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Liquid carbon pathway unrecognised

By Christine Jones, Australian Farm Journal

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At most cropping conferences when soil carbon is discussed, the conclusion drawn is that it is not possible to lift levels to a significant extent in a short timeframe. Most scientists contend it is a useful factor to consider for agronomy but not for carbon sequestration. But Dr Christine Jones disagrees, she contends soil carbon can be increased quickly for both purposes and that most scientists are using a flawed model to measure carbon.
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A soil carbon improvement of only 0.5% in the top 30cm of 2% of Australia's estimated 445 Million hectares of agricultural land would safely and permanently sequester the entire nation's annual emissions of carbon dioxide.

Sequestering atmospheric carbon in soil as humified organic carbon would also restore natural fertility, increase water-use efficiency, markedly improve farm productivity, provide resilience to climatic variation and inject much-needed cash into struggling rural economies.

The 'soil solution' to removing excess carbon dioxide from the earth's atmosphere is being overlooked because current mathematical models for soil carbon sequestration fail to include the primary pathway for natural soil building.

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 lose carbon, they lose structure, water-holding capacity and nutrient availability. Understanding the soil building process is therefore of fundamental importance to the future viability of agriculture.

Biological CCS

'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 year-round photosynthesis, often combined with high rates of synthetic fertilisers which inhibit the plant-microbe bridge.

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

Roth C model

The Roth C model was developed to mathematically predict the movement of carbon in and out of soils. The model is based on the assumption that most carbon enters soil as 'biomass inputs', that is, from the decomposition of plant leaves, plant roots and crop stubbles. The Roth C model provides useful estimations of soil carbon fluxes in conventionally managed agricultural soils, but fails 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 the 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 stubbles, dead leaves or dead roots. 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)], belonging to the phylum Glomeromycota. The term VAM is no longer used as not all AM fungi have vesicles.

It is well known that mycorrhizal fungi access and transport 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 carbon and nutrients between species. Plant growth is usually higher in the presence of mycorrhizal fungi than in their absence.

What is less well known is that in seasonally dry, variable, or unpredictable environments (that is, in most of Australia), mycorrhizal fungi can play an extremely important role in plant-water dynamics, 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 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 microflora. Humus can form relatively deep in the soil profile, provided plants are managed in ways to 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.

The biological soil environment required for humus formation is supported by Yearlong Green Farming practices such as Pasture Cropping and diverse multi-species cover crops. It is also possible for humification to occur in annual cropping systems provided bare fallows are avoided, soil is kept covered at all times and biology friendly fertilisers are used rather than products with anti-microbial effects.

Pasture Cropping

A change from annual to perennial groundcover can double levels of soil carbon in a relatively short time. This is not surprising, given that photosynthesis and the 'liquid carbon pathway' are the most important drivers for soil building. Photosynthesis occurs for a much greater portion of the year in perennial pastures. Further, the permanent presence of a living host provides a reliable supply of soluble carbon and suitable habitat for colonisation by mycorrhizal fungi.

The practice of Pasture Cropping, where an annual crop (preferably sown without herbicide) is grown out-of-phase with perennial pasture, can result in higher rates of soil building than under perennial pasture alone. This is due to year-round transfer of soluble carbon to the root-zone and the maintenance of the humification process in the non-growth period of the perennial.

Interestingly, the growth of an annual crop direct-drilled into perennial pasture can be equal to, or better than, the growth of an annual crop planted alone. This may reflect higher levels of biological activity, improved soil structure, enhanced nutrition, greater water-holding capacity and water balance advantages (such as hydraulic lift and hydraulic redistribution), as well as the microclimate benefits attendant upon co-existence with perennials.

Such benefits are not observed when annual crops or pastures are present for only part of the year, leaving soil bare at other times. Indeed, where groundcover is inadequate, soils frequently deteriorate, leading to problems with structure, sodicity, aluminium toxicity, waterlogging, mineral imbalance, salinity, erosion and colonisation by weeds.

Although there is clear evidence that both annual crops and perennial pastures can benefit from being appropriately combined in a mutualistic fashion, it will take time to ascertain the best species combinations for the varying soils encountered across the cropping zones of eastern, southern and western Australia.

To date, the stand-out perennial grass for Pasture Cropping has been Gatton Panic, which grows in a surprisingly wide range of environments ranging from central Queensland through northern, eastern and central NSW, Victoria, and the southern, central and northern agricultural regions of Western Australia. The leaves and stems Gatton Panic contain several naturally occurring N-fixing endophytes which appear to assist with crop nutrition - provided large quantities of inorganic nitrogen are not applied.

Soil carbon lifts significantly

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.

A change from annual to perennial-based agriculture can double soil carbon levels in the topsoil within three to five years, particularly when the starting point is below 2%. Soil carbon increases of 0.5-1% could therefore be achieved relatively easily with simple changes to land management across the agricultural zones of eastern, southern and western Australia.

Almost 60% of the Australian continent is currently used for food production. The resilience of the resource base to climatic extremes will become of increasing national and international significance in coming decades.

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.

In conventionally managed agricultural soils the 'biomass in, carbon dioxide out' process predominates. It will become increasingly difficult to farm productively if we fail to progress from this 'soil depletion' type of management, particularly in a warming, drying environment.

Next issue: Carbon sequestration options

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Find out more:

Allen, M.F (2007) 'Mycorrhizal fungi: highways for water and nutrients in arid soils'. Soil Science Society of America, Vadose Zone Journal Vol 6 (2) pp. 291-297. www.vadosezonejournal.org

Leake, J.R., Johnson, D., Donnelly, D.P., Muckle, G.E., Boddy, L. and Read, D.J. (2004). Networks of power and influence: the role of mycorrhizal mycelium in controlling plant communities and agroecosystem functioning. *Canadian Journal of Botany*, 82: 1016-1045. doi:10.1139/B04-060

Other articles by Dr Christine Jones can be found at www.amazingcarbon.com