Liquid carbon pathway unrecognised

At cropping conferences when soil carbon is discussed, a conclusion usually drawn is that it is not possible to lift levels to a significant extent in a short timeframe. Most scientists contend carbon is a useful factor to consider for agronomy but not for 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.

Christine Jones is rekindling awareness of a biological pathway for quickly increasing carbon in depleted cropping soil. Existing models she says don't account for the pathway and significantly underestimate the potential of cropping soils to sequester carbon.

A soil carbon improvement of only 0.5% in the top 30 centimetres 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 (CO_2) 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 CO_2 is converted to soil humus has been occurring for millions of years. Indeed, it is the only mechanism by which topsoil can form. When soils lose carbon, they also lose structure, water-holding capacity and nutrient availability.

Understanding soil building is thus fundamentally important to future viability of agriculture. Rebuilding carbon-rich topsoil is also the only practical and beneficial option for productively removing billions of tonnes of excess CO_2 from the atmosphere.

'Biological sequestration' begins with photosynthesis, a natural process during which green leaves turn sunlight energy, CO_2 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.

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

i) Turning air into wood: Formation of wood requires photosynthesis to capture CO_2 in green leaves, followed by lignification, a 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 CO_2 in green leaves, followed by humification, a process within the soil whereby simple carbon compounds are joined together into more complex and stable molecules to form the structure of the soil.

How can it be that trees are still turning CO_2 into wood, but soils are no longer turning CO_2 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 leaves.

Building stable soil carbon is a four-step process that begins with photosynthesis and ends with humification. The humification part of the equation is absent from most broadacre agricultural produc-

ABOVE: Jones contends that the plant bridge provided by perennials in pasture cropping is what allows for large increases in soil carbon in a relatively short time.

INSET: Despite providing organic matter and protection to soil, chemical fallow stubbles maintained without perennials will achieve only slow increases in carbon content.

tion systems, as are the year-round green leaves required to fuel the photosynthetic process and provide carbon in liquid form.

These factors have been overlooked in models of soil carbon sequestration such as Roth C.

Roth C model

The Roth C model was developed by scientists to mathematically predict movement of carbon in and out of soils. It is based on the assumption that most carbon enters soil as 'biomass inputs', that is, from decomposition of plant leaves, plant roots and crop stubbles.

The model provides useful estimations of soil carbon fluxes in conventionally managed agricultural soils but fails to account for carbon sequestration in soils actively fuelled by soluble carbon.

Data from the Australian Soil Carbon Accreditation Scheme (ASCAS), which measures soil carbon under regenerative agricultural regimes, will enable models such as Roth C to be recalibrated.

When carbon enters the soil ecosystem as plant material (such as crop stubble), it decomposes and returns to the atmosphere as CO_2. 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 buffering of soil temperatures, they do not necessarily lead to increased levels of stable soil carbon.

Conversely, soluble carbon streaming into the soil ecosystem via the cytoplasm of mycorrhizal fungi can be rapidly stabilised by humification and permanently retained in soil, provided appropriate land management systems are in place.

Mycorrhizal soluble C

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 plant roots.

There are many different types of mycorrhizal fungi. The species important to agriculture are often referred to as arbuscular mycorrhizae (AM) or vesicular arbuscular mycorrhizae (VAM) belonging to the phylum Glomeromycota.

It is well-known that mycorrhizal fungi access and transport nutrients such as phosphorus and zinc in exchange for carbon from their living host. They also have the capacity to connect individual plants and can facilitate the transfer of carbon and nitrogen 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. Under appropriate conditions, the major portion of soluble carbon siphoned into short-lived mycorrhizal hyphae undergoes humification, a process in which simple forms of carbon are resynthesised into highly complex polymers.

Humification

These large, high-molecular-weight molecules are made up of carbon, nitrogen, soil minerals and soil aggregates. The resultant humus is a stable, 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 in agricultural soils. Labile organic carbon arises principally from biomass inputs (such as crop residues) which are readily decomposed.

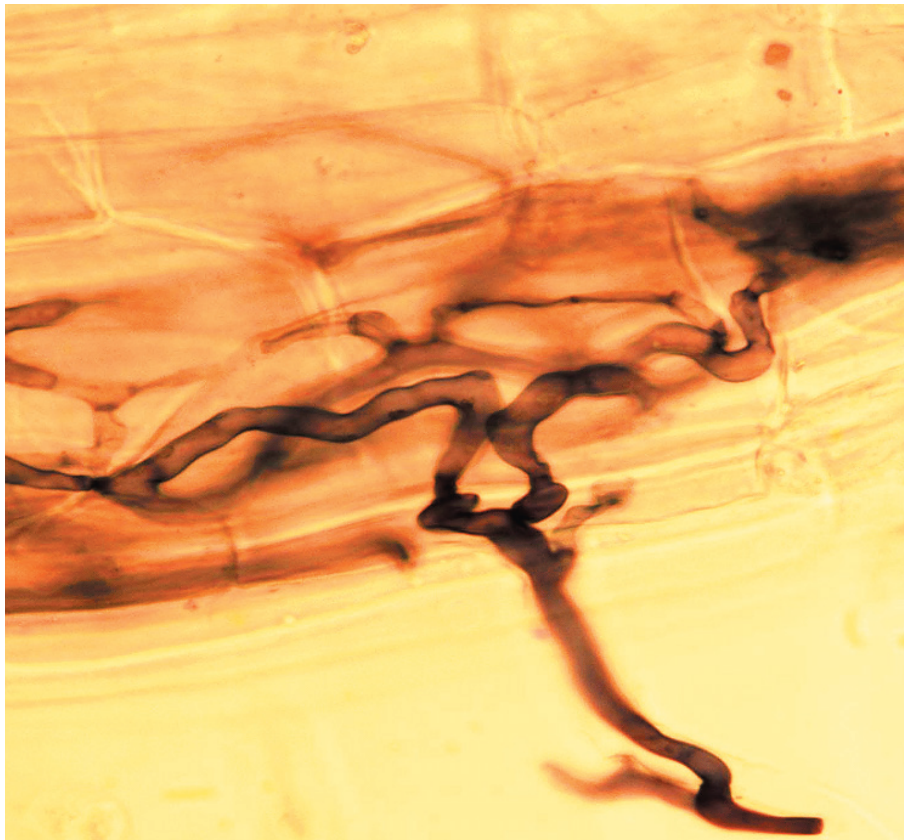
Conversely, most humified carbon derives from direct exudation or transfer of soluble carbon from plant roots to mycorrhizal fungi and other symbiotic or associative microflora. Once atmospheric CO2 is sequestered as humus, it has high resistance to microbial and oxidative decomposition.

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 humic substances such as humic and fulvic acids and compost teas — particularly when combined with microbial inoculants.

The biological soil environment required for humus formation is commonly found in association with year-long green farming practices such as pasture cropping.

It is also possible for humification to occur in annual cropping systems, provided long fallows are avoided, soil is kept covered at all times and biologically-friendly fertilisers are used rather than products with anti-microbial effects.

A change from annual to perennial groundcover can double levels of soil carbon in a relatively short time. This is not surprising, given photosynthesis and the 'mycorrhizal carbon highway' are the most important drivers for soil building.



Although mycorrhizae don't make humus, it is difficult to start the humification process without them. They bring large quanitites of soluble C into the soil from plant roots, which feeds the microbes involved in the complex process. Photo: Jill Clapperton.

Pasture cropping

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 may be due to year-round transfer of soluble carbon to the root-zone and maintenance of the humification process in the non-growth period of the perennial.

Interestingly, the growth of an annual crop planted out of phase with a perennial pasture can also 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, water balance advantages (such as hydraulic lift and hydraulic redistribution) and microclimate benefits attendant upon co-existence with perennials.

Such benefits are not available to annual crops or pastures grown in the absence of perennials. Indeed, where perennial groundcover is inadequate, soils frequently deteriorate, leading to problems with structure, sodicity, 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 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 of Gatton Panic contain several naturally occurring nitrogen-fixing endophytes, which appear to help with crop nutrition.

Soil C lifts markedly

Under appropriate conditions, 40%-60% of carbon fixed in green leaves can be transferred to soil and rapidly humified, resulting in rates of soil carbon sequestration in the order of five to 20 tonnes of CO_2 per hectare per year.

In some instances, soil carbon sequestration rates above 20 tonnes of CO_2 per hectare per year have been recorded where there were virtually no 'biomass inputs', suggesting the mycorrhizal carbon highway was the primary mechanism for soil building.

A change from annual to perennially 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 thus 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 increasingly be of national and international significance in coming decades. Every 27 tonnes of carbon sequestered biologically in soil represents 100 tonnes of CO_2 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, CO_2 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

Find out more:

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Reference: 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>.