As. J. Food Ag-Ind. **2009**, Special Issue, S307-S317

Asian Journal of Food and Agro-Industry
ISSN 1906-3040
Available online at www.ajofai.info

Applied Organic Systems, Carbon Farming and Climate Change

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Abstract

This paper will review a range of proven methods to increase soil carbon in organic farming systems as well as showing the science behind these methods. Published studies show that organic farming systems are more resilient to the predicted weather extremes of climate change. The studies showed that many organic systems have higher yields than conventional farming systems in weather extremes such as floods and droughts due to better water use efficiency and soil structure. This is due, in part, to the better water holding of soils rich in organic matter, especially humus. Increasing soil carbon can reduce the greenhouse gases created by agriculture and assist in ameliorating the effects of climate change on farm production. Increasing soil carbon will ensure good production outcomes and farm profitability. Soil carbon, particularly the stable forms such as humus and glomalin increase farm profitability by increasing yields, soil fertility, soil moisture retention, aeration, nitrogen fixation, mineral availability, disease suppression, soil tilth and general structure.

Keywords:

Introduction

Experts expect that climate change will have a negative effect on our food supply due to more frequent adverse weather events leading to increasing crop failures. This is particularly relevant in several of the world's major food producing regions such as temperate Asia, China, Northern India, Sub Saharan, North and Southern Africa, Southern North America, the temperate and subtropical regions of South America, Mediterranean Europe and temperate Australia. Many of the predicted weather scenarios such as increases in prolonged droughts and short very intense rain events are already a fact of life and causing significant crop failures. The security of our food supply concerns all of us.

So what has organic agriculture to do with climate change? One of the central tenets of organic farming is to improve soil health and productivity by increasing organic matter (carbon) levels, particularly humus. In doing this organic farming can remove significant amounts of the carbon dioxide (CO_2) from the atmosphere and increase water use efficiency.

Organic Systems Use Water More Efficiently

Humus is one of the most important components of organic matter. It stores from 20 to 30 times its weight in water so that rain and irrigation water is not lost through leaching or evaporation. It is stored in the soil for later use by the plants *(Handrek 1990, Stevenson 1998, Zimmer 2000, Handrek and Black 2002).*

Research shows that organic systems use water more efficiently due to better soil structure and higher levels of humus. *(Lotter 2003, Pimentel 2005) 'Soil water held in the crop root zone was measured and shown to be consistently higher by a statistically significant margin in the organic plots than the conventional plots, due to the higher organic matter content in the organic treated soils.' (Lotter 2003).*

The open structure of soil allows rain water to quickly penetrate the soil, resulting in less water loss from run off. *'The exceptional water capture capability of the organic treatments stood out during the torrential downpours during hurricane Floyd in September of 1999. The organic systems captured about twice as much water as the CNV* [conventional] *treatment during that two day event' (Lotter 2003).*

Greenhouse Gas Abatement

Very importantly organic agriculture can help reverse climate change. Published peer review scientific studies in North America and Europe show that best practice organic agriculture emits less greenhouse gases than conventional agriculture and the carbon sequestration from increasing soil organic matter leads to a net reduction in greenhouse gases. *(Mader et al 2002, Pimentel 2005, Reganold et al 2001).*

Two published studies *(Mader et al 2002 and Pimentel 2005)*, in peer reviewed scientific journals, of long-term comparison trials (21 and 22 years) of conventional and organic systems have found that the organic systems, use less fossil fuels and therefore emit significantly lower levels (around 30% less) of greenhouse gases.

The long term apple comparison trial conducted by Reganold et al in Washington USA showed that the organic system was more efficient in it energy use. *'When compared with the conventional and integrated systems, the organic system produced sweeter and less tart apples, higher profitability and greater energy efficiency.' (Reganold et al 2001).*

A significant tenet of organic agriculture is to build up soil fertility by increasing the levels of organic carbon compounds in the soil. This is primarily achieved by using photosynthesis to convert atmospheric CO_2 and using management techniques that covert these plants into soil organic matter. *'Sufficient organic material should be regenerated and/or returned to the soil to improve, or at least maintain, humus levels. Conservation and recycling of nutrients is a major feature of any organic farming system.' (National Standard 2005).*

Organic agriculture helps to reduce greenhouse gases by converting atmospheric 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.

According to Dr Christine Jones, one of Australia's leading experts on carbon sequestration:
'Every tonne of carbon lost from soil adds 3.67 tonnes of CO_2 gas to the atmosphere. Conversely, every 1 t/ha increase in soil organic carbon represents 3.67 tonnes of CO_2 sequestered from the atmosphere and removed from the greenhouse gas equation.'
'For example, a 1% increase in organic carbon in the top 20 cm [8 inches] of soil represents a 24 t/ha [24,000 lbs/acre] increase in soil OC which equates to 88 t/ha [88,000 lbs/acre] of CO_2 sequestered." (Jones 2006).

A 100 acre farm that had a 1% increase in organic matter would be removing 8,800,000 lbs of CO_2 from the atmosphere. A million acres = 88,000,000,000 lbs. The figures in this article are ballpark figures because the variability of dynamic systems makes it virtually impossible to give precise numbers. These are rounded off to make them easy to understand and are accurate enough to give people an understanding of the concepts.

The consensus is that burning 1 liter petrol produces 2.3 kg of CO_2. This means that a 1% increase in organic matter per hectare (2.5 acres) is equivalent to sequestering the carbon from 38,260 liters of petrol (About 10,000 gallons). In the case of my car it is equivalent to 1000 tanks of fuel. If I used one tank a week it is the equivalent of all the fuel I would use over 20 years. If as a farmer I sequestered 1% over 10 hectares (25 acres) it would be 200 years of fuel. Another way of looking at it would be that 1 hectare (2.5 acres) equals the equivalent of 20 cars in a year- a million hectares equals the emission of 20 million cars per year.

Data from the Rodale Institute's long-running comparison of organic and conventional cropping systems confirms that organic methods are far more effective at removing carbon dioxide from the atmosphere and fixing it as beneficial organic matter in the soil. According to the Rodale Institute *"U.S. agriculture as currently practiced emits a total of 1.5 trillion pounds of* CO_2 *annually into the atmosphere. Converting all U.S. cropland to organic would not only wipe out agriculture's massive emission problem. By eliminating energy-costly chemical fertilizers, it would actually give us a net increase in soil carbon of 734 billion pounds."* (*Rodale 2003).*

The correct farming techniques can sequester carbon into the soil and reverse the 25% of greenhouse gases created by agriculture in developed nations. 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

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 50 to 20% of sulphur in the soil
- Has many sites that hold minerals and consequently dramatically increases the soils TEC (The 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 neutralise 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 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
- Decreases water loss from run off
- 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

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 comes 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 CO_2 absorbed by plants is deposited into the soil as organic matter in the form of bud sheaths that protect the delicate root tips and 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 bio available to protecting plants from disease.

Research has shown that plant roots put many tons of complex carbon molecules and bio available 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 bio available 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 bio available 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 where weeds are cut down, pulled or grazed and 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. This has become the basis of the emerging organic no till and minimum till systems where crops are planted into pastures or previously sown cover crops. The critical issues in these systems is the choice of the right species for the pasture and cover crops, and the management of these so that they do out compete with the crop for sunlight, water and nutrients. Rolling, grazing or cutting can usually achieve this. These techniques can leave a thick cover of mulch that will suppress weeds, conserve water and encourage beneficial micro organisms.

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 fertilisation 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.

Use Microorganisms to Convert Soil Carbon into Stable Forms

The stable forms of soil carbon such as humus and glomalin are manufactured by microorganisms. *Ingham (2003).* They convert the carbon compounds that are readily oxidised into CO_2 into stable polymers that can last thousands of years in the soil. *Handrek (1990).*

Some of the current conventional farming techniques result in the soil carbon deposited by plant roots being oxidised and converted back into in carbon dioxide. This is the reason why soil organic matter (carbon) levels continue to decline in these farming systems. The other significant depositories of carbon are the 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. It is also essential that farming techniques stimulate the species of soil microorganisms that create stable carbons, 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

Avoid 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 ratios of between 20 to 1 and 30 to 1. In other words every ton of nitrogen applied results in the bacteria consuming between 20 to 30 tons of soil carbon. This equates to between 73.4 to 110.1 tons of CO_2 that will be released into the atmosphere.

Synthetic Nitrogen Fertilisers Deplete Carbon

Scientists from the University of Illinois analysed the results of a 50 year agricultural trial and found that synthetic nitrogen fertiliser resulted in all the carbon residues from the crop disappearing as well as an average loss of around 10,000 kg of soil carbon per hectare. This is around 33,000 kg of carbon dioxide per hectare on top of the many thousands of kilograms of crop residue that is converted in to CO_2 every year.

The researcher found that the higher the application of synthetic nitrogen fertiliser the greater the amount of soil carbon lost as CO_2. This is one of the major reasons why conventional agricultural systems have a decline in soil carbon while organic systems increase soil carbon. (Source: Acres USA)

Freshly deposited carbon compounds tend to readily oxidise 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 fertilisers 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 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 utilise 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 fertilisers changes the soil biota to favour 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 also 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 ground breaking book 'Silent Spring' *(Carson 1962).* Since then there have been regular studies confirming the damage agricultural chemical are causing to our soil biota. *(Cox 2001, 2002).*

Recently the work of one of the world's leading microbiologist, 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. Many of the herbicides and fungicides have been shown to kill off beneficial soil fungi (*Ingham 2003*). 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. In addition, 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. As a result of this opinions have shifted, with many farming industries pushing no till using herbicides and GMOs as sustainable agriculture. The pendulum of opinion is beginning to swing back to tillage now that the various problems of chemical no till systems are emerging.

Tillage will always have a role in weed management, soil aeration and building soil health. Appropriate tillage does increase soil carbon and ensure minimal erosion. *(Reganold et al 1987, Zimmer 2000.)* It is important that tillage does not destroy soil structure by pulverising 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 in tack, 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 tynes, 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 however this should be kept shallow at around one inch (25mm) to avoid destroying the soil structure. The fine inch layer of soil on the top acts as a mulch to suppress weed seeds when they germinate and conserves 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 broad-acre farms.

Avoid Erosion

Erosion is one significant ways that soil carbon is lost. The top few inches 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.

Encourage Vegetation Cover

Vegetation cover is the best way to prevent soil and carbon loss. As stated in the previous section *'Managing Weeds to Increase 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.

There are various forms of organic no till systems that sow directly into rolled, grazed or cut cover crops and pastures with very effective yields. As the soil carbon builds up, the yields increase with many outperforming the conventional crops in the district.

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.

Conclusion

Climate change is one of the major issues affecting all of us on our planet. Increasing soil carbon can reduce the greenhouse gases created by agriculture and assist in ameliorating the effects of climate change on farm production. Increasing soil carbon will ensure good production outcomes and farm profitability. Soil carbon, particularly the stable forms such as humus and glomalin increase farm profitability by increasing yields, soil fertility, soil moisture retention, aeration, nitrogen fixation, mineral availability, disease suppression, soil tilth and general structure. Research shows that these soils have improved water use efficiency due to the ability of humus to hold over 20 times its weight in water.

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