Carbon and Catchments

Inspiring REAL CHANGE in natural resource management

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"The real voyage of discovery consists not in seeking new landscapes but in having new eyes"
[Marcel Proust]

Imagine how farming could be if all agricultural soils were magnificent. Full of energy. Brimming with life that we could hear, see, smell and 'feel'? When we nourish soils with purpose, passion and pleasure, soil life responds in kind. As above, so below. When you look at your soil, you see your management reflected. We all want soils to be 'healthy'. But where to start?

It is **life** that gives soil its structure, enabling the infiltration and retention of moisture, restoring water balance across the landscape and reversing the processes of desertification. It is **life** that provides natural fertility, sequestering carbon, nitrogen and sulphur from the atmosphere and increasing the availability of phosphorus and trace elements in the root zone.

The fundamental question is therefore "how do we get life back into soil?"

CARBON, CARBON, CARBON

CARBON (C) is the basic building block for all life on - and in - the earth. We cannot live without it. Neither can our soils. Vibrant, living soils also require air and water. It is difficult for these inclusions to be retained in the absence of good soil structure, which requires soil carbon. Carbon is the driver for every aspect of soil health and soil function - the MASTER KEY to every door.

Carbon provides the structural basis for thousands of different compounds. It is so common, we take it for granted. We often take hydrogen (H) and oxygen (O) for granted too - but where would we be without H_2O - our precious, life sustaining water? The significance of soil water is becoming more apparent as we lose soil carbon. Low soil water-holding capacity and low levels of soil organic carbon go hand in hand.

An understanding of the role of carbon in soils and of the balance of gases in our atmosphere, is essential to our understanding of life on earth. Atmospheric carbon is an extremely valuable resource. When sequestered in topsoil as organic carbon, it brings with it a wealth of environmental, productivity and quality of life benefits.

Sadly, around 50 - 80% of the organic carbon that was once in the topsoil has been lost to the atmosphere over the last 150 years or so, due to our failure to take care of the earth as a living thing. By inference, degraded soils have the potential to store up to 5 times more organic carbon in their surface layers than they currently hold, provided we **change** the way we **manage** the land.

Anything that causes bare ground results in the loss of organic carbon. If bare earth is produced by chemical or mechanical means, we burn fossil carbon in the process, further adding to atmospheric pollution.

The importance of soil CARBON

With appropriate changes to land management, agricultural soils have the capacity to sequester and store large volumes of carbon, sourced from the atmosphere via green plants. Increasing soil carbon can significantly improve levels of biological activity, nutrient cycling, aggregate stability, resistance to erosion and ultimately biodiversity, productivity and profitability. Improvements in soil carbon levels can also reduce the impact of dryland salinity, virtually eliminate sedimentation in rivers and streams, vastly improve water quality and restore perennial streamflow.

Soil carbon is the one single, measurable factor that underpins the solution to multiple natural resource management problems. 'Managing the Carbon Cycle' is about turning carbon loss into carbon gain. And 'managing' means just that!!!

Soil carbon, water balance and RIVER HEALTH

The health of terrestrial and riverine ecosystems are intrinsically linked. Rivers and streams exist only because of the catchments that feed them, and cannot be regarded as separate entities to those catchments. Yearlong Green Farming techniques that improve the quality and perenniality of groundcover, restoring soil surface condition, porosity, aggregate stability and water balance not only confer production advantages to landholders, but also **ensure that water passes through a series of biological filters on its journey to rivers and streams**.

When water runs on the top of the ground, or on top of the subsoil, we witness the all too familiar flash flood syndrome, with rivers carrying too much and then too little water, while freshwater aquifers continue to decline. Many once 'perennial' streams are now ephemeral, simply due to losses in groundcover, soil carbon and soil porosity in their catchments.

Healthy, porous topsoils assist with the infiltration of water to transmissive aquifers and provide perennial base flow, improving the quality and year-round availability of water and markedly enhancing general river health.

Soil carbon means WATER - for all

The apparent climate shift in many subtropical regions of the world has highlighted the significant linkage of the carbon and water cycles. Glenn Morris (Morris 2004) extensively researched the water holding capacity of humus (a stable form of soil carbon) and concluded that within the soil matrix, one part of soil humus can, on average, retain four parts of soil water.

From this we can calculate how water storage in the top 30 cm of soil (roughly the top 12" in old terms) is influenced by changes in the level of soil organic carbon. The majority of Australian topsoils have bulk densities in the range 1.2 to 1.8 g/cm^3. We will assume an average soil bulk density of 1.4 g/cm^3.

Table 1. Relationship between levels of soil organic carbon (OC) in the 0-30 cm soil profile and additional soil water holding capacity. Average soil bulk density 1.4 g/cm^3

Change in OC concentration	Change in OC stock (kg/m^2)	Extra water (litres/m^2)	Extra water (litres/ha)	CO_2 sequestered (t/ha)
1%	4.2	16.8	168,000	154
2%	8.4	33.6	336,000	308
3%	12.6	50.4	504,000	462
4%	16.8	67.2	672,000	616

The data in Table 1 show 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/cm^3, for every 1% increase (in absolute terms) in the level of soil organic carbon. That's 168,000 litres, or almost 20,000 **extra** buckets of water that could be stored per hectare, in **addition** to the water-holding capacity of the soil itself.

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.

As the landscape becomes drier, evaporation rates increase, degraded soils continue to lose their capacity to hold water and rivers lose their life-lines - the fresh-water aquifers that feed them.

Re-balancing the soil water equation and re-balancing the soil carbon equation have many factors in common. Both processes require soil building, which in turn requires that carbon dioxide from the atmosphere be sequestered in soil as organic carbon.

Soil water balance

Factors that **reduce soil organic carbon levels** and upset the **soil water balance** include

- Loss of perennial groundcover
- Intensive cultivation
- Bare fallows
- Stubble burning and pasture burning
- Continuous grazing

Most conventional agricultural practices include one or more - or all - of the above. Over the last 50 to 100 years, soil organic carbon levels in many areas have fallen by at least 3% (in absolute terms). **This represents the LOSS of the ability of soil to store around 504,000 litres of water per hectare.**

One inch (25mm) of rain delivers 250,000 litres of water per hectare, while two inches (50mm) delivers 500,000 litres per hectare.

If the soil has reduced porosity due to the structural changes that accompany losses in soil carbon, millions of litres of water move **across** the landscape as run-off - gathering both soil and nutrients - to cause recharge, discharge and sedimentation problems in lower landscape positions.

Carbon dioxide emissions

In addition to water losses from the landscape, a 3% reduction (in absolute terms) in soil organic carbon in the 0-30 cm soil profile represents 462 t/ha extra carbon dioxide (CO_2) emitted to the atmosphere, contributing to increased levels of greenhouse gases.

Building soil carbon

How does the gas, carbon dioxide (CO_2), become sequestered as soil carbon?

The ‘way in’ for soil carbon is the process of photosynthesis in green leaves. In this process, plants use the energy from the sun to convert carbon dioxide and water into glucose and oxygen, ‘essentials’ for most other life on the planet. Each molecule of glucose formed in green leaves sequesters six molecules of carbon dioxide from the atmosphere. Plants use this glucose to make a wide variety of other carbon compounds, many of which are translocated to roots.

The cheapest, most efficient and most beneficial form of organic carbon for soil is exudation from the actively growing roots of green plants. Organic carbon additions are governed by the surface area of plant roots per unit of soil, the rate of growth of new roots and the degree of association with symbiotic or associative microflora such as mycorrhizal fungi. The more active, fibrous plant roots and rhizosphere microflora there are, the more carbon will be exuded into the soil matrix and, most importantly, humified. The decomposition of plant roots can also be an important source of carbon in some soils.

Yearlong Green Farming (YGF)

Yearlong Green Farming (YGF) has three main principals:-

- presence of green plants for as much of the year as possible
- carbon translocated to soil by root activity
- soil cover maintained at all times to enhance microbial habitat

Variations on the Yearlong Green theme are limited only by human creativity.

One approach is to double crop grain and forage species, so that soil building continues for most of the year. For example, a direct drill winter cereal could be followed by direct drill forage sorghum, or multi-species forage mix. The summer forage crop will not only enhance soil biological activity, but will be more profitable than maintaining a bare summer fallow.

Alternatively, a summer grain crop could be followed by mixed species winter forage (eg oats, triticale, legumes). Yearlong Green Farming practices are most beneficial when they include livestock, because **strategic** grazing maximises the sequestration of soil carbon.

Let us consider two very practical ‘real life’ examples of Yearlong Green Farming (YGF) practices – one relating to broadacre cropping and the other to regenerative grazing.

Pasture Cropping

The quickest and most cost effective way to restore degraded cropland is through a grazed perennial pasture ley (Charman and Roper 2000). Ironically, the good work is undone when conventional cropping resumes. Thanks to the brilliant insight and visionary thinking of innovators Darryl Cluff and Colin Seis, landholders wishing to build soils through a Yearlong Green technique now have the opportunity to combine annual crops and perennial grasses in the revolutionary ‘one-stop-shop’ land management technique known as Pasture Cropping (Cluff and Seis 1997).

Many of the benefits of Pasture Cropping can be attributed to having perennial grasses and cereals together, side by side in space and time. Rhizosphere exudates from perennial grass roots evolve into highly stable soil aggregates, significantly improving structure throughout the soil profile, while the high sugar forms of carbon exuded by the fast-growing roots of annual cereals stimulate a broad spectrum of biological activity in the topsoil.

In this positive feedback loop, CO_2 respired by plant roots and soil microbes, slowly moves upwards through the topsoil and increases the partial pressure of CO_2 beneath the crop/pasture canopy, enhancing photosynthetic potential. As money makes money, so carbon makes carbon - but only when the management is right.

Under conventional cropping regimes, the beneficial exudates from crop roots are negated by cultivation and/or and harsh chemicals. Over time, soil carbon levels become so low that soil is essentially ‘dead’ and has low nutrient status and little ability to store water. The prime purpose of bare fallows - water storage - becomes self-defeating. Bare soil is also an open invitation to weeds.

Planned Grazing

Grazing animals, plants, soil biota and soils have co-evolved for over 20 million years, resulting in highly complex - and sensitive - inter-relationships. What are these communication pathways in soil? In what way do living things below ground respond to changes above ground? What are the triggers? How can we incorporate the soil’s needs into grazing management?

Levels of biological activity in soil vary enormously over space and time. They are affected by moisture, temperature, pH, oxygen concentration and the availability of a carbon source (energy). All of these factors are strongly influenced by the way plants are grazed. Of particular interest to this discussion is the supply of carbon compounds to soil biota, in terms of timing, quality and amount.

In a green grass plant, there is generally more nitrogen in the leaves than in the roots, and more carbon in the roots than in the tops. When the leaves are removed by grazing, the plant responds immediately to re-adjust this balance. Some carbon (in the form of soluble carbohydrate) is mobilised to the crown for the production of new leaves, some is lost to the soil as pruned roots and some is actively exuded into the rhizosphere (the soil surrounding plant roots) where it can have profound stimulatory effects on soil biota.

If plants are grazed more-or-less continuously, they will have poorly developed root systems and there will be very little carbon available for injection into the soil at each grazing event. The animal-plant-soil ecosystem will decline to a steady-state equilibrium where not much happens other than further deterioration.

When grazing is optimised by ensuring that the most desirable plants (from the animal’s perspective) have recovered sufficiently for their root systems to be well established before re-grazing, the net effect of grazing is an increase in soil carbon (energy) levels.

The carbon exuded from the roots of grazed plants stimulates the rhizosphere flora involved in the acquisition and transfer of nitrogen, phosphorus and other nutrients, assisting rapid regrowth of leaves. This enhances energy and nutrient flows. Appropriately managed grazing also stimulates the microbial production of a wide range of plant growth stimulating substances in soils, including natural hormones, enzymes and vitamins.

The optimisation of the grazing process helps to synchronise nutrient mineralisation with plant demands. This reduces losses from the soil ecosystem. Under continuous grazing, particularly in seasonal rainfall environments, the supply and demand for nutrients such as nitrogen rarely match, leading to imbalances and contributing to ‘problems’ such as soil acidity. It is one of nature’s paradoxes that increased levels of soil biological activity not only improve nutrient availability, but also minimise soil nutrient losses and stabilise soil pH.

Managing the carbon cycle

In cropped or grazed paddocks managed regeneratively, actively forming topsoils behave as carbon SINKS. That is, more carbon is sequestered than is lost, improving soil health, structure, vitality and function. If soil carbon levels are low, soil water relationships and natural nutrient cycles rapidly deteriorate. Getting started in lifeless, compacted soils where the soil engine has shut down is the hard part. The longer we delay, the more difficult it will be to re-sequester soil carbon and re-balance the soil water equation

Carbon and nitrogen

Like carbon, nitrogen moves between the atmosphere and the topsoil in a ‘cycle’. The main difference is that green plants provide the ‘way in’ for atmospheric carbon, whereas the ‘way in’ for atmospheric nitrogen is nitrogen-fixing bacteria in plant leaves, stems and rhizosphere. These bacteria use the carbon fixed by plants for energy. Humic substances forming in the soil matrix around active plant roots contain both carbon and nitrogen sequestered from the atmosphere. Thus soils acting as net sinks for carbon are also acting as net sinks for nitrogen. The flip side is that soils losing carbon are losing nitrogen too.

Rewarding landholders for farming in ways that build new topsoil and raise levels of soil carbon and organic nitrogen would have a significant impact on the vitality and productivity of Australia’s rural industries, as well as reducing levels of greenhouse gases.

As a bonus, regenerative farming practices result in the production of food much higher in vitamin and mineral content and lower in herbicide and pesticide residues than conventionally produced foods.

Carbon credits

The capacity for appropriately managed soils to sequester atmospheric carbon is enormous. The world's soils hold three times as much carbon as the atmosphere and over four times as much carbon as the vegetation. **Soil represents the largest carbon sink over which we have control.**

If financial incentives for soil carbon sequestration became the prime focus of primary production, farm enterprises such as meat, wool or grain could become of secondary importance as an income source. This would reduce the potential for destructive land management practices and provide a large incentive for ‘greener’ forms of agriculture.

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 or 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. It’s about turning carbon loss into carbon gain.

Soil formation vs soil loss

The true bottom line for any agricultural practice, is whether soil is being formed or lost. If it is being lost, farming will eventually become both ecologically and economically impossible.

The building of new topsoil depends on us, and our future depends on building new topsoil. This is the greatest challenge facing the planet’s rapidly expanding human population.

Soil loss figures usually assume an average bulk density (weight per unit volume) of around 1.4 g/cm^3. One millimetre of soil erosion (about the thickness of a 5-cent coin), represents 14 t/ha soil loss.

If productive soil continues to erode, debates about the optimum enterprise mix, pasture species, fertiliser rate, percentage of trees, riparian buffers or any other 'detail' over which we seem to argue endlessly, are irrelevant. They amount to re-arranging the deck chairs on the Titanic.

Historically, research efforts in the soil science arena have concentrated on reducing the rate of erosion. The Universal Soil LOSS equation (USLE) was devised to estimate losses from various agricultural activities. The concept of building new topsoil has rarely been considered. Isn’t it time we developed a Universal Soil FORMATION Equation (USFE) to estimate rates of soil formation?

Healthy groundcover, high root biomass and high levels of associated microbial activity are fundamental to the success of any technique for building new topsoil. Many people have built new topsoil in their vegetable or flower gardens. The next step is to learn how to build new topsoil on our farms. If the land management is appropriate, evidence of new topsoil formation can be seen within twelve months, with quite dramatic effects often observed within three years.

Dryland salinity in perspective

When moisture rises in the soil profile, it is often accompanied by salts, which concentrate on the soil surface through the process of evaporation. The key factor in reversing dryland salinity is to always have a small amount of fresh water slowly moving **downwards**, flushing salts from the root zone. Fresh water has a lower density than salt water and will sit above the salt, provided the soil is capable of retaining sufficient moisture for this purpose.

Most areas of Australia currently experiencing dryland salinisation were grasslands or grassy woodlands at the time of European settlement, as recorded in explorers journals, settlers diaries and original survey reports from the early to mid 1800s. It is intriguing therefore, that clearing the woody vegetation that began encroaching in the late 1800s is repeatedly cited as the ‘cause’ of dryland salinity.

It is important to view the ‘transient tree phase’ in perspective. There is no doubt that the removal of any kind of perennial vegetation will have an effect on water balance. However, to insist that dryland salinity is the result of tree clearing is a misrepresentation of the facts, particularly when twisted in the current form ‘if we put the trees back, we can solve the problem.’ It is the overlooked understorey, or more particularly, the groundcover and soils, which have undergone the most dramatic changes since European settlement. The real cause of dryland salinity is reduced levels of soil carbon and soil biological activity, leading to the loss of soil integrity and water balance.

Inspiring REAL change in land management

We cannot afford to look at ‘air’ or ‘water’ or ‘soils’ in isolation. In the natural world there are thousands of inter-relationships and feedback loops. Change one factor and we change them all. All are connected.

Every management decision counts.

Reversing desertification at local, regional and global levels requires a whole of landscape approach. The bottom line is that soils low in humic substances and biological activity cannot effectively hold carbon, nitrogen, air or water. These precious natural resources either move to the atmosphere, or are transported off-site, creating salinity, sedimentation and eutrophication ‘problems’.

To turn things around we need inspired, motivated people, working in relationship with each other and with their land to foster innovative designs for a new agriculture. We do not know how this regenerating landscape will ‘look’ - nor do we need to - it will be an evolving work of art. Ecological processes are never static. Our expertise will be directed to understanding process and function in a changing world.

Do we want more SOIL? More CARBON? More NITROGEN? Clean WATER?

Those outcomes are entirely in our hands.

Our role, as managers of the carbon cycle, is to ensure that as much carbon as possible is returned to soils and as little as possible goes into the air.

CONCLUSION

Extraordinary things happen to plants, animals and people when soils are renewed. In any business it’s good business to give the customers what they want. When your soil talks, listen. Healthy soils are not just about carbon, nitrogen, air and water. They are about PEOPLE, including you and me. We’re all in this boat together. Let’s build a good one!!

“The invariable mark of wisdom is to see the miraculous in the common”
[Ralph Waldo Emerson]

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