Organics and Soil Carbon:

Increasing Soil Carbon, Crop Productivity and Farm Profitability

by Andre Leu

This paper explains how atmospheric carbon is introduced into the soil and how it is stored in stable forms. It identifies the farming techniques that are responsible for the decline in soil carbon and gives alternative practices that do not damage carbon. Increasing soil carbon will ensure good production outcomes and farm profitability. Soil carbon, particularly the stable forms such as humus and glomalin, increases farm profitability by increasing yields, soil fertility, soil moisture retention, aeration, nitrogen fixation, mineral availability, disease suppression, soil tilth and general structure. It is the basis of healthy soil.

Organic agriculture also helps to reduce greenhouse gases by converting atmospheric carbon dioxide (CO_2) into soil organic matter. Some forms of conventional agriculture have caused a massive decline in soil organic matter, due to oxidizing organic carbon by incorrect tillage, the overuse of nitrogen fertilizers and from topsoil loss through wind and water erosion.

Why is carbon important to productive farming?

Soil carbon is one of the most neglected yet most important factors in soil fertility, disease control, water efficiency and farm productivity. Humus and its related acids are significantly important forms of carbon. Below is a summary of the benefits of humus

Humus improves nutrient availability:

· Stores 90 to 95% of the nitrogen in the soil, 15 to 80% of phosphorus and 20 to 50% of sulphur in the soil
· Has many sites that hold minerals and consequently dramatically increases the soil's TEC (total exchange capacity or amount of plant available nutrients that the soil can store)
· Stores cations, such as calcium, magnesium, potassium and all trace elements
· Prevents nutrient leaching by holding them
· Organic acids (humic, fulvic, ulmic and others) help make minerals available by dissolving locked up minerals
· Prevents mineral ions from being locked up
· Encourages a range of microbes that make locked up minerals available to plants.
· Helps to neutralize the pH
· Buffers the soil from strong changes in pH

Humus improves soil structure:

· Promotes good soil structure which creates soil spaces for air and water
· Assists with good/strong ped (soil particle) formation
· Encourages macro-organisms (ie earthworms and beetles etc) that form pores in the soil.

Humus directly assists plants:

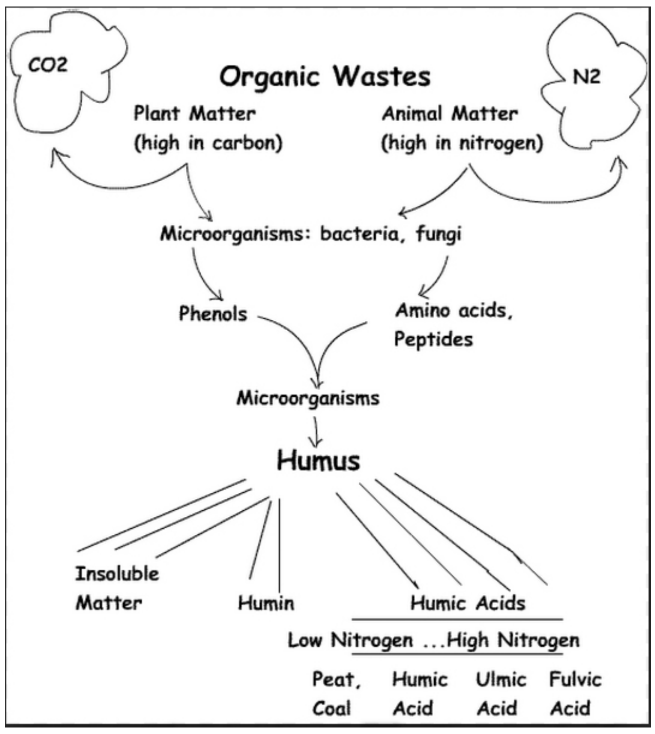
· The spaces allow microorganisms to turn the nitrogen in the air into nitrate and ammonia
· Soil carbon dioxide contained in these air spaces increases plant growth
· Helps plant and microbial growth through growth stimulating compounds
· Helps root growth, by making it easy for roots to travel through the soil

Humus improves soil water relationships:

· The open structure increases rain absorption
· Water loss from run off is decreased
· Humus molecules soak up to 20 times their weight in water
· It is stored in the soil for later use by the plants.
· Improved ped formation helps the soil stay well drained

The processes to increase soil carbon can be divided into three steps

1. Use plants to grow soil carbon
2. Use microorganisms to convert soil carbon into stable forms
3. Avoid farming techniques that destroy soil carbon



1. Use plants to grow soil carbon

The most economical and effective way to increase soil carbon is to grow it. Plants get between 95 and 98% of their minerals from the air and water. If we look at the chemical composition of an average plant, Carbon, Hydrogen and Oxygen account for over 95% of the minerals. The remaining 5% or less come from the soil. These minerals are combined using the energy of the sun via photosynthesis to produce the carbon based compounds that plants need to grow and reproduce.

The 'Carbon Gift' - how plants increase soil carbon

It is estimated that between 30-60% of the atmospheric carbon dioxide (CO_2) absorbed by plants is deposited into the soil as organic matter, either in the form of bud sheaths that protect the delicate root tips or as a range of other root excretions.

These complex carbon compounds contain the complete range of minerals used by plants and are one of the ways that minerals are distributed throughout the topsoil. They feed billions of microbes – actinomycetes, bacteria and fungi that are beneficial to plants. Research shows that the greatest concentrations of microorganisms are found close to the roots of plants. This important area is called the Rhizosphere. These organisms perform a wide range of functions from helping to make soil minerals bioavailable to protecting plants from disease.

Research has shown that plant roots put many tonnes of complex carbon molecules and bioavailable minerals per hectare into the soil every year and are a very important part of the process of forming topsoils and good soil structure.

This means that well managed plants can put more bioavailable nutrients into the soil than they remove from it. Also the nutrients they put into the soil are some of the most important to the crop, to beneficial organisms and to the structure and fertility of the soil.

Managing weeds to increase soil carbon

If we look at weeds from this perspective, we can see that if we prevent the weeds from choking our crop, especially from getting the important sunlight, they can be increasing the fertility and health of the soil and actually helping our crop, rather than hindering it.

If the weeds are managed properly, and their residues are allowed to return to the soil, their nutrient removal from the soil is zero. In fact, as they are adding between 30% to 60% of the organic compounds they create through photosynthesis into the soil, they are increasing soil fertility.

Studies of weed fallows and the microorganisms that they feed show that they help with increasing the bioavailability of the minerals that are locked into the soil. Soil tests show an increase in soil fertility after weed fallows and when plants are grown as green manures. It is one of the reasons why ground cover fallows restore soil health. They return tonnes of carbon into the soil, feed the microorganisms that make nutrients bioavailable and reduce soil pathogens.

The important thing is to ensure that the soil has adequate levels of all the minerals and moisture necessary for growth and that the weed management practices allow the crop to be the dominant plants.

Techniques are encouraged where weeds are cut down, pulled or grazed so that their residues will return to the soil will feed the crop. Cutting and grazing plants will result in significant percentages of roots being shed off so that the weed or cover crop plants can re-establish an equilibrium between their leaf and root areas.

These cast off roots not only add carbon and feed the soil microorganisms, they release nutrients to the crop and significantly lower nutrient and water competition. This addition of nutrients encourages the crop roots to grow deeper in the soil, below the weed roots resulting in larger crop root systems and better access to water and soil nutrients.

With these techniques, we are actually increasing the efficiency of the farm surface area capturing sunlight and using photosynthesis to make the carbon based molecules that eventually result in the fertile soils that feed our plants.

It is the nutrients that we lose off farm, either through selling the crop, through soil leaching or erosion, that need to be replaced every year. Good fertilization should always ensure that our soil has the optimum level of all the necessary minerals. If we do not replace the minerals that we remove from our soil when we sell our crop, we are mining our soil and running it down.

One of the reasons why good organic farmers notice that weeds do not become a problem in their systems is because they ensure they have excellent soil nutrition and health by using weed management techniques that build up the soil. **The process becomes one of effective weed management rather than weed eradication.**

One of the problems with herbicides is that by killing the ground cover plants, they stop the food supply that feeds these beneficials, thereby lowering the count of beneficial species. Consequently soil borne pathogens like Phytophthora and Fusarium can take over, as the various species that kept them under control are significantly reduced.

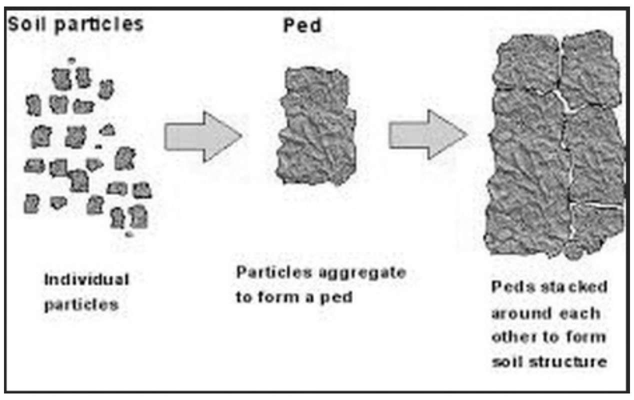
2. Use microorganisms to convert soil carbon into stable forms

The stable forms of soil carbon such as humus and glomalin are manufactured by microorganisms. They convert the carbon compounds that are readily oxidized into CO_2 into stable polymers that can last thousands of years in the soil.

Some of the current conventional farming techniques result in the soil carbon deposited by plant roots being oxidized and converted back into carbon dioxide. This is the reason why soil organic matter (carbon) levels continue to decline in these farming systems.

The other significant depository of carbon is soil organisms. Research shows that they form a considerable percentage of soil carbon. It is essential to manage the soil to maintain high levels of soil organisms.

Also it is essential that farming techniques stimulate the species of soil microorganisms that create stable carbon, rather than stimulating the species that consume carbon and convert it into CO_2.



Creating stable carbon

The process of making composts uses microbes to build humus and other stable carbons. The microorganisms that create compost continue working in the soil after compost applications, converting the carbon gifted by plants roots into stable forms. Regular applications of compost and/or compost teas will inoculate the soil with beneficial organisms that build humus and other long lasting carbon polymers. Over time these species will predominate over the species that chew up carbon into CO_2.

Regular applications of composts and/or compost tea also increase the number and diversity of species living in the soil biomass. This ensures that a significant proportion of soil carbon is stored in living species that will make minerals plant available and protect the health of the plants.

Composts bring a significant number of other benefits

Research shows that good quality compost is one of the most important ways to improve soil. It is very important to understand that compost is a lot more than a fertilizer. Compost contains humus, humic acids and most importantly a large number of beneficial microorganisms that have a major role in the process of building healthy soils.

Compost provides the following benefits:

Humus
· Adds humus and organic matter to the soil
· Inoculates soil with humus building microorganisms.
· Improves soil structure to allow better infiltration of air and water.
· Humus stores 20 times it weight in water and significantly increases the capacity of soil to store water

Nutrients
· Mineral Nutrients
· Organic based nutrients
· Contains a complete range of nutrients
· Slow release
· Does not leach into aquatic environment

Beneficial micro-organisms
· Supplies a large range of beneficial fungi, bacteria and other useful species
· Suppresses soil pathogens
· Fixes nitrogen
· Increases soil carbon
· Release of locked up soil minerals
· Detoxifies poisons
· Feeds plants and soil life
· Builds soil structure

3. Avoid using farming techniques that destroy soil carbon

The continuous application of carbon as composts, manures, mulches and via plant growth will not increase soil carbon levels if farming practices destroy soil carbon. The following are some of the practices that result in a decline in carbon and alternatives that prevent this loss.

Reduce nitrogen applications
Synthetic nitrogen fertilizers are one of the major causes of the decline of soil carbon. This is because it stimulates a range of bacteria that feed on nitrogen and carbon to form amino acids for their growth and reproduction. These bacteria have a Carbon to Nitrogen ratio of around 30 to 1. In other words every ton of nitrogen applied results in the bacteria consuming 30 tons of carbon. The quick addition of these nitrogen fertilizers causes the nitrogen feeding bacteria to rapidly multiply, consuming the soil carbon to build their cell walls.

This process results in the stable forms being consumed causing a decline in the soil carbon levels. The best analogy is money in a bank. The addition of the large doses of nitrogen fertilizer is the equivalent of a large withdrawal.

Freshly deposited carbon compounds tend to readily oxidize into CO_2 unless they are converted into more stable forms. Stable forms of carbon take time to form. In many cases it requires years to rebuild the bank of stable carbon back to the previous levels.

Ensuring that a carbon source is included with nitrogen fertilizers protects the soil carbon bank, as the microbes will use the added carbon, rather than degrading the stable soil carbon. Composts, animal manures, green manures and legumes are good examples of carbon based nitrogen sources

Where possible plant available nitrogen should be obtained through rhizobium bacteria in legumes and free-living nitrogen fixing microorganisms. These microorganisms work at a stable rate fixing the nitrogen in the soil air into plant available forms. They can utilize the steady stream of newly deposited carbon from plant roots to create amino acids, rather than destroying humus and other stable carbon polymers.

Carbon eaters rather than carbon builders
The use of synthetic nitrogen fertilizers changes the soil biota to favor microorganisms that consume carbon, rather than the species that build humus and other stable forms of carbon. By stimulating high levels of species that consume soil carbon, the carbon never gets to increase and usually continues to slowly decline.

The use of composts with microorganisms that build stable carbons will see soil carbon levels increase if the farm avoids practices that destroy soil carbon.

Reduce herbicides, pesticides and fungicides
Research shows that the use of biocides (herbicides, pesticides and fungicides) causes a decline in beneficial microorganisms. As early as 1962, Rachel Carson quoted research about the detrimental effect of biocides on soil microorganisms in her groundbreaking book 'Silent Spring'. Since then there have been regular studies confirming the damage agricultural chemicals are causing to our soil biota.

Recently the work of one of the world's leading microbiologists, Dr. Elaine Ingham, has shown that these chemicals cause a significant decline in the beneficial microorganisms that build humus, suppress diseases and make nutrients available to plants. She reports that many of the herbicides and fungicides have been shown to kill off beneficial soil fungi. These types of fungi have been shown to suppress diseases, increase nutrient uptake (particularly phosphorus) and form glomalin.

Glomalin is a stable carbon polymer that forms long strings that work like reinforcing rods in the soil. Research is showing that they form a significant role in building a good soil structure that is resistant to erosion and compaction. The structure facilitates good aeration and water infiltration.

Avoiding the use of toxic chemicals is an important part of the process of developing healthy soils that are teeming with the beneficial species that will build the stable forms of carbon.

Use correct tillage methods
Tillage is one of the oldest and most effective methods to prepare planting beds and to control weeds. Unfortunately it is also one of the most abused methods resulting in soil loss, damage to the soil structure and carbon loss through oxidation when used incorrectly.

It is important that tillage does not destroy soil structure by pulverizing or smearing the soil peds. Farmers should be aware of the concept of good soil 'tilth'. This is soil that is friable with a crumbly structure. Not a fine powder or large clumps. Both of these are indicators of poor structure and soil health. These conditions will increase the oxidation of organic matter turning it into CO_2.

Tillage should be done only when the soil has the correct moisture. Too wet and it smears and compresses. Too dry and it turns to dust and powder. Both of these effects result in long term soil damage that will reduce yields, increase susceptibility to pests and diseases, increase water and wind erosion and increase production costs.

Tillage should be done at the correct speeds so that the soil cracks and separates around the peds leaving them intact, rather than smashing or smearing the peds by travelling too fast. Good ped structure ensures that the soil is less prone to erosion.

Deep tillage using rippers or chisel ploughs that result in minimal surface disturbance while opening up the subsoils to allow better aeration and water infiltration, are the preferred options. This will allow plant roots to grow deeper into the soil ensuring better nutrient and water uptake and greater carbon deposition.

Minimal surface disturbance ensures that the soil is less prone to erosion and oxidation thereby reducing or preventing carbon loss.

Control weeds without soil damage

A large range of tillage methods can be used to control weeds in crops without damaging the soil and losing carbon.

Various spring tines, some types of harrows, star weeders, knives and brushes can be used to pull out young weeds with only minimal soil disturbance.

Rotary hoes are very effective, but should be kept shallow at around 25mm to avoid destroying the soil structure. The fine 25mm layer of soil on the top acts as a mulch to suppress weed seeds when they germinate and conserve the deeper soil moisture and carbon. This ensures that carbon isn't lost through oxidation in the bulk of the topsoil.

There are several cultivators with guidance systems that ensure precision accuracy for controlling weeds. These can be set up with a wide range of implements and can be purchased in sizes suitable for small horticultural to large-scale crop farms.

Organic farmers in the USA, Europe and Australia are using these to get excellent control over weeds in their crops.

Avoid erosion
Erosion is one significant way that soil carbon is lost. The top few centimeters of soil is the area richest in carbon. When this thin layer of soil is lost due to rain or wind, the carbon is lost as well.

Avoid burning stubble
Practices such as burning stubble should be avoided. Burning creates greenhouses gases as well as exposing the soil to damage from erosion and oxidation.

Encourage vegetation cover
Vegetation cover is the best way to prevent soil and carbon loss. As stated in the previous section 'Managing weeds to increases soil carbon', it is not always necessary to eradicate weeds. Effective management tools such as grazing or mowing can achieve better long term results.

Bare soils should be avoided as much as possible
Research shows that bare soils lose organic matter through oxidation, the killing of microorganisms and through wind and rain erosion. Cultivated soils should be planted with a cover crop as quickly as possible. The cover crop will protect the soil from damage and add carbon and other nutrients as it grows. The correct choice of species can increase soil nitrogen, conserve soil moisture through mulching and suppress weeds by out-competing them.