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THE CHARADE OF "CARBON POLLUTION"

WE SEE TOO much bad science, lack of scientific accuracy, and imprecision. The most appalling and consistently bad example is reference to "carbon" when carbon dioxide is intended, but there are plenty more. Known falsehoods are blithely repeated. Why are scientists and scientific societies not protesting?

There is no need to open the newspaper: there are examples on the front page. On the front page of the *Australian* of January 28: "Wong presses on with 5pc carbon reduction target". There was a (slightly) more comforting main headline, "Be truthful on climate change: science boss", but no reference to carbon or carbon dioxide. Inside the paper Bjorn Lomborg wrote that "spending on R&D would produce ... breakthroughs ... needed to fuel a carbon-free economy for the entire planet". Carbon-free? Carbon underpins the life of the planet!

Under the main headline, the British government's chief scientific adviser, Dr John Beddington, urged more honest disclosure of uncertainty about the speed of climate change and less hostility to sceptics. Australia's chief scientist, Dr Penny Sackett, said she shared his concerns. I would urge both of them to go further and encourage a culture of precision. We also have a right to expect protests about such things from our august scientific bodies—the royal societies, the Academy of Science, the science teachers' associations. Our Prime Minister has a desire to lead the world in the whole matter—perhaps we could lead the world in differentiating between carbon and carbon dioxide!

Forgive me, I am a polluter! Well, that is what many, including the United States Environment Protection Agency, are claiming, simply because we produce carbon dioxide. The Agency has proclaimed carbon dioxide a pollutant, which it is not, by any stretch of the imagination or sophistry. The explanation was that the level of carbon dioxide in the atmosphere is so important that President Obama had to have power over deci-

sions regardless of Congress. Thus he was able to give some commitment at Copenhagen.

In Australia, though there has not yet been a formal declaration that carbon dioxide is a pollutant, it is implicit in the Carbon Pollution Reduction Scheme (CPRS). Why not a Carbon Dioxide Management Scheme? Or Greenhouse Gas Management Scheme, to include methane and nitrous oxide? There are many things in our environment that we need to monitor and manage, and the level of carbon dioxide in the atmosphere, though important, is just one.

Yes, we need to understand the carbon cycle better, to nudge parts of it forward, or slow certain processes so specific compounds do not accumulate, but it is carbon dioxide management, not elimination.

Every free-living creature on earth oxidises carbon, thus producing carbon dioxide. We also oxidise other carbon compounds to get energy when we need it, so life on earth is absolutely underpinned by a carbon economy. Yes, we may produce too much carbon dioxide, but it is not toxic, just sitting innocently there in the atmosphere waiting to be incorporated into carbohydrates by the process of photosynthesis. Many people are now surprised to learn that if carbon has an effect on global temperature it is through physical rather than any chemical (toxic) effects.

Too much common salt (sodium chloride) is bad for you, can make you sick, even kill you. There is a lot about, especially in sea water. Salt must be declared a pollutant or poison, too!

REPEATED FALSEHOODS

THEN THERE ARE the public announcements by people of what they must know are falsehoods. One example in the energy debate, where everyone wants renewables, is the proclamation by leaders opening a new wind farm that it will supply electricity for *x* thousand (40, 50, 60) homes. We

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all know, and the proclaimer must know, that on a lovely calm day it might not power even one. A second example is the government campaign in which a certain action fills a given number of black balloons, representing carbon dioxide emissions, which then float to the ceiling. Carbon dioxide is heavier than air, and a balloon full of it would sink to the floor.

Then there is the magic of electric cars. Matt White on Channel Seven said, "Imagine never having to drive into a service station again." It turns out to be so only if you never stray far from home or friends. (He fails to mention the price tag for this "freedom": a GM Volt costs about \$60,000 compared with a petrol-driven car of like size and performance under \$20,000.) The electric car people claim their cars are pollution-free, have no carbon footprint—clearly a falsehood, as these cars have to be manufactured.

Loose talk—with untruths or mis-statements of scientific facts, misleading the general public and encouraging an anti-scientific culture of imprecision—is a dangerous game.

THE ELEMENT CARBON

IT IS WORTHWHILE restating some facts about carbon and the "carbon economy" that are not generally understood, especially about so-called greenhouse gases and global warming, and including the now fashionable "biochar".

Carbon (C), the sixth element in the Periodic Table that older people learned at school, is in fact the core element in a huge range of compounds—millions of them—part of a marvellous cycle which extends through the air, all living creatures, the soil, the energy stores... It isn't just essential to life; it *is* life! About one fifth of our weight is C; but all in combined forms, almost all with hydrogen (H) and oxygen (O) as carbohydrates (CHOs) and proteins (CHONs). The bonds between the C and H and O represent the greatest energy store on earth. Breaking down—oxidising—these CHOs releases the energy and produces carbon dioxide.

Is carbon nasty? A very small amount of the C on earth exists on its own as elemental carbon, C, in two common forms: charcoal (sometimes called biochar) a rather inert substance, though in fine suspension—smoke—it can be injurious to health; and a crystalline form, diamond, a very hard substance that mainly damages the wallets of men, but is also useful as hard tips for drilling gear. So C itself is not nasty. Perhaps the question ought to be: Is carbon dioxide nasty?

All the loose anti-scientific talk implies that it is. Brendon O'Neill in the *Australian*, November 2, 2009, reported on a new children's book, *Panic Little Ones, It's the Carbon Monster*, which has a picture of a sooty,

blackened monster—carbon dioxide made hideous flesh with a grotesque grin on its face. Carbon dioxide is a colourless, odourless gas involved in the metabolism of these children, their life and energy, the nice green plants around them and the fruit and vegetables that nourish them!

Many more complex compounds are made using solar energy and carbon dioxide as a base, some in due course stored as coal and oil, and these can be dirty in the sense that black is dirty, but that does not make them evil. Yet Tim Flannery, in his book *The Weather Makers*, calls oil and coal "rascally fuel" and alleges that in using them that we are "pilfering the buried bounty of this alien world". This is nonsense: all are parts of a wondrous carbon economy. Rather, these are marvels of the planet, by-products of biological processes, part of a vast, complex and exciting cycle—which, like so many other things, humans must responsibly manage.

IS THERE TOO MUCH CARBON?

THERE CANNOT BE too much or too little of the element carbon in the totality of the compounds—the amount is fixed—yet every day someone writes or talks about there being too much carbon. Because of its role as the basis of life in the wrap-around living "skin" of the Earth, the amount is huge, even just in the form of carbon dioxide: probably 700–800 billion tonnes in the atmosphere; probably more than 2000 billion tonnes in all of the living organisms and creatures associated with the soil; and a staggering roughly 40,000 billion tonnes in the oceans. This huge oceanic reservoir of carbon dioxide nourishes the green organisms such as algae in the waters of the seas in the same way as it nourishes green things on land, possibly involving a greater total quantity of carbon dioxide.

It is relevant that warmer sea water holds less carbon dioxide in solution than colder water. On the other hand, sea warming would mean more photosynthetic activity, and therefore more carbon dioxide uptake, by the myriad of microscopic plants and animals in it. Further, the ocean current mixing of deeper colder water and warmer surface water plays a part—carbon dioxide is most soluble in cold water under pressure. The whole system is very complex, involving a global system of currents.

Is there too much carbon dioxide? Setting aside whether too much of this in the earth's atmosphere is the main cause of air temperature rise (or whether it is in fact rising at all, for that matter) we will look at several aspects of the wonderful carbon cycle that underpins our lives on Earth. Notwithstanding the range and complexity of the C compounds on earth, we can manage parts of the cycles to reduce the amount of various

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carbon compounds, including carbon dioxide in the atmosphere. We can oxidise less C, we can capture some of the carbon dioxide and lock it away in domed rock formations, and we can increase the turning of carbon dioxide into other carbon compounds, especially ones that are stable and can be put out of the way, such as in plants and soils. However, in doing so we must stress the importance of sound research, and be reminded from time to time that the processes obey the laws of nature, which are immutable.

THE MARVELLOUS CARBON ECONOMY

WITH COMPOUNDS OF carbon the basis of life on earth, at the core is that great marvel, green plants, and we should never lose our awe at the seedling shoot emerging from the soil—and its tip turning green within a few hours. This tip turning green affirms two things: first, that yet another power line to the sun has been added to the vast number already connected; and, second, another draw-down of carbon dioxide from the atmosphere has been turned on, enlarging the manufacturing "floor" area for the earth's carbohydrates (CHOs). These CHOs are made by C from the carbon dioxide bonding with hydrogen (H) and oxygen (O) from water. As is usual in chemical bonding, energy is latent in these bonds, and can be released as needed, under the right circumstances. The process of green plants capturing this energy is called photosynthesis and the release of the energy in living creatures is called respiration.

Most people know this much, but from here on confusion reigns, perhaps understandably, because the living things and various allied processes develop a vast array of organic compounds with C combined with varying ratios of H and O, and sometimes only with H. There are short chains with six carbons (such as glucose), others with twelve (such as sucrose), and many more complex ones such as cellulose, of which the estimated annual turnover is a trillion tonnes. Plants make, store and use these CHOs, and other living organisms then use plants as their food source, sometimes digesting the CHOs for energy almost immediately, or storing it in their tissues for later use, breaking the bonds to release the energy. For animals we associate this with breathing—taking in O, and then disposing of (breathing out) the carbon dioxide. All sorts of arrangements are involved in these living things: CHOs used in building the plant's stem and leaves and the animal's flesh

and muscles and fat, especially with nitrogen (N) to form proteins, which are chains of amino acids, CHO plus N. So carbon dioxide (O-C-O) the raw material of photosynthesis and the product of all carbohydrate and hydrocarbon oxidations, is, like water (H-O-H), just about everywhere there is life, a vital part of the system.

As well as the CHOs mentioned above, there are many other groups of organic compounds in nature. (Humans have manufactured some more synthetic compounds.) A few examples of these compounds, all consisting mostly or entirely of C, H and O, will illustrate their importance: methyl alcohol (methylated spirits), ethyl alcohol (usually just known as "alcohol"), acetic acid (vinegar), butyric acid (which occurs in butter and cod-liver oil); and then there are the hydrocarbons, our fuels and oils, such as methane, high-octane liquids and, with longer chains of carbon molecules, oils and greases, and finally coal. The lower carbon hydrocarbons all ignite easily, the higher numbers take a bit more effort, but all oxidise to give carbon dioxide and water.

We all know protein is vital in life, so the supply of nitrogen is important and must be managed. There is a vast reservoir of N in the atmosphere—80 per cent of it, so hundreds of times more than carbon dioxide—and N is best brought into the living system from the atmosphere by farmers using the legume plant family which host bacteria on their roots and exchange CHOs for N compounds. Plants need adequate N to give

good yields, and if farmers cannot fit growing legumes into their operation they may use synthetic N fertilisers, made by using fossil fuel energy and producing carbon dioxide. Australian farmers have been better than most at using legumes to access N from the atmosphere.

STORING OF SOLAR ENERGY

THIS WIDE RANGE of compounds of carbon is all about us, sometimes used soon after formation, sometimes stored, to be used after varying amounts of time in various ways. The soonest energy released is by the green plant that "made" the CHO, oxidising some C to live at night and maintain the parts of the plant. Some CHOs may last longer as part of the structural tissues of the plant, eventually removed in parts used for human or animal food. Some may only be broken down after the death of the plant, what we call rotting. It may then form compounds in soil. Some may last much longer in plants with big hard structures—shrubs and trees—forming wood, which is

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nearly pure CHOs, mostly cellulose, stable but fascinatingly variable in durability. Some woods are largely resistant to rotting or attack by termites and especially if kept dry may last hundreds of years.

Humans, over much of their existence, have used solar energy stored in wood form as a convenient source of energy, released to keep themselves warm or cook food. The longevity of wood explains why trees are so important in locking up—sequestering—carbon. We grow the trees and leave them standing in the forest. Unfortunately this interferes with a long tradition of humans seeing trees as a resource for firewood and timber, so the issue of locking up is hotly debated. There is also the ever present risk of bushfires, which release enormous amounts of carbon dioxide.

There is a vast amount of cellulosic material often just left as waste. One fascinating approach proposed by Dr Berhan Ahmed of Melbourne University is to feed some of this wood debris to termites, which then becoming a foodstuff for fish or poultry—a novel food chain.

Humans have always consumed parts of plants—fruits, grains, stems, roots—first as hunter-gatherers, then in time as farmers, obtaining their needs more easily. Animals have directly or indirectly based their existence on the CHOs of plants, eating the leaf and stem as an energy source, so some CHOs have been eaten, digested and excreted, usually onto the soil. Some have lasted a bit longer as the body of the animal, broken down only after death. That reaching the soils, partly digested, called manure, is of special interest—it is important in the possible sequestration of carbon in soil. On the other hand, the animal parts that are sold for food tend to be consumed and oxidised far from the site of production. If this happens in a different country, to whom should the carbon dioxide be debited in a carbon dioxide taxing scheme? In Australia, a food exporting country, how can we be fair to our farmers?

Then there are the very, very long-life CHOs. The remains of the organisms that make them, or eat them, have become trapped, buried and compressed in deep layers of the earth, and where there is little or no oxygen many compounds may form with only C and H—we call them hydrocarbons, typically gas, oil and coal. It takes little imagination to see all of these various compounds as the bounty of the earth as it was bathed in sunshine in a much earlier time.

In organic chemistry, which is the study of these compounds, a striking feature is the unity of it all. It all derives from that plant shoot "plugging in" to the sun and beginning photosynthesis and, significantly, producing oxygen. There would be little or no oxygen on the planet without the green plant and the C economy.

So we have various forms of circulating solar energy: from a same-day cycle to longer life, entering

the life of plants and creatures and involved in their storage organisms, and much longer-term solar energy storage, as in the wood of trees, and very long-term storage in things like coal and oil and gas. The speed with which C is cycled is clearly an important consideration once we decide we want to slow down the accumulation of carbon dioxide in the atmosphere. Modern humans are interacting with the cycle in such a way as to accumulate some compounds more rapidly than is desirable, but now that we have recognised this there are clearly many technologies and approaches that we can use to balance the parts of the cycle and access other forms of energy. Whether we need financial incentives to save ourselves is a moot point.

THE LOOSE SURFACE OF THE EARTH: SOIL

WE USE THE term *soil* to describe the loose surface of the earth in which plants grow. It is mostly broken-down rocks, which release some chemicals—in effect a blanket wrapped around the earth. The composition of this soil is highly variable, depending on how it is made—and managed by humans. It begins as mineral matter, then is progressively colonised by plants and soon incorporates their carbon compounds in various stages of rotting, as well as the manure from animals that feed on the plants, and so on.

The term *soil organic matter* is used by some people to describe any or all of this non-mineral material. Discussion of it gets very complicated indeed, partly because of the interactions with plants, animals, a myriad of insects and micro-organisms in and above the soil—and for much of the land area of the planet the individual farmer or forester contending with the vagaries of climate and product prices. The type and amount of plant growth relate to which minerals came from the disintegrating rocks (or in more recent times, have been added by humans as fertiliser), as plants need about fifteen different minerals to thrive. Once living things colonise the soil, there is a steady accumulation of carbonaceous material, and as a general rule plants grow better as this increases to a point where production and break-down are in balance. If a soil has little non-mineral material it tends to become hard and unproductive and may erode. The study of plants interacting with soil and climate is called plant ecology and the nurture of plants growing in the soil for higher yield is called agronomy.

It is no surprise that there are many carbon compounds associated with the soil, much of it cycled through what we call the OM (organic matter) cycle.

The most visible forms of carbonaceous material associated with plants growing in soil are litter and mulch, mostly CHOs like cellulose from plant remains,

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some of it CHON, protein from parts of plants that have died and remain on the surface. Through other biological activity in the surface layer of the soil, some gradually becomes a second very important category, compounded organic matter actually incorporated into the soil. When plants are growing in the soil, we need to be aware of the C:N ratio of this litter, because if it is too high the creatures and micro-organisms living on it will take up N that would otherwise be available for plant growth—commonly called nitrogen draw-down. Thus, mulching can lead to stunting of our desired plants through N deficiency. Simply having a lot of litter is not a prescription for higher yield—it must be of the right composition.

Soil organic matter, this carbonaceous material which enters into the life of the soil, is molecules generally composed of carbon, nitrogen, sulphur and phosphorus (C, N, S, P) in quite standard proportions—like any other chemical compound, a fact poorly understood. Having a good amount of this molecular OM can transform the soil as it plays a powerful role in soil physics and chemistry, forming the equivalent of soil particles, binding sandy soils together, or dispersing clay soils by keeping pores open and acting as attachment sites for cations (such as potassium and calcium and sodium) in the soil. It can have a hugely beneficial effect, reducing risks of erosion and increasing moisture penetration and storage. Because it is composed of C N S P in fixed proportions, it cannot be formed unless supplies of all four are available in the right ratio. Once litter becomes the food base for small creatures and micro-organisms this is an important mechanism for molecules of OM forming in the soil.

Recognition of this molecular structure and form, and the need for the other elements, is significant when sequestration of C in soils is being considered. When some CSIRO scientists recently pointed out that there is therefore a cost in building up this genuine soil organic matter, they were ridiculed by ignorant people.

BIOCHAR

WE HAVE NOTED that carbon also exists in elemental forms, one long known as charcoal, now fashionably as "biochar", produced either in "natural" burns or in managed firing of carbon compounds with restricted oxygen—virtually letting the material smoulder. The process is called pyrolysis, using special equipment to

control the oxygen supply so much of the C is not oxidised but remains as elemental carbon.

Thus true biochar is an inert form of C. Burying this in soil is another thing entirely from building up the soil OM comprising C N S P, as biochar is inactive in the soil and its presence does nothing to change the chemistry of the soil. It may have a physical effect, in so far as creatures and organisms can live in cracks in it, and it may give modest improvement in water-holding capacity. A variety of material of ill-defined composition from the burning of various materials high in C—residues of plant growth, feedlot waste, urban green waste—is being paraded as biochar, although it is a composite of ash and other products. For example, in two products both described as Biochar, one from poultry litter, the other from green waste, total P was 3.4% and 0.01% respectively, N was 0.8% and 0.14%, and C was 27% and 48%. The pH of the material, using calcium chloride extraction, was 13.0 and 8.1.

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What a nightmare it would be to manage application against soil acidity and nutrient availability targets—and to get carbon credits for its use! Yet, in a highly undisciplined manner, having taken extraordinary liberties with definition, a whole mystique has grown up around biochar, with Tim Flannery describing it as "the single most important initiative for humanity's environmental future" and Malcolm Turnbull—and perhaps Tony Abbott—being persuaded that it is the way of massive sequestration of C in soils.

Once the material is analysed and a recognised definition of biochar is used, along with a clear understanding of soil chemistry and physics, it is very unlikely that these sweeping claims about its effectiveness can be valid. In pure form, elemental and unreactive, this C interacts very slowly, some remnants lasting hundreds of years, so there is no doubt that the material could be used for sequestering—storing—C. On the other hand, it would be cheaper just to tip it into an old mineshaft or quarry than to spend money and energy distributing it on the soil and mixing it.

Wild claims are made about the benefits of mixing these various chars with soil: that thousands of years ago in the Amazon rainforest it led to less fertiliser use and higher crop yields and helped the "terra preta" soils retain moisture and fertility; that in Western Australia, one wheat farmer, Ian Stanley, has had improvements of crop yields of 15 to 20 per cent and that instead of emitting 86 kilograms of carbon dioxide per tonne of wheat he stores 1.9 tonnes of carbon dioxide. On this basis Tim Flannery estimates that, given assistance in setting

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up pyrolysis plants, within twenty years biochar will be responsible for locking up one to two billion tonnes of C globally each year.

Professor Johannes Lehman of Cornell University, USA, asserts that biochar exhibits "basic properties of stability and capacity to hold nutrients ... more effective than other OM in soil ... is not merely another type of compost or manure but is more efficient at enhancing soil quality than any other organic soil amendment". Quite apart from the loose use of terms, this is beyond belief and suggests that he is not writing of true biochar.

As far as field crop residues are concerned, even if char is produced, the huge energy cost in gathering the scattered material from the field to central sites where the pyrolysis machines are located, forming the char and spreading it back over the soil and incorporating it into the soil must be questioned. Perhaps of greatest importance, it is denying huge amounts of carbonaceous material to the natural biological systems—what we call "nature's web of consumers and decomposers" which in due course use the material as their natural food and through living processes incorporate the C into the soil forming the much more important reactive C N S P material. Carting it away and using it even in a noble-sounding process like pyrolysis is akin to returning to the stubble burning of 100 years ago! Modern conservation farming with zero tillage (ZT), now widely adopted in Australia, retains a maximum of CHOs for biological activity, steadily increasing C storage in soil, towards a new equilibrium.

Undoubtedly biochar can filter, can "spread out" clay particles, and pores and cracks in it can provide a hiding place for micro-organisms and very small creatures, but little beyond this. But elemental C is not chemically reactive, and cannot enter the biological life of the soil, cannot replace any fertiliser. So the enthusiasm for it is astonishing.

Of course, if it isn't real biochar, but a mixture of ash and charcoal of variable composition, it may well contain mineral nutrients like potassium and sulphur and phosphorus. It has been known for millennia that ash from the fireplace, a mixture of charcoal and ash, fertilises plants, and that where a farmer had burnt heaps of stumps or logs there was biochar—and ash which of course has various minerals in it. An alternative explanation for the Amazon soils is that, instead of moving farming in a slash-and-burn long-rotation pattern, material was continually brought from the forest to a central site, thus maintaining mineral levels. Claims of the farmer in Western Australia suggest he is using ash as well, not pure C.

There is a clue in the publicity of the company Anthroterra, which aims to produce a "biochar mineral complex". The head of Anthroterra enthuses, "We'll be taking the traditional processes of the Amazon Indians

and producing a new generation fertiliser with twenty-first-century science. It's a mixture of material science and metallurgical wizardry." Yes, "wizardry". A report in the December 2009 *Farm Journal* was headed "Feedlot manure biochar stands out"; in a trial at Wollongbar Primary Industries Research Institute in Northern New South Wales it was superior municipal waste biochar. One can imagine the variability, and at times richness in minerals, of this material and plead for some discipline, standard names, analysis of material, registration—and restoring some semblance of science to this work. Let's underpin our research work and climate change studies with scientific rigour.

On a related note, one can feel good about the supernatural views of Rudolf Steiner in his biodynamic farming, or long for the transmutation of organic material into nutrients dreamed of by Lady Eve Balfour, but in the end the laws of nature prevail. We are not alchemists: we cannot fabricate minerals from organic material. Plant growth is determined by the supply of some essential mineral nutrients to plants growing in a satisfactory physical environment.

Even given the extravagant claims for biochar, net gain in energy is unlikely in many situations and the amount of extra C storage beyond that occurring progressively through adoption of ZT is questionable. How much more C can be sequestered in soil? The CSIRO is quoted as estimating that the Australian landscape can store an extra one billion tonnes of carbon in the soil and vegetation each year for the next forty years. This process would actually become more difficult and unlikely as the forty years passed—and could not be repeated *ad infinitum*.

THE GRAND SEQUESTRATION OF THE PAST

THE SITUATION AND past behaviour of many farmers are also being misrepresented—typically by Tim Flannery and Jared Diamond and some ABC programs. Despite what they claim, over the last half-century there has been great stress by agricultural scientists and farmers on increasing active soil organic matter, since two seminal research reports in the 1950s—based on Donald and Williams's work at Crookwell in New South Wales and John Russell's at Kybybolite near Naracoorte in South Australia. There has been clear understanding of the difference between litter and the largely biologically inert carbon formed in pyrolysis, and on the other hand carbonaceous material active in the life of the soil. Admittedly they set equal store by the soil having good physical structure, good supplies of nitrogen, and an adequate level of P and N, but the system they used in fact involved a huge amount of carbon sequestration as a consequence of seeking other goals.

The introduction of sub clover in the middle decades of the twentieth century was one of the most important events in the economic history of southern Australia. Until then the amount of herbage—CHO material—land owners could produce was limited by low levels of some plant nutrients. There was low interception of the abundant sunlight and poor access to the abundant atmospheric nitrogen—thus soils had very modest levels of true OM. Late in the nineteenth century it was recognised that the Australian soils were deficient in P—over the ages it had been washed off the old continent, into the sea food chains, and deposited by birds on islands. Applying P to the old lands into which sub clover had been introduced caused huge increases in plant growth—photosynthesis, the making of plant CHO. The farmers tried using the rock phosphate from Nauru and Ocean Island just crushed, but it was too slow in releasing its nutrients into the soil. It was found that treating it with sulphuric acid made the P more soluble, more available, and growth responses much more immediate. Where one sheep grazed before, now five or more could graze.

Though the impact on the economy was enormous—the wool boom of the 1950s—looking back the sequestration of C in the soil was just as important. Treatment of the P rock with acid formed calcium sulphate—gypsum—and knowing it was harmless, the makers of fertiliser did not go to the expense of removing it. Donald's Crookwell work discovered that the really important soil OM was the compound of C N S P, so a source of sulphur was vital. The vast accumulation of OM in soils might not have occurred without that gypsum! Surface litter, while useful mulch, does not enter the cycles in the same way or confer such benefit on soils.

The long-term experiments at Kybybolite, and later work at Hamilton in Victoria, have given good information on the soils of grazing lands, especially the vast sequestration of C in C N S P form. From about 1920 to 1956 an addition of 90 kilograms per hectare per year of P fertiliser resulted in a rise of more than 2500 kilograms of this OM per hectare compared with land not fertilised—nearly three times the "native" level. The greatest annual gains were in the early years and though the increase continued, there was a tailing off, the level of OM coming into equilibrium with climatic factors and land use. Tillage for cropping is known to cause breakdown of some OM so the recent widespread adoption of ZT has caused further gains in C sequestration.

These chapters in our history are important in the

current debate on soil sequestration of C. First, it is probable that over large areas of farmland, certainly in southern Australia, much of what could be done has been done and OM levels have been raised to near equilibrium. It is probable that many of those who could sequester high levels have done so already and those who have not will be difficult to persuade to do so. Second, we must recognise that high soil OM—the real, reactive stuff—which contains the sequestered C is only built up if there is a supply of P and S and N. Historically the P and S have come from the added manufactured fertiliser, the N from the legume growth stimulated by these fertilisers and the C from carbon dioxide in the atmosphere. Thus the cost of sequestration, on many soils, will be the continued addition of P and S. This may be particularly important in developing countries—perhaps the financial donations of the developed countries to reduce global C levels should be spent on supply chains for fertiliser.

The huge importance of phosphorus in all of these energy transactions should be noted—forming adenosine di- and tri-phosphates and being involved in stages of the equations for photosynthesis and respiration. Though some plants have adapted to operating at a slightly lower level of P, a low content of P in soils generally spells a low level of plant activity. A search by some bio-technicians for plants that do not need fertilisers is like seeking a way to defy gravity.

HOW MUCH CAN WE STORE?

ALL OF THESE considerations suggest that we can sequester more C but the process will not be simple. First, though the publicly promoted view is of "our degraded landscapes" waiting for someone to raise OM levels, the truth is otherwise: a large proportion of our cropping area is managed by good farmers who have raised the OM level of much of their farm land to near the equilibrium, and there is limited scope for more. For a variety of reasons some farmers have not so improved their land: some of them may be responsive to financial incentives to change their systems. And would such incentives be fair to those who have already done so at their own expense?

Second, we need to recognise the different emphases of different farming systems. The capture of the word *organic* by one particular schema for production may lead people to believe it is more likely to sequester C than commercial farming, but mainstream farmers have

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had as great a concern for building up soil OM and sequestration, and in any case sequestration is more likely to succeed with systems that do not eschew the use of mineral fertilisers. Organic systems are generally less precise and other elements may be limiting, so their yields are lower and greenhouse gas emission per unit of food output is often higher.

Third, we need to allow for the costs of raising the level of other elements like P and S—the other elements needed. Finally, we must recognise the law of diminishing returns. Even on the more backward properties there will not be a linear increase for long; it will tail off, and not be repeatable.

There is also talk of planting a large number of trees on the assumption that they will quickly grow into big trees storing a lot of carbon. The notion that we have endless niches for tree planting in suburbia and vast areas of marginal farmland simply waiting to be planted to trees to sequester C fails to understand the limitations of climate, land and soil. The blue gum plantations in southern Australia are not on marginal

land, but on country suitable for productive grazing, even cropping using newer technology. We must count the production lost against the return from the trees, and the carbon sequestered against the carbon economy of the crop or pasture land.

There is plenty of diversity in the carbon-based system—but the rules of chemistry and physics still apply. It deserves precision from us: such as calling carbon dioxide "carbon dioxide", not "carbon"; understanding the wonderful C system and economy, the life of the Earth, not alien fuel; using precise analytical systems to inform our use of soil amendments, knowing when a compound is a fertiliser; and, finally, recognising that much about C sequestration is not new, that it must be grafted onto an already productive and innovative farming activity which has already raised soil C levels.

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