FDI Feature Interview

24 September 2015

Soil Carbon, the Backbone of Soil Fertility: Emeritus Professor Robert White

Key Points

- Carbon is the backbone of organic matter and its presence in soil is essential for soil health.
- The amount of soil organic carbon is a balance between the rate of carbon inputs and the rate of decomposition. Input rate depends on the vegetative growth supported by the soil, and decomposition rates depend on the nature of the organic matter and environmental conditions.
- The right chemical, physical and biological properties are fundamental for soil health and soil organic carbon affects these properties.
- To increase organic carbon levels in soil it is important to either increase the rate of carbon input, decrease the rate of decomposition, or both.
- In 2010, a review by CSIRO of soil carbon in Australian soils concluded that soil organic matter had decreased in most cropping soils since land clearing occurred. Although conservation tillage can slow this decrease, over time soil organic matter generally shows an absolute decrease under such practices.

Summary

Carbon is the fundamental component of organic matter. It is fixed into plant organic compounds by photosynthesis from atmospheric carbon dioxide. The predominant pathway for carbon into the soil is through plant residues. It is also present, however, in soil as calcium carbonate. The quantity of soil organic carbon in the soil is a balance between the input rate from vegetative growth and the rate of decomposition of plant litter and dead roots. Attaining the right chemical, physical and biological properties are fundamental for healthy soil, and soil organic carbon affects several of these properties. Soil organic carbon promotes healthy soil structure and, in turn, provides a favourable habitat for soil organisms and plant roots. Unfortunately, the 2010 review of Australian soils concluded that soil organic carbon had decreased in most cropping soils since land clearing.

Commentary

FDI: *What constitutes carbon in soil and how does it differ from carbon dioxide?*

RW: Carbon (chemical symbol C) is the backbone of soil organic matter. Carbon, in the form of the gas carbon dioxide (CO_2), is fixed by photosynthesis in green plants and converted into organic compounds in the plant cells. The predominant pathway for C to enter soil is via plant residues – leaf litter, stems, branches, whole trees, and from root death and decay. Also, herbivores graze on plants and deposit their faeces on the soil, adding to the C input. Hence, C enters the soil mainly at the soil surface. Most plant roots occur in the top 15 to 20 cm of soil, so the end result is that C as organic matter accumulates in topsoil and decreases with depth.

Carbon inputs from plants and animals are the food source for a diverse range of soil organisms, from earthworms, insects and nematodes to microorganisms, predominantly fungi and bacteria. In feeding on this organic matter, the organisms grow, multiply and die, when their residues form the basis for another generation in successive cycles. During this process of decomposition, provided that oxygen is available, CO_2 is produced to return to the air, and mineral nutrients are released to nourish the growth of new organisms and plants. Recalcitrant residues from both plants and soil organisms that are not decomposed accumulate to form soil humus. The process of C inputs and decomposition is called C turnover, and the complete soil-plant-atmosphere process is called the C cycle.

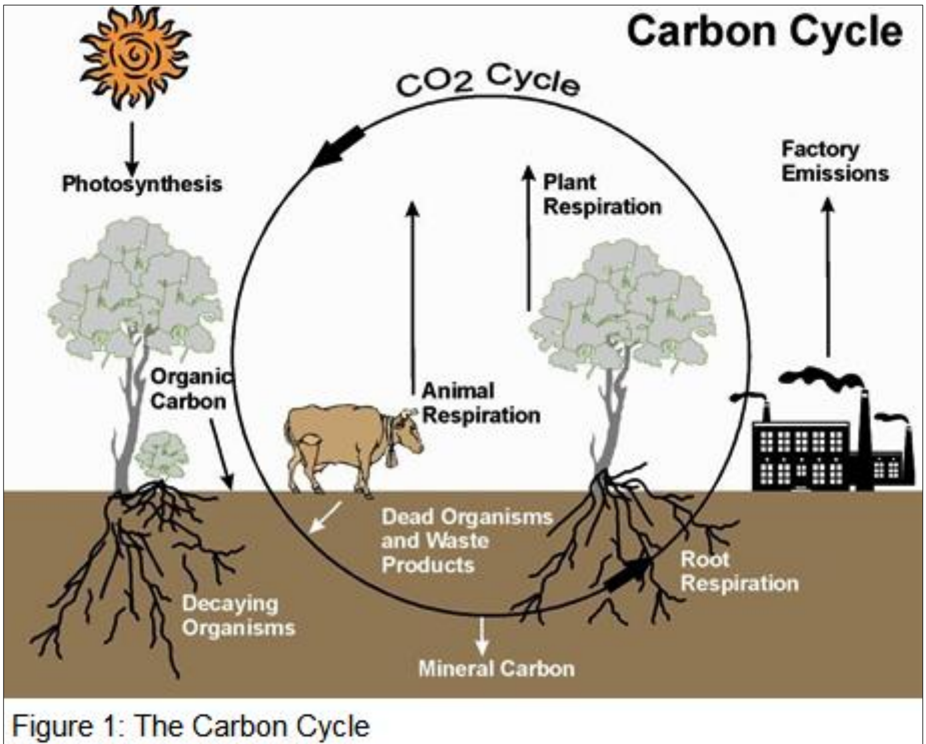

Figure 1: The Carbon Cycle
Source: The Quivira Coalition

Other forms of C in soil occur as the mineral calcium carbonate (calcite), which is usually derived from limestone sediments deposited under ancient seas. Calcium carbonate may also form in soils under dry climates.

FDI: *What are the main factors that control the amount of organic carbon in a soil?*

RW: The amount of soil organic carbon (SOC) is a balance between the rate of C inputs and the rate of decomposition of organic matter. The input rate depends on the vegetative growth supported by the soil and, as in the case of crops that are harvested, how much of that vegetation is deposited as plant residue. In the case of tropical rainforest, the return of litter, branches and dead trees can be up to 5-7 tonnes (t) C per hectare (ha) per year (yr). With dryland cereal crops in Australia, the amount returned is much less (0.5-1.5 t/ha/yr), provided that stubble is not burnt.

The decomposition rate depends on the nature of the organic matter – young leguminous residues, for example, decompose rapidly whereas woody residues decay very slowly – and the soil and environmental conditions. In cool humid climates, such the Australian Alps, even though vegetative growth is modest, decomposition rates are very slow so that thick, humified organic layers build up to form peat. Blanket peat bogs, as they are called, are more common in north-west Europe, as in Ireland and the Scottish uplands (see Figure 2). Organic matter is usually low (less than 1% C) in soils of hot dry regions, unless they remain wet in a drainage depression, when peat may form. Soil disturbance, through tillage for example, accelerates organic matter decomposition, whereas SOC normally builds up under permanent pasture. Organic matter is generally more stable in clay than in sandy soils.

Erosion by wind or water (especially sheet erosion) can deplete soil organic matter because the top layer of soil is removed, sometimes being blown out to sea or washed into rivers.

Figure 2: Example of a blanket peat layer. Note the penknife size for scale.
Source: Author

FDI: *What role does this organic carbon play in soil health?*

RW: Attaining the right chemical, physical and biological properties is fundamental for soil health. SOC affects several of these properties. For example, during C turnover essential elements such as nitrogen, phosphorus and sulphur are made available to the decomposing organisms and to plants (the process of nutrient cycling). As explained earlier, organic inputs provide the foodstuff for a host of non-carbon fixing soil organisms, some of which may produce growth-promoting compounds in the soil adjacent to roots (the rhizosphere). Humus compounds attach to clays, and fungi and bacteria produce sticky substances that all contribute to the creation and stabilisation of aggregates, which are the building blocks of soil structure. In turn, a good soil structure provides a favourable habitat for soil organisms and plant roots, through allowing gas exchange (aeration), drainage and the storage of plant-available water. Figure 3 shows excellent aggregation in a clay soil under a permanent grass cover crop.

A variety of microbes is generally good for soil health.

Figure 3: Example of a well-aggregated clay soil under a permanent grass crop.
Source: Author.

FDI: *How can the soil organic carbon content of soils be increased?*

RW: The general principle for increasing SOC is to increase the rate of C input, or decrease the rate of organic matter decomposition, or both. As indicated above, natural C inputs are highest under tropical rainforest. Inputs under temperate grassland can be 2-3 t C/ha/yr. Inputs under cropping systems are lowest, especially under continuous cultivation, but can be somewhat higher under no-till and other forms of conservation tillage. The greater the amount of crop residue (straw, stubble and roots) that can be returned to the soil, the better. Recycling as much as possible of the residues from all kinds of harvested crops (trees, cereals, grazed pastures, orchards and vineyards) is beneficial for maintaining or increasing SOC.

In cases where SOC has been run down, bringing in organic matter from an external source can be used to increase SOC. Examples are compost, manures, straw mulches and bio-charcoal ("biochar"). One should note, however, that transferring organic matter from one site to another in this way leaves the source site depleted of nutrients and can increase soil acidity at that site over time. Alternatively, the land use can be changed. The most reliable way to increase SOC is to change from cropping to pasture (achieving for permanent pastures increases of 0.3-0.6 t C/ha/yr, usually measured to 0.3 m depth), or to plantation trees. Also, cover crops of grasses and/or broadleaf species can be part of a rotation system, or sown in the mid-rows of orchards and vineyards. Although claims are made that biologically active preparations can increase SOC, this is only realistic if substantial amounts of organic material are applied at the same time. Figure 4 shows an example of the topsoil of a degraded cropping soil being restored to health through the addition of 100 m^3/ha of straw composted with pig manure, some 18 months before this photo was taken.

Figure 4: Topsoil of a degraded granitic soil rejuvenated by a large application of straw composted with poultry manure.
Source: Author.

FDI: *What is the condition of Australian soils in relation to soil organic carbon?*

RW: In 2010, a review by CSIRO of soil C in Australian soils concluded that soil organic matter had decreased in most cropping soils since land clearing. Although conservation tillage could slow this decrease, there were generally still absolute decreases in soil organic matter under such practices. Except for the coastal fringe and Tasmania, much of Australia has a relatively low rainfall and is warm to hot. A good illustration of the effect of low rainfall, which limits plant growth and hence litter return, and high average temperatures, which accelerate the rate of organic matter decomposition, is shown by data on soil C presented on the Soil Quality website (www.soilquality.org.au), hosted by the University of Western Australia with inputs from the six Australian states.

The most comprehensive data come from Western Australia (the southwest cropping and pasture zone), where 38 per cent of 1,131 sites examined have a soil C stock (0-30 cm) of 20-40 t/ha, which corresponds to a content of 0.5-1% C. Soil C content decreases with depth, so the highest content at a site occurs in the top 10 cm. At these WA sites, 35 per cent had C contents >2% in the top 10 cm. As well as the influence of rainfall and temperature, soil C contents vary with soil texture with the benchmarks being greater than or equal to 0.5% for sandy soils and greater than or equal to 1.75% for clays. One might contrast these results with those from Tasmania where, of 218 sites, 55 per cent have soil C stocks of 60-120 t/30 cm (corresponding to 1.5-3% C) and 54 per cent had greater than 4% C in the top 10 cm. Reflecting higher average temperatures and less reliable rainfall than in Tasmania, data from Queensland show a flatter distribution of C values, with only 25 per cent of sites in the eastern Darling Downs having 0.75-1% C in the top 10 cm and 28 per cent of sites in the west central zone having 1.25-1.5% C. Although to generalise over such a range of climates and soil types is difficult, it appears that the majority of Australian agricultural soils would benefit from an increase in C content.

FDI: *What are the possibilities for farmers to benefit financially through storing organic carbon in their soils under the Australian Government's Carbon Farming Initiative (CFI)?*

RW: Under the CFI, farmers can change their land management practice to one or more approved methods to earn Australian Carbon Credit Units (ACCUs). As originally set up, the CFI regulations were extremely complex and for a period of time no method for soil C sequestration was approved, so that farmers did not engage. The regulations have progressively been simplified and currently several methods for storing soil C have been approved, such as converting from cropping to grazing systems, sustainable intensification (including nutrient and soil acidity management, new irrigation and pasture renovation), stubble retention, and conversion to pasture. There is now a choice of either a 25 or 100 year commitment period and, for some methods, C storage values derived from the Full Carbon Accounting Model can be used to calculate ACCUs, rather than farmers being required to measure and verify soil C changes. Nevertheless, the system remains complex and, as of 14 August 2015, of the 381 eligible projects on the Emissions Reduction Fund register, only eight involved soil C storage. Furthermore, for conversion from cropping to grazed pasture, economic analysis shows that, even using a high ACCU value of $24 per tonne of CO_2 equivalent, in nearly all cases of switching from cropping to sheep or cattle grazing, a farm's gross margin per ha would be substantially reduced. In addition, methane emissions from the grazing animals would in most cases negate the benefits of increased soil C storage, from the viewpoint of offsetting greenhouse gas (GHG) emissions.

FDI: *What are the main conclusions to be drawn from our current preoccupation with storing organic carbon in soils?*

RW: Soil scientists have long advocated that increased soil organic matter is beneficial for soil fertility and resilience to changing conditions. Hence, the current focus on increasing soil C to offset Australia's GHG emissions can indirectly be a boon to soil health and agricultural productivity. However, the aim of sequestering C in soil for a long period is to an extent contrary to the aim of improving soil health through increased organic matter, for the reason that in the former case the C stored should be in an inert form, whereas in the latter the benefits depend on the degradable components of the organic matter and their rate of turnover.

Conversion of productive cropland to pasture, the most effective way of increasing soil C, is generally not economically viable unless a very high credit value is offered, and even then the effect of increased C storage may negated by methane emissions. The best option might be to improve the soil C content of degraded land when an increased gross margin per ha, augmented by a C credit, could make the operation profitable. For this option and other approved methods, such as sustainable intensification and stubble retention, a farmer needs to do a cost-benefit analysis of the change. Improving soil C levels should be a benefit to society through better soil health and agricultural productivity; but if achieved through the incentive of government C credits, it should be recognised as a taxpayer subsidy to farmers that will make little contribution to offsetting Australia's GHG emissions.

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About the Interviewee: Emeritus Professor Robert White has many years of experience in research and higher education institutions and he aims to use this experience to advise and assist individuals and organisations trying to improve agricultural productivity and environmental outcomes around the world. His research and teaching have taken him to China, India, the United States, New Zealand, South Africa, Chile, the United Kingdom and Australia. He has published an internationally acclaimed textbook, *Principles and Practice of Soil Science* (in its fourth edition with Wiley Blackwell, UK) and more specialised texts focussed on the wine industry, such as *Soils for Fine Wines and Understanding Vineyard Soils*, now in its second edition (both with Oxford University Press, New York). He has undertaken reviews and consulting work for the former Victorian Department of Primary Industries (now Economic Development, Jobs, Transport and Resources), the Grape and Wine R and D Corporation (now part of the Australian Grape and Wine Authority), and the former R and D Corporation Land and Water Australia. He is an Honorary Life Member of Soil Science Australia and a Life Member of the International Union of Soil Sciences.

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