Introduction to Conservation Agriculture

GRAIN SA
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By Mahlathini Organics

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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

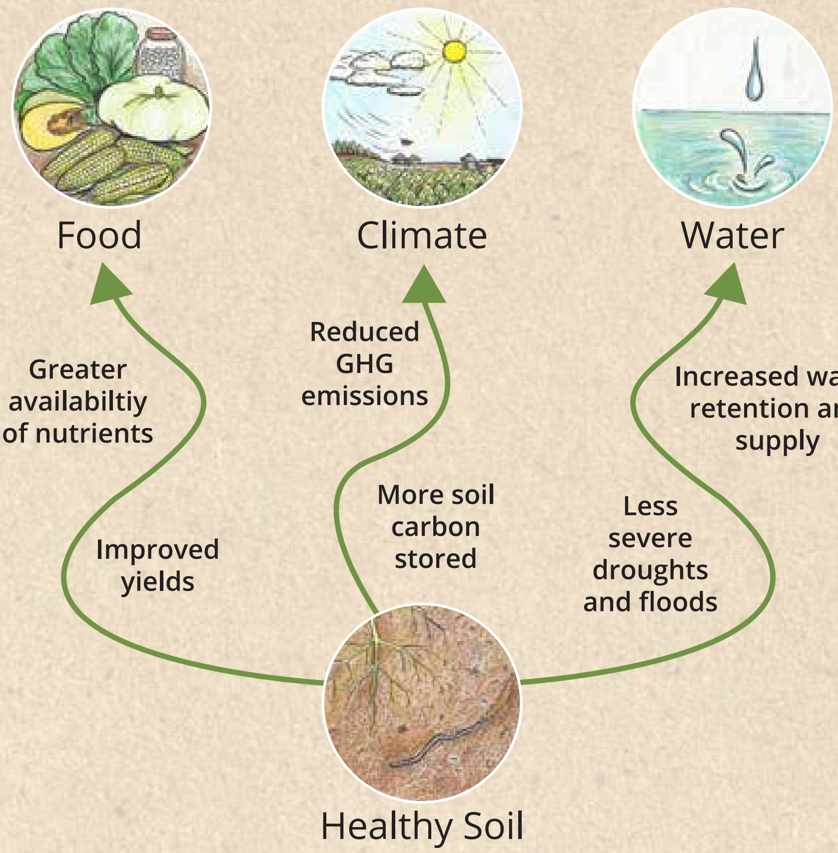


Figure 1: Healthy soil diagram *(Based on Centre for Food safety 2015. Soil and Carbon; Soil solutions to climate problems)*

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.

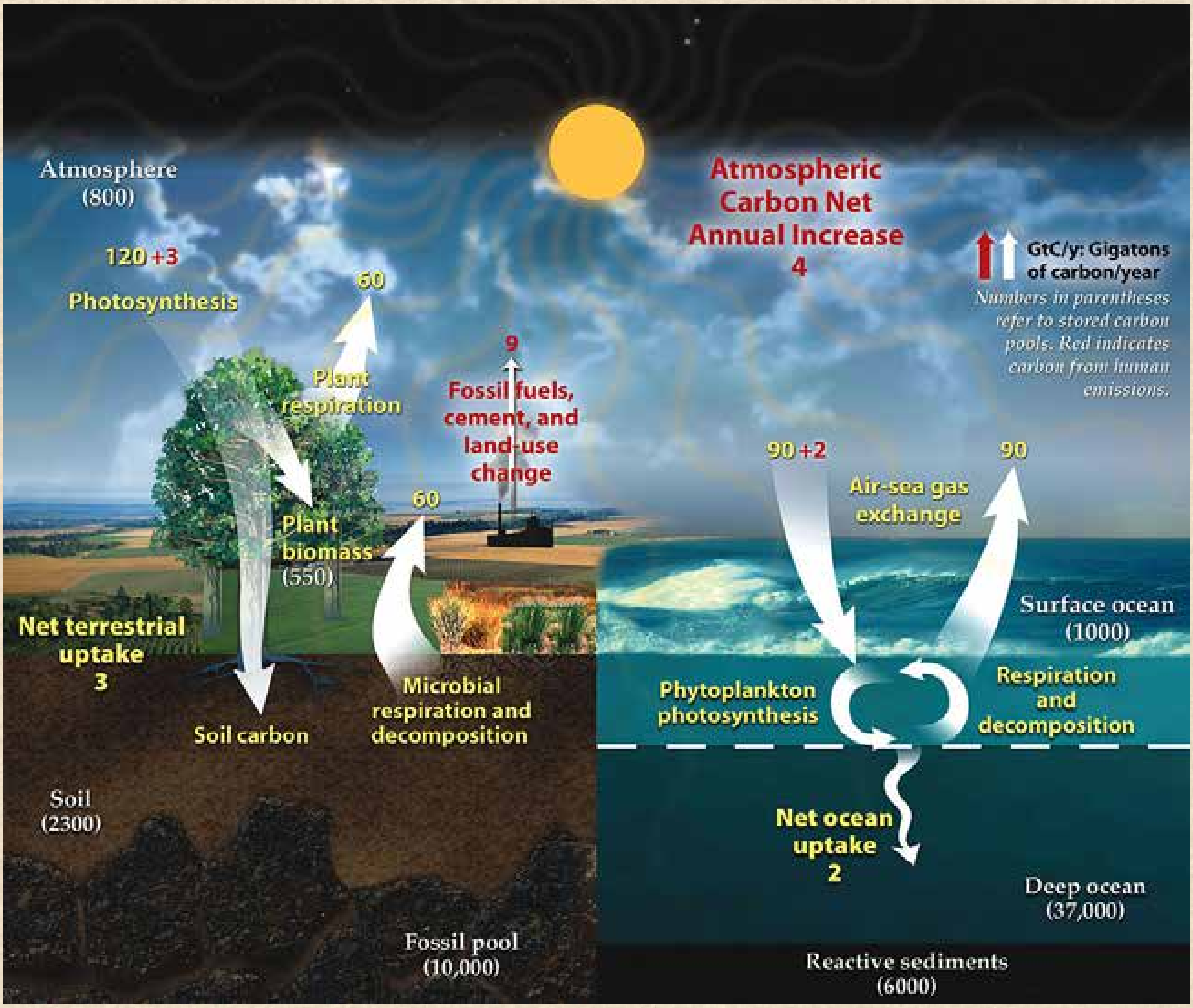


Figure 2: The Carbon cycle *(From: https://commons.wikimedia.org/wiki/File:Carbon_cycle.jpg#/media/File:Carbon_cycle.jpg)*

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 805 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

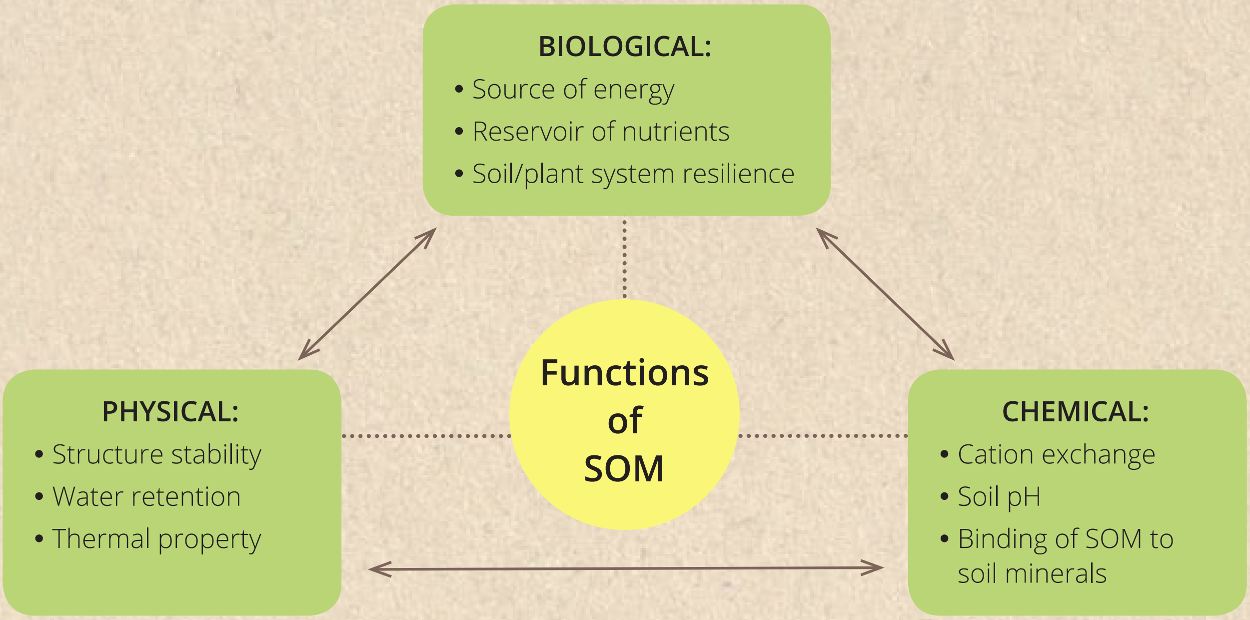


Figure 3: Functions of SOM

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

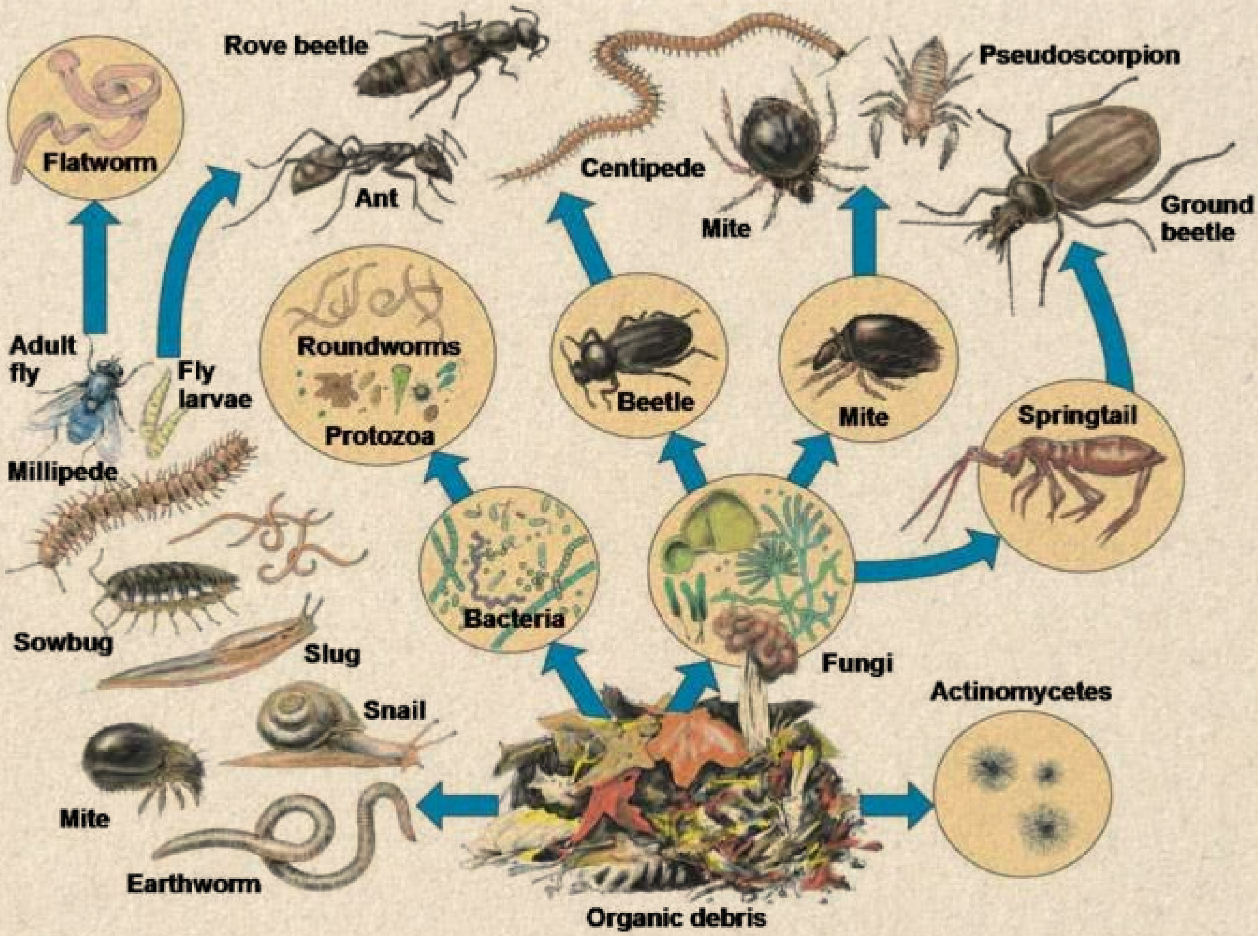


Figure 4: Micro-organisms and small living creatures in the soil *(From: Life in the Soil – www.wunderground.com)*

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.

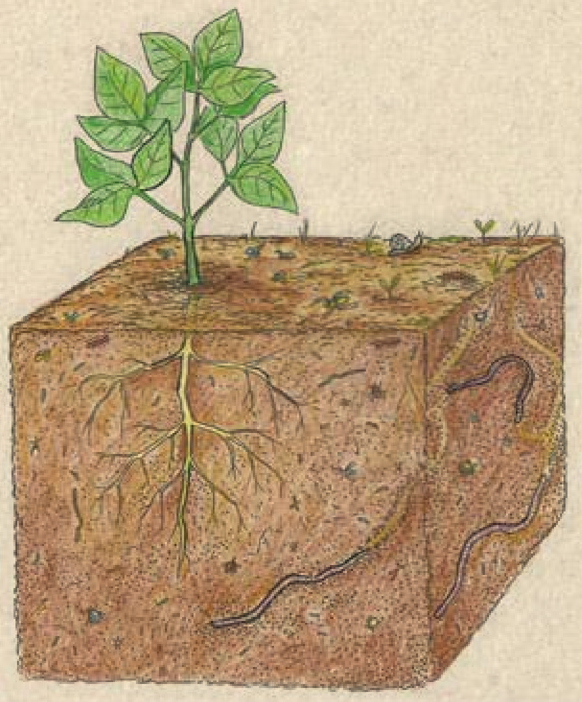


Figure 5: A healthy soil has lots of organic matter, earthworms and other tiny animals in it.

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.

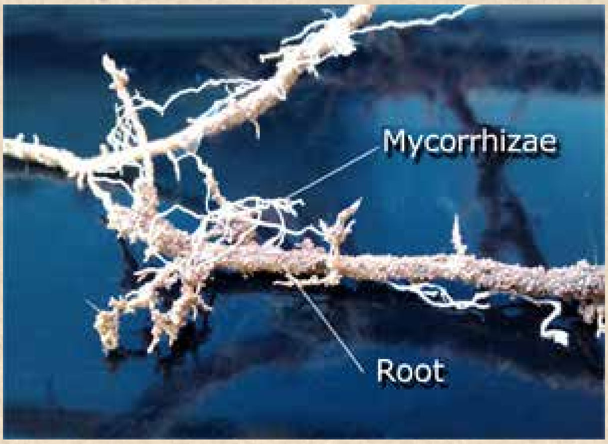


Figure 6: Mycorrhizal fungi grow very closely associated with plant roots and create networks of filaments (hyphae) within the soil

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

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.

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.

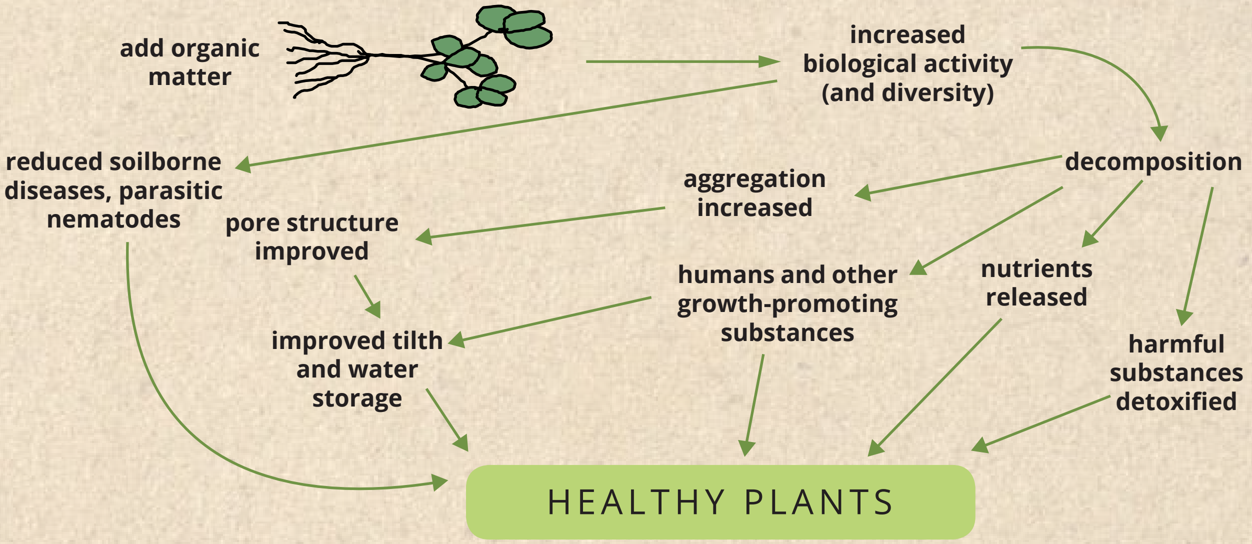


Figure 7: Adding organic matter results in many changes in the soil. *(From Building soils for better crops, 2009)*

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.

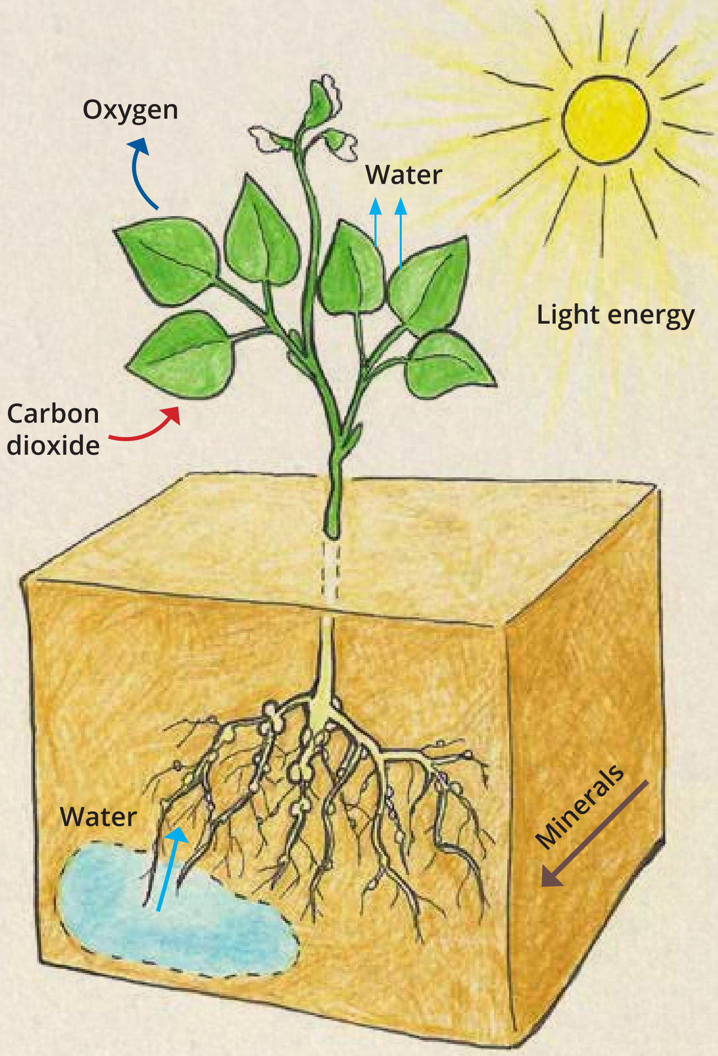


Figure 8: Photosynthesis
(from: mages.wisegeek.com/photosynthesis-process-diagram.jpg)

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 thorugh 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

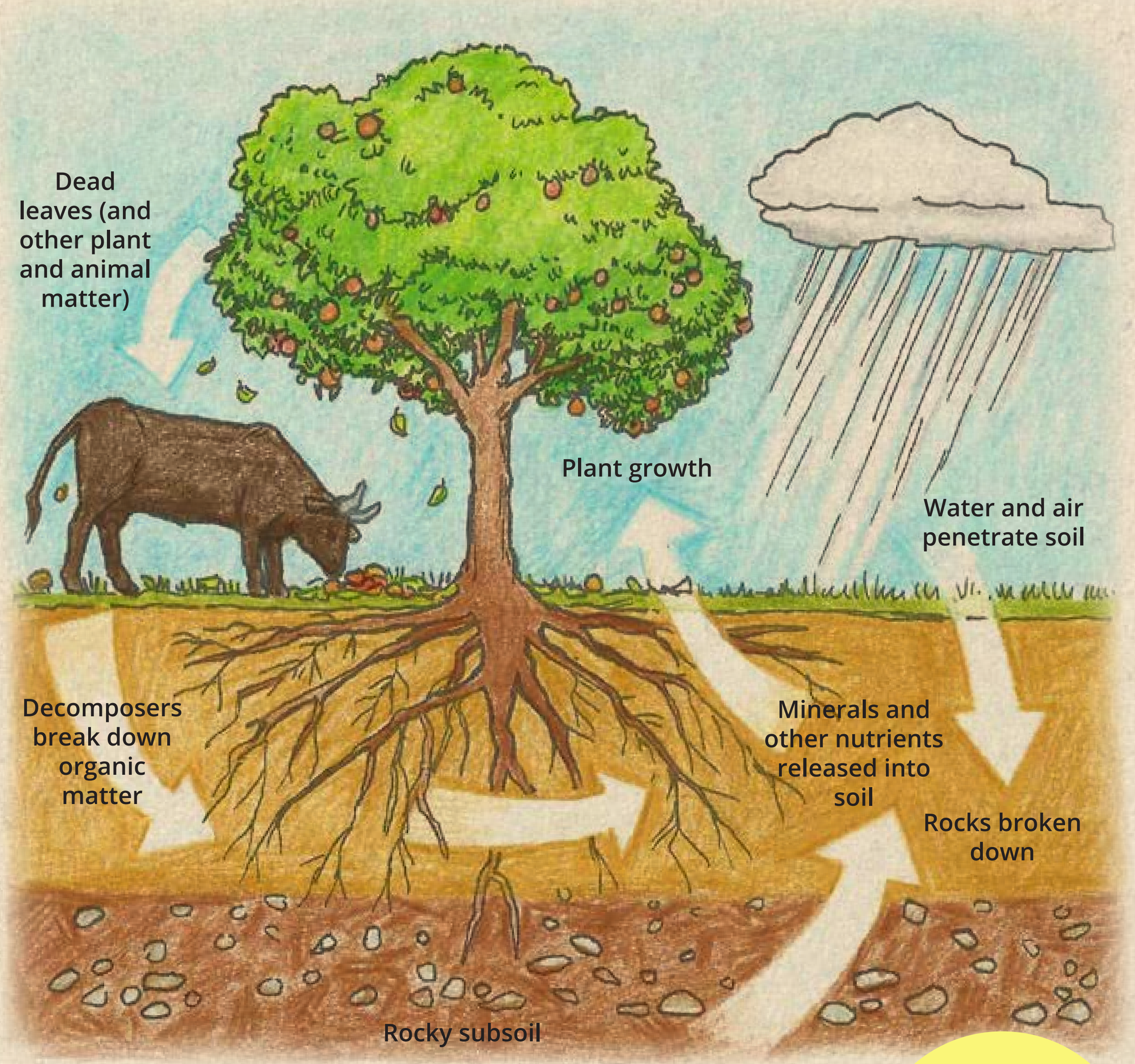


Figure 9: The Nutrient cycle.
All the goodness (nutrients) from fruits, leaves, branches, whole plants, animal manure and dead animals decompose and go back into the soil. The nutrients are taken up by plants in the soil, with the help of microbes and in this way are recycled (used again and again). 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.

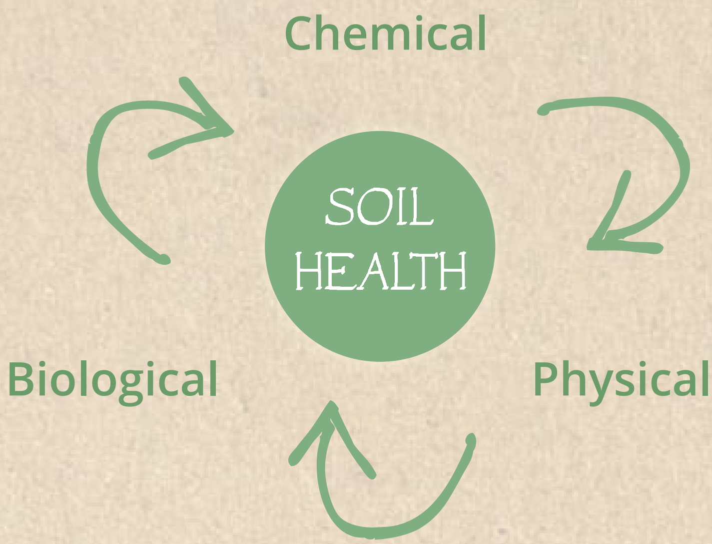


Figure10: Soil Health depends on physical, chemical and biological characteristics

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

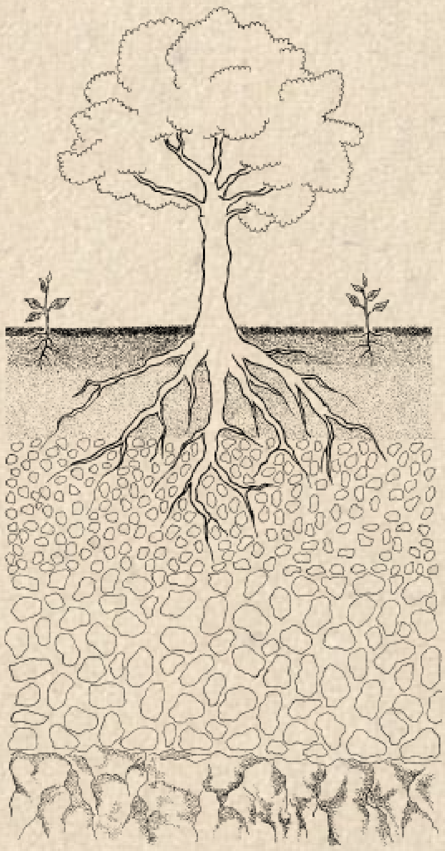


Figure 12: A typcial soil profile
(From: FARMESA2003. A study guide for FFS. Soil and water conservation.)

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.

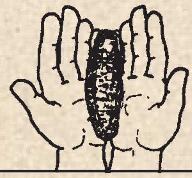
All types of soil need organic matter to increase their fertility, or plant food. Sandy soil needs to be given organic matter to increase its ability to hold water and plant food or nutrients. Clay soil needs to be given organic matter to increase its ability to hold air in the soil and to release the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

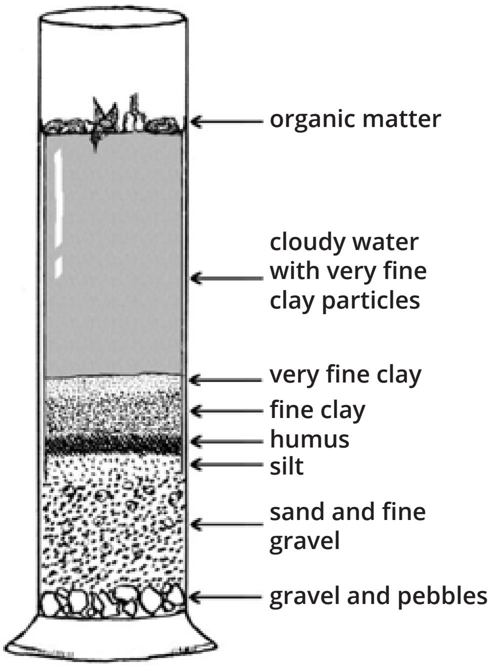


Figure 13: Bottle test showing proportion of soil separates *(From: WHC Manual, WRC, 2010)*

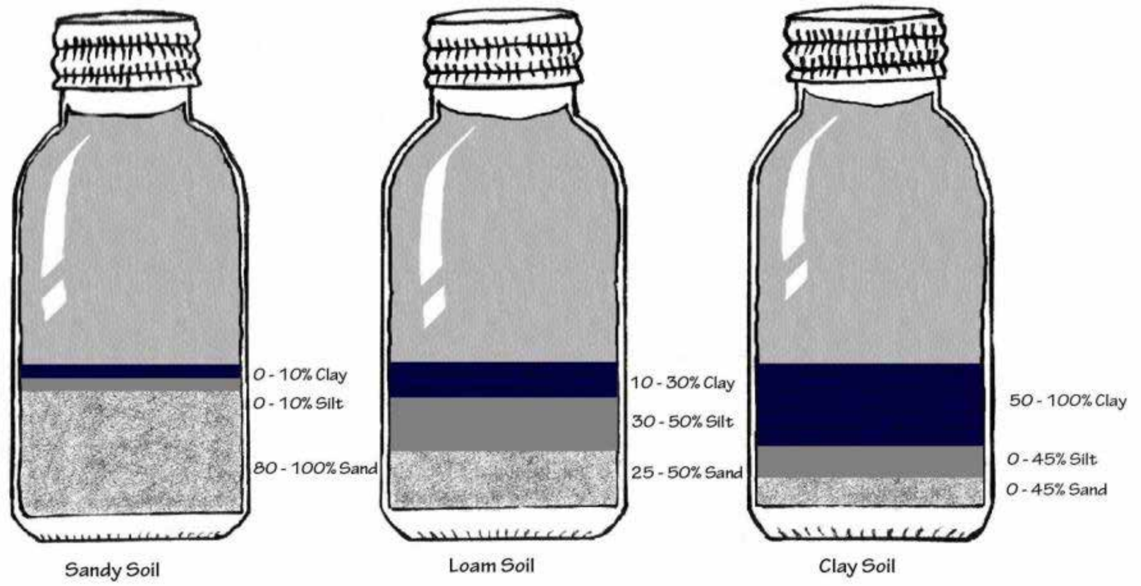


Figure 14: Using the bottle test to estimate the proportion of soil components in a sample

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.

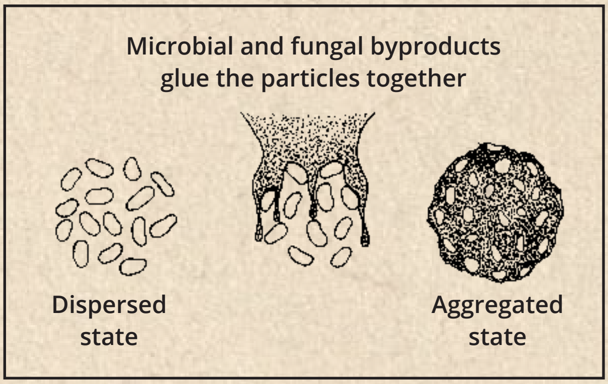


Figure 15: The dispersed soil participles are clumped together into aggregates

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

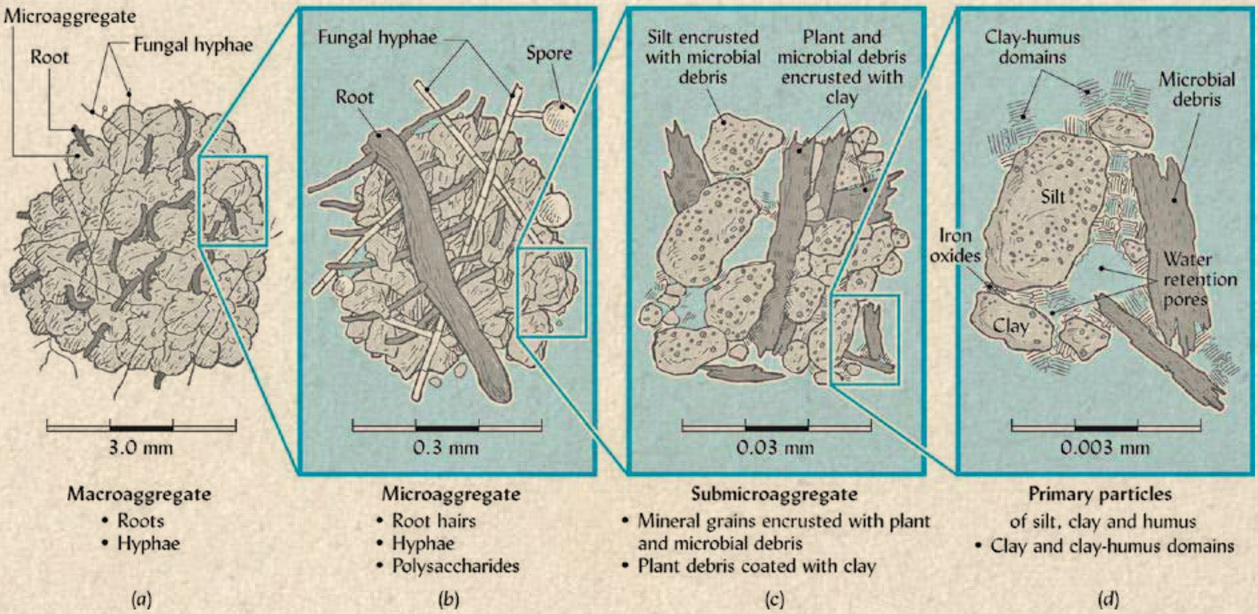


Figure 16 (above): Soil aggregates are groups of soil particles that are glued together by microbial and fungal by products. Very small aggregates group together to form larger aggregates

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 compaction.

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 infiltration, 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.

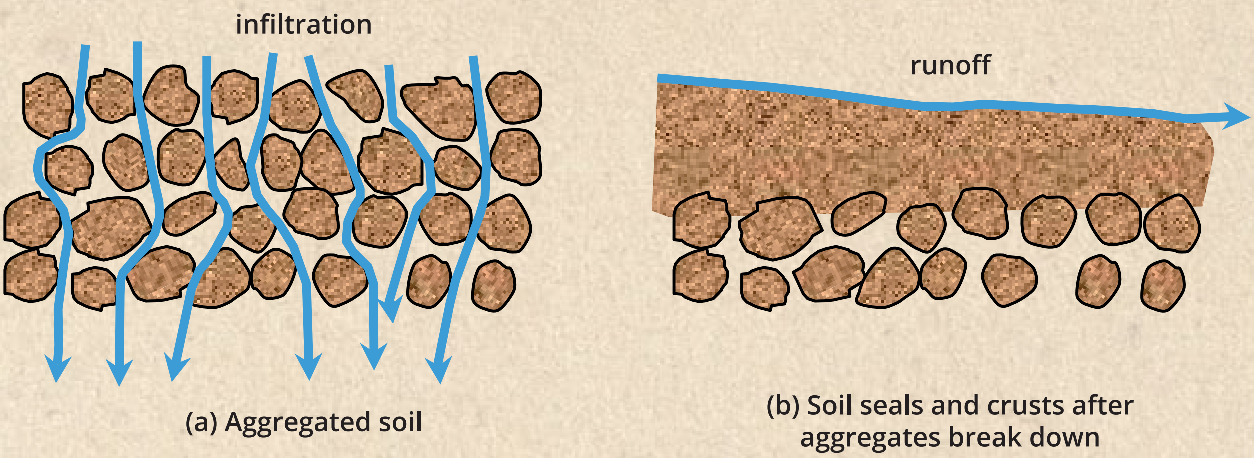


Figure 20: Changes in soil surface and water-flow pattern when seals and crusts develop

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-

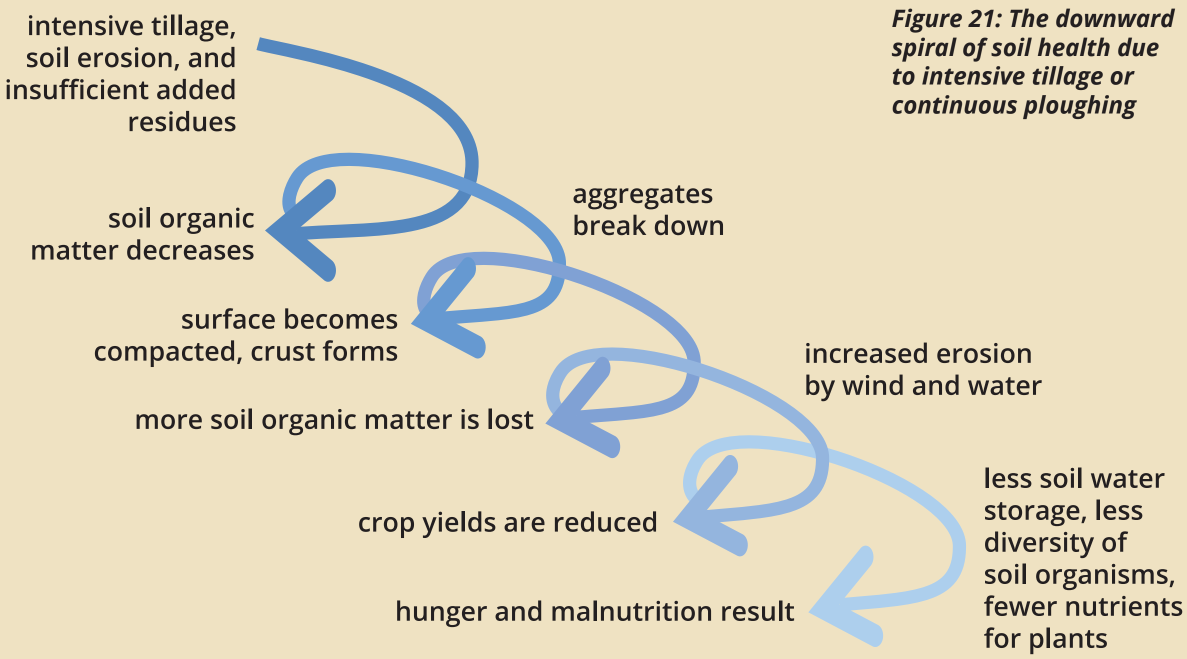


Figure 21: The downward spiral of soil health due to intensive tillage or continuous ploughing

References

Centre for Food Safety, 2015. Soil and Carbon: Soil solutions to Climate Problems.

Cooperband, L., 2002. Building Soil Organic Matter with Organic Amendments. A resource for urban and rural gardeners, small farmers, turfgrass managers and large-scale producers. University of Wisconsin-Madison, Center for Integrated Agricultural Systems.

Jones, C., 2015. SOS - Save Our Soils, Acres USA, Vol. 45, No. 3

Kittredge, J., 2015. Soil Carbon Restoration: Can Biology do the Job? Northeast Organic Farming Association / Massachusetts Chapter, Inc.

Magdoff, F. and Van Es, H., 2009. Building Soils for Better Crops. Sustainable Soil Management series, 3rd Edition, SARE Handbook Series, Book 10.

Conservation Agriculture

Introduction

Conservation agriculture (CA) aims to conserve, improve and make more **efficient use** of **soil**, **water** and **biological** (e.g plants, animals, insects and microbes) resources.

Basic principles of conservation agriculture

CA is based on the following three principles that should be used SIMULTANOUSLY:

- **Minimum mechanical soil disturbance:** the soil is not ploughed! The seeds are planted directly into a mulch covered field using specialised no-till planters.

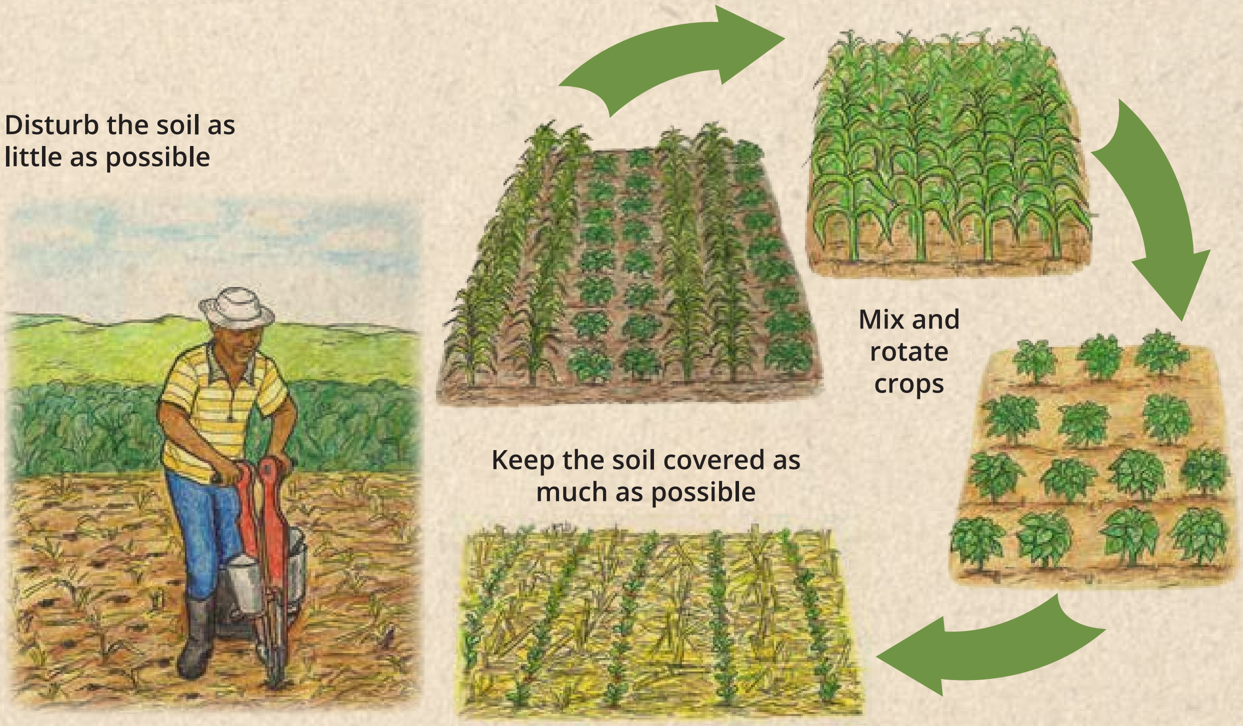
Women planting a field covered with crop residue using hand planters (called MBLI planters). No ploughing was done.

- **Permanent organic soil cover (mulching):** The crop residue is left on the field, mulching is introduced or a cover crop is planted.

A CA maize field with crop residue into which soya beans have been planted. And a field with nice thick cover of around 20cm in depth - which is ideal *(from H Smith, GSA, 2015)*

- **Diversified cropping (Including cover crops):** It is important to mix (intercrop, and diversify) and rotate the crops to reduce weeds, control pests and diseases and improve soil fertility.

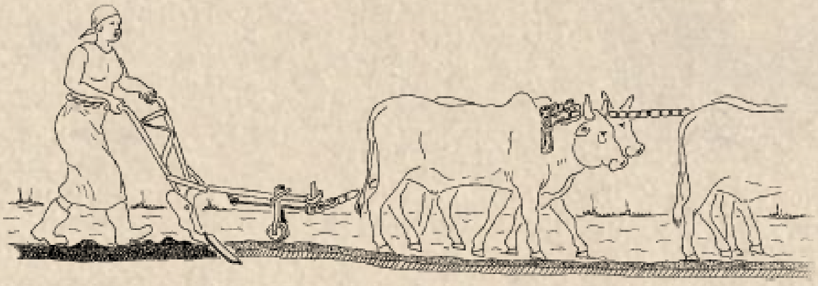
A field inter cropped with beans and maize planted in double rows or tram-lines *(from Mahlathini Organics, 2015)*



The application of all these CA principles then makes it easy to follow other good agricultural practices, such as:

* **Integrated soil fertility and acidity management:** CA improves soil fertility and thereby reduces the amount of fertilizer required and saves time, money and energy. It is possible to have a sustainable biological system without the use of fertilizers.
* **Integrated weed management:** CA reduces the need for herbicides over time. It is possible to have complete weed control without using chemicals.
* **Integrated pest and disease management:** Management of pests and diseases includes crop diversification, timing of planting, promotion of natural balances between pests and predators in insects and naturally occurring microbes as well as physical control methods. This reduces the need for expensive pesticides and fungicides to a minimum.
* **Integration of animals:** Systems that include fodder production and management for livestock create an added benefit. This practice can include winter and summer forage crops such as Dolichos, sunnhemp, fodder rye, black oats, fodder radish and hairy vetch, as well as longer term grass species. Besides improving the physical, chemical, biological and water holding properties of the soil, such species, including annual or perennial cover crops, can successfully be used as animal feed.

Minimum tillage and zero tillage are techniques within CA that point towards the amount of disturbance of the soil. For zero tillage the soil is disturbed only where the seed is planted. For minimum tillage there may be lines ripped or small basins dug for planting of seed. The whole field is NEVER ploughed.



An example of minimum tillage using an oxen drawn Magoye ripper, which just makes a small furrow where the seeds will be planted. The rest of the soil is not ploughed or turned over.

(From: FARMESA 2003. Study guide for FFS. Soil and water conservation. SIDA)

Repeated ploughing, use of excessive chemical fertilisers, herbicides and pesticides and mono cropping has led to a number of negative impacts on the environment including:

- A decrease in the organic matter of the soil
- Break down of biological, physical and chemical properties of macro aggregates in the soil leading to
  - – Crust formation and compaction
  - – Wind and water erosion and loss of topsoil and
  - – Fewer soil organisms, lower soil fertility and
  - – Reduced water infiltration and content
- Increased amount and costs of fertilizers and other agro chemicals.

Fertilizer leads to less water, less air and less life in the soil. Then more fertilizers, pesticides and other chemicals need to be added to compensate for this and keep crops growing.

Minimum Soil disturbance

The idea is to disturb the soil as little as possible; to till the soil only where the seed and fertility amendments (fertilizer, manure, compost) are to be placed.

Disturbing the soil as little as possible has the following benefits:

- It ensures minimum destruction of the soil structure,
- It does not expose soil to wind and water erosion
- It allows slower mineralization of organic matter, hence organic matter build-up.
- It causes little disruption to the life of organisms that reside in the soil, which improve the soil structure
- It saves on time, energy and money as there is less ploughing and fertility amendments are placed only in the planting areas.

The pictures on the right show some minimum soil disturbance options for smallholder farmers. Note that the area between the planting basins and rip lines is not disturbed and that the soil is covered by a mulch formed from crop residues. The picture at the top shows planting basins prepared using a hand hoe. In the picture below, rip lines are prepared using a ripper tine, with seed and fertilizer boxes attached to the beam of a standard animal drawn planter.

Soil cover

The soil needs to remain covered either with crop residues, other types of mulch or growing plants at all times. Generally in CA the crop residue is left on the field to cover the soil. Other types of mulch can also be placed between the rows and planting basins or planting holes.

Mulch not only reduces soil erosion, it can reduce soil temperature by at least 4°C, creating better conditions for soil organisms to thrive.

When properly managed soil cover has the following benefits:

- It improves water infiltration resulting in a higher soil water content
- It helps in reducing direct raindrop impact and run-off in the field; thus reducing soil erosion
- It reduces evaporation and conserves soil moisture
- It keeps the soil temperature even and cool
- It helps to suppress weeds
- It provides for food and a conducive environment for soil organisms that are important for biological processes and soil fertility.

***Above and below:** Soil cover provided by maize stover or residue from a previous season.*

Mr NT Madondo's field intercropped with maize and beans (from H Smith, 2015)

Mix and rotate crops

As we are aiming to mimic nature, we want to create as much diversity in our fields as possible. Diversity ensures a natural balance in the field. This includes creating a living soil, protection against weeds, using water efficiently and minimising pest and disease attack on crops.

Biodiversity on top of the soil equals biodiversity below the soil, which includes the presence of living roots in the soil for the entire year. Maximum cover on top of the soil by plants either living or dead serve as armour to the soil just as our skin protects us from the sun and the rain. It keeps the soil cooler in summer and warmer in winter. This all leads to the build-up of carbon in the soil, which is vital for our farm's sustainability. **For every 1% of added carbon to the soil, the water holding capacity of that soil doubles.**

Mixed cropping involves planting various crops together in one plot. Plants can either be inter-planted at the same time (inter-cropping) or crops can be rotated. This means that different crops are planted in the same place at different times. Using both inter-planting and crop rotation in your field is a good idea.

In this system food crops are mixed with soil enriching crops that

- can fix nitrogen into the soil (legumes) and cycle plant nutrients
- grow fast and provide a lot of above-ground (leaf) and below-ground (root) biomass and
- improve soil biology, soil fertility and soil structure both when they are growing and when they are decomposing in the soil.


A cover crop mixture of fodder rye, fodder radish and black oats is growing in a maize field late in season.

These crops are called **cover crops**. Generally they would also have other benefits as food crops for people and or livestock.

Mixed cropping has the following benefits:

- Soil fertility replenishment – N-fixing legumes add 'top-dressing fertilizer' to the soil.
- Crops better use the nutrients in the soil. Different crops have different feeding zones and will therefore not compete for nutrients. The exploitation of different soil layers by different crops also helps prevent formation of a hard pan.
- It helps to control diseases and pests as the life cycles of these pests and diseases are broken by the introduction of a different crop
- The soil structure benefits when the soil is occupied by the roots of many different plants, because –
  - the roots move the soil;
  - the roots create a network of living matter which dies and rots to create humus;
  - when the roots die they leave tunnels which improve the porosity and drainage;
  - roots secrete weak acids to dissolve minerals in the soil then draw these back up in solutions;
  - roots also secrete a portion of their photosynthetic energy in the form of sugars that feed the microbes, which in turn provide soil mineral nutrients to the roots.

An example of intercropping

Maize can be planted together with legumes such as beans or cowpeas and pumpkins. This process has many benefits, including addition of nitrogen to the soil, soil water conservation and weed suppression.

Above: *Two intercropped plots (In Bergville area, 2014). Maize and beans are planted together on the left and maize and cowpeas are planted together on the right of the picture.*

The maize on the left is slightly smaller and yellower than the maize on the right. The beans are also slightly yellower. This shows that the cowpeas add more nitrogen and provide more nitrogen for growth of the maize than the beans. Growth is generally very good.

Above: *A plot of maize and beans that have been planted as an intercrop. Both crops are growing well and there is no weed competition.*

When crops are planted in the same place at different times it is called crop rotation.

An example of crop rotation

(From http://www.proteinresearch.net/html_images/crops/soybeans/pamphlets/no-till-pamphlet-july-2014.pdf: A case study of no till production by Tony da Costa of Manjoh Ranch, Nigel SA)

When using rotations it is best to have at least three different crops. A good rotation that will also provide fodder for livestock is to plant maize in season 1 (October-November) followed by a winter cover crop of black oats the next winter in February-March (which is for grazing), followed by soya beans the next year (October-November).

Bergville grainSA SFIP, 2014

https://iowalearningfarms.files.wordpress.com/2012/09/cover_crop_closeup1.jpg

http://www.agprofessional.com/news/chinese-farmers-grow-15-less-soy-201516

How to implement Conservation Agriculture

There are a number of different planting systems within conservation agriculture (CA). The choice depends largely on how much land you plan to cultivate and your access to no-till planting equipment and labour. It also depends a lot on the type of soil you have and the cover on top of the soil.

The three main systems are:

- Hand planting
- Animal drawn no-till planters and
- Tractor drawn no-till planters

CA is a process of moving away from a high external input system towards a low external input system. We are aiming to maximise yields while using as little herbicides, fertilizers and pesticides as possible. The success of reaching our aim will depend largely on the quality of implementation of the three CA principles: a) not ploughing or disturbing the soil, b) keeping the soil covered with organic material or mulch, and c) the use of crop rotations and cover crops.

When we start to do CA it may take a while for the system to balance or to work well and for crops to grow well. In the first few years there are likely to be some problems with weed infestation, lack of organic matter in the soil and soil infertility issues, including acidity in the higher rainfall areas.

On smaller plots it is easy to introduce mulch to reduce the weed competition and this works for field crops as well as vegetables. On larger plots, while this is still possible, we usually spray herbicides on the field to kill weeds before and at planting, as well as after planting. As the ground cover increases and the weed seed stocks/ reserves in the soil decreases, less and less herbicide will be needed. The aim is to get to a point where no herbicide will be required.

***Above:** A plot of cabbages planted using the no-till method. Note the mulching that stops weeds from growing.* *From: Mr Simon Hodgson, Cover Crop Solutions, 2014*

Reducing weeds by intercropping

Single planted plots have more weeds, because of the space between the rows of plants. Intercropped plots form a canopy that covers the soil a lot more quickly than single crop plots. This suppresses further weed growth.

Intercrop plots, with close spacing of crops may require only 1 weeding, or under ideal conditions no weeding at all. Single crop plots require 2-3 weedings in the season.

***Left:** A plot of beans where weed competition has reduced the growth and plants are yellowing.*

***Right:** A maize and bean intercropped plot showing the lack of weeds and good growth of both plots.*

(Pics from GrainSA SFIP, Bergville 2014)

Timely Preparation and Planting

Preparing the fields and planting in time is very important.

What operation?	When?
Land Preparation (digging basins, ripping, digging furrows)	July – October
Pre planting spray of herbicides	September- October (2 weeks before planting and at planting)
Application of basal fertility amendments (manure, compost, fertilizer*, lime)	October- November (at planting or 2 weeks before planting)
Planting; spray pesticide (cutworm and stalk borer), single crops and intercrops	October -November
First weeding and relay planting of legumes as intercrop or cover crop	As soon as weeds appear, 1-2 weeks after planting
Second weeding and top dressing; check for stalk borer and spray pesticide if required (5% shot hole damage on maize leaves)	December-January, just before top dressing (4-6 Weeks after planting)
Relay crop planting of winter cover crops and final weeding. Watch for pest damage during tasseling and cobbing and spray pesticide if required	February- March
Harvesting	May-June
Post-harvest management	June-July

**consider eco-friendly fertilisers where possible*

Land preparation for hand planting

NOTE: We have given very general recommendations for quantities of manure and fertilizer, based on a summer rainfall area of 700-800 mm rain per year with clay-loam (20-30% clay in topsoil) soils that tend towards being acidic. The maize yield target for this specific example is 4-8 ton $ha^{-1}yr^{-1}$ Maize plant populations could range between 40,000 to 70,000 plants per hectare.

Planting basins

Seeds are planted not along the usual furrow but in small basins or pits that can be dug with hand hoes without having to plough the whole field.

Step 1: Prepare basins [July–October]

- ✱ Remove weeds from the previous season
- ✱ Dig basins 15cm long x 15cm wide x 15cm deep
- ✱ Basins should be arranged in rows. Basin spacing is 60cm in the row and 90cm between rows. A spacing of 75cm X 75cm can also be used.

The type and amount of fertilizer is specific for your field. If you do not have a soil sample result to work from there are general rules of thumb one can follow for your area.

***Above:** A field with basins prepared and waiting for planting.*

Step 2: Add manure [Sept–Oct]

- ✱ Apply 5-10 handfuls or one spade full of manure/compost in each basin and cover lightly with soil. If lime is being applied mix it in with the manure. Apply ½ food tin (250g) per basin. This is equivalent to 1ton/ha.
- ✱ It is good to apply manure and lime some time before planting to allow these slow acting compounds to start working.

***Above:** (left) Adding manure to a basin and (right) adding lime to the basins using a matchbox.*

Step 3: Planting [November–December]

- Plant after good rains, when the soil is damp but not too wet and sticky.
- If fertilizer is being applied, apply 1 level cool drink bottle cap or teaspoon per basin of MAP (around 4,2g/basin). Place this to one side of the hole and cover lightly with soil first before placing the seeds in the basin
- Place 3 pips (seeds) in each basin
- Cover the seeds with soil

***Right:** Adding one bottle top of fertilizer per basin*

Proper weeding can increase your yield by 50%

Step 4. Weeding & thinning [December–February]

- 1st Weeding: as soon as weeds start emerging
- Thinning: 2-3 weeks after germination, leaving 2 plants per basin
- 2nd weeding: 4-6 weeks after crop emergence

Step 5. Top dressing with limestone ammonium Nitrate (LAN) [January–February]

- Apply LAN at 5-6 leaf stage; Use half a cool drink bottle cap or half a teaspoon full per basin of LAN (2,5g/basin).
- Do not broadcast the fertilizer – apply it carefully near the base of each plant. In this way, all the fertilizer goes directly to the plant, nothing is wasted. Only apply fertilizer to moist soil – not dry.

Top dressing with half a teaspoon of LAN per basin.

Step 6. Harvest [March–July]

- Remove cobs and leave stalks standing in the field
- Cut stalks at the base
- Spread the cut stalks in the field, between rows

Step 7. Management in dry season [June–September]

- Remove weeds that are still in the field
- Prepare basins in the same positions as last season and start all over again!

Shallow planting furrows

This CA system uses a hand hoe and again you do not have to plough the field before planting. Like the planting basins, land preparation is best done before the onset of the rainy season from July to October.

Step 1. Prepare furrows
[July-October]

- Remove weeds from previous season (either mechanically or chemically)
- Dig furrows 5-10cm wide and approximately 2-5cm deep. Spacing depends on the planting system used. Space rows 50cm, 75cm or 90cm apart for maize. If the rows are spaced wide apart then more plants can be placed in the rows; for example one can use a 90cm between-row x 40cm in-row plant spacing, or one can plant in a square grid of 50cm between x 50cm in row spacing. For beans an in-row spacing of 10cm is used with 25cm, 30cm or 50cm between rows.

  NOTE: The closer (denser) plants are to each other, the more they protect the soil and suppress weeds

***Above:** Lines of string have been placed to indicate the spacing for furrows – here 25cm for two rows of beans and 50cm for 2 rows of maize.*

It is easier to weed when crops are planted further apart, but it is also easier for the weeds to grow.

Step 2. Add manure
[September–October]

- Apply 2 spades -full of manure or compost per meter of row
- If lime is being applied mix it in with the manure. Apply 1 food tin (500g)) per metre of row.

It is good to apply manure and lime some time before planting to allow these slow acting compounds to start working

***Right:** Applying lime in the planting furrows*

Step 3. Planting
[November–December]

- Plant after good rains
- If basal fertilizer, such as MAP is available, apply 2 level cool drink bottle caps or ½ of a matchbox per meter of row.
- Place seeds 10cm-50cm apart in the rows, depending on whether you are planting legumes or grains
- Cover the seeds with soil

Step 4. Weeding [December–February]

- 1st weeding is done as soon as weeds start emerging
- 2nd weeding is done around 4-6 weeks after crop emergence

Proper weeding can increase your yield by 50%

Step 5. Top dressing with limestone ammonium nitrate [January–February]

- Apply LAN at 5-6 leaf stage; Use a quarter of a cool drink bottle cap or a quarter of a tea-spoon full per plant of LAN (1,25g/plant). For beans you can use about half of this recom-mendation as they make their own Nitrogen and adding to much fertilizer can favour leaf growth over seeding.
- Do not broadcast the fertilizer –apply it carefully near the base of each plant.

Step 6. Harvest [March–July]

- Remove cobs and leave stalks standing in the field
- Cut stalks at the base, flatten or leave standing
- Spread the cut stalks in the field, between rows

***Right:** A field with good cover of maize stalks and remains. A relay cover crop is germinating through this cover.*

Step 7. Management in dry season [June–Sept]

- Remove weeds that are still in the field
- Prepare the rows in the same positions as last season and start all over again!

Tramline intercropping

This is a CA system of spacing field crops in an intercropping system that minimises potential competition for light, water and nutrients, optimises the use of available land surface and max-imises production. This can be done using hand or animal-drawn planters.

- 2 Rows (tramlines) of maize are planted 75cm apart with an in-row spacing of 30cm
- Then, in the 1.5m spacing between tramlines of maize, 2 rows of legumes are planted; with 50cm between rows and 3-5cm in row spacing.
- Pumpkins can be spaced evenly along the tram line of maize at a reasonably low density to avoid crowding.

It is possible to use a **close spacing system** with tramlines as well. The idea is to plant the crops as close together as possible so that crop canopy forms early in the season reducing the need for weeding. Here the two rows of maize are planted with a spacing of 50cm between and 25-50cm in row spacing (depending on the desired plant population) and the two rows of beans are planted with a 25cm between row and 10cm in row spacing.

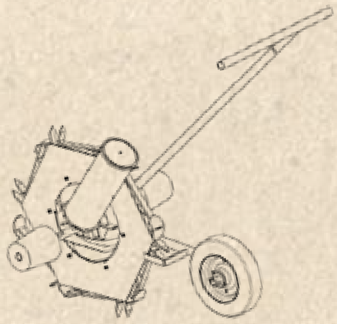
For this tramline system a mixture of basins and rows can be sued, where basins are prepared for planting the maize and beans are planted in rows in between the maize basins.

Using hand planters

No-till hand planters are designed to make small holes or openings in the soil and deliver either just the seed or seed and fertilizer into these holes. This leads to an absolute minimal disturbance of the soil and also decreases the labour needed for planting significantly.

There are a few different designs of hand planters that can be tried out and that are available. Some examples are shown below.

The Haraka hand planter



The Haraka planter shown here is a hand pushed rolling or rotating no-till punch planter that places seed of different kinds of crops including maize, beans and small seeded crops like cabbages, sorghum and cover crops 30cm apart in the row as it is being pushed. Fertilizer, if being applied, is placed on top of the soil next to the seed after planting. The Haraka planter is adapted for both sandy and clay soils. For clay soils, to assist in soil penetration to 4,5cm planting depth, weights can be added to the side of the wheel.

It is suitable for planting small to medium sized fields between 0.5 and 5 ha. The planter is currently one of the fastest type of hand planting tools and is supplied through Growing Nations and Eden Equip (www.eden-equip.co.za)

The MBLI hand planter

Afritrac (www.afritrac.co.za)supplies the Mealiebrand MBLI hand planter. This works similarly to a hoe and places both seed and fertilizer in two small holes alongside each other. Seed is placed in the hollow pipe handle of the planter and fertilizer is carried in the small pouch carried on the planter's back. Seed plates are available for a number of different seed types including maize, beans and smaller seeded grains such as sorghum. This planter is easy to use and adapted for sandy to medium high clay soils. It is most suitable for small fields up to 1ha in size.

The Matraca jab planter

The Matraca planter, a well-known jab planter imported from Brazil, supplies both seed and fertilizer alongside each other in two small holes at planting.). It is pushed into the ground and then pulled open like a lever or pair of scissors to release the seed and fertilizer. It is well adapted to sandy and clay soils, but needs reasonable arm strength to handle well. It is suitable for small fields up to 1ha in size. It is currently supplied by Inntrac Trading (www.inntrac.co.za)

Animal drawn planters

There are various types of animal drawn planters to use in CA systems. The first option is to only use a **ripper** to open furrows into which fertiliser and seed are manually (by hand) placed and covered by soil (see photo).

***Right:** Animal drawn ground ripper (from www.afritrac.co.za*

The second option is a complete **animal drawn no-till planter** that is designed for seed and fertilizer placement in the furrow made by a ripper tine attached to the planter. A basic and cheap version, modified from the well-known Safim planter, is offered by Afritrac (www.afritrac.co.za).

The **Napick planter**, imported from Brazil, is a more sophisticated animal drawn planter, but costs considerably more. Because of the springs and wheels on this planter, it is much easier to turn at the edges of the field.

Weeding

A combination of **agronomic** (mulching, mixed cropping, cover crops and crop rotation), **chemical** (herbicides) and **mechanical** (hand hoeing) methods of weeding can be used, depending on how serious the weed problem is and whether the chemicals and equipment can be obtained.

One of the most important benefits smallholder farmers want is for cover crops to control weeds.
- Roland Bunch

Herbicides

Advantages of chemical weed control

Herbicides allow us to control weeds and reduce the number of tillage operations as well as the critical timing needed for operations. This has allowed the widespread adoption of CA practices. Herbicides reduce the amount of human labour necessary.

Disadvantages of chemical weed control

Injury or damage to non-target species, crop injury or damage, herbicide carryover, weed resistance, container disposal problems and more recently, surface and groundwater contamination and the associated potential health risks from human exposure are risks. Another risk is poisoning from the actual application of the herbicides, if it is not done correctly.

A high degree of technical knowledge and skill is required for effective utilization of chemicals. Safety measures should always be used with chemical weed control.

***Right:** It is important to wear the necessary protective clothing – to wear goggles, a mouth and nose ventilator or mask, gloves, gumboots and a protective plastic suit. Sometimes people find it difficult to wear the whole kit. A minimum of goggles, gloves and boots should be worn at all times.*

Using herbicides in Conservation Agriculture

Apply **non-selective herbicides** using a knapsack sprayer 2 weeks prior to soil preparation and planting. Apply the **pre-emergence herbicides** at planting.

Examples of **pre-emergence herbicides** are:

- Alachlor such as Lasso, Sanachlor, Alanex
- S-metolachlor + safener such as Dual S Gold
- Acetochlor such as Trophee CS, Relay, Guardian

NOTE: These herbicides kill weeds before they come up.

Examples of **non-selective herbicides** (which kill every growing plant) are:

- Glyphosate such as Roundup, No-plough, Mamba, Senator etc)
- Paraquate such as Gramoxone, Agro-quat (VERY POISONOUS!)

NOTE: These herbicides will only work if applied to green, actively growing weeds!

Spraying herbicides

Start with a non-selective herbicide that will kill both grasses and broadleaf weeds. Glyphosate is one such herbicide and it is commonly known by the name of ***Roundup*** (produced by the Chemical Company Monsanto). It is generally used at a rate of 2-4l/ha, depending on the type and severity of weed infestation. This means that you will put 200-320ml of Roundup in each 16l of water to fill up a knapsack sprayer.

The speed at which you walk and the speed at which you pump the handle of the knapsack sprayer will determine how much of the herbicide you are spraying onto an area of ground. As a general rule the lever is pumped 1x every second. So if you walk at a steady pace (not fast and not slowly), spraying with the nozzle at knee height and recite the word 'one thousand' over and over again making one pump stroke per 'one thousand' – you should be doing it almost correctly.

Mostly, an application volume of 200l/ha is recommended. To see how close you are to this rate it is important to first practice and calibrate your spraying rate. This can be done by marking out an area of 10mx10m on hard dry ground. Then fill up the knapsack sprayer with 2litres of water. The operator should be able to walk and pump at a speed that means the 2l of water will cover the 10mx10m area.



***Right and below:** It is important to make sure that the fittings are all working correctly during a test spray. A facilitator and new operator calibrate their walking and pumping speed and a good walking and pumping 'rhythm' is set up by experienced knapsack users. Note the distance of the nozzle from the ground.*

Tips for spraying of herbicides

- Weeds should be sprayed when in active growing stage, preferably at 4 to 10 cm in height
- Spray in the cool part of the day
- Do not spray when there is dew on the weeds, this dilutes the herbicide
- Do not spray when there is a wind blowing
- Do not spray when rain is pending
- Use clean water to dilute the herbicide
- Calibrate the sprayer before using to ensure the correct dose is applied.
- Wear protective clothing and use the mouth and nose ventilator.
- Dispose of the empty containers by washing out first and then burying.
- It is important to know whether chemicals can be mixed together or whether they need to be sprayed separately. Some of this information will be given on the label of each chemical. Some of the chemicals react and interfere with each other, so mixing them will change how they react or stop them from reacting.
- Only make up enough diluted mixture that will be used immediately
- When working with undiluted chemicals it is VERY important to wear the protective clothing. All chemicals are poisonous in undiluted form and can be taken up into the human body through the skin and by inhaling. Gloves and a mask are an absolute minimum.

***Above:** The nozzles are at the tip of the sprayer where the liquid sprays out. The best nozzle for herbicides is known as an even or flat fan nozzle.*

- Storage of chemicals in a safe, lockable area where children do not have access is very important. Do not store the chemicals in cool drink bottles that can be mistaken and drunk from. All containers need to be clearly labelled.
- Cleaning and maintenance of the knapsack sprayers is also important. After use, rinse with 3 full volumes of clean water – and push clean water through the nozzles as well.
- Do not always use the same type of chemical to prevent weeds from building-up resistance
- Use as many agronomic methods as possible (crop rotation, cover crops, mulching) to gradually replace the use of chemicals in weed control.

It is possible to control weeds effectively without herbicides IF agronomic practices are implemented well.

Do’s and don’ts of spraying with herbicides

Herbicides are not a solution to lack of weed management. When your weeds are too large there is no herbicide that will deal with the problem!

***Right:** Herbicides cannot take the place of good management. If weeds have been allowed to grow too large, herbicides cannot solve this problem.*

Herbicides can also kill your crops if you are not careful. Roundup will definitely kill maize and beans, as will Gramoxone. So once the crops are growing it is best to do hand weeding.

***Above:** Left – An example of crops that were sprayed with herbicide after germination – where the farmer did not realise that the herbicides will also kill his crop. Middle; Necrotic spots and lesions where herbicide has drifted onto maize plants when applied in between the rows (in this case Gramoxone was used) and Right: An example of inter-row spraying of Roundup later in the season, which killed the beans that were planted there but only partially controlled the weeds that were already too mature for effective spraying.*

Herbicide spraying programmes

There are two general spray programmes that have been tried and tested in the smallholder context. Here the assumption is that the grasses such as nutsedge and couch grass will be significant problems.

***Right:** A Yellow nut sedge plant.*

Roundup (Glyphosate) kills fast growing (green) broadleaf plants and grasses. If it comes into contact with your crops it will kill those as well. So it needs to be sprayed 1-10 days before the crops are planted. Do not enter and work in a field that has just been sprayed. It needs to be left for at least 24 hours. Glyphosate does not work well or at all on plants that are not actively growing or are old.

Gramoxone is a non-selective quick acting post emergence herbicide for brodleaves and grasses. Like Roundup it will kill anything it comes into contact with. It is a contact herbicide, so acts immediately and does not build up in the plants or in the environment. It is however a lot more poisonous to humans and animals than Roundup, especially in its undiluted form. It is partially inactivated on contact with the soil.

Dual Gold is mainly taken up through the shoots of germinating plants and seedlings. Weeds are therefore killed before emergence, at emergence or shortly after emergence. It is taken up mainly through shoots, rather than roots of plants.

1. **Glyphosate and S-Metolachlor:**

a. Use Roundup turbo or max, 2 weeks before planting

b. If it is still too dry and the soil is bare then –

   i. Spray Roundup later just after planting (just after planting (assuming there has been some rain) or

   ii. Spray Roundup just before planting and Dual Gold mixed with pesticides (Decis Forte) just after planting

OR

2. **Paraquate**

a. Spray Gramoxmone 2 days to just before planting if there is longer grass and bigger weeds (Roundup is not so effective on these) and

b. Spray Dual Gold mixed with pesticide (Decis Forte) just after planting if there are problems with grasses such as nut sedge and couch grass.

Dual Gold Must have rain within 2 weeks of spraying otherwise it becomes completely ineffective. If too much is sprayed it can kill beans or affect their germination. The same is true for Roundup. It is thus important to be very careful with herbicides if intercropping and crop rotation systems are to be used.

Roundup cannot be sprayed on bare ground or even if there is quite a lot of dust or dry loose soil in the field. This inactivates the Roundup.

Improving soil health

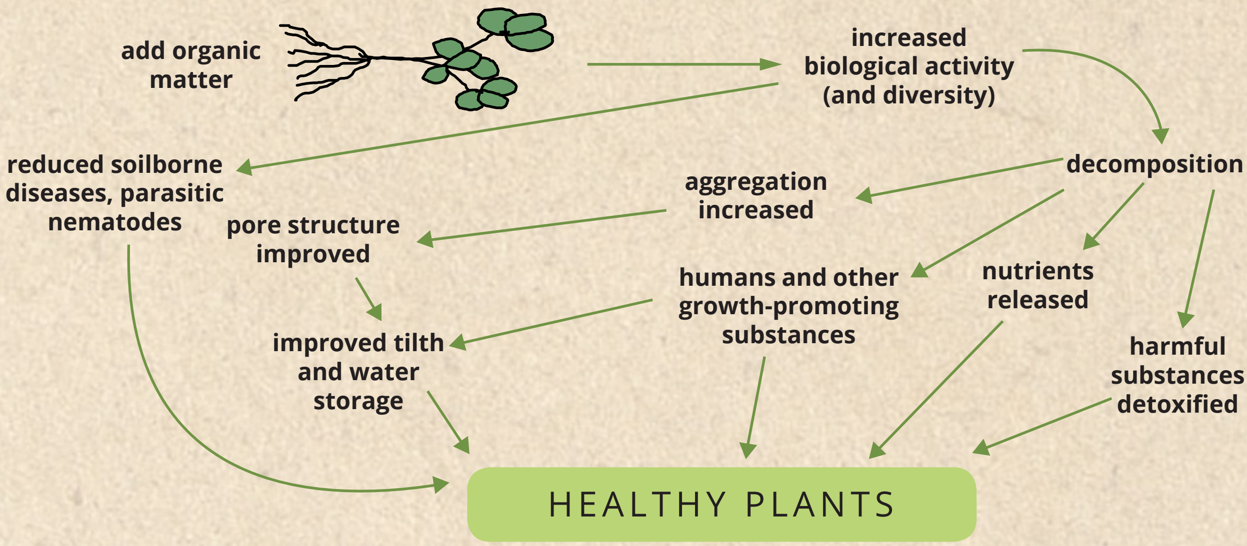
Chemical fertilisers can restore soil fertility quickly because the nutrients are available to the plants as soon as they dissolve in the soil. However they do not improve soil structure and there are other disadvantages to using them.

CA leads to a reduction in fertiliser use, with improved soil health and improved yields. Working with soil cover, crop rotation and cover crops is important to reach this goal.

We want to move from this ... ... to this

There are many natural ways or products for improving soil health and fertility. Composting and manuring are common examples. This is where manure (dung) from animals and compost (humus) is added to the soil. Other examples include the use of liquid manures and brews, organic or eco-friendly fertilisers, green manuring and cover crops, nitrogen fixing trees, crop rotation, mixed cropping and earthworm farming.

Adding organic matter results in many changes in the soil.



A comparison between chemical fertilisers and natural soil fertility methods

Chemical Fertilisers: Disadvantages	Natural soil fertility methods: Advantages
✱ Chemical fertiliserfertilisers are quick-acting, short- term plant boosters. ✱ They can negatively impact on organic matter and soil structure ✱ Beneficial life in soil including earthworms are negatively impacted ✱ Chemical fertiliserfertilisers alter vitamin and protein content of certain crops making them more vulnerable to diseases. ✱ Growing plants often take up a lot of nitrates which makes growth soft and sappy and this is what pests love ✱ Over time essential elements can be "locked up" and are therefore not available to plants. This reduces the fertility of the soil and plants can be more susceptible to disease and pest attack. ✱ The activity of many soil organisms is inhibited. ✱ The soil tends to become acidic ✱ FertiliserFertilisers meet the basic nutrient needs of soil NPK but what about all the other elements? ✱ FertiliserFertilisers are inorganic. They are manufactured in factories and this is not sustainable and leads to climate change ✱ FertiliserFertilisers are expensive to produce and buy ✱ Chemical fertiliserfertilisers are easily leached out. This can lead to pollution of water sources	✱ We are working with nature and natural laws ✱ Natural methods and products of improving soil fertility work to address the issue as a whole - by increasing a variety of nutrient sources and levels, improving soil structure, water holding capacity and microbial activity (improving and encouraging life in the soil) ✱ When we use our own natural soil fertility methods, such as compost or cover crop seeds, we are in charge, we don't have to rely on anybody ✱ It is sustainable because we can keep making compost/use natural methods ✱ Nothing goes to waste and we recycle ✱ We use what we have or can afford ✱ It is cheaper to rely on and support natural processes than it is to buy external inputs and agrochemicals. ✱ Although it takes time for organic matter to decompose into humus and before the nutrients are released, these nutrients continueto improve soil fertility and soil structure for a long time. ✱ Nutrients are not as easily lost or leached out and they are recycled in the soil ✱ Crops produced in healthy soils are naturally healthy and show more resistance to disease and pests ✱ An increase in organic matter improves infiltration and soil water content and reduces the likelihood of erosion

Soil Nutrients

All living things are composed of the basic elements of the earth. Plants consist mainly of hydrogen, oxygen, carbon, nitrogen, phosphorus, potassium and smaller quantities of magnesium, sulphur and calcium as well as many other elements in very small amounts (these are called trace elements).

The following table summarises the nutrients that plants need to grow well.

Element	Common available form	Source
Needed in large amounts		
Carbon	CO_2	Atmosphere
Oxygen	O_2 and H_2O	Atmosphere and soil pores
Hydrogen	H_2O	Water in soil pores
Nitrogen	NO_3^- and NH_4^+	Soil
Phosphorus	$H_2PO_4^-$ and HPO_4^{-2}	Soil
Potassium	K^+	Soil
Calcium	Ca^{+2}	Soil
Magnesium	Mg^{+2}	Soil
Sulfur	SO_4^{-2}	Soil
Needed in small amounts		
Iron	FE^{+2} and FE^{+3}	Soil
Manganese	Mn^{+2}	Soil
Copper	Cu^+ and Cu^{+2}	Soil
Zinc	Zn^{+2}	Soil
Boron	H_3BO_3	Soil
Molybdenum	MoO_4^{-2}	Soil
Chlorine	Cl^-	Soil
Cobalt	Co^{+2}	Soil
Nickel	Ni^{+2}	Soil

Plants need three main kinds of nutrients:

- **Nitrogen (N) –** provides growth and green leaves;
- **Phosphorus (P) –** for healthy roots and fruit formation and provides hte plant with energy;
- **Potassium (K) –** for general health and healthy flowers and fruit and for providing plants with nice thick plant stems.

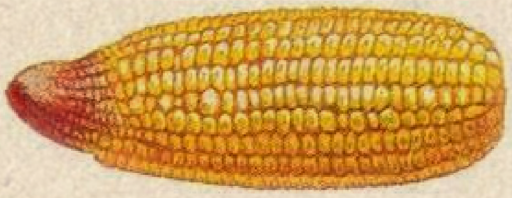
All three of these nutrients are found in healthy s oils and good compost or manure. You can also increase the amount of these nutrients in the soil by mulching and crop rotations, especailly by mulching/rotating with leguminous crops like beans, peas, pigeon peas and Acacia (thorn tree leaves) or comfrey, using liquid manures and planting cover crops or green manures.

***Right:** A legume with root nodules that contain nitrogen fixing bacteria*

***Above:** A mulch formed from mazie stover after the maize has been harvested. This mulch will provide nutrients and improve soil structure and water holding capacity of the soil.*

Nitrogen (N)

Nitrogen is essential throughout the growing season. If the maize plant runs out of N at a critical time, ears are small and protein content is low. Kernels at the tip of the ear do not fill.



How do you know if your soil needs more nitrogen?

You will know your plants need nitrogen when the leaves are turning yellowish, instead of a strong bright green. There can be general yellowing of the older leaves and the whole plant may be light green.

How can you add nitrogen to your soil?

This element is found in most manures (cattle, sheep, pig, goat, chicken and rabbit). There is more nitrogen in chicken and goat manure. These must be dried before being used in the garden. Otherwise they can be too strong and 'burn' the plants.

Nitrogen can also be added to soil through **legumes**. These are plants that form nodules or little knots on their roots. These nodules 'fix' nitrogen from the air, so that the plant can take it up through its roots. There are microorganisms (bacteria) in the roots that help to 'fix' the nitrogen. After the roots of the plant die the nitrogen is released into the soil and can be used by surrounding or following plants.

The bacteria in the root knots bind free nitrogen from air in the soil and releases nitrogen after the plant dies

Examples of legumes that we often grow:

- Groundnuts
- Cowpeas
- Beans (including soybeans)
- Peas
- And fodder crops such as vetch, lucerne, clover and forage peas.

There are less common crops and also many long living plants and small trees that also fix nitrogen. Some examples are chick-peas, mung beans, lentils, pigeon peas, lab lab, velvet beans and tree lucerne.

Some legumes are grown only as green manures, and are not used for food. These include lab lab, velvet beans, lucerne, clover, hairy vetch and lupins. These give a lot more nitrogen to the soil than our food plants, because we flatten them onto the soil surface when they are still green. This is why we call them green manure cover crops. We can also plant our food crops in between these legumes through *intercropping*.

Right: Hairy vetch has fine leaves, and delicate purple flowers, as well as hairy stems as the name implies.
http://www.fsl.orst.edu/forages/main.cfm?PageID=178&specid=41&use=Forage

Phosphorous

In maize production shortages of phospphorus interfere with pollination and kernel fill. Ears are small, often twisted and with undeveloped kernels.

How do you know if your soil needs more phosphorous?

You will know your plants need more phosphorous when they do not grow fast, as they should. The leaves may also start to show unusual red or pinkish colours, especially around the edges. If your plants are small and will not grow, even when compost is added, then you almost certainly have a severe phosphorous deficiency. This can also be caused by acidity in the soil.

How can you add phosphorous to your soil?

Many soils are poor in phosphorous. It is also a bit difficult to add phosphorous to the soil in an organic way, as most of the sources of phosphorous are tricky to work with. They include urine, bones, hair, feathers and blood. Usually we add these as ingredients to compost.

Natural rock phosphate can be added directly to the soil. This is also not easily available. Another good source of phosphorous is bone meal. You can usually buy this from an agricultural supply store – but it is not cheap.

One other way of adding phosphorous is to place bones in a fire, for a few hours. You can then grind them into a powder more easily. This powder can be spread on your garden beds or your compost heap.

The manure from animals grazing in areas where there is not much phosphorous will also have little phosphorous. You may need to bring in phosphorous in the form of chemical fertiliser. The usual source is called Superphosphate. Another chemical fertiliser known as MAP (Mono-ammonium Phosphate) can also be used. It is a good practice to correct any soil P deficiencies before starting with CA.

Potassium

Potassium shortages in maize shows up in the ears with poorly filled tips and loose, chaffy kernels.

How do you know if your soil needs more potassium?

You will know your plants need potassium when the plants become brittle and the leaf edges become brown and dry. When fruit does not form properly, you should also suspect a lack of potassium. Other signs can be hard to distinguish. One of these is a yellowing around the veins of the leaves. This could also be caused by diseases – so it can be difficult to know.

How can you add potassium to your soil?

Good sources of potassium are chicken manure and fresh woodash. Never use ash from coal, as this is very poisonous to the soil and plants. Another good source of potassium is a plant known as comfrey. This plant has large hairy leaves and grows in wet shady places. The leaves contain a lot of potassium. These can be used to mulch your vegetable beds and also to make liquid feeds for your plants (We will look at liquid feeds later in this section).

Above: Comfrey
From: Useful Plants for Land Design, Pelum

The other elements or minerals needed in smaller quantities, such as Magnesium, Zinc and Iron, are found in most manure and in compost.

Other important nutrients:

Calcium (Ca): Promotes plant fibre and strong plant tissue, promotes early root formation and seedling growth, aids in the uptake of nutrients, balances pH

Magnesium (Mg): Essential for the formation of Chlorophyll and formation of sugars, a carrier of phosphate and starches through the plant, promotes the formation of fats and oils, vital for healthy growth.

Sulphur (S): Increases root development, helps maintain the dark green colour, stimulates seed production, necessary for protein production, flavor and odour in many fruits and vegetables.

Micro or trace elements (nutrients needed in smaller quantities)

Iron (Fe): Is an oxygen carrier, enhances chlorophyll formation, metabolizes RNA, enhances green color of produce

Boron (Bo): Promotes early root formation and growth, improves health and sturdiness, increases yield and improves quality of fruits and vegetables. Improves the performance and availability of both calcium and silica.

Zinc (Zn): Essential for enzymatic reactions in cells and promotes plant growth.

Copper (Cu): Is needed for Chlorophyll production, catalyzes several plant reactions and necessary for making protein.

Manganese (Mn): Activates many metabolic reactions, increases absorption of calcium, magnesium and phosphorus, speeds germination and plant maturity.

Molybdenum (Mo): Enhances absorption of nitrogen by plants

Chlorine (Cl): Involved in photosynthesis and chlorophyll production, stimulates enzyme activity, helps control water loss and moisture stress.

Cobalt (C): Is needed in nodules of legumes for nitrogen fixing bacteria

Sodium (Na): Helps in water regulation and photosynthesis

These nutrients are important to plants for health and survival. They are equally important to animals and human health. This is because we get our nutrients from plants who take up essential nutrients from the soil. If our soil is healthy our plants benefit by being healthy and we in turn benefit from the variety of nutrients available.

Soil acidity

What is soil acidity?

Soil acidity can influence plant growth and limit crop yield. Minerals or nutrients needed by plants to grow are dissolved in the water inside the soil. This is a bit like salt or sugar dissolved in a glass of water.

Soil acidity is when the soil is "sour". It is a bit like a glass of water that has vinegar dissolved in it. In places where it rains a lot, some of the minerals can be washed out of the soil. The soil then becomes acidic. The use of chemical fertiliserfertilisers over a long period of time can also make the soil acidic.

If there is too much acid in the soil, some minerals or plant food will dissolve too quickly and the plants cannot use them. Other minerals will not dissolve at all, so again, the plants cannot use them. Phosphorus is one of the minerals that cannot be used by plants when the soil is acidic – even if it is in the soil.

Above: *An example of a maize field and the small stunted growth cause by soil acidity*

What causes acidity?

Acidic parent rock material, high rainfall and leaching of elements like calcium (Ca), magnesium (Mg), and phosphorous (K), decay of organic matter leading to release of organic acids into the soil, harvesting high yields (therefore removing plenty of Ca, Mg and K from the soil) and widespread use of nitrogen (N) fertiliserfertilisers cause soil acidity.

How do you know if your soil is acidic?

You will know your soil is acidic if you provide compost or manure and water for your plants, but they do not grow. The plants remain small and stunted. This is a common problem.

Maize plants growing in acidic soil will have stunted shoots and leaves that are stubby and die back at tips. The leaf color is dull green with leaves and stems developing purple tints similar to phosphorus deficiency. Roots are short and stubby and lack fiber.

***Above:** (left) a maize root system grown in normal soil and (right) a maize root system grown in acidic soil*

pH is a measure of the soil's acidity or alkalinity. In water, it normally ranges from -1 to 14, with 7 being neutral. A pH below 7 is acidic and above 7 is alkaline. Soil pH is considered an important variable in soils as it controls many chemical processes that take place. It specifically affects plant nutrient availability by controlling the chemical forms of the nutrient. The optimum pH range for most plants is between 5.5 and 7.0. Soils below a pH (KCL) of 4,5 are considered to be very acidic/sour.

The primary cause of acid soil infertility is Aluminium toxicity and unavailability of existing Phosphorus (P) as well as Magnesium (Mg) and Molybdenum (Mo).

Acid saturation measures the total amount of exchangeable acidity or ion (cations). This differs for sandy and clay soils and thus a measure of acid saturation is given which indicates this for each type of soil. For growing maize acid saturation should not be higher than 20%

How will you solve the problem of acidity?

The only practical way of dealing with soil acidity is to add lime to the soil. The ideal agricultural lime is produced from limestone and/or dolomite rocks and consist primarily of calcium (Ca) and magnesium (Mg) carbonates. Lime can be bought and is a white powder, or grey granules. It can either be dug into your soil, at least as deep as the roots of the crop you are growing or be spread across the surface, or placed on the surface of the soil to be incorporated over time through natural processes.

Without the benefit of a soil sample analysis result a general rule of adding 1-2 tons/ha of lime every 2-3 years can be used.

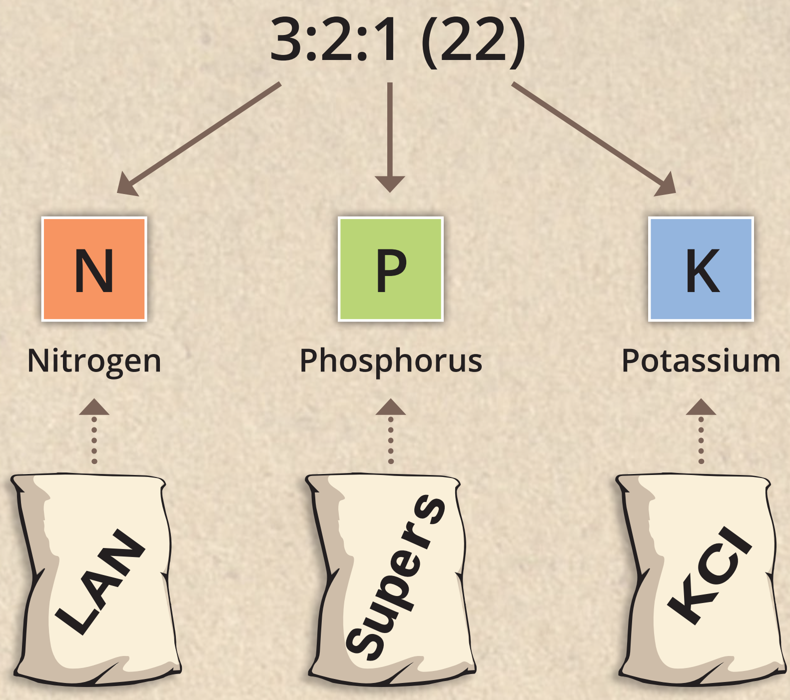
Usually lime is added 2 or 3 months before planting, as it is slow acting in the soil. If you add Lime at the same time as you are planting your crop, you will only see the main effect of the Lime in the next season. It is a good practice to correct soil acidity through the addition of lime before starting with CA.

Inorganic fertilisers

These are chemcials that you buy that contain the main plant nutrients or food in specific amounts.

The capital letters in brackets (N, P, and K) are called the chemical symbols. If you buy compound fertiliserfertilisers, they may use these letters instead of writing out the name in full. An example is N:P:K or 3:2:1 which means the fertiliser contains 3 parts N to 2 parts P and 1 part K.

Compound fertiliser iso soil nutrient treatments



It is also possible to buy the fertilisers that supply a single nutrient at a time such as LAN, Supers and KCL.

There are many different fertilisers that can be bought that supply different amounts of the main nutrients. To know how much of each element you have to add, a soil sample analysis is done by a laboratory. These results will generally tell you how much of each nutrient is required.

It is also possible to use manure in stead of fertiliser and to use manure and fertiliser mixtures. Below is a table of common fertilisers and manures and the quantities of nutrients they provide.

Fertiliser Name	Chemical composition		
	%N	%P	%K
SINGLE FERTILISERS			
LAN (limestone ammonium nitrate) (28)	28	-	-
Urea (46) **more concentrated than LAN but more acidifying*	46	-	-
MAP (Monoammonium phosphate (33)	11	22	-
Single supers (10,5)	-	10,5	
KCL (Potassium Chloride) (50)	-	-	50
MANURES			
Cattle, horse	0,5	0,3	0,5
Improved Cattle	2,0	1,5	2,2
Goat	0,9	0,5	0,8
Improved Poultry	4	2,7	1,4
FERTILISER MIXTURES			
2:3:4(30)+0,5% Zn	6,7	10	13,3
3:2:1 (25) + 0,5% Zn	12,5	8,3	4,2

Notes to the table on the previous page:

***NOTE 1:** You will see that the singler fertilisers add much higher concentrations of the nutrients than the fertiliser mixtures. It is easier to be accurate with the single fertilisers, but you will need to 'mix' them on your farm if you are applying them at the same time. As the mixtures have already been mixed together, this step is removed.*

***NOTE 2:** Animal manures differ according to where hte animals come from and what they have been eating. If their diet is poor, the quality of the manure will be poor and very few nutrients will be available. Animal manures contain a lot less of each nutrient per weight than fertilisers. They do however also have other benefits in the soil and improve organic matter content and soil health. Larger quantities of manure are required; generally in the order of 5 x more than fertiliser.*

***NOTE 3:** Improved manures, those that have been composted, provide much higher nutrient quantities.*

Here is an example of a fertiliser reommendation given for growing maize, for a soil sample around the Bergville area in KZN.

The following are fertiliser options (given in bags/ha) using DAP, MAP, Single Supers, 2:3:4 (38), KCl, LAN and urea for a specific soil sample.

***Soil sample yield target (t/ha) 4.0** – the amount of fertiliser added will increase the yield up to a point. So it is possible to decide on your target yield. There are a number of different combinations of fertilisers possible to give the correct amounts:*

- 4.0 bags/ha DAP; 1.0 bags/ha LAN or 0.6 bags/ha urea.
- 3.6 bags/ha MAP; 2.1 bags/ha LAN or 1.3 bags/ha urea.
- 7.6 bags/ha Single Supers (10.5%P); 3.6 bags/ha LAN or 2.2 bags/ha urea.
- 6.3 bags/ha 2:3:4(38); 1.7 bags/ha LAN or 1.0 bags/ha urea. The 2:3:4 would supply more than sufficient K.

Soil sample yield target (t/ha) 7.0

- 4.0 bags/ha DAP; 7.4 bags/ha LAN or 4.5 bags/ha urea.
- 3.6 bags/ha MAP; 8.6 bags/ha LAN or 5.2 bags/ha urea.
- 7.6 bags/ha Single Supers (10.5%P); 10.0 bags/ha LAN or 6.1 bags/ha urea.
- 6.3 bags/ha 2:3:4(38); 8.1 bags/ha LAN or 4.9 bags/ha urea. The 2:3:4 would supply more than sufficient K.

Soil sample yield target (t/ha) 10.0

- 4.0 bags/ha DAP; 10.3 bags/ha LAN or 6.3 bags/ha urea.
- 3.6 bags/ha MAP; 11.4 bags/ha LAN or 7.0 bags/ha urea.
- 7.6 bags/ha Single Supers (10.5%P); 12.9 bags/ha LAN or 7.8 bags/ha urea.
- 6.3 bags/ha 2:3:4(38); 11.0 bags/ha LAN or 6.7 bags/ha urea. The 2:3:4 would supply more than sufficient K.

From these recommendations it can be seen that to increase the target yield, more LAN is added and most likely as a top dressing when the maize is knee high. It is important to split the applications of N as it can be washed away and moves down into the soil profile where it may not be available for plants.

Micro dosing

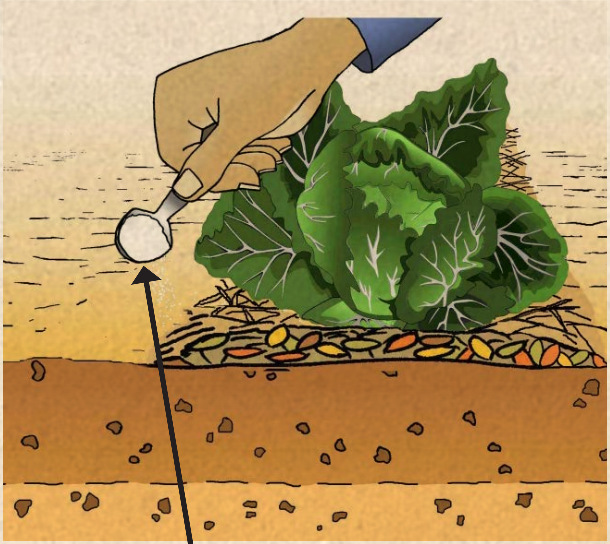
Micro dosing is a method of adding small quantities of fertiliser directly adjacent or next to plants where they can use it, rather than placing the fertiliser in bands or spreading it across the whole field. In this way much less fertiliser is used. This method is practised with CA. It is also recommended that fertiliser, manure combinations are used and that as little fertiliser as possible is used.

Below is a table that give general recommendations for use of fertiliser and manure when planting maize in a CA system.

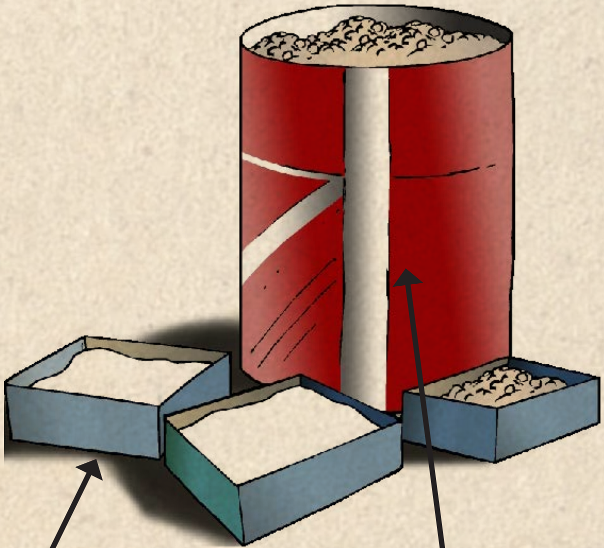
Fertiliser and Manure Quantities

Unless a soil sample specifically mentions the need for potassium (K), it is assumed that the higher clay soils (especially in KZN) as a rule do not need extra additions of potassium.The grey blocks represent a general recommendation for the midlands in KZN.

NAME	Element	Amount/ha	Amount/m2	Measuring
LAN (Basal)	28% N	100kg/ha = 355kg LAN	35.5g/m2 18 g /meter of row 9 g/planting basin	2 match boxes 1 matchbox ½ match box
LAN (top dress)	28%N	40kg/ha ~140kg LAN	10g/m2 5g/meter row 2.5g/planting basin	2 cooldrink bottle tops 1 cooldrink bottle top/ 1 teaspoon ½ cooldrink bottle top/ ½ teaspoon
Supers	10.5% P	40kg/ha = 380kg supers	39g/m2 20g/meter row 10 g/planting basin	2 match boxes 1 match box ½ matchbox
MAP (33) (supplies N and P)	11% N, 22% P	55 kg/ha P, 30kg/ha N = 250kg MAP	18g/ m2 8,3g/meter row 4,2g/planting basin	1 match box/ 1 table-spoon ½ match box 1 cooldrink bottle top/ 1 teaspoon
KCL	50% K	20kg/ha = 40 kg KCL	4g/m2 2 g/meter of row 1g/planting basin	1 cooldrink bottle top ½ bottle top (½ tea-spoon) ¼ bottle top (½ tea-spoon)
Lime		1ton/ha	1kg/m2 500g/meter row 250g/planting basin	1 large jam tin ½ large jam tin (or 1 normal food tin) ¼ large jam tin (½ food tin)
MANURE: Cattle/ goat	5kg/t N 2kg/t P 3kg/t K	10 tons/ha	10kg/m2 5kg/ meter row 2.5kg/planting basin	4 heaped spade fulls 2 spade fulls 1 spade full/ 4 large jam tins



1tsp/cool drink bottle top~2.5- 5g



1matchbox/ tablespoon~15-25g

1 large tin~400-900g

Measuring 1 metre using the length of a spade

Cover crops

With green manure/cover crops we use plants to improve and protect the soil. Green manures and cover crops have thus far been understood to be crops grown by themselves, with the primary aim of increasing soil fertility and which are then ploughed back into the soil when they are in the flowering stage and still green.

In CA and as smallholders, we use cover crops somewhat differently:

Maize and cowpea intercrop

Relay cropping of winter cover crops: saia oats, fodder radish and vetch

Collecting seed of winter cover crops

Firstly, rather than always being planted alone, cover crops are usually planted together with the main food crops and at about the same time (intercropped), or they are planted among the main food crops just before these crops are harvested (relay intercropping). Now farmers can improve their soil without dedicating extra land to growing these crops

Secondly, cover crops are cut or rolled down after their seed is harvested, so that we can use the seed as food for humans and animals and replant them

Thirdly, the cover crops are cut or rolled down and left on top of the soil as we do not disturb the soil through ploughing – the organic matter on the soil surface can protect the soil from sun, wind and rain and provide extra soil fertility.

Fourthly, we plant cover crops to control weeds, pests and diseases. Cover crops compete with weeds and very effectively prevent or suppress them from growing. Cover crops 'push' or 'pull' pests and diseases out of the fields and/or away from food crops, since they are either liked or disliked by them.

2

Advantages of planting cover crops (CCs)

1. **Increased organic matter and soil nutrients:** CCs are capable of adding as much as 50 metric tons/hectare (MT/ha) or more of organic matter (green weight) to the soil each year. This organic matter has various positive effects on the soil, such as recycling nutrients back into the soil, pumping nutrients up to the soil surface, and improving the soil's water-holding capacity. It can also increase the total amount of nutrients in the soil, improve its nutrient balance, increase the number of macro and microorganisms (very small animals in the soil, many of which also help a farmer's crops grow better), improve the acidity of soil (i.e.: buffer soil pH) and sequester carbon.

   Organic matter makes soil nutrients, including those supplied by chemical fertilizers, more accessible to crops. In the case of phosphorus, this is particularly important: in acidic soils, phosphorus may become four to five times more available to plants when surrounded by organic matter.

2. **Nitrogen fixation:** Legumes (plants that produce their seeds inside pods) are able to fix nitrogen (N) from the atmosphere into a plant-usable form that accumulates in plant tissues. Legumes can thereby add large quantities of nitrogen to farmers' soils. Most of the widely used legume CCs are capable of producing more than 50 kg N/ha; some a lot more.

3. **Weed and pest control:** CCs can also be an important factor in reducing the cost and the labour required for controlling weeds. Herbicide use is either reduced or eliminated, since many CC species are able to smother weeds. Some species of CC can be used in place of other chemicals. For example, mucuna (velvet bean) and lablab beans kill nematodes, while sunnhemp (*Crotalaria ochroleuca*) can be used to control pests that eat stored grain. Brassicas (plants in the cabbage family) have an allelopathic effect that inhibits the germination of small seeded weeds. Rye, wheat and hairy vetch also produce compounds that inhibit weeds.

4. **Soil cover and erosion control:** The soil cover provided by many CCs can be very important for soil conservation. The soil cover, or mulch, that is provided by a CC also greatly improves drought resistance. The residues add organic matter to the soil, which increases infiltration of water into the soil and increases the water-holding capacity of the soil, while run-off and erosion is reduced substantially. Cover crops protect soil aggregates from the impact of rain drops by reducing soil aggregate breakdown.

***Left:** Runoff in a field planted to maize only has washed away some of the younger and germinating plants*
***Right:** On the same field intercropping with a cc has reduced the runoff a lot and crops are doing well*

5. **Mycorrhizal Fungi:** Cover crops increase mycorrhizal fungus activity promoting a symbiotic relationship with the plants' roots for water and nutrient uptake. Plants provide the polysaccharides and the mycorrhizal fungus provide the protein to form a glycoprotein called glomalin which promotes soil aggregate stability (more macro-aggregates) and improved soil structure. Mycorrhizal fungus grows better in undisturbed soils. No-till and actively growing roots promote this reaction to occur. The majority of soil microbes are located next to growing roots with 10,000 times more microbes located in the rhizosphere next to the root than in bare soil.

   The soil microbial biomass and enzymatic activity increases with cover crop usage. Cover crops increase SOM, macroporosity, soil permeability, mean aggregate size, and aggregate stability (macro aggregates vs. micro-aggregates).

Roots, fungal hyphae and their secretions stabilize soil aggregates and promote good soil structure, thus preventing compaction and increasing soil water holding capacity and nutrient cycling

6. **Additional benefits:**

- ✱ CCs can provide food for humans and fodder for animals, including cattle and poultry.
- ✱ CCs can provide economic benefit through sale of fodder, hay and seed

Livestock grazing on a fodder rye and clover mixture of cover crops *(from: S Hodgson, 2014)*

- ✱ CCs can reduce pest attack and problems on staple crops including nematodes in growing crops and various pests in stored grain. CCs can be used as a trap crop for insects if the cover crop is killed before planting maize. Some green cover crops attract army worm, cutworms and slugs so the cover crop needs to be killed 3 to 4 weeks before planting maize.
- ✱ Letting cover crops grow and mature (flower) may allow populations of beneficial insects to increase.
- ✱ CCs can reduce incidence of diseases in crops, notably root rots and other fungal diseases.
- ✱ CCs can alleviate soil compaction through improved root sysems and soil structure.
- ✱ CCs increase the solar energy harvest (through photosynthesis) to increase carbon in the soil.

- CCs provide food for macro- and micro-organisms and other wildlife.
- CCs increase organic carbon, cation exchange capacity, aggregate stability and water infiltration.

Disadvantages of planting CCs

1. **Opportunity cost of land:** Farmers normally will not plant something that only improves their soil if the land could instead be planted with either food crops or cash crops. Unless the CCs also produce food, the land used to grow CCs must have no other valuable use
2. **The slow results:** Soil improvement is a long-term process that may not be immediately noticeable to the farmer. Usually, concrete, visible results are not apparent until well into the second cropping cycle. This slow appearance of results – improved soils – that are often difficult for people to believe, further complicates the adoption of CCs.
3. **Dry season problems:** Often CCs must produce their organic matter at the end of the wet season, or must continue to grow during the dry season. Grazing animals, wild animals, termites, agricultural burning, bush/veld fires or several other problems may destroy organic matter or growing plants before the farmer can use them the following rainy season.
4. **Timing (also called "synchronization"):** The nutrients provided by the CCs, especially nitrogen, must be available to crops when they need them in order to raise productivity. CCs will boost farmers' productivity only if the nutrients are available to the crops at the right time. In many systems, the correct timing is either impossible or very difficult to achieve. Therefore, the efficiency of the systems is reduced.

Nutrient cycling and release with cover crops

Generally cover crops consist of mixtures of grasses and or grains and legumes to balance the need for inclusion of both carbon (C) and nitrogen (N) to build the soil. Both C and N are needed to form soil organic matter. Grass cover crops may contribute N as scavengers or legumes may fix additional N. Grasses contribute more carbon than legumes. The carbon to nitrogen ratio (C:N) determines how organic matter is decomposed, at which rate and which nutrients are released or held in more stable forms. At C:N ratios of less than 20, N is released. The average C:N ratio in the soil is around 10-12:1 indicating that N is available.

Nitrogen uptake depends on how much nitrogen is in the soil, the climate (temperature and water), cover crop species, seeding rate, planting and die back or killing date. Winter grass cover crops (such as saia oats and annual ryegrass) accumulate soil N in autumn and winter due to fast root growth. After the boot stage (when the stems start to thicken and lengthen), there is not much additional nitrogen uptake with grasses. Legumes accumulate nitrogen longer into the spring. Grasses and or brassica species absorb and recycle nitrogen if excess N occurs from manure or fertilizer. Legumes are used to supplement N for the next crop if more N is needed for fertilization.

The release of N depends on cover crop species, growth stage, management, and climate. For example:

- An early spring kill of grasses promotes a lower C:N ratio and a faster release of N.
- Legumes tend to have a lower C:N ratio but if either grasses or legumes are allowed to reach full maturity, N release is delayed.
- Slower N release occurs more in dry weather than in wet years due to decreased microbial activity needed to decompose residues and release N
- N uptake of cover crops varies from 57 to 296 kg N/ha. If 50% of N is recycled, cover crops may supply 25 to 132 kg N/ha to the next crop
- Late planted cover crops may not have as much vegetative growth but may impact soil and water quality through reduced soil erosion.

Types of cover crops

Mostly mixtures of grasses, legumes and brassicas (cabbage family) are used. The general rule is to plant as many different types of cover crops together as possible. The most efficient organic matter building process is through a diverse range of cover crops that help to maintain a diverse microbial community.

When five or more species or types are planted together, such as grasses, cereals, brassicas, legumes and chenopods (a family of plants that includes spinach, beetroot, amaranthus and lamb's quarters or chenopodium), synergistic effects start to be noticed. More phenolic compounds are produced in the plants and microorganisms. These compounds have a role to play in the fixation of nitrogen and also in building resistance to insect and disease attack.

We can choose the combination of cover crop mixes depending on the season, the rainfall and the requirements of the soil in our situation. For smallholder farmers we would be looking mostly for mixes with good grazing and food potential.

***Top:** Amaranthus species are good cover crops and also provide food as indigenous greens*

***Below:** Chenopodium or lambs quarters similarly is a highly nutritious vegetable*

Examples of commonly used cover crops

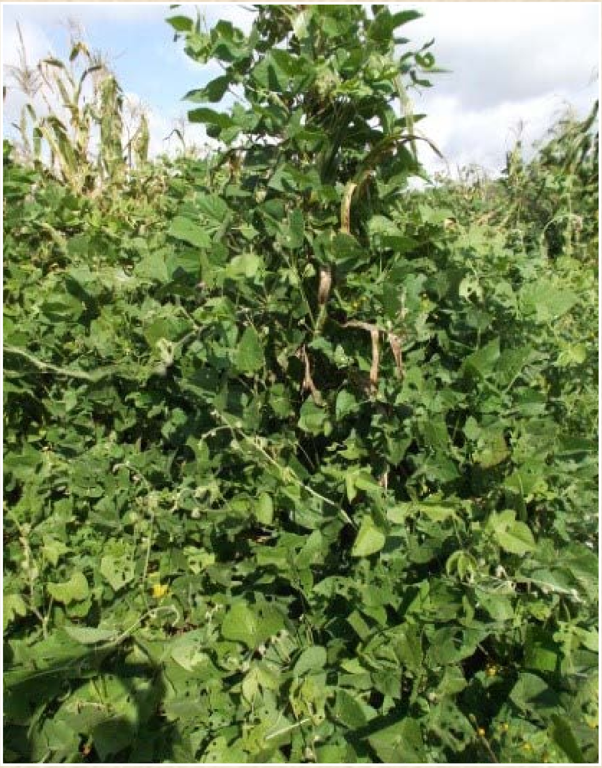
Annual cover crops that are used as rotations with summer and winter grain crops are the most common. Cover crops need to be good fodder for livestock as well as having soil building and soil health improvement properties. In the South African conditions they need to be tolerant to bad quality soils that are often acidic or sandy and to heat and drought stress.

Legumes

Common cover crop options for legumes:

Warm season	Cool season
• Dolichos (*Lablab purpurea*) • Sunnhemp (*Crotalaria juncea*) • Cowpea (*Vigna unguiculata*) • Lucerne (*Medicago sativa*) • Velvet beans (*Mucuna pruriens*) • Soybean (*Glycine max*) • Mung bean	• Hairy vetch (*Vicia villosa*) • Burmedic (*Medicago polymorpha*) • Red clover (*Trifolium pratense*) • Forage pea/field pea (*Pisum sativum*)

Dolichos beans (*Lablab purpureus*)
Lablab is remarkably adaptable to wide areas under diverse climatic conditions and soil types with pH varying from 4.4 to 7.8. Being a legume, it can fix atmospheric nitrogen to the extent of around 170 kg/ha besides leaving enough crop residues to enrich the soils with organic matter. It is a drought tolerant crop and grows well in dry lands with limited rainfall. The crop prefers relatively cool seasons (temperature ranging from 14-28°C) with the sowing done in July-August. It is an extremely good high protein animal fodder for the dry season and is highly preferred by cattle. It seeds throughout the dry season and will not provide seed under heavy grazing conditions. *(Truter et al 2015) (http://www.lablablab.org/html/general-information.html).*



***Right:* Lablab grows prolifically and seeds late in the season going into winter. It provides full ground cover while maize is dying back**

Sunnhemp (*Crotalaria juncea*)
This is a tropical legume that has huge potential as a cover crop. It is planted in the warm season and is an annual that produces large quantities of biomass. It is a good fodder for livestock and grows in low fertility sandy soils. It has a suppression effect on plant parasitic nematodes and fixes around 120kg/ha of nitrogen.www.biomassproducer.com.au

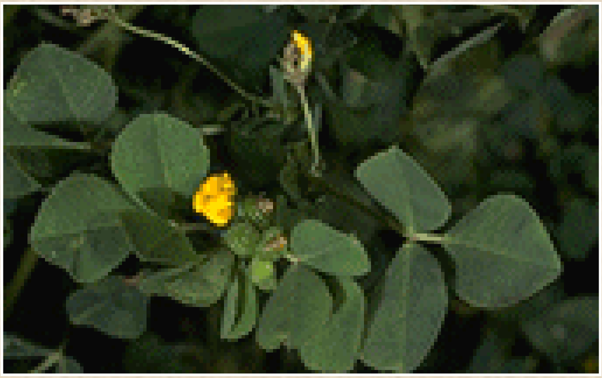
***Left:* Sunnhemp grows tall and straight and seeds quickly producing high biomass and protein rich fodder**

Lucerne/Alfalfa (*Medicago sativa*)
This is a perennial flowering plant in the pea family and is grown as an important livestock fodder crop. It is also considered a good crop for promoting the presence of beneficial insects such as predatory and parasitic wasps. It is hardy and drought tolerant. This deep rooted crop breaks up hard soils and recycles nutrients bringing trace elements to the soil surface. It can be cut and hay can be produced, or grazed directly. It is planted in spring. It fixes between 180-250kg/ha of nitrogen. *www.agricol.co.za*

***Above:* Lucerne can be cut and fed to livestock 2-3 times per season. It produces a very high value hay**

Bur Medic (*Medicago polymorpha*) is a legume that is closely related to alfalfa/ lucerne. They fix around 120kgN/ha. They are true annuals flowering, setting seed and dying within one growing season (60 to 100 days). The germinate and grow quickly and can tolerate a wide range of soil pH. They can be used for fodder. *http://ucanr.org/sites/asi/db/covercrops.cfm*

***Right:** Medics are used very successfully in dryland conditions with poor quality soils*



Hairy Vetch (*Vicia villosa*)
These legumes are planted in autumn and although a bit slow to establish as drought and cold tolerant once growing. They can grow in a wide range of different soil types and different pH and also do well in sandy soil. They show good N fixation at around 140kg/ha of N.

https://commons.wikimedia.org/wiki/File:Hairy-Vetch_(4709732410).gif

***Left:** Hairy vetch is one of the most rewarding cover crops. The small leaves and high biomass means fast decomposition and a significant increase in organic matter in the soil*

Red Clover (*Trifolium pratense*)
This is sown as a cool season cover crop and is shade tolerant if sown into a maize crop towards the end of the season. It fixes around 140kg/ha of Nitrogen and can be grazed in winter. *http://www.plantcovercrops.com*

***Right:** Clovers do well on highly clay and acidic soils where other cover crops may struggle. They are well adapted to cool wet conditions*

Forage pea (*Pisum sativum*)
These are winter legumes and good fodder crops for livestock. They are not very drought tolerant and require non acidic soil for optimum growth.

***Left:** The forage peas are a little slow to germinate and cannot tolerate very hard soils and dry conditions.*

Grasses, cereals and brassicas

Common cover crop options for grasses, cereals and brassicas include the following:

Warm season	Cool season
• Babala/ pearl millet (*Pennisitum glaucum*) • Forage sorghum (*Sorghum bicolor*) • Sunflower • Buckwheat • Teff	• Black/saia oats (*Avena strigosa*) • Fodder rye (*Secale cereale*) • Fodder radish (*Raphanus Sativus Olieformis*) • Other bassicas including: kale, rape, turnips and mustard • Barley • White oats • Stooling rye

Cereal/ fodder rye (*Secale cereale*)
This is sown in autumn and forms dense stands and a large root mass. It is quite drought and cold tolerant and good for problem soils such as rocky or sandy soils.
http://www.kingsagriseeds.com/cool-season-annuals

***Right:** The grain can also be kept as food for livestock and humans and is comparatively high in protein*

Black oats (*Avena strigosa*)
This is a good cool season cover crop and is a valuable fodder crop for livestock, with good nutrition quality and high protein content. It is quite hardy, can tolerate low pH soils and improves soil aggregation and soil structure. It also mobilises C alcium (Ca) in the soil.
http://www.kingsagriseeds.com/cool-season-annuals

***Left:** Black oats forms one of the standard cover crop mixes as it has a strongly boosting effect on soil health and soil microbial life*

Babala/pearl millet (*Pennisitum glaucum*)
This is a quick growing summer annual used for grazing and silage. It has a well developed root system and good drought tolerance. It can tolerate low soil fertility, and high temperature. It performs well in soils with high salinity or low pH. Because of its tolerance to difficult growing conditions, it can be grown in areas where other cereal crops, such as maize or wheat, would not survive. In many parts of the world including Africa and India it is staple food eaten as a porridge or fermented into a local beer. Flatbreads, cakes and biscuits are also common.
www.en.wikipedia.org www.great-secret-of-lifecom

***Above:** Pearl millet is a good food for both livestock and humans*

Forage sorghum (*Sorghum bicolour*)
This sorghum type grows very tall and produces a large amount of vegetative growth. It is drought and heat tolerant and produces good animal fodder. It is also known as sweet sorghum.
www.youtube.com

***Right:** Forage sorghum is a very good cattle fodder and also known as sweet reed in more local cultures, it is eaten like sugarcane*

Fodder radish (*Raphanus Sativus Olieformis*)
It is a fast growing cool season cover crop which is immune to many brassica diseases, such as clubroot. It has a weed suppression effect and is a good grazing crop for livestock. It is cold tolerant and has positive effects on soil health and soil structure. It grows large very quickly and has a large nitrogen uptake of around 20kg/ha. It has a positive effect on acidic soils and fixes Aluminium (Al).
http://msue.anr.msu.edu/news/cover_crop_grazing_with_sheep_lessons_learned_from_recent_msu_extension_dem, www.cdiowa.org

***Left:** Fodder radish and oats mixture and the large root that cracks open and aerates soil as well as being a particularly sought after fodder for cattle*

Seed inoculation

Inoculation may be defined as the process of adding effective bacteria to the host plant seed before planting. The purpose of inoculation is to make sure that there is enough of the correct type of bacteria that multiply in the roots of a legume plant forming nodules where these bacteria fix atmospheric nitrogen for the nutrition of the plant. These inoculants can be bought and added to legume seeds prior to planting Inoculants are specific to each type of legume.
www.groworganic.com.

More recently inoculants containing beneficial fungi such as mycorrhizae have also been developed. These assist in general soil health and plant growth.

The general rule is to mix cereals/ grasses, legumes and brassicas into the mixture. Any combination of these can wok well- depending on the local conditions and preferences. Remember to try and use as many different types and species as possible.

Warm season cover crop mixes

A good mixture is the following:

- Dolichos (Lab-Lab beans)
- Fodder sorghum and Sunnhemp.

***Right:** A trial plot with the summer mix of cover crops*
(from: H Smith, 2014)

Cool season cover crop mixes

Various combinations of black oats fodder rye, vetch fodder radish and fodder peas are possible.

***Right:** A plot with fodder pea, oats and rye grass;*
***Far Right:** A mix of hairy vetch, fodder peas and fodder rye.*
(From S Hodgson SACCS, 2014)

References

Hoorman J.J. 2015. *Using Cover Crops to Improve Soil and Water Quality.* Cover Crops & Water Quality, Extension Educator Ohio State University Extension, Lima, Ohio

Bunch, R. 2012. *Restoring the soil. A Guide for Using Green Manure/Cover Crops to Improve the Food Security of Smallholder Farmers.* Canadian Foodgrains Bank, Winnipeg, Canada.

Hodgson, S. 2015. *Cover crop mixes.* Cover Crop Solutions. Box 195 Umlaas Road 3730 E-mail: wensim@mweb.co.za.

Sait, G. 2015. *It's cocktail time. The amazing potential of engineered biodiversity.* In Nutrition Matters. www.nutri-tech.com.au.

Truter, W., Dannhauser, C., Smith, H. and Trytsman, G. 2015. Conservation Agriculture - Integrated crop and pasture-based livestock production systems. A series of articles on various crops. *SA Grain Magazine*, http://www.grainsa.co.za/