Extract from **Australian Farm Journal** Edition 338 3 July 2008

Liquid carbon pathway

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The process whereby gaseous carbon dioxide is converted to soil humus has been occurring for millions of years. Indeed, it is the only mechanism by which deep topsoil can form.

Not only is rebuilding carbon-rich topsoil a practical and beneficial option for productively removing billions of tonnes of excess carbon dioxide from the atmosphere, but when soils gain in carbon, they also improve in structure, water-holding capacity and nutrient availability.

Understanding the soil building process is therefore of fundamental importance to the future viability of agriculture.

Building topsoil is a biological process

'Biological carbon capture and storage' begins with photosynthesis, a natural process during which green leaves transform sunlight energy, carbon dioxide and water into biochemical energy. For plants, animals and people, carbon is not a pollutant, but the stuff of life. All living things are based on carbon.

In addition to providing food for life, some of the carbon fixed during photosynthesis can be stored in a more a permanent form, such as wood (in trees or shrubs), or as humus (in soil). These processes have many similarities.

i) Turning air into wood. The formation of wood requires photosynthesis to capture carbon dioxide in green leaves, followed by lignification, a biological process within the plant whereby simple carbon compounds are joined together into more complex and stable molecules to form the structure of the tree.

ii) Turning air into soil. The formation of topsoil requires photosynthesis to capture carbon dioxide in green leaves, followed by exudation of simple sugars from plant roots and humification within biologically active soil aggregates. Humification is a process whereby simple carbon compounds are joined together into more complex and stable molecules. The formation of humus requires a vast array of soil microbes, including mycorrhizal fungi, nitrogen fixing bacteria and phosphorus solubilising bacteria, all of which obtain their energy from plant sugars (liquid carbon).

How can it be that trees are still turning carbon dioxide into wood, but soils are no longer turning carbon dioxide into humus?

The answer is quite simple. In order for trees to produce new wood from soluble carbon, they must be living and covered with green leaves. In order for soil to produce new humus from soluble carbon, it must be living and covered with green, actively growing plants.

Building stable soil carbon is a four-step process that begins with photosynthesis and ends with humification. Many broadacre agricultural production systems fail to build stable soil carbon at depth due to lack of sufficient photosynthetic capacity and/or the use of high rates of synthetic fertilisers or other chemicals that inhibit the plant-microbe bridge.

These factors have been overlooked in most models of soil carbon sequestration.

The 'biomass model'

Models designed to mathematically predict the movement of carbon in and out of soils are generally based on the assumption that carbon enters soil as 'biomass inputs', that is, from the decomposition of leaves, roots and crop stubbles. These models provide useful estimations of soil carbon fluxes in conventionally managed agricultural soils, but fail to account for the significant levels of carbon sequestration observed in soils actively fuelled by soluble carbon.

When carbon enters the soil ecosystem as plant material (such as crop stubble), it decomposes and returns to the atmosphere as carbon dioxide. Hence the lamentation "my soil eats mulch", familiar to home gardeners and broadacre croppers alike. While plant residues are important for soil food-web function, reduced evaporative demand and the buffering of soil temperatures, they do not necessarily lead to increased levels of stable soil carbon.

Conversely, soluble carbon channelled into soil aggregates via the hyphae of mycorrhizal fungi can be rapidly stabilised by humification, provided appropriate land management systems are in place.

Mycorrhizal carbon

The types of fungi that survive in conventionally managed agricultural soils are mostly decomposers, that is, they obtain energy from decaying organic matter such as crop residues. As a general rule these kinds of fungi have relatively small hyphal networks. They are important for soil fertility and soil structure, but play only a minor role in carbon storage.

Mycorrhizal fungi differ quite significantly from decomposer fungi in that they acquire their energy in a liquid form, as soluble carbon directly from actively growing plants. There are many different types of mycorrhizal fungi. The species important to agriculture are often referred to as arbuscular mycorrhiza (AM), [previously known as vesicular arbuscular mycorrhiza (VAM)]. The term VAM is no longer used as not all AM fungi have vesicles.

It is well known that mycorrhizal fungi access and transport water - plus nutrients such as phosphorus, nitrogen and zinc - in exchange for carbon from their living host. They also have the capacity to connect individual plants below ground and can facilitate the transfer of nutrients between species. This is one reason why above-ground diversity is important. Plant growth is usually higher in the presence of mycorrhizal fungi than in their absence.

What is less well known is that mycorrhizal fungi can play an extremely important role in humification and soil building processes.

Humification

Under appropriate conditions, a large proportion of the soluble carbon channelled into aggregates via the hyphae of mycorrhizal fungi undergoes humification, a process in which simple sugars are resynthesised into highly complex carbon polymers. Humus polymers are made up of carbon and nitrogen from the atmosphere, combined with a range of minerals from the soil. These organo-mineral complexes form a stable and inseparable part of the soil matrix that can remain intact for hundreds of years.

Humified carbon differs physically, chemically and biologically from the labile pool of organic carbon that typically forms near the soil surface. Labile 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 microflora. It is ‘microbial carbon’ as opposed to ‘plant carbon’.

Humus can form relatively deep in the soil profile, provided plants are managed in ways that encourage vigorous roots. Once atmospheric carbon dioxide is sequestered as humus it has high resistance to microbial and oxidative decomposition.

The soil conditions required for humification are diminished in the presence of herbicides, fungicides, pesticides, phosphatic and nitrogenous fertilisers - and enhanced in the presence of root exudates and humic substances such as those derived from compost.

Yearlong Green

The biological soil environment required for humus formation is supported by farm practices that promote diverse green cover for as much of the year as climate allows. Yearlong Green Farming practices include adaptive high density short duration grazing, pasture cropping and multi-species cover crops.

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Remember, photosynthesis and the ‘liquid carbon pathway’ are the most important drivers for soil building. Living hosts (green plants) provide soluble carbon and the necessary habitat for colonisation by mycorrhizal fungi.

Restoring soil

Under appropriate conditions, 30-40% of the carbon fixed in green leaves can be transferred to soil and rapidly humified, resulting in rates of soil carbon sequestration in the order of 5-20 tonnes of CO_2 per hectare per year.

In some instances, high soil carbon sequestration rates have been recorded where there were virtually no ‘biomass inputs’, suggesting that the liquid carbon pathway was the primary mechanism for soil building.

Every 27 tonnes of carbon sequestered biologically in soil represents 100 tonnes of carbon dioxide removed from the atmosphere. As a bonus, it also enables more reliable and profitable production of nutritious food.

Currently, most agricultural land is a net carbon source. That is, the soil is losing more carbon than it is sequestering. A biology-friendly approach to crop production - and carefully planned grazing of pastures and rangeland - would enable agricultural land to become a net carbon sink (that is, soil sequestering more carbon than it was losing).

If all farmland was a net sink rather than a net source for CO_2, atmospheric CO_2 levels would fall at the same time as farm productivity and watershed function improved. This would solve the vast majority of our food production, environmental and human health ‘problems’.

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Find out more:

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