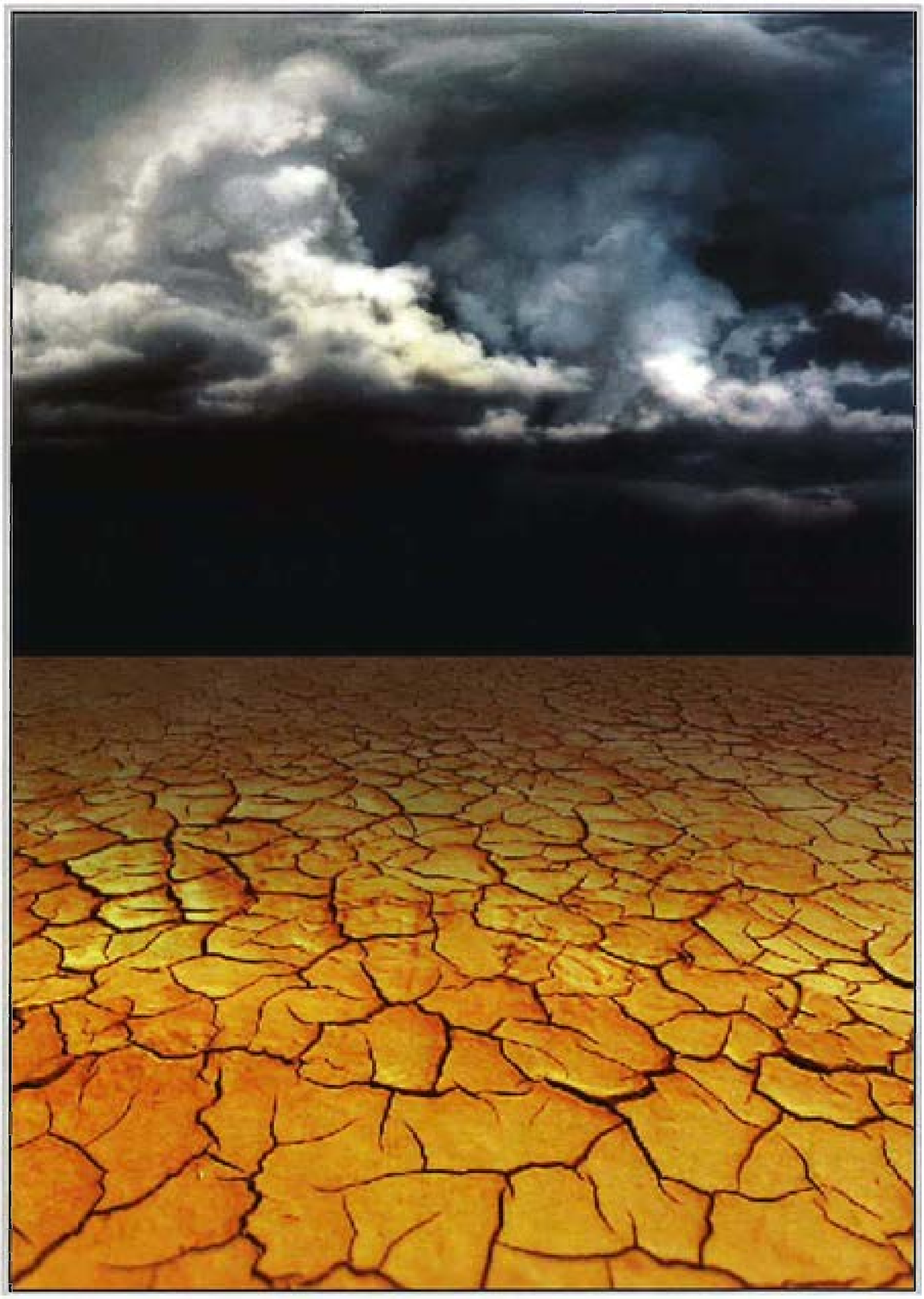
Soil Carbon Sequestration

Author: Edward O. Percy

Are we prepared for this in the future under current farming practice?



Or do we continue to aspire to this:

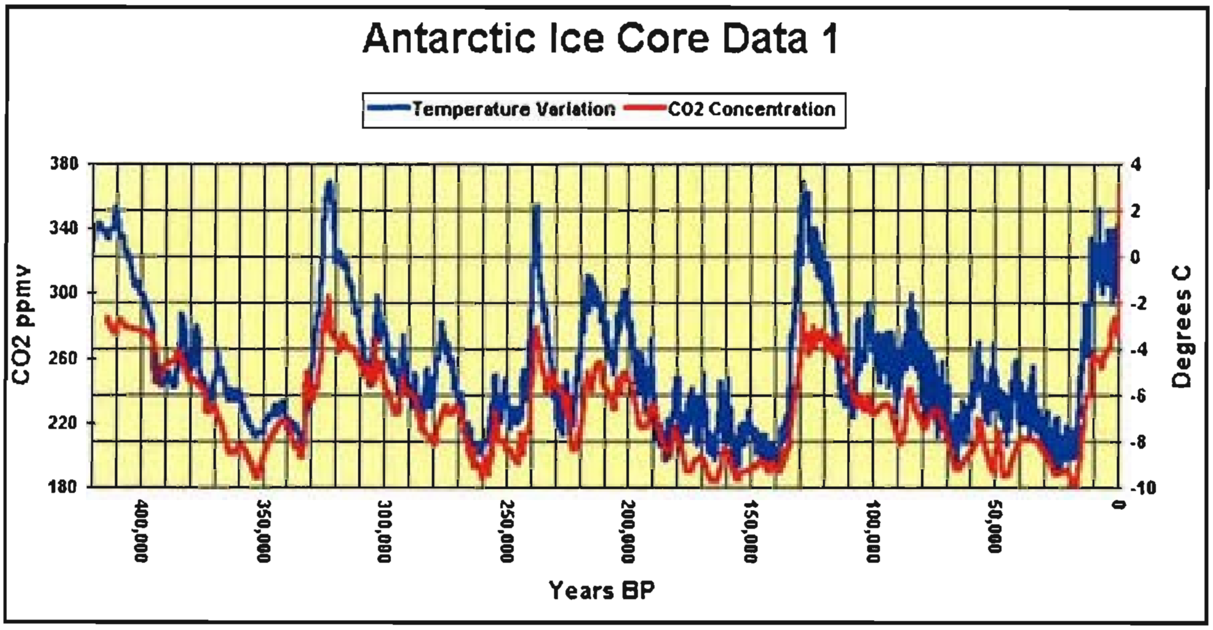
Forward

"The nation that destroys its soil destroys itself" (Roosevelt 1937).

"In the last 50 years we have degraded 30% of global topsoil" (Prince Charles – speech at Copenhagen 15 December 2009

The world has become incensed with the conundrum of global warming and climate change. The pretense is that man, through the 20th century, has increased output of harmful greenhouse gases into the atmosphere and is causing global warming. The solution is perceived to be that we must do something about it by cutting back our emissions of greenhouse gases and stop deforestation.

Certainly this movement is positive by making everyone aware of the consequence of burning finite fossil fuel resources to the detriment of our surroundings and cutting down our forests. That global warming is wholly caused by humans burning fossil fuels and deforestation is an argument still debated. Global warming is arguably happening, but has it been happening for decades. Core samples were taken from the Antarctic ice and data was extracted to show that the level of CO2 (a greenhouse gas) has been tracking in line with global temperatures for up to 400,000 years.



Regardless of whether it is humans or whether it is just earth's natural evolutionary process, humans are dealing with their own conscience by attempting to do something about it.

It isn't just global warming that is our concern though. Pollution is a big problem that is possibly overshadowed by the global warming phenomenon. Industrial wastes such as harmful gases and chemicals, agricultural pesticides, fertilisers and insecticides are the most important causes of soil pollution. Soil management practices, fertilizer and animal waste applications and irrigation practices are harmful if not administered correctly. Pollution of water in most countries is a grave issue. Pollution of the air we breathe is another major concern for the human race. The human race is willingly polluting the fundamentals of the very reason we are alive – earth, water, and air.

World population is likely to hit nine billion by the middle of the century. As a consequence pressures are coming on our food and water supplies. Not just the quantity but the quality. To keep up with demand for food farmers need to produce more, but to do so they need to remain financially viable and the costs associated with global warming, for example the ETS in New Zealand, are putting pressure on this principle.

We exist because the earth, the sun and the earth's atmosphere exists. By taking heed of earth's natural processes can we sequester carbon in our soils to support the atmosphere, improve the quality of our water, enhance our soils processes to grow healthy plant life, and keep our farmers financially viable? Is New Zealand resting on its "Clean Green" laurels while the rest of the world steams ahead – in particular Australia?

> Soils are a main determinant of ecosystems and as such are an essential cornerstone of human life and prosperity. Increasing population pressure and severe erosion, pollution and desertification issues are threatening this rather scarce commodity, resulting in competition between agricultural and industrial purposes, urban planning and nature conservation.[16]

Acknowledgements

The author would like to acknowledge the efforts of the Sustainable Growing New Zealand, Soil Foodweb New Zealand and Delta in association with the Golden Gate Lodge, Cromwell for putting on a stimulating two day seminar in Cromwell in June this year. The seminar was titled 'Farming Soil – Starting Today'. From this seminar the author meet a myriad of interesting people and gained inspiration for this resource.

Special mention to Cherryle Prew of Soil Foodweb New Zealand, and Ray Annan of Sustainable Growing Solutions who are walking me through how to farm biologically.

At the seminar the author met Dr. Christine Jones. At the seminar the author was still largely a skeptic of alternative methods to farming but Dr. Jones presented the scientific foundation to how soils work such that his taste buds were teased.

Acknowledgement also to Nicole Masters who is at the forefront of soil farming education in New Zealand and although the authors contact with her was brief, armed with a better understanding of the material he has little doubt there will be more contact in the future.

Contents

Introduction

This resource focuses on 'Soil Carbon Sequestration'. Is it possible to sequester carbon in soils? How? What are the upsides to doing so? Could the carbon sequestered in soils enter the Emissions Trading Scheme and be traded?

Like soils are the foundation to our very being, this resource is the foundation to the knowledge required to further investigate the practicalities of farming for carbon and incorporating soil carbon in a tradable scheme. The endeavor of this resource is to provide a broad understanding of the science behind the formation and storage of carbon in soils and touches on why we should, or need to do it.

The author, Edward Percy, is a farmer who has applied conventional methods of farming all his life. Edward leases a 1,000 hectare family farm in the Wairarapa in partnership with the farm manager, and manages a small sheep farm in Central Otago. He has a degree in commerce, is a registered valuer, and has practiced as a valuer for a number of years in both urban and rural environments. So, on the outside he appears to epitomize a kiwi male, conventional and solid in his methods. But convention needs to be challenged when learning and observation dictate the need for a different approach. So as part of his study he has incorporated some of what he has learnt into how he practices as a farmer, and how he manages the land and most importantly the soils that are the foundation to its existence.

Ingrained in the authors being is a desire to go back to the beginning and thoroughly understand how things work. For a farmer soils are the beginning. Very topical now is the ETS. Also pertinent is the increasing cost of farming which is tampering with profit margins and ultimately survival of farm businesses. So by studying soils and how they could feature in the ETS, and at the same time how soils can increase the quantity and improve the quality of the goods produced on farm, this resource is fundamental to farming in the future.

The author took this topic on, looking at it from a layman's point of view. Meaning as an agricultural farmer, a custodian of farmland, and a farm business owner. So key to him buying into what soil carbon sequestration can do for farming in New Zealand he needs to be assured that profitability could be maintained, if not enhanced, be assured that future generations of the land he farms can live off it, and be assured that whatever grows on his land is as healthy as possible.

Executive Summary

The importance of this resource is in firstly understanding the natural biological processes in our soils that act to capture carbon as part of the carbon cycle and secondly, how do we farm to sequester carbon and what are the benefits/reasons for doing so. Ultimately this forms the basis for discussion into how New Zealand farmers can move forward into an era of carbon trading, pollution policing, and productivity pressure.

This resource begins with a simplified look at the carbon cycle, one of the most important processes for life on earth. Then it looks at what soil carbon actually is and how it is cycled through the process of photosynthesis, the only way carbon can be cycled. Once the cycle of carbon is understood it moves onto a more in-depth look at soils and what is called the 'Soil Food Web', the web of microorganisms that design the makeup of the soils. More specifically the part that Mycorrhizal Fungi plays in sequestering carbon. This section helps you understand how carbon works in the soils and forms the basis for the more practical part of this resource which is applying it to New Zealand Farming.

At this point this resource has established that carbon can be sequestered in soils. Now it works through how it is sequestered, and what it means by that is what farming practices are needed to sequester carbon, for example – grazing management practices, no-till farming, groundcover, water management, biological farming, composting, and trees. What are the reasons/benefits that warrant practicing to sequester carbon i.e. becoming carbon farmers.

This resource touches on soil carbon as a tradable resource in a carbon trading scheme and provides some examples of what is happening overseas but draws short of providing a conclusion on how this could be implemented and/or whether it should.

The goal of this resource is to provide UNDERSTANDING about Soil Carbon Sequestration and from that, makes a call on whether New Zealand farmers need to be taking more notice or not.

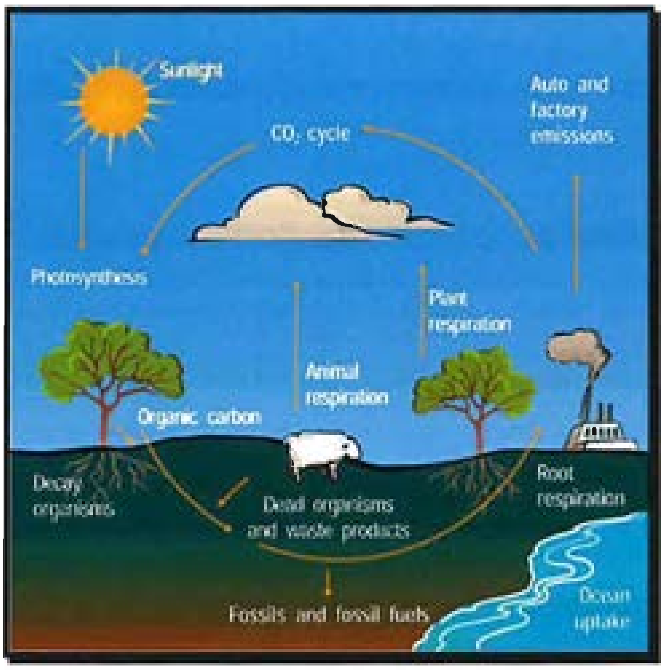
Biological Process of Carbon in Soils

This section of the resource explains the journey that carbon takes to become stable in soils. It explains the carbon cycle, the process of photosynthesis, the food web in soils, Mycorrhizal Fungi that uses carbon gifted by plants and in-turn feeds the plants, and humus. This is a scientific endeavor by an author of unscientific background but use of contacts made during the year and the massive array of resource written on the internet, in magazines and books has made it possible.

The Carbon Cycle

The carbon cycle is the life source of life. Sunlight energy, ground water, atmospheric CO_2, and plants conspire to make life happen through photosynthesis. Photosynthesis converts these components to glucose in the plant which, through a number of chemical reactions converts to carbohydrates, proteins, fats, feeding the plant itself and its roots. From the root of the plant a complex array of things occurs exchanging carbon for nutrients. The soil food-web makes this occur through various exchanges of food and excrement, and conversion of food into plant available nutrients, also aerating the soils and building structure. Organic matter is created when plants die, or are grazed, and when animals excrete, which the soils also consume and build on. Carbon is released back into the atmosphere through the breaking down of organic matter, from respiration of animals, and respiration of plants and plant roots. CO_2 is also released by industry. Carbon is also stored in the soil under the right conditions.

Carbon exists in the environment (non-living environment) as carbon dioxide (CO2) in the atmosphere and dissolved in water forming HCO3-, carbonate rock (limestone and coral), deposits of coal, petroleum, and natural gases derived from once-living things, and dead organic matter e.g. Humus in the soil. Carbon enters the living world primarily through photosynthesis of plants and algae that use the energy of light to convert carbon dioxide to organic matter. Carbon returns to the atmosphere and water by respiration (as CO2), burning, decay (producing CO2 if oxygen is present, methane CH4 if it is not).[1] This is what is called the carbon cycle:



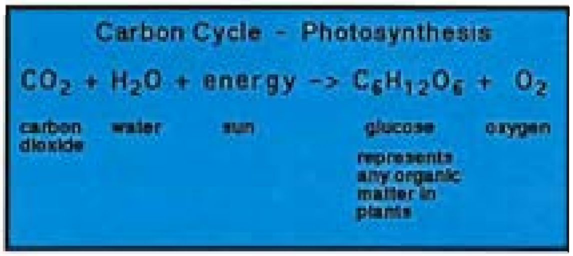
'Photosynthesis is the only process that can take CO2 out of the atmosphere. It separates the C atom from the O atoms, releasing Oxygen and incorporates the C in the plant, or transfers it to the soil where it becomes humus or other forms of Carbon. Some of it is released into the air if plants die and oxidize or dry out, or rot, releasing C in the form of methane. Soil Carbon takes two main forms:'[2]

1. 'Decomposed bodies of microbes such as bacteria, fungus, nematodes and root systems that die when plants are grazed as well as other decomposed plant residues. These forms of Carbon can be cycled quickly, within weeks. This is called "Labile" carbon.'[2]

2. 'The Carbon that is incorporated into the soil itself, such as humus. In these forms it can remain stable for thousands of years. Total Organic Carbon is the amount of C stored in the soil. It can be measured very accurately. While soil carbon is subject to "flux" – different amounts can be measured according to time of day, time of year, and weather conditions – averaging techniques make assessing the amount of increase or decrease in soil C percentage possible.' [2]

Dr. Christine Jones – "There is a carbon pathway from gas, as carbon dioxide, which has to be fixed in leaves as glucose, which is liquid. It goes through the plant and then, to come out of the roots, you have to have microbial associations around the roots that then take that into the soil, in particular, mycorrhiza that use that carbon."[3]

<u>Photosynthesis – From light to sugar</u>

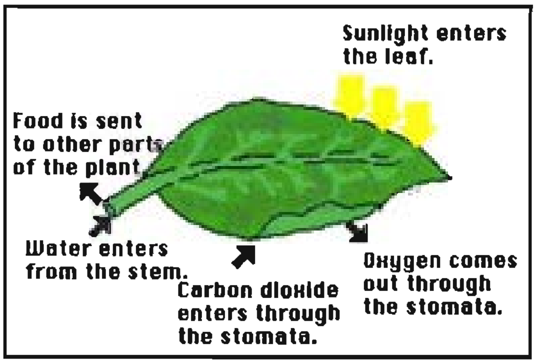


Photosynthesis is the great converter of sun, air and water into life, feeding us all, and the most important part in the creation of carbon in our soils.

Photosynthesis is the process that incorporates enzymes in leaves, CO2 from the air, water H2O, and light energy.[21]

'A major part of the carbon cycle occurs as carbon dioxide is converted to carbohydrates through photosynthesis. Carbohydrates are utilized by animals and humans in metabolism to produce energy and other compounds.'[21]

'Animals inhale oxygen and exhale carbon dioxide. Green plants are the only plants that produce oxygen and make food, which is called photosynthesis. Photosynthesis means



"putting together with light." This takes place in chloroplasts, which have chlorophyll in them. Chlorophyll absorbs the sunlight. From sunlight, green plants combine carbon dioxide and water to make sugar and oxygen. Green plants use sugar to make starch, fats, and proteins. There are tiny pores called stomata. Carbon dioxide and oxygen enter and leave through the stomata respectively.'[22]

We can write the overall reaction of this process as:

$$6H_2O + 6CO_2 + \text{Energy} \text{ ----------> } C_6H_{12}O_6 + 6O_2$$

General names for **carbohydrates** include sugars, starches, saccharides, and polysaccharides. The name "carbohydrate" means a "hydrate of carbon." [21]

'Photosynthesis requires 15MJ of sunlight energy for every kilogram of glucose produced. If the same 15MJ of incoming light energy makes contact with a bare surface, such as bare ground, it is reflected, absorbed or radiated - as **heat**, usually accompanied by moisture. Thus the respective area of the earth's surface covered by either actively growing crops and pastures, or bare ground, has a significant effect on local, regional and global climate.'[8]

'Through a myriad of chemical reactions, the glucose formed during photosynthesis is resynthesized to a wide variety of carbon compounds, including carbohydrates (such as cellulose and starch), proteins, organic acids, waxes and oils. Carbon atoms can link together to form long chains, branched chains and rings, to which other elements, such as hydrogen and oxygen, can join. The energy captured during photosynthesis and stored in carbon compounds serves as 'fuel' for life on earth. Carbohydrates in grasses, fruits, vegetables and grains provide energy for animals and people - and carbon stored in previous eras as 'fossil fuels' (hydrocarbons) such as coal, oil and gas - provides energy for vehicles, machinery and industry.'[8]

Soil Food Web

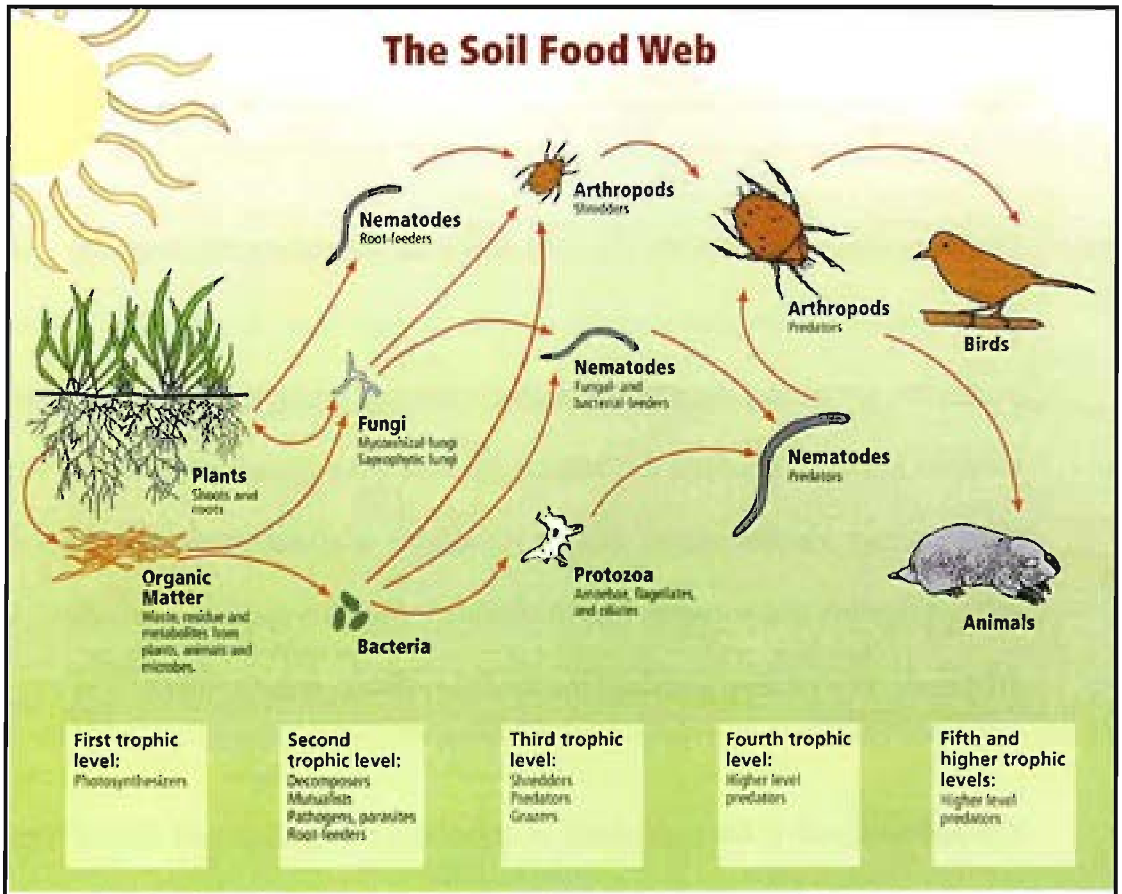
Diving now beneath the surface we delve into the underworld, dirt. The diversity of a healthy soil is amazing. Photosynthesis converts light energy, CO2 gas and water into a carbohydrate liquid that flows through a plant, to its roots and exchanges sugars and protein for nutrients in the soil. These nutrients are made available by the soil food-web through an intricate recycling and conversion system, building a soil structure that not only provides nutrients but cleanses and controls water, and stabilizes the land. Following are excerpts from the "Soil Biology Primer" published by Soil and Water Conservation Society in Cooperation with the USDA Natural Resources Conservation Service, providing an understandable synopsis of what makes up the soil food-web:

> An incredible diversity of organisms makes up the 'soil food web'. These organisms range in size from the tiniest one-celled bacteria, algae, fungi, and protozoa, to the more complex nematodes and micro-arthropods, to the visible earthworms, insects, small vertebrates, and plants.

As these organisms eat, grow, and move through the soil, they make it possible to have clean water, clean air, healthy plants, and moderated water flow.

There are many ways that the soil food web is an integral part of landscape processes. Soil organisms decompose organic compounds, including manure, plant residue, and pesticides, preventing them from entering water and becoming pollutants. They store nitrogen and other nutrients that might otherwise enter groundwater, and they fix nitrogen from the atmosphere, making it available to plants. Many organisms enhance soil aggregation and porosity, thus increasing infiltration and reducing runoff. Soil organisms prey on crop pests and are food for above-ground animals.

The soil food web is the community of organisms living all or part of their lives in the soil. A series of conversions of energy and nutrients, as one organism eats another, demonstrates the soil food web in the diagram below. All food webs are fueled but the primary producers: the plants, lichens, moss, photosynthetic bacteria, and algae that use the sun's energy to fix carbon dioxide from the atmosphere. Most other soil organisms get energy and carbon by consuming the organic compounds found in plants, other organisms, and waste by-products. A few bacteria, called chemoautotrophs, get energy from nitrogen, sulphur, or iron compounds rather than carbon compounds or the sun. As organisms decompose complex materials, or consume other organisms, nutrients are converted from one form to another, and are made available to plants and to other soil organisms. All plants – grass, trees, shrubs, agricultural crops – depend on the food web for their nutrition.



Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html.

Growing and reproducing are the primary activities of all living organism. As individual plants and soil organisms work to survive, they depend on interactions with each other. By-products from growing roots and plant residue feed soil organisms. In turn, soil organisms support plant health as they decompose organic matter, cycle nutrients, enhance soil structure, and control the populations of soil organisms, including crop pests.

Organic matter fuels the food web. Soil organic matter is the storehouse for the energy and nutrients used by plants and other organisms. Bacteria, fungi, and other soil dwellers transform and release nutrients from organic matter. Organic matter is many different kinds of compounds – some more useful to organism than others. In general, soil organic matter is made of roughly equal parts of humus and active organic matter. Active organic matter is the portion available to soil organisms. Bacteria tend to use more simple organic compounds, such as root exudates or fresh plant residue. Fungi tend to use more complex compounds, such as fibrous plant residues, wood, and soil humus.

Intensive tillage triggers spurts of activity among bacteria and other organisms that consume organic matter (convert it to $CO2$), depleting the active fraction (active fraction organic matter: organic compounds that can be used as food by microorganisms. The active fraction changes more quickly than total organic matter in response to management changes).

Practices that build soil organic matter (reduced tillage and regular additions of organic material) will raise the proportion of active organic matter long before increase in total organic matter can be measured. As soil organic matter levels rise, soil organisms play a role in its conversions to humus – a relatively stable form of carbon sequestered in soils for decades or even centuries.

Where do soil organisms live? The organisms of the food web are not uniformly distributed through the soil. Each species and group exists where they can find appropriate space, nutrients, and moisture. They occur wherever organic matter occurs – mostly in the top few inches of soil, although microbes have been found as deep as 10 miles (16 km) in oil wells. Soil organisms are concentrated:

Around roots: The biosphere is the narrow region of soil directly around roots. It is teeming with bacteria that feed on soughed-off plant cells and the proteins and sugars released by roots. The protozoa and nematodes that graze on bacteria are also concentrated near roots. Thus, much of the nutrient cycling and disease suppression needed by plants occurs adjacent to roots.

In litter: Fungi are common decomposers of plant litter because litter has large amounts of complex, hard-to-decompose carbon, fungal hyphae (fine filaments) can "pipe" nitrogen from the underlying soil to the litter layer. Bacteria cannot transport nitrogen over distances, giving fungi an advantage in litter decomposition. However, bacteria are abundant in the green litter of younger plants, which is higher in nitrogen and more simple carbon compounds than the litter of older plants. Bacteria and fungi are able to access a larger surface area of plant residue after shredder organisms, such as earthworms, millipedes, and other arthropods, break up the litter into smaller chunks.

On humus: Only fungi make some of the enzymes needed to degrade the complex compounds in humus. Much organic matter in the soil has already been decomposed many times by bacteria and fungi and/or passed through the guts of earthworms or arthropods. The resulting humic compounds have little available nitrogen.

On surface of soil aggregates: Biological activity, in particular that of aerobic bacteria and fungi, is greater near the surfaces of soil aggregates than within aggregates. Within large aggregates, processes that do not require oxygen, such as denitrification, can occur.

In spaces between soil aggregates: Those anthropods and nematodes that cannot burrow through soil move in the pores between soil aggregates.

When are they active? In temperate systems, the greatest activity occurs in late spring when temperature and moisture conditions are optimal for growth. However, certain species are most active in the winter, others during dry periods, and still others in flooded conditions.

Many different organisms are active at different times and interact with one another, with plants, and with the soil. The combined result is a number of beneficial functions, including nutrient cycling, moderated water flow, and pest control.

Mycorrhizal Fungi

Mycorrhizal fungi are fundamental in the transportation of carbon to the soils from plants. This fungi attaches to roots and while grabbing nutrients form the soil to feed the plant simultaneously take sugars (which have carbon) from the plants to donate to the soils.

'Mycorrhizae are a group of naturally occurring fungi that have a symbiotic relationship with plants and trees. The fungi send out thread-like growths to the soil, where they extract nutrients for themselves. The fungi pass these nutrients on to roots, which in turn support the fungi by providing them with nourishing fluids.' [4]

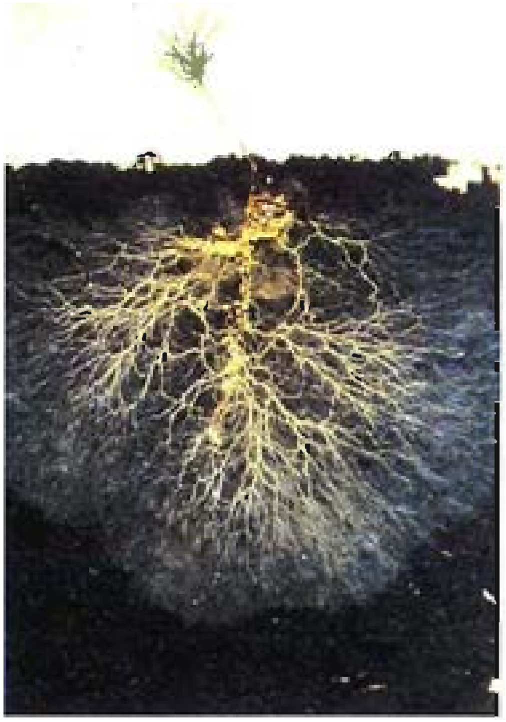
The word "mycorrhiza" (plural: mycorrhizae or mycorrhiza) comes from the Greek language and literally means "fungus roots." [4]

'Mycorrhizal fungi are tiny, harmless critters that attach themselves to plant roots and actually help plants to make use of water and organic nutrients in the soil. They live on the roots of roughly 95% of all earth's plant species. In exchange for what they provide the plant, the plant offers the fungi a meal of sugars (fixed carbon) produced by the photosynthesis process.'[4]

'This is like having a second set of roots for the plants. Thus, plants, trees, and shrubs with a well-established mycorrhizal fungal root system are better able to survive droughts and transplant shock. They also absorb more nutrients from the soil. Mycorrhizal fungi also boost a plant's immune system, making them resistant to soil-borne pathogens. In addition, they help to keep parasitic nematodes away. The fungi can help the plants' uptake of phosphorus in the soil, and the increased surface area of the roots increase plants' ability to draw water from parched soils – drought resistance.'[4]

'Carbon is the currency for most transactions within and between living things. Nowhere is this more evident than in the soil. Here, carbon is king. Mycorrhizal fungi, which are totally dependent on dissolved organic carbon from green plants, trade carbon with colonies of bacteria located at their hyphal tips in exchange for macro-nutrients such as phosphorus, organic nitrogen and calcium, trace elements such as zinc, boron and copper, and plant growth stimulating substances (Killham 1994, Leake *et al.* 2004).'[5]

In the picture adjacent the tiny filaments of mycorrhizal fungi extending from a plant's roots illustrate this symbiotic relationship, dramatically increasing a plant's ability to collect moisture and nutrients.[8]



Exudation[8]

Around 30-40% of the carbon fixed by grass plants during photosynthesis can be exuded into soil to form a microbial bridge - that is - to nurture the microbes that enhance the availability of essential plant nutrients. In this way, actively growing crops and pastures provide 'fuel' for the soil engine. Carbon compounds and the microbial populations they support are essential to the creation of topsoil from the structureless, lifeless mineral soil produced by the weathering of rocks. However, exudation does not occur to any significant extent if high rates of water-soluble nutrients such as phosphorus and/or nitrogen have been applied. These high analysis fertilisers disrupt the sensitive biochemical signalling mechanisms between plants and soil microbes. Provided the microbial bridge is intact, organic carbon additions are governed by the volume of plant roots per unit of soil and their rate of growth. The more active green leaves there are, the more healthy roots there are, the more carbon is exuded. The breakdown of fibrous roots pruned into soil through rest-rotation grazing can also be an important source of carbon in soils.[8] See the photo above showing an example of how root systems change with the amount of green leaf above the ground.

The dark coloured carbon sequestered around the roots of perennial grasses is readily observed in light coloured soils. (Photo Christine Jones).[8]

Humus

Humus, which is mostly made up of carbon, is the end result of a decomposition process (humification) of organic matter. Organic matter is mostly plant residue and animal remains. The humification process supplies the soil food web with nutrients which are in-turn made available to plants. Bacteria, fungi, protozoa, nematodes, anthropods, all dine on organic matter converting it to nutrient available for the next in the food web chain. Humus is the end of the chain; organic matter that has reached a point of stability.

'In soil science, humus refers to any organic matter that has reached a point of stability, where it will break down no further and might, if conditions do not change, remain essentially as it is for centuries, if not millennia.'[6]

'It is a complex mixture including proteins, lignin (plant cell walls); fats, carbohydrates, and organic acids. These acids, humic acids and chelates, provide a storehouse of essential plant nutrients. It helps make some nutrients more soluble and available to plants. It provides high water absorption and holding capacity and contributes to good soil structure. It buffers the soil and protects plants from drastic changes in pH.'[7]

'Sequestering organic carbon in soil is one thing. Keeping it there is another. Soil carbon moves between various 'pools', some of which are short-lived while others may persist for thousands of years. The active sequestration of atmospheric carbon is most effective when combined with land management practices and biology friendly fertiliser strategies that enhance the soil food-web and foster the conversion of relatively transient forms of organic carbon to more stable forms. If soil is of high ecological integrity, soil microbes, especially fungi, resynthesise and polymerise labile carbon (mostly exuded from plant roots) into high molecular weight stable complexes, referred to collectively as humic substances. Humus, a gel-like substance that forms an integral component of the soil matrix, is the best known of the long-lived stable organic fractions. Humus is composed of large, complex molecules made up of carbon, nitrogen, soil minerals and soil aggregates. It is an inseparable part of the soil matrix that can remain intact for hundreds, sometimes thousands, of years. Humified carbon differs physically, chemically and biologically from the labile pool of organic carbon that typically forms in agricultural soils. Labile organic carbon arises principally from biomass inputs (such as crop residues) which are readily decomposed. Conversely, most humified carbon derives from direct exudation or transfer of soluble carbon from plant roots to mycorrhizal fungi and other symbiotic or associative micro flora. Once carbon is sequestered as humus it has high resistance to microbial and oxidative decomposition.' [8]

'The humification process does not occur in most broadacre agricultural production systems, due to lack of the year-round green leaves required to fuel the photosynthetic process and maintain vital components of the soil food-web. In the absence of humification, the carbon exuded from plant roots (or added to soil as plant residues, manure or compost) simply oxidises and recycles back to the atmosphere as carbon dioxide. Humic substances have significance above and beyond the relatively long-term sequestration of atmospheric carbon. They are extremely important in terms of pH buffering, inactivation of pesticides and other pollutants, improved plant nutrition and increased soilwater- holding capacity. By chelating salts, humic substances can also effectively ameliorate the symptoms of dryland salinity. Increasing the natural rate of humification in soil therefore has highly significant benefits for the health and productivity of agricultural land.'[8]

<u>Soil Carbon</u>

'Soil Carbon is one of the many resting places of Carbon as it cycles throughout the biosphere (the livable area on the planet – "The place on earth's surface where life dwells"). Carbon is the basic chemical building block of all life on Earth. It also resides in mineral form in rock formations and in fossil fuels, such as coal and oil, as well as in the ocean. The amount of Carbon on Earth is fixed. So the many processes of nature that use it need to access a supply of it and have somewhere to let it go. The result is a cycle as Carbon moves between the oceans, rocks, soils and atmosphere.'[9]

'There are 38,000 Gigatonnes (Gt) of carbon stored in the oceans, 2,500 Gt/C in soil, 750 Gt/C in the atmosphere, and 650 Gt/C in forests, grasslands, and other vegetation. (The

Greenhouse effect is caused by the cycle getting out of balance, resulting in the atmosphere housing more on a rolling basis than it was designed to hold in order to manage stable weather patterns.)' [9]

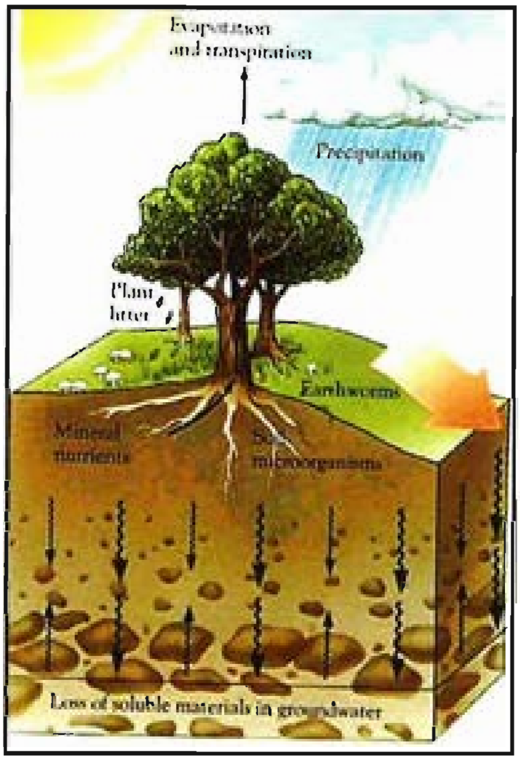
It has been researched and noted that organic matter levels were much higher in the mid 1800's than they are now.

> Noted Polish explorer and geologist, Sir Paul Edmund [Count] Strzelecki, travelled widely through the colonies of south-eastern Australia during the period 1839 to 1843, collecting minerals, visiting farms and analysing soils. One of the questions Strzelecki posed was what factors determine soil productivity? He collected 41 soil samples from farmed paddocks of either high or low productivity. The analyses revealed that the most important determinant of soil productivity was the level of soil carbon (measured as organic matter in Strzelecki's day).[10]
>
> Of the 41 samples analysed, Strzelecki (1845) found ...
>
> - The top 10 soils in the high productivity group had organic matter levels ranging from 11% to 37.75% (average 20%). The lowest ranking 10 soils in the low productivity group had organic matter levels ranging from 2.2% to 5.0% (average 3.72%)[10]
>
> - The soils with the highest organic matter levels also had the highest moisture holding capacity, with an 18-fold difference in capacity to hold moisture between the lowest and the highest (Strzelecki 1845). [10]

Strzelecki's data indicate that organic matter levels in the early settlement period were around five to ten times higher than in many soils today. The soil test data from Strzelecki is consistent with the writings of first settlers, who described soils in the early settlement period as soft, spongy and absorbent. The 1840s journal of George Augustus Robinson, for example, contains numerous references to the extremely fertile and productive soils encountered by pastoralists in the mid-1800s (Presland 1970).[10]

Soil carbon and soil moisture

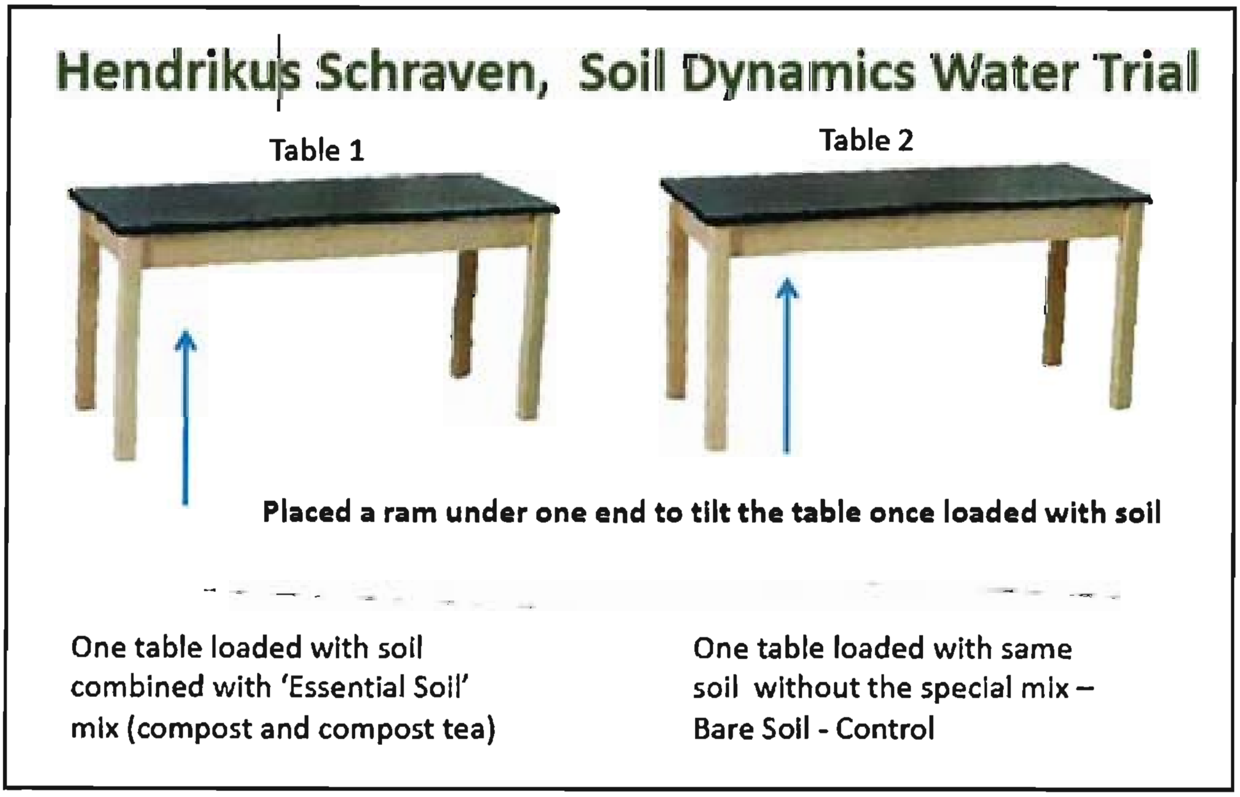
'In addition to enhancing nutrient availability, carbon performs many other functions in soil, including the maintenance of soil porosity, aeration and water-holding capacity. Glenn Morris (Morris 2004) extensively researched the water holding capacity of humus (an extremely stable form of soil carbon) and concluded that within the soil matrix, one part of soil humus could, on average, retain a minimum of four parts of soil water. From this relationship it can be calculated that an increase of 16.8 litres (almost two buckets) of **extra** plant available water could be stored per square metre in the top 30 cm (12") of soil with a bulk density of 1.4 g/cm3, for every 1% increase (in absolute terms) in the level of soil organic carbon. This equates to 168,000 litres of water that could be stored per hectare, in **addition** to the water-holding capacity of the soil itself (Jones 2006).'[11]



'The flip side is that the same amount of water-holding capacity will be lost when soil carbon levels fall. Low soil moisture and low levels of soil organic carbon go hand in hand. Soil organic carbon levels in many areas have fallen by at least 3% (in absolute terms) since the time of European settlement, **This reduction in soil carbon content represents the LOSS of the ability of soil to store around 504,000 litres of water per hectare.'**[11]

The greatest problem for a lot of hill country farms with regard to their soils is slipping. The current solution is planting trees. But by planting vast areas in trees takes good sheep & beef country out of production for a long time, if not indefinitely. Trees are the most efficient converter of CO_2 to carbon so as far as the ETS is concerned it has merit.

A good biologically healthy soil can prevent slipping however. As can be seen from the pictures below the ability of a soil, that is more biologically alive, to retain water and not slip is significant:



Hendrikus Schraven, Soil Dynamics Water Trial

Table 1 Table 2

Rain Events Applied: Collection devices to collect sediment and water

3 x 10 year storm events applied. Ie

5mm /hour for 30 minutes
40mm/hour for 40 minutes
5mm /hour for 30 minutes

At the end of this they applied a 50 year storm event.

5mm/hour for 30 minutes
50mm/hour for 30 minutes
5mm/hour for 30 minutes.

Hendrikus Schraven, Soil Dynamics Water Trial

Table 1 Table 2

- **Soil Loss from the Treated Table (1) was 98% less than Bare Soil Table 2.**
- **Treated Table (1) had 32% less water run-off than Bare Soil Table 2.**
- **Side issue: Water Run-off water of better quality than the initial water source used for the trial.**

Check out for more detail; http://www.hendrikus.com

So if New Zealand hill country soils were biologically alive then as well as preventing the occurrence of slipping they can still produce under a pastoral farming operation, which is arguably a more intensive and productive use of the land, and also potentially eligible for carbon credits for carbon sequestered.

Capturing just 1mm more rain per year means:[15]

- 1 litre more usable water per square kilometre
- 10,000 litres more water per hectare
- 1,000,000 litres more per square kilometre
- Less drought, because more water stays in the soil to recharge rivers, springs and wells
- More forage, because plants can also use that water

Fertiliser

On the whole it is considered detrimental to the soil food web to fertilise with conventional fertilisers such as Super Phosphate or Urea. "Nature doesn't provide what it doesn't need" says local soil scientist Cherryle Prew of Soil Food Web New Zealand. If phosphate is applied to the soils then the mycorrhizal fungi dies away because it is not needed. Likewise if Urea is applied then the nodules on the roots of nitrogen fixing plants such as clovers dissipate due to not being required. So the chain in the food web is broken and soils suffer as a consequence. Carbon cannot be stored in the soil as a consequence.

The CSIRO (Commonwealth Science and Research Organisation) reported that conventional fertilisers contribute to the loss of drought-resistant native perennial grasses which are critical in the sequestering of carbon in pasture soil.[17]

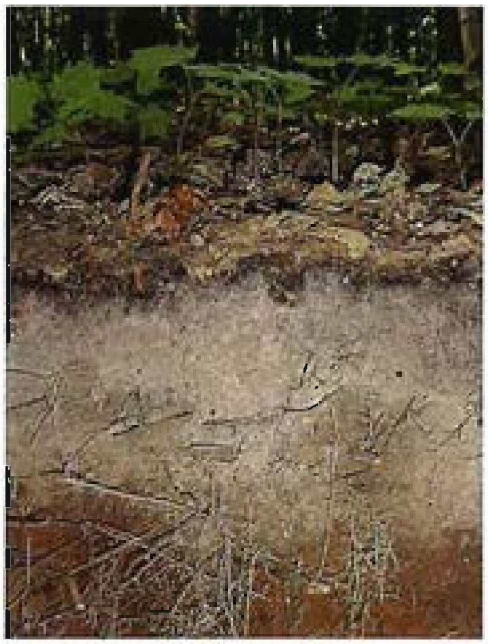
'Fertiliser inputs means grazing pressure has to be increased to get higher returns to cover the input costs. "Pastures tend to lapse towards annual dominance under these conditions and erosion risks increase." Some native perennial grasses are fertiliser tolerant.' [17]

So if we are going to apply fertilizer, especially nitrogen, what is the best practice. 'Best practice nitrogenous fertilizer management includes choosing a fertliser containing ammonia instead of nitrates, avoid applying nitrogenous fertilizer when soils are warm and/or water logged, avoid applications of nitrogenous fertilisers to non-north-facing slopes during warmer seasons, apply nitrogenous fertilisers only when rye plants are at least 2-leaf stage, cocksfoot at 3-leaf.' [17]

'Mycorrhizal fungi and associative bacteria are very strongly inhibited by excessive soil disturbance and the high levels of water-soluble phosphorus and nitrogen commonly used in modern agriculture (Killham 1994, Leake *et al.* 2004). Where soils have been subjected to cultivation and/or the application of MAP, DAP, superphosphate, urea or anhydrous ammonia, the suppressed mycorrhizal colonisation of plant roots significantly reduces carbon flow. The structural degradation of agricultural soils, accompanied by mineral depletion in food, has largely been the result of the inhibition of this natural carbon pathway. When carbon supply is limited by the loss of the primary pathway for sequestration, the physical, chemical and biological functions normally performed by healthy soil are markedly reduced.'[11]

Soil Carbon Sequestration

Carbon Sequestration



'What is Soil Carbon Sequestration? Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately reemitted. This transfer or "sequestering" of carbon helps off-set emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity. Soil carbon sequestration can be accomplished by management systems that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil fauna activity. Continuous no-till crop production is a prime example.'[12]

Carbon sequestration is 'The process of removing carbon from the atmosphere and depositing it in a reservoir.[14]

Modification of agricultural practices is a recognized method of carbon sequestration as soil can act as an effective carbon sink offsetting as much as 20% of 2010 carbon dioxide emissions annually.[13]

Carbon Farming

There are methods farmers can use to encourage the soil processes discussed above that increase soil carbon and improve the quality of our soils, and in-turn plants, water and animals. Below is an excerpt from the Carbon Farming Handbook 2009 detailing the various farm management practices that help increase the ability of the soil to build and hold soil carbon:

> Carbon farming is a new way to describe a collection of techniques which can increase soil organic carbon in agricultural land. Land management practices that encourage healthy, growing soil microbial communities and, in so doing, create soil organic carbon and strengthen the natural resource base, include the following:
>
> - 100% Ground Cover 100% of the time – this is a carbon farmer's goal. Soil covered by plants cannot be blown or washed away. It is cooler and more attractive to microbes than if it was exposed to the sun. Therefore overgrazing, (or "flogging the land", in Australian parlance) and burning grasses and stubble and ploughing are anti-carbon actions. In fact, they release tonnes of carbon into the atmosphere. These practices, along with clearing native vegetation and methane emissions, have put Agriculture officially in 2nd glance, behind oil-burning energy, as the biggest source of Australia's Greenhouse Gas emissions.
>
> - Grazing Management – stock are concentrated in small paddocks for short periods (days) so that they graze evenly and at the same time till the soil with their hooves, stomping old grass and manure into it. The plants are then left to grow a full head of foliage sot that their roots go down as far as possible in the soil. When they are grazed, the roots die back upwards in proportion to how much of the foliage was

eaten, Overgrazing can cause the roots to shrink so short they struggle to get started again. So short grazing periods and long periods of rest are best.

- No till cropping – ploughing disturbs the microbes and dries out the topsoil. It also releases tonnes of CO2 per hectare. No till techniques sow the seed in the top soil without tearing off the existing foliage or applying herbicides which are also bad for microbes. There are several no till techniques, including "Pasture Cropping" and "Advanced Sowing". One direct drills the seed into pasture while the other slices a line though the pasture and inserts the seed. The crop grows up above the pasture and can be harvested or grazed. The pasture usually thickens and grows more vigorously after such treatment.

- Mulching – this takes two forms: 1. covering bare earth with hay or dead vegetation. This protects the soil from the sun, cools it, and attracts soil producing microbes. It also holds water where it can be used instead of letting it run off immediately. 2. Cutting down and desiccating tall, dead plants and thistles to form a layer of litter on the soil and allow the sun to penetrate and foster plant growth. Gardeners know the value of mulching.

- Water Management Systems – Water is essential to the carbon growing process. Several systems have emerged for maximizing use of water that falls on a farm. Two names are prominent: Natural Sequence Farming (NSF) and Yeoman's Keyline System. NSF slows the flow of water through the landscape by returning eroded gully's and creeks to swampy meadows and chains of ponds that they were when white settlers arrived. The water stays long enough to make more grass and plants grow, rather than rushing down widening gullies carrying the topsoil away.

NSF is based on the natural topography of the land. So is Keyline Planning. It uses the shape of the land to determine the layout and position of farm dams, irrigation areas, roads, fences, farm buildings and tree lines. Both methods increase soil fertility and carbon.

- <u>Biodynamics</u> – this is a method of treating soil, based on the theories of mystic and theorist Rudolf Steiner. He postulated that vital forces or energies flowed throughout the universe and that these can be harnessed to increase plant growth. Biodynamics adopts a homeopathic approach to preparing natural fertilizer and times activities to align with cycles of the moon and the stars. Many ordinary, sober farmers report great results with biodynamic preparations.

- <u>Biological Farming</u> – this is the umbrella term for the use of natural compounds to stimulate biological activity in the soil. These compounds range from compost teas (distilled after analysis of the soil for deficiencies), worm juice (active enzymes created from worm castings), Biosolids (human effluent) which needs to be plowed into the soil for hygiene and odour reasons (not a favourite of carbon farmers), Nitrohumus (treated human effluent, needs no ploughing), probiotics (beneficial microbes brewed for a long time in a food source medium) etc.

- <u>Composting</u> – this largely involves breaking down manure into a rich humus ready to spread on the fields. There is also a growing movement for recycling green wastes from cities for use on agricultural lands.

- <u>Trees</u> – Trees scattered across grasslands ("Grassy woodlands") provide shelter for stock and wildlife and also have the effect of causing the soil adjacent to be richer in carbon. They can also assist in water management. And they help lift yields and productivity in both livestock and crops, with increases of between 20% and 40%.

Each of these methods is a natural, sustainable way to enhance activity in the soil and build soil carbon.

Maintaining soil structure

Once we have a soil that is active and structurally supporting the carbon cycle we need to keep it that way. Sequestering carbon to offset greenhouse gases is one reason why it is good to maintain the soil structure that keeps carbon sequestered, but there are other benefits that improve the ability of the soils to support what grows in them to reward the plants for their part in the carbon cycle.

'Soil structure is not permanent. Aggregates made from microbial substances are continually breaking down and rebuilding. An on-going supply of energy in the form of carbon from the rhizosphere exudates of actively growing plant roots will maintain soil structure. If soils are left without a cover of green plants for long periods they become compacted - or in the case of light soils - blow or wash away.'[18]

'Soil building requires green plants and soil cover for as much of the year as possible. A mix of warm-season and cool-season perennials enables response to rain at any time. In grazing enterprises, rest-rotation management is absolutely essential. For broadacre cropping, the presence of out-of-season groundcover ensures stability, long term productivity and soil building - rather than soil destruction.' [18]

'**Any farming practice that improves soil structure is building soil carbon.** When soils become light, soft and springy, easier to dig or till and less prone to erosion, waterlogging and with less dryland salinity - then organic carbon levels are increasing. If soils are becoming more compact, eroded or saline - organic carbon levels are falling. Water, energy, life, nutrients and profit will increase on-farm as soil organic carbon levels rise. The alternative is evaporation of water, energy, life, nutrients and profit if carbon is mismanaged and goes into the air.' [18]

Measuring Soil Carbon

"Can the amount of carbon sequestered in our soils be measured?" This is probably the first question the author is asked when discussing soil carbon sequestration. New Zealand's Emissions Trading Scheme incorporates forests as sequesters of carbon and thus tradable under the scheme. Physical measurement of carbon locked up in trees can be done but the ETS has provided a guideline for the calculation of carbon in a forest without having to physically visit the forest. The guideline is based primarily on the age of the forest.

Soils can be measured. There is several soil carbon trading/reward schemes available in Australia. In one, the "Australian Soil Carbon Accreditation Scheme", a hydraulically operated coring tube mounted on the back of a flat deck vehicle, can drill to over one metre.

'The cores that are extracted are analysed for bulk density and total soil carbon concentration (%). The soil carbon stock (tC/Ha) is the cumulative total determined by multiplying (%) by the bulk density for each depth of a sample – there are eight different depths drilled. Tonnes of carbon dioxide equivalent sequestered per hectare (tCO2-e/ha) is calculated by multiplying the carbon stock by 3.67. Every tonne of carbon lost from soil adds 3.67 tonnes of carbon dioxide to the atmosphere. Conversely, every one tonne increase in soil carbon represents

3.67 tonnes of carbon dioxide sequestered from the atmosphere and removed from the greenhouse equation.'[8]

A promising innovation in soil carbon measurement has been the calibration of Laser Induced Breakdown Spectroscopy, or LIBS, which provides an easy-to-use portable approach for reliable field assessment of the carbon content of soils (DOE/Oak Ridge National Laboratory, 2009). The simplicity and portability of the LIBS technique for the determination of soil carbon enables greater flexibility than the current laboratory based techniques. [8]

'We can measure the soil carbon pool with a range of analytic techniques. Traditionally this has involved field sampling and then lab work that needs to run for weeks. CSIRO has developed a simple, fast and inexpensive technique for measuring carbon in soils. Using mid-infrared (MIR) spectroscopy, CSIRO has been able to generate a spectra or 'fingerprint' of any soil. This creates a picture of the various minerals and organic carbon amounts in the soil. Soil carbon within a paddock is highly variable from one spot to another, and also varies from year to year with crop production and other factors that determine inputs and loss rates. An important part of measuring soil carbon is sampling right across the paddock and over time so that this variation is accounted.' [16]

Developing procedures to reduce the cost of soil carbon measurement and increase the confidence in soil carbon estimation for a given cost are important targets of current research.[16]

So measuring soil carbon isn't necessarily easy and inexpensive but definitely achievable at the present time. With further research as mentioned above by CSIRO it would be hoped that measuring becomes easier. Given that forestry is not necessarily measured physically under the ETS but calculated on guidelines set by policy makers it is assumed that this could also be the case for soil carbon given time to assess the variability in New Zealand soils.

Soil Carbon in New Zealand Soils

There has been comparatively minimal research into soil carbon levels in New Zealand soils compared with Australia. A paper written by a group of scientists from Waikato University Department of Earth and Ocean Sciences in 2007 measured the loss or gain in soils that had been measured 17 to 30 years ago on land that had been under pastoral management for that period. On average soils had lost significant amounts of C ($-2.1 kgCm^{-2}$) since initial sampling.[23]

This equates to approximately one tonne of carbon per hectare per year. This doesn't sound like a lot but over 50 years that's 50 tonne lost per hectare which means 183.5 tonnes per hectare of carbon dioxide has been emitted into the atmosphere. Over 100 hectares that's 18,350 tonnes CO_2. Cumulatively, the impacts of seemingly small annual losses can be large.

'New Zealand soils were originally low in nutrients and fertility has been enhanced by application of P fertilizers together with N fixation by clovers. In recent years, intensification has continued, in particular N fertilizer application has increased from 50 Gg in 1989 to 342 Gg in 2003 to increase production mainly on dairy farms (Parfitt et al., 2006). The long-term impacts of these large changes in soil management and increases in fertility on soil properties are not well understood at national scales (Sparling & Schipper, 2004).'[23]

It has been suggested that because most of New Zealand farm was converted from forest there was a high input of carbon from previous forest vegetation. This together with the high productivity of our pastures and temperate climate it was thought that carbon in the soils was relatively steady. But as the research above shows, with increased use of fertilisers and intensity of farm management practices over an extended timeframe, we are in fact loosing carbon.

Trading Soil Carbon

The United Nations Framework Convention on Climate Change (UNFCCC or FCCC) is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro from 3 to 14 June 1992 which had the objective to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Subsequently there have been Conferences of the Parties (COP) to this framework annually since 1995. The Kyoto Protocol was the result of a COP in 1997 in Japan and established legally binding obligations for developed countries to reduce their greenhouse gas emissions.

In 2000 at Hague, Netherlands and in 2001 at Bonn, Germany there was discussion on Carbon Sinks in Forests and Agricultural lands. So sequestration of carbon in land/soils is widely accepted to be possible and consequently tradable.

There are examples around the globe of schemes set up to farm, measure and trade soil carbon.

Australia: Soil carbon is being sold and purchased in Australia. There are several schemes in Australia including Prime Carbon, Carbon Link, Australian Soil Carbon Accreditation Scheme (ASCAS).

Australia's equivalent to the Emissions Trading Scheme, the Carbon Pollution Reduction Scheme (CPRS) will apparently recognise soil carbon credits but the required legislation has not yet been passed so detail is not certain. It seems likely that soil carbon credits will be saleable on a regulated voluntary market where land management practices have been changed and accumulated carbon can be measured. Reports of the potential value of these credits range from $10 to $25/tonne CO2 Eq. Land management changes include applying biological preparations in place of solid fertilisers, replacing annual with permanent pasture, and moving from conventional cultivation to no-till. These are pilot schemes looking for Government backing.[20]

United States: The Chicago Climate Exchange (CCX) is the world's first and only active voluntary, legally binding integrated trading system with offset projects worldwide. Basic CCX specifications for soil carbon management offset projects include conservation tillage which requires a minimum of five year contractual commitment to continuous no-till or strip-till (conservation tillage) on enrolled acres. Tillage practice must leave at least two-thirds of the soil surface undisturbed and at least two-thirds of the residue remaining on the field surface. [11]

CCX soil carbons offsets are projects involving sequestration of carbon in soil resulting from the adoption of conservation tillage and activities in designated states, counties and parishes in the U.S. and Canada. Soil carbon offsets are issued on a per acre per year basis. The offset issuance rate depends on the region in which the practice is being undertaken. For example, enrolled producers in Illinois may be issued offsets at a rate of 0.6 metric tonnes of CO2 per acre per year and producers in central Kansas may be issued offsets at a rate of 0.4 metric tons CO2 per acre per year. The different offset issuance rates reflect the carbon sequestration ability of the soils. [11]

Portugal: 'The Portuguese Government soil carbon offsets project, commenced in July 2009, aims to sequester 0.91 million tonnes of CO_2 in the soil beneath 42,000 hectares of sown diverse perennial pasture from 2010 to 2012 (Watson 2010). This equates to the sequestration of 10.85tCO_2/ha/yr.'[11]

'In addition to the carbon payments they receive, participating Portuguese farmers are reported as "enjoying the environmental spin-offs of greater biodiversity, higher soil fertility, higher water infiltration rates, less erosion, less desertification, fewer fires, less floods, improvement in water quality, less dependence on concentrated feed for their herds in protracted dry periods and better milk and meat quality" (Watson 2010).'[11]

New Zealand: there is no provision for soil carbon trading in New Zealand. The author heard David Whitehead from Landcare Research – NZ Agriculture Greenhouse Gas Research Centre – speak at a seminar in Cromwell June 2010. He and his research team understood the importance of soil carbon and organic matter in soils. The data presented was limited, comparing carbon levels in mostly forested land or high country land in the 1980s to pastoral (Sheep & Beef and Dairy) systems on the same land in 2004. The data showed a minimal increase in carbon and in some situations, on dairy farm conversions, a decline in carbon levels. No comparison has been made to land run under carbon farming/biological methods to assess the potential to increase carbon. An Info Sheet found on www.carbonfarming.org.nz was somewhat dismissive of the need for soil carbon farming for carbon credits given the predominantly pastoral systems in New Zealand which already have relatively high levels of soil carbon, but given the implications to New Zealand farmers if they were to account for carbon it advises that soil tests for soil organic matter be taken every 4-5 years to improve knowledge of soil carbon.

Following is an excerpt from that info sheet mentioned above:

"Unlike Australia, New Zealand grassland already has relatively high soil carbon contents (average around 11% organic matter). Adding more is not as easy as it might be in areas with very low carbon to start with (e.g. less than 2% OM in Figure 1). Most Australian soils fall into this category. Also, carbon accumulation rates are greater in cool than in warm climates, poorly drained rather than well-drained soils and in light rather than heavy textured soils. In contrast, New Zealand has a benign climate with relatively well drained, medium to heavy textured soils."[20]

Case Study

The author has recently taken on the management of a small farm on the Crown Terrace, Central Otago. Half the farm had been cropped for barley over the last 10 years but had been put into red clover in the last year to help improve the soils and fix nitrogen. The other half of the farm had been under sheep and beef pastoral management for many years. Before he started his study in soil carbon sequestration he obtained a regular soil test and applied the recommended fertilisers including Phosphate, Potassium and Lime.

Recently he had his soils biologically tested to assess the food web activity under ground level. These uncovered some interesting results. Before turning the soil a few visual assessments were made by the soils expert from Sustainable Growing Solutions, Ray Annon.

- There was a lot of old dead litter and aging sheep feces lying on the surface. That they had not been broken down for some time indicating a lack of fungal activity in the soils.

- The grass around rabbit burrows was greener than the pasture around it indicating that there were nutrients in the soil that had been unlocked by the rabbits but that are not being unlocked naturally by the soils.

Then we dug a hole.


- The worm counts in the paddocks that have been cropped in barley for an extended period were almost devoid of worms. Two small worms per spade.

- The red clover had no nitrogen fixing nodules on the roots and there was no evidence of mycorrhizal fungus on the roots.

- The worm count in the paddocks that have been pasture for an extended period tallied 12 per spade, which was much better than the cropped paddocks but relatively low as compared to a biologically active soil; 25 per spade is considered a good count.

- The soil was clumpy, not breaking down easily and was greyish in colour, not the rich brown of a soil full of carbon.

The biological soil result showed:

- High bacterial activity in the soils (bacterial dominated), low fungal activity, and a bacteria: fungi ratio out of balance. 1:1 is ideal for paddocks in pasture.

- A lack of protozoa activity accounting for the poor distribution of nutrients from the soils to plant roots.

- A need for mycorrhiza in the soils to create the link between plant roots and the soil.

As a result of these findings an application of compost tea (100 litres/ha), humic (10 litres/ha), seaweed powder (500g/ha), molasses, lime (5kg/ha), mycorrhiza (10g/ha) has been applied. A seed mix of grasses including Fescue, Perennial Rye, Timothy Rye, and Cocksfoot, red clovers including Red Quinn, Tarras, Pawera, together with Huia white clover, Chicory and Plantain have been direct drilled into existing pasture October this year.

It became apparent to the author that although New Zealand has a perceived carbon rich soil due to its predominance in pastoral systems, the biology that makes and stores carbon in this pastoral case study was nearly non-existent. So given that the author was running a pastoral system under conventional methods of fertilizer and chemical applications, and regular tilling he was indeed depleting the ability of the soil to sequester carbon. So how is it that New Zealand rests on the perception that our soils are carbon rich and therefore need not keep up with the high level of research and innovation happening overseas, especially given that soils are our life source.

Conclusion

This resource has journeyed through the intricacies of soil science and has broadened the authors mind when looking at a piece of dirt. Previously he had a heavy reliance on main stream soil tests, measuring the level of only a handful of nutrients and minerals, and following up with recommended fertilizer and chemicals. Little notice was taken of those processes that work the carbon cycle. Following the research completed for the project he has discovered that the carbon cycle is without doubt the life force of our being, and realized that his ignorance is not sustainable.

The author has found that soils can sequester carbon, both labile carbon and more stable carbon like humus which can be stable for thousands of years. In order to enhance the ability of soils to sequester carbon there are management practices that are important including keeping a groundcover of pasture growing 100% of the time, no-till cropping, grazing management (not over grazing and even grazing), mulching, better water management systems, composting, planting trees, farming biologically. All contributors to the food web need to be looked after which means little or no disturbance, good recycling of organic matter, a balance of fungi and bacteria that suits the plant grown.

The benefits of providing the soils with the right environment to thrive and store carbon are many. Soils carbon is vital to the maintenance of healthy soils by improving structure, allowing the soils to breath and hydrate (better infiltration of air and water), and hold onto nutrients that feed plants and microorganisms. Soil carbon is important in soil water-holding capacity, not only holding water for dry periods, but filtering a better quality liquid into aquifers. This water holding capacity is instrumental also in holding land together under heavy rain duress – preventing slips. A healthy soil rich in humic substances is effective in inactivating pesticides and other pollutants as well as buffering PH. Above all a healthy soil is rich in plant available nutrients, feeding plants, feeding animals, feeding us. Productively our land is better off with high carbon content soils. Environmentally we are better off if carbon is sequestered underground. Financially returns are better for not only added quantity but quality of produce. What about our health, of course it is enhanced.

Let's not forget that soil carbon is traded around the world with good examples of this working in Australia, The United States of America and Portugal. So there is potential to make money while saving the planet, as well as all those other benefits mentioned above.

Ultimately though, as good as all this sounds the author has been left with many questions. There is so much information on the internet and in reference material that reasons that a healthy soil can solve many of the existing problems in agriculture and horticulture in relation to pollution, water quality, slipping and at the same time possibly provide an income stream through carbon trading.

The problems New Zealand farmers face in the future include pollution of waterways, stopping our land slipping, increasing production to maintain profitability, retention of the global perception of New Zealand as 'Clean Green'. Outlined below are a few of the issues the authors perceives to be pertinent:

- Dairy farmers get a hard knock about leaching into water ways and ruining the quality of our water and aqua life. Can farming for carbon stem this leaching and at the same time maintain production of our cow herd.

- Orchardists in New Zealand are big users of weed killers, fungicides and insecticides. A lot of the chemicals they use are either ban or heavily regulated overseas. Is it possible that a healthy soil that symbiotically exchanges its healthy disposition to the trees and in-turn fruit could reduce the need for these chemicals?

- New Zealand's ETS as it stands now could cripple many highly geared New Zealand farmers through the added expense to cover their methane and CO2 emissions. The ETS is designed to get farmers to change their ways by finding ways to counter their emissions such as reforestation of marginal hill country. But is the answer at our feet? Could it be that if we were to change the way we treated our soils i.e. less or no soluble fertilizer application, no spray, and no-till policy with ground cover 100% of the time, that indeed we could build the carbon in our soils, build the health of our soils and plants, measure the carbon sequestered and trade it?

- New Zealand is recognized as 'Clean Green' but are we? We still widely use chemical sprays, our soils on the whole have poor structure and natural nutrient properties, we madly apply soluble fertilisers which are largely leached straight into our waterways disturbing the all-important food-web of fungi, bacteria, microorganisms and insects on the way, and the more our soils are depleted the more fertilizer and spray we need to apply. Can we as a nation retain the 'Clean Green' perception in the future?

The author would like to say yes to all the above questions. Through better educating himself he managed to convince himself that there is a better way to farm. But although he was convinced in his own mind and happy to gradually convert his operation to biological, he was not convinced this was a silver bullet that could be widely accepted overnight. What is required is a paradigm shift for an innately conservative society of New Zealand farmers who are mostly heavily geared and on the whole slow to accept change.

This concept smells a little like an organic/hippie thing to do. Any hint of organics, biodiversity, or anything tending alternative is likely to be shunned by conservatism without effective education by the right people.

What the author hopes this resource has done is provide an understanding of the processes that happen in our soils given an ideal biological situation, and the benefits they could bring. He hopes that there can be more research into soil carbon farming. Not only that but more education to farmers; not from financially driven outfits selling products that ultimately harm our soils and are gradually taking us back to the dark ages.

In 50 to 100 years it could be too late for New Zealand. Our soils could be severely depleted and unable to produce to a level that keeps farmers profitable. Without action as custodians of our nations land there will be no land worth being custodian to.

The author is interested in furthering his research and in-turn his confidence to be able to help the paradigm shift process that is required if New Zealand is to overcome issues of the future.

And so the author leaves you with the following piece from 'Soil carbon - can it save agriculture's bacon?' by Dr. Christine Jones, PhD Founder, Amazing Carbon.

Changing the face of agriculture

Since 1960, global food production has doubled. At the same time, the soil resource on which food production is based has become seriously degraded. The impoverishment of agricultural soils through depleted levels of biological activity and reduced carbon flow poses a greater threat to human existence than climate change. In many regions of Australia, the effects of lower than average rainfall over the past decade have been compounded by loss of soil resilience and reduced moisture-holding capacity (Fig.4).

The picture adjacent shows Cropping over an old fence-line clearly demonstrates the extent to which soil has been depleted by conventional farming practices. Paddocks on either side of the fence have a history of high nitrogen application (Photo Richard May).

It has been calculated that in the next 50 years, the planet will need to produce as much food as it has in the entire history of humankind. The way we produce that food will require a radical departure from business as usual.

The statement that small farmers need to ‘get big or get out’ overlooks the fact that profit is the difference between expenditure and income. In years to come we will perhaps wonder why it took so long to realise the futility of trying to grow crops in dysfunctional soils, relying solely on increasingly expensive synthetic inputs. Economic development is only sustainable if it strengthens, rather than depletes, natural resources. The soil’s ability to produce nutrient dense, high vitality food - which after all, is agriculture's real purpose - depends on appropriate management. Enhancing the natural flow of carbon to soils will result in increased microbial diversity, improved nutrient cycles, enhanced soil water-holding capacity, greater resilience, improved catchment health - and a more satisfying, profitable future for farmers. The longer we delay undertaking regenerative changes to land management based on biology friendly farming practices that rebuild carbon-rich soils, the more soil carbon and soil water will be lost, exposing an increasingly fragile agricultural sector to escalating production risks, rising input costs and vulnerability to climatic extremes.

It's time to move away from depletion-style, high emission, chemically based industrial agriculture and get serious about grass-roots biologically based alternatives.

The future of Australia depends on the future of our soil - and our willingness to look after it. Rebuilding soil productivity via the restoration of natural carbon flow and the sequestration of stable soil carbon is the only means of saving agriculture's bacon - and ensuring a future for human society as we know it.

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