisms, earthworms, and insects feed on plant residues and manures for energy and nutrition, and in the process they mix organic matter into the mineral soil. In addition, they recycle plant nutrients. Sticky substances on the skin of earthworms and other substances produced by fungi help bind particles together. This helps to stabilize the soil aggregates, clumps of particles that make up good soil structure.

Organisms such as earthworms and some fungi also help to stabilize the soil's structure (for example, by producing channels that allow water to *infiltrate*) and, thereby, improve soil water status and aeration. Plant roots also interact in significant ways with the various microorganisms and animals living in the soil.

The fresh *residues*, or **"dead" organic matter**, consist of recently deceased microorganisms, insects, earthworms, old plant roots, crop residues, and recently added manures. This part of soil organic matter is the active, or easily decomposed fraction and is the main supply of food for soil organisms As these organic materials are decomposed by the "living," they release many of the nutrients needed by plants and they also create humus. Organic chemical compounds produced during the *decomposition* of fresh residues also help to bind soil particles together and give the soil good structure.

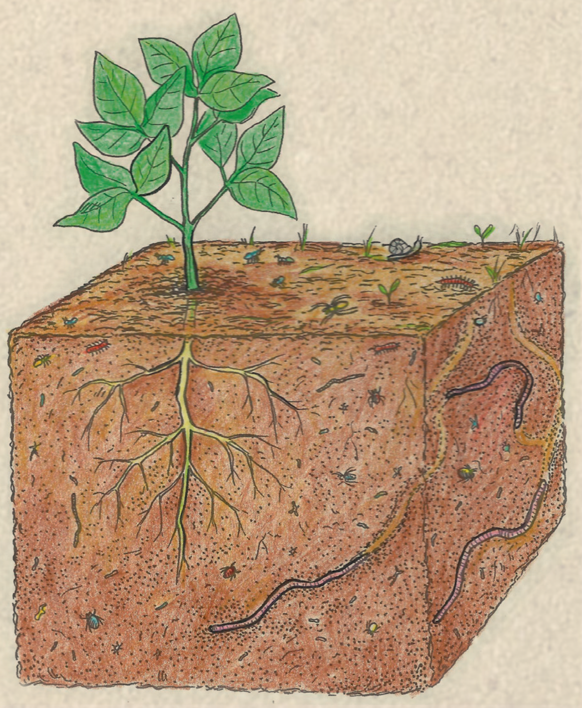


***Figure 5:** A healthy soil has lots of organic matter, earthworms and other tiny animals in it.*

The well-decomposed organic material in soil, the **"very dead"**, is called *humus*. Micro-orangisms turn the simple sugars or liquid carbon exuded from plant roots into humus. These simple carbon compounds are joined together into more complex and stable molecules. The formation of **stable humus** requires a large number of different kinds of soil microbes, including mycorrhizal fungi, nitrogen fixing bacteria and phosphorus solubilising bacteria, all of which obtain their energy from plant sugars (liquid carbon).

One principle of nature is that the more biodiversity there is in a system, the healthier and more resilient it is.

The types of fungi that survive in *conventionally* managed agricultural soils are mostly decomposers; they obtain energy from decaying organic matter such as crop residues. Generally, these kinds of fungi have relatively small *hyphal networks*. They are important for soil fertility and soil structure, but play only a minor role in carbon storage.

Mycorrhizal fungi differ from decomposer fungi in that they get their energy in a liquid form, as *soluble* carbon directly from actively growing plants. There are many different types of mycorrhizal fungi. Mycorrhizal fungi access and transport water - plus nutrients such as phosphorus, nitrogen and zinc - in exchange for carbon from plants.

Some of this soluble carbon is also channelled into soil aggregates via the hyphae of mycorrhizal fungi and can undergo humification, a process in which simple sugars are made up into highly complex carbon *polymers*. The soil conditions required for humification are reduced in the presence of herbicides, fungicides, pesticides, phosphate and nitrogen fertilisers - and enhanced in the presence of root exudates and humic substances such as those derived from compost.

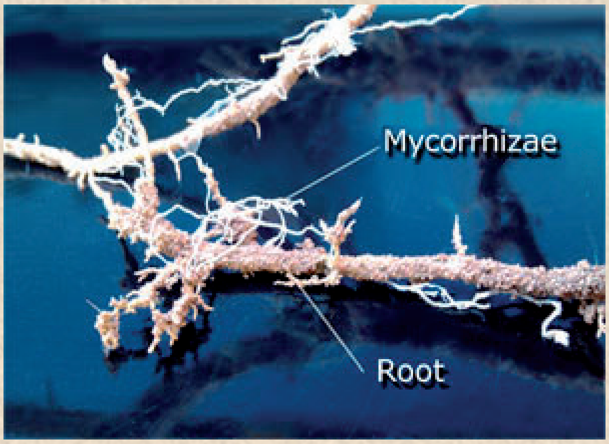


Figure 6: ***Mycorrhizal fungi grow very closely associated with plant roots and create networks of filaments (hyphae) within the soil***

(From: http://www.heartspring.net/mycorrhizal_fungi_benefits.html)

Humus holds on to some essential nutrients, storing them for slow release to plants. Humus also can surround certain potentially harmful chemicals and prevent them from causing damage to plants. Because it is so stable and complex, the average age of humus in soils is usually more than 1,000 years. The already well-decomposed humus is not a food for organisms, but it's very small size and chemical properties make it an important part of the soil.

DICTIONARY:

Decomposition – breakdown of organic matter from a complex to a simpler form

Molecules – smallest part of a chemical compound/substance

Symbiotic relationship – a close and long term interaction between two different life forms or biological species

Residues - materials left after agricultural or natural processes, organic matter

Humus - is the stable, mature portion of organic matter or compost found in the soil and helps with moisture and nutrient retention

Humification is the process of forming humus

Conventionally managed agriculture – commercial farming using agrochemicals and mono cropping

Hyphal networks – part of the vegetative growth of a fungus that resembles long branching filaments or thin tubes

Rizosphere – soil zone immediately surrounding the roots.

Mycorrhiza - are types of fungi (moulds) that create a symbiotic relationship with plant roots

Polymer- a larger molecule made up of a chain or network of smaller molecules

Soluble- dissolves in water

Good amounts of soil humus can reduce drainage and compaction problems that occur in clay soils and improve water retention in sandy soils by enhancing soil aggregation.

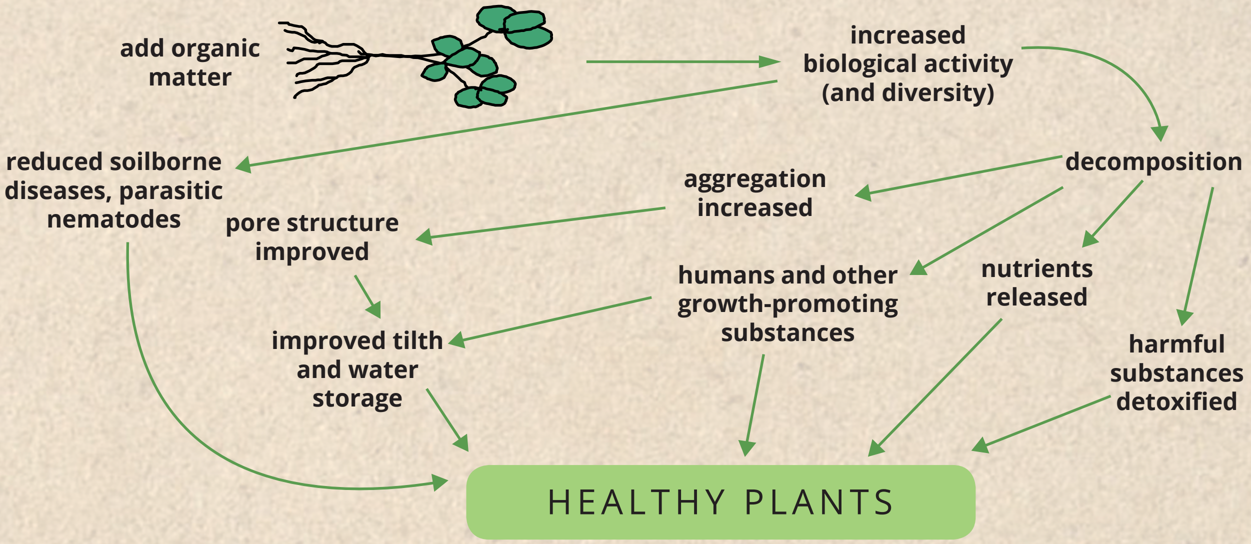


Figure 7: Adding organic matter results in many changes in the soil. *(From Building soils for better crops, 2009)*

Organic matter increases the availability of nutrients . . .	
Directly	**Indirectly**
• As organic matter is decomposed, nutrients are converted into forms that plants can use directly. • *Cation Exchange Capacity* is produced during the decomposition process, increasing the soil's ability to retain calcium, potassium, magnesium, and ammonium. • Organic molecules are produced that hold and protect a number of *micronutrients*, such as zinc and iron.	• Substances produced by microorganisms promote better root growth and healthier roots, and with a larger and healthier root system plants are able to take in nutrients more easily. • Organic matter contributes to greater amounts of water retention following rains because it improves soil structure and thereby improves water-holding capacity. This results in better plant growth and health and allows more movement of mobile nutrients (such as nitrates) to the root.

Turning air into soil

The process whereby carbon dioxide is converted to soil humus has been occurring for millions of years. Rebuilding carbon-rich *topsoil* is a practical and good option for productively removing billions of tonnes of excess carbon dioxide from the air. When soils gain in carbon, they also improve in structure, water-holding capacity and nutrient availability.

The formation of healthy soil requires *photosynthesis* to capture carbon dioxide in green leaves.

Plants use energy from the sun, carbon dioxide from the air and water and minerals from the soil to make up their food. Food is usually made in the green parts (often the plants leaves).The process of making food using chlorophyll and sunlight is called photosynthesis. When plants photosynthesize and make carbohydrates in their *chloroplasts*, they use some of those compounds for their cells and structure, and some they burn for their life energy. But they "leak" or exude a significant amount of these compounds as "liquid carbon" into the soil. Microbes use this energy to create complex stable forms of soil organic matter, or humus.

One of the more remarkable things that soil scientists are learning about plants and soil organisms is that they seem to have co-evolved in a mutually beneficial relationship. As we have learned more about soil biochemistry we have discovered that, through root *exudates*, plants are able to control their local environment – to regulate the local soil microorganisms, to cope with being eaten by animals, to bring distant nutrients closer, to alter the *chemical* and physical properties of nearby soil, and to inhibit the growth of competing plants.

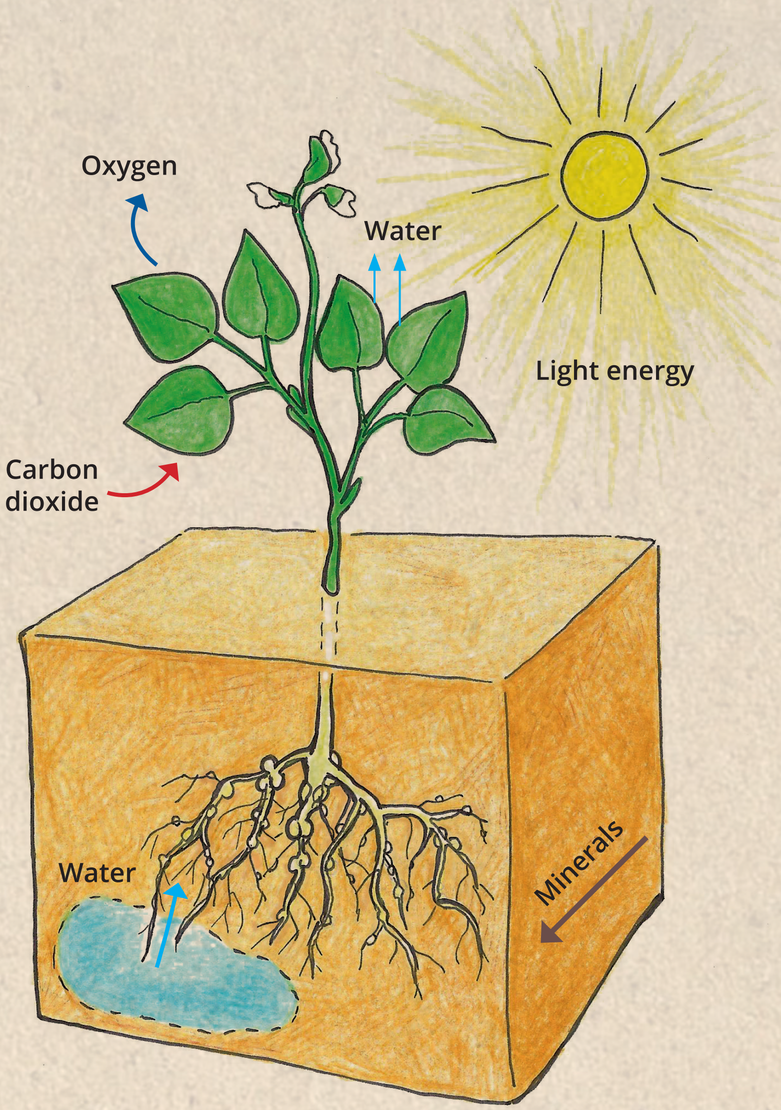


***Figure 8:** Photosynthesis*
(from: mages.wisegeek.com/photosynthesis-process-diagram.jpg)

The zone of soil around the roots (the rhizosphere) provides an ideal habitat and good supplies of energy-rich organic matter. In return, microbes around the root release nutrients and plant-growth promoting compounds, while at the same time providing a level of suppression against plant pathogens. As microbial activity increases, the conversion of soil organic matter to humus increases which also results in carbon sequestration. The formation of gum and polysaccharides by microbes and earthworms promotes the formation of stable soil aggregates and increases the ability of the soil to retain plant-available water and nutrients.

Between 20–40% of the sugars produced by plants are exuded through their roots to the rizosphere

DICTIONARY:

CEC – Cation exchange capacity (is the total capacity of a soil to hold exchangeable cations (Positively charged particles). It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification.

Micronutrients – Those nutrients or plant foods needed in very small amounts

Topsoil - is the upper layer of soil (usually 5-20cm deep). It has the highest concentration of organic matter and microorganisms and is where most of the Earth's biological soil activity occurs.

Photosynthesis – is a process used by plants and other organisms to convert or change light energy from the sun into chemical energy or sugar

Chloroplast – These are small structures inside plant cells which work to convert light energy of the Sun into sugars that can be used by cells.

Chemical - is a substance composed of certain and specific elements, building blocks or parts

Exudate - is the emission, expulsion, sweating or oozing of a fluid from one substance into another

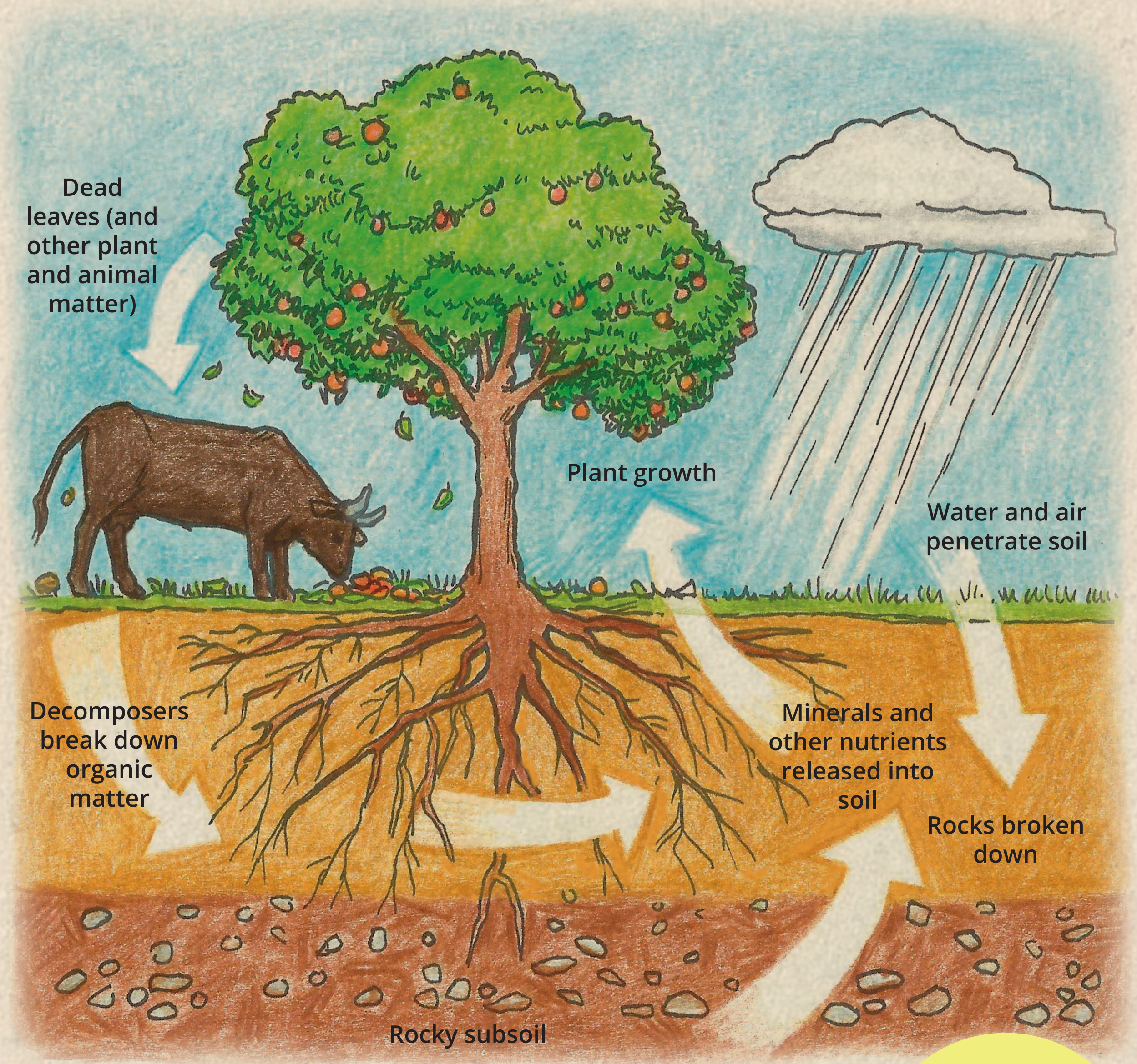


Figure 9: The Nutrient cycle.
All the goodness (nutrients) from fruits, leaves, branches, whole plants, animal manure and dead animals decompose and go back into the soil. The nutrients are taken up by plants in the soil, with the help of microbes and in this way are recycled (used again and again). The life of a plant is therefore a cycle and nothing is ever wasted.
(From:http://www.sswm.info/category/concept/nutrient-cycle)

Everything goes round and round in a continuous cycle.

Characteristics of healthy soil

Thecomplex interaction between the physical, chemical and biological properties of the soil has a major influence on soil fertility and health.

Although creating a healthy soil is mostly a biological process, it is influenced by the interactions that occur between the physical, chemical and biological components of the soil. Biological activity is driven by temperature, and requires appropriate levels of air, water and suitable nutrition. The physical properties of the soil will affect air and water exchange, which will influence biological processes such as *respiration*. This in turn will influence the ability of soil organisms to decompose organic matter and release nutrients for uptake by plants. The activity and diversity of soil organisms is also influenced by soil chemistry e.g. *pH*. The growing plant, and more specifically the activity of roots and material released from roots (exudates etc), also plays a significant part in maintaining microbial activity.

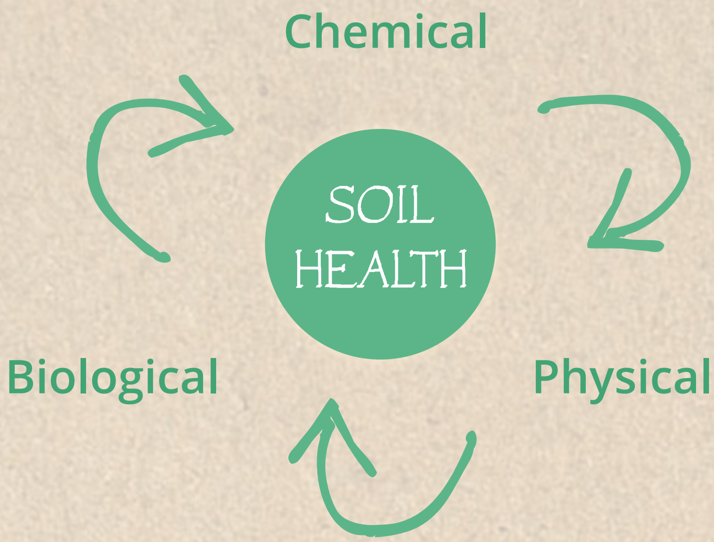


***Figure10:** Soil Health depends on physical, chemical and biological characteristics*

Physical components

The physical properties of soil are determined by the balance between sand, silt and clay particles, which determines soil texture. These particles combine with various forms of organic matter to form soil aggregates. The size and distribution of these aggregates through the soil profile determines soil structure, which influences soil stability, erosion risk, ease of cultivation and *compaction*. Soil structure directly affects the movement of air and water through the soil profile, which in turn affects biological activity, root development, crop establishment and tolerance to environmental stress.

Chemical components

The *mineral* content of the underlying soil parent material has a major influence on soil chemical properties of the soil. Of particular importance from a soil health perspective is the impact that soil chemistry has on the development of plant-microbe interactions. For example, soils that are based on limestone have a tendency to be rich in calcium, andto also be also alkaline, which can restrict the uptake of nutrients such as phosphorus and manganese.

This in turn can reduce root mass and root exudate production, restricting both microbial activity and plant response to microbial growth promotion. Soil pH influences microbial populations, encouraging bacteria to dominate alkaline soils and fungi to dominate acidic soils. A better balance of bacteria and fungi can be found at more neutral soil pH values. Bacteria require simple sources of soluble organic matter and have high multiplication rates, while fungi can utilise more complex insoluble forms of organic matter and have relatively low multiplication rates.

Biological components

During its conversion from plant and animal residues to humus, soil organic matter has a direct impact on soil health. Un-decomposed organic material provides a food source for macro-organisms such as earthworms.

DICTIONARY:

Respiration – breathing of plants

pH – an indiction of how acidic or alkaline a soil is.

Chemical – structure, composition and properties of substances

Compaction – compressing of soil particles into a more dense mass

Mineral – An inorganic substance in naturethat occurs naturall in rocks nad the soil

Figure 11: An earthworm in a clod of soil showing the soil channels, earthworm casts and soil aggregates.
(From H.Smith, 2015)

Earthworms mix partially decomposed organic matter with soil minerals as the material passes through the gut, creating channels for air and water movement as they go.

Microbes thrive in the earthworm casts, completing the conversion of organic matter to plant-available nutrients and humus. This humus can bind sand, silt and clay into stable soil aggregates, while at the same time providing exchange sites for nutrients and improving water retention. This results in increased soil fertility and yield potential.

Soil composition

What is soil?

Soil contains abundant plant and animal life, as discussed above. There are four main components of soil: mineral matter, organic matter, air and water. Soil **minerals** are made through the breaking up of the basic elements or minerals of the earth. These are initially found in the form of rocks or 'parent material'. Over a very long time, these rocks are broken down into small particles through rain, wind, sun and soil organisms and mixed with air and water. This becomes soil that can support plants and micro-organisms to grow. Like people, plants cannot live and grow without water, air and food.

The **mineral** matter (45%) is made of sand, silt and clay size particles—the basic texture of the soil. The soil **water** (25%) contains dissolved minerals and is the main source of water and nutrients for plants. The **air** (25%) in the soil is needed for plant roots and soil microorganisms to obtain oxygen. **Organic matter** (5%) includes plant and animal materials in various stages of decomposition and is discussed above.

Parent material breaking down to form 1 cm of soil can take between 200-1 000 years

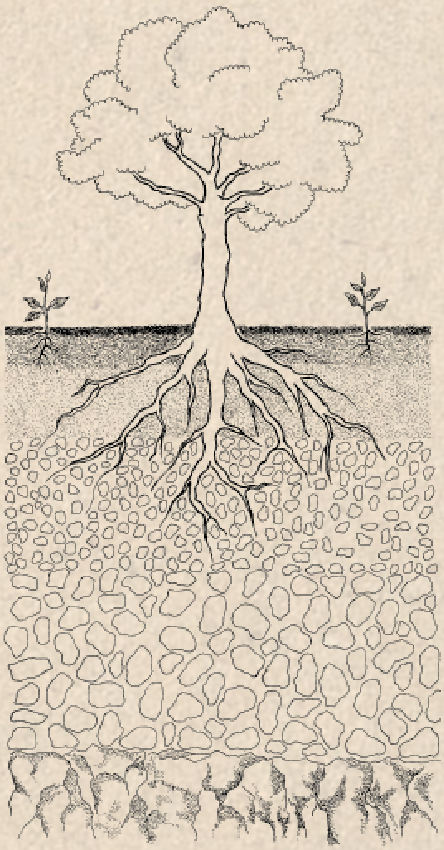


Figure 12: A typcial soil profile
(From: FARMESA2003. A study guide for FFS. Soil and water conservation.)

Characteristics of soil texture types

Sandy soil	
Good things about this type of soil	Bad things about this type of soil
* It is easy to dig and work with * It warms up quickly in spring after winter * It is good for root crops * Water and air can get into the soil easily	* It gets dry quickly * It does not keep much fertility * It does not hold water well
Loam soil (Mixture of sand and clay)	
Good things about this type of soil	Bad things about this type of soil
* Holds water well * Best for root growth * Contains organic matter, like	* This soil can be hard when dry
Clay soil	
Good things about this type of soil	Bad things about this type of soil
* Holds water well and for a long time * Holds fertility well and for a long time	* Hard to work; heavy * Slow to warm up in spring * Sticky when wet * Hard when dry

It is important to know which soil type you have. Crumbly and loose soil holds the most water and the most air, which is what plants need to grow. To make your soil more crumbly (whether it is sandy, loam or clay) you need to keep adding lots of manure, compost and mulch. Never walk on the planted areas, especially if they are wet.

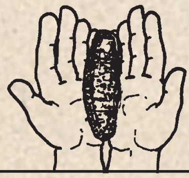
All types of soil need organic matter to increase their fertility, or plant food. Sandy soil needs to be given organic matter to increase its ability to hold water and plant food or nutrients. Clay soil needs to be given organic matter to increase its ability to hold air in the soil and to release the plant foods that are there.

* Sand makes the soil loose.
* Silt is very fine sand. It holds water and plant food better than rough sand, but it is easily washed out of the soil.
* Clay is the sticky part of the soil that holds it together. It holds water like a sponge.

The best soils according to texture class are called loams and they are an equal mixture of sand, silt and clay.

How to tell your soil texture type

You can tell how much sand, silt or clay (commonly called texture) is in your soil by how it feels. Wet some soil and roll it into a ball between your hands. Then roll this little ball into a sausage. Below is a table that describes how you can tell what type of soil you have.

What soil looks like	What soil feels like	When rolled into a sausage		The soil is ...
Very sandy	Very rough	Cannot be rolled into a sausage		Very sandy *0-5% clay*
Quite sandy	Rough	Can be rolled into a sausage, but it cannot bend		Sandy *5-10% clay*
Half sandy and half smooth	Rough	Sausage can bend a little		Sandy loam *10-15% clay*
Mostly smooth	A little sandy, quite smooth, but not sticky	Sausage can bend about half way round		Loam or silt loam *15-35% clay*
Mostly smooth	A little sandy, quite smooth and sticky	Sausage can be bent more than halfway round		Clay, loam or sandy clay *35-55% clay*
Smooth	Smooth and sticky	Sausage can bend into a ring		Clay *More than 55%*

Another method of identifying the proportion of soil participles in a soil is to conduct a "bottle test".

To do this, take a bottle and fill a third of it with soil. Pour water into the bottle until it is almost full, place a lid on and shake it vigorously for a few minutes in order to separate the soil particles. Leave the bottle to settle, and note what happens over the next few hours. You will see that the substances settle in layers, the heaviest at the bottom and the lightest on top.

The layer of water above the settled material remains cloudy for a long time because it contains clay particles which are so small that they stay suspended in the water. Substances which are lighter than water (organic matter like leaves, seeds, spores, and insect and animal waste) float on the surface.

Heavy particles such as gravel, pebbles and sand fall quickly to the bottom of the bottle. The finer elements then accumulate – first the silt, followed by humus and then the fine and very fine clay. These layers vary in colour and consistency.

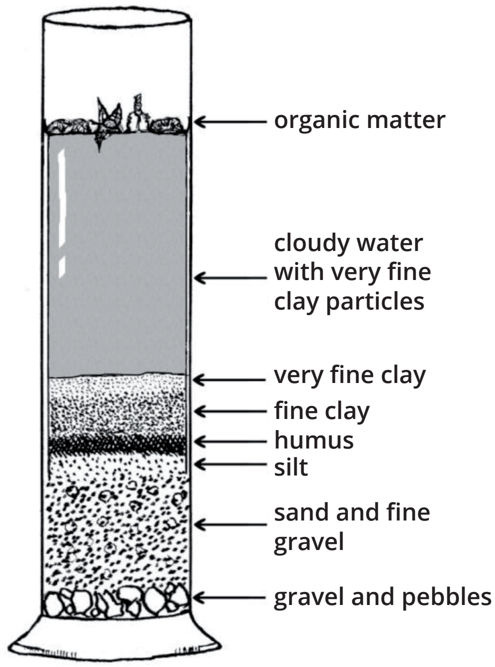


***Figure 13:** Bottle test showing proportion of soil separates* *(From: WHC Manual, WRC, 2010)*

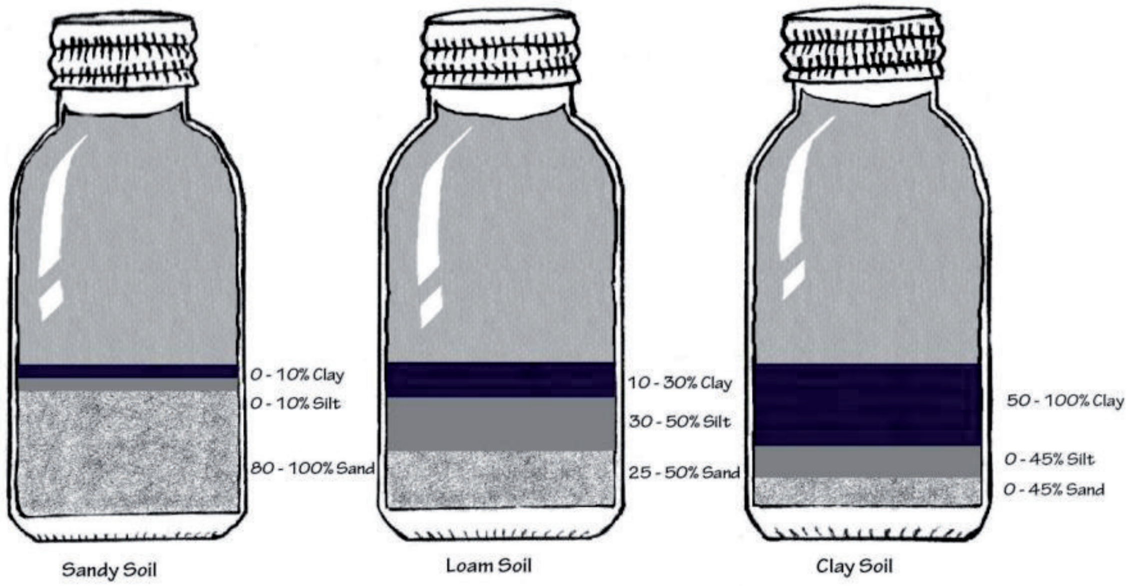


***Figure 14:** Using the bottle test to estimate the proportion of soil components in a sample*

Soil structure

Soil structure describes the grouping or arrangement of primary particles (sand, silt, clay and organic matter) into larger, secondary particles called *aggregates*. It is the shape that soil takes, determined by the way in which individual soil particles clump or bind together.

Micro-organisms play an important role in soil aggregate formation and structure.

Aggregates are the fundamental unit of soil function and play a role similar to that of root nodules in legumes, creating a protected space. The aggregate is helped to form by hyphae of mycorrhizal fungi that create a "sticky-string bag" that envelops and entangles soil particles. Liquid carbon exudates from plant roots and fungi enable the production of glues and gums to form the aggregate walls.

Inside those walls a lot of biological activity takes place, again fuelled by the carbon exudates. Most aggregates are connected to plant roots, often fine feeder roots, or to mycorrhizal fungal networks too small to be seen. The moisture content inside an aggregate is higher than outside, and there is lower oxygen pressure inside. These are important properties enabling nitrogen-fixation and other biochemical activities to take place.

Soil structure affects the movement of water and air in the soil, as well as root penetration and biological activity. For example, a dense structure greatly reduces the amount of air and water that can move freely through the soil and it is difficult for roots to penetrate such soil.

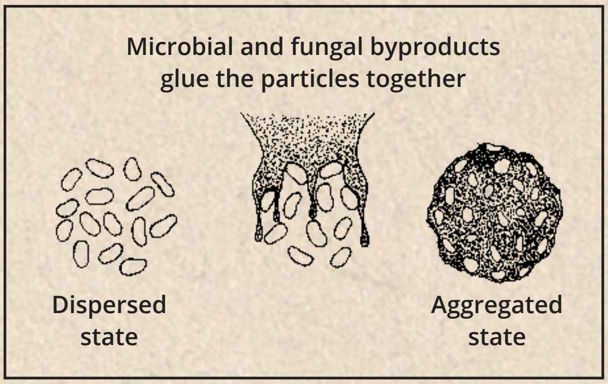


***Figure 15:** The dispersed soil participles are clumped together into aggregates*

http://www.soilandhealth.org/01aglibrary/010117attrasoilmanual/Soilmgt3.gif

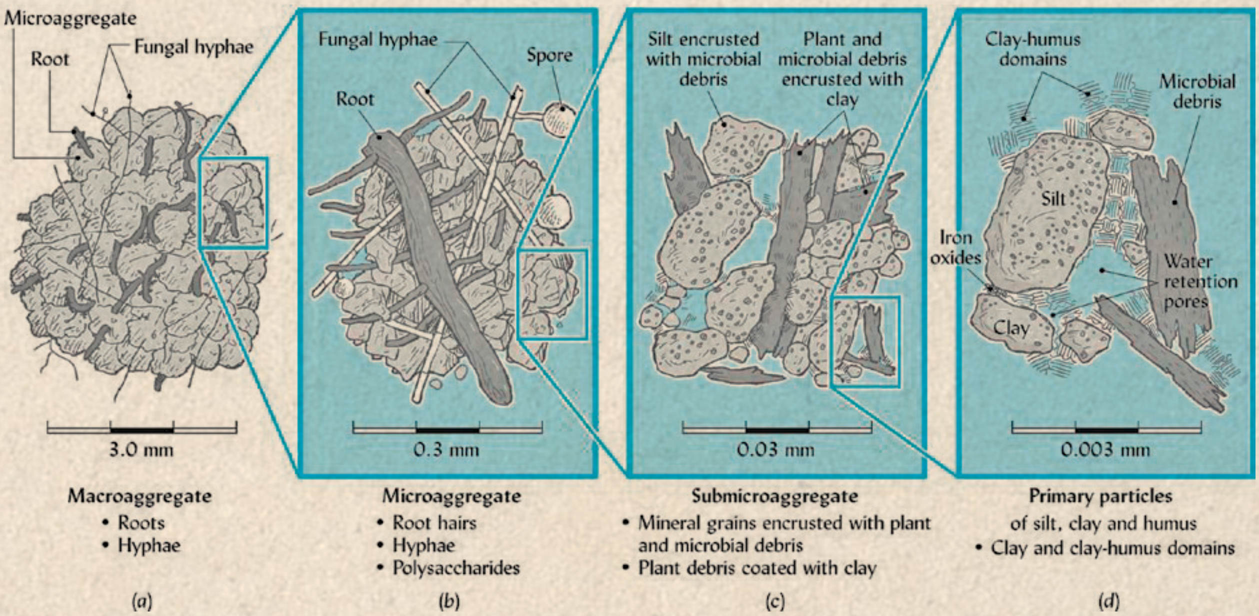


***Figure 16 (above):** Soil aggregates are groups of soil particles that are glued together by microbial and fungal by products. Very small aggregates group together to form larger aggregates*

Soil aggregates protect the soil against wind and water erosion

***Figure 17:** Roots, fungal hyphae, and their secretions stabilize soil aggregates and promote good soil structure, thus preventing com-paction.*

Identification of Soil Structure

The structure of the surface layer of the soil is usually weak to strongly granular or blocky, but a degraded surface layer can be crusted, platy, or structure-less (massive or single grained). This is important as soil crusting reduces water and air infil-tration, destroys soil life and increases run-off and erosion.

***Figure 18:** The different structures that soil can take*

http://ecomerge.blogspot.com/2010/05/what-soil-aggregates-are-and-how-its.html

The more soil organic matter (SOM) there is in the soil, the more macro-aggregates can form and the better the soil structure becomes.

***Figure 19:** (Left) The difference in colour and structure caused in a soil by increasing the soil organic matter. (Right) Cover crops growing through a thick layer of organic matter.*

http://thegrowingclub.com/2015/02/article-moving-beyond-drought-in-mind-space/,https://iowaenvironmentalfocus.files.wordpress.com/2014/12/15127396042_c1b408b873_k.jpg

Soil Degradation

Degradation most commonly occurs when erosion and decreased soil organic matter levels initiate a downward spiral resulting in poor crop production. Soils become compact, making it hard for water to infiltrate and roots to develop properly. Erosion continues and nutrients decline to levels too low for good crop growth.

Tillage or ploughing usually starts this degradation process. Fields that have been ploughed a lot tend to crust, seal and compact more than non-till fields with lots of crop residues and a living plant cover with active roots and fungi. Tillage also reduces infiltration and the water holding capacity of the soil due to poor structure and thereby increases water run-off and erosion.

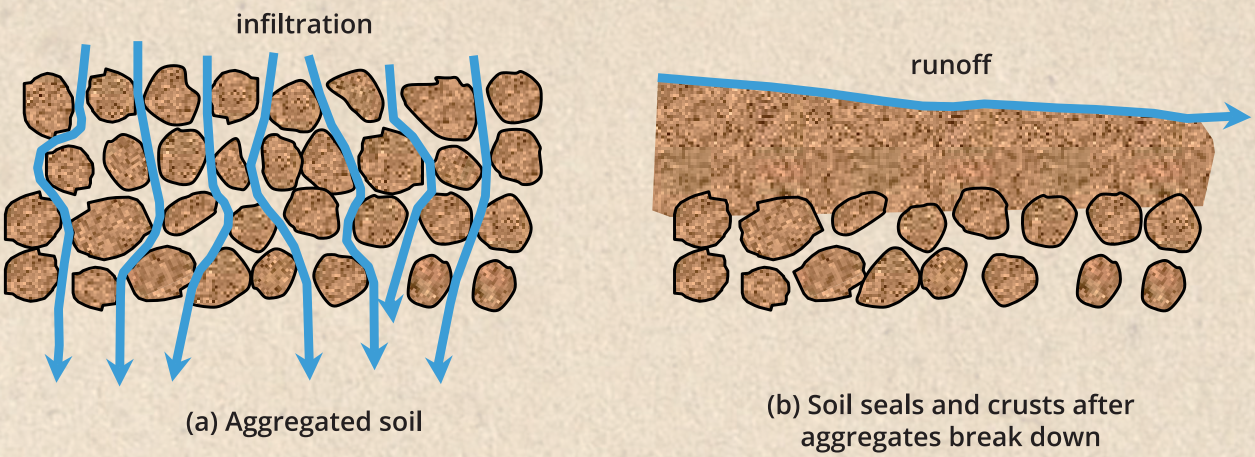


***Figure 20:** Changes in soil surface and water-flow pattern when seals and crusts develop*

It can also reduce the germination of seeds and root growth. It makes the soil a lot more prone to wind erosion when it is dry.

A dust storm on the farms around Bloemfontein in the Free State in October 2014

(From: GSA, 2015)

Soil crusting caused by ploughing and breakdown of soil structure

(From: http://cropwatch.unl.edu/archive/-/asset_publisher/VHeSpfv0Agju/content/should-you-apply-uan-and-residual-herbicides-in-a-tank-mix-on-emerged-corn-

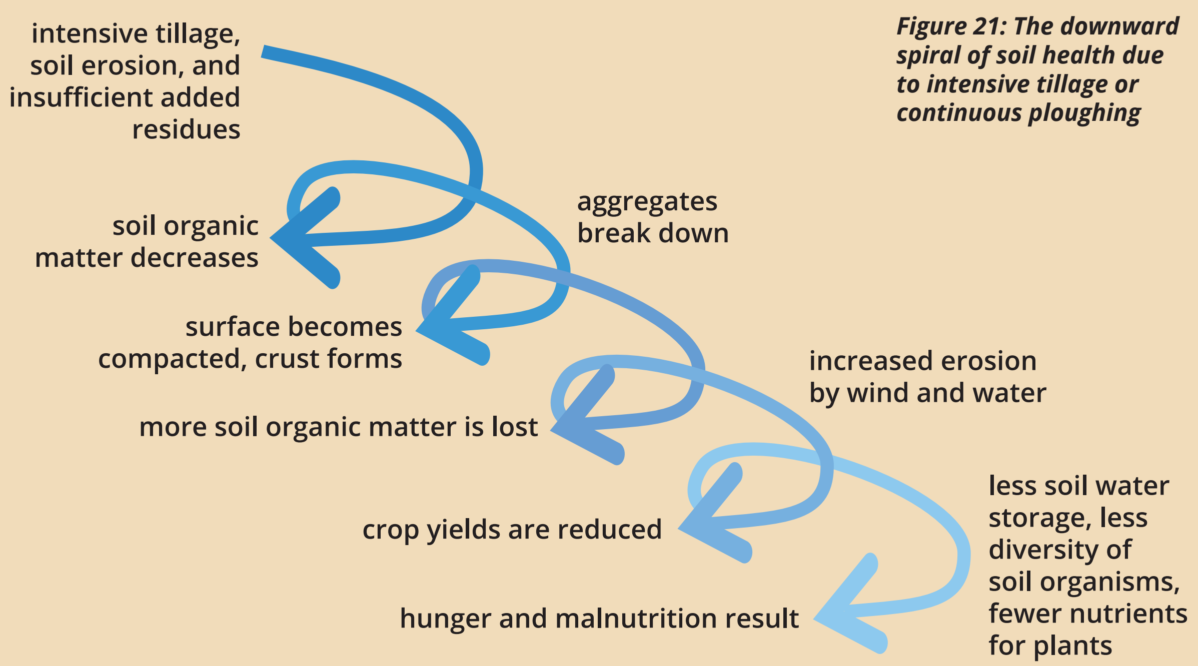


Figure 21: The downward spiral of soil health due to intensive tillage or continuous ploughing

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