‘Biological Pathways to Carbon Rich Soil’

Explanatory notes and webinar Q&A

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The following notes provide additional information and links to the literature

The truth about trees

Sequestration of carbon in monoculture plantations of *Pinus radiata* has been promoted as a means to assist New Zealand meet emission reduction targets.

A closer analysis of the data however, clearly shows short-rotation plantation forestry is not a long-term solution. Most estimates of the carbon storage potential of plantation forestry consider only the carbon removed from the atmosphere by actively growing trees, ignoring a complete life-cycle analysis.

Once full account is taken of the extremely short life-span of the harvested product, coupled with carbon losses from soil, the fossil fuel required for ground preparation, planting, forest management, harvesting, transport and processing, the net sequestration attributable to short-rotation plantations is not only negligible - but more often than not, negative.

Over half of New Zealand’s harvested wood is exported, with 96% going to China, Korea and India (1). Here the wood is used for a variety of purposes including fuel, sawdust, packaging, plywood, particle board, fibreboard, concrete formwork and lumber. The aggregate decay curve for wood exported to those three countries shows carbon stocks are halved in just over two years (1).

As a result, exported logs, which account for more than half of New Zealand’s timber production, are treated as an instantaneous emission under the Kyoto Protocol (1). Harvested wood products remaining within New Zealand also have a limited lifespan. The half-life of solid wood is 30 years while paper and paperboard have a half-life of only two years (1).

The net effect is that the carbon stored in New Zealand’s harvested wood products is returned to the atmosphere in less time than it takes to grow the trees. When the energy required for ground preparation, maintenance, harvesting and transport is taken into account, the carbon balance is negative. It has been estimated that in order for positive net carbon storage to be achieved, the area planted to *Pinus radiata* would need to be doubled in size roughly every 20 years (2).

The prospect of ever-increasing areas of land being devoted to short-rotation forestry, for little - if any - net sequestration benefit, requires careful consideration. Even if not harvested, all of the carbon stored in trees is returned to the atmosphere when the trees die or are lost in fires. Further, plantations of monoculture *Pinus radiata* lack biodiversity and are at odds with many aesthetic and cultural values (3).

In addition to the data from complete life cycle analyses revealing short-rotation plantations of *Pinus radiata* emit more carbon to the atmosphere than is sequestered, it has also been shown that pines emit monoterpenes that deactivate the hydroxyl radicals involved in the photo-oxidation of methane (4). Photo-oxidation is the largest natural sink for methane and hydroxyl radicals are pivotal to this process (5). It has been postulated that the increasing areas being planted to pine trees in many regions of the world could be contributing to the recent - and largely unexplained - rapid rise in global methane concentrations, as a result of reduced sink capacity (4).

Not just any carbon and not just anywhere

New Zealand requires a carbon capture and storage option that increases biodiversity, supports cultural values, provides long-term removal of carbon from the atmosphere and enhances the value of exported products.

Soil is by far the largest terrestrial sink for carbon. The world’s topsoils hold three times as much carbon as the vegetation. When subsoils are taken into account, that figure doubles. Despite their lower carbon concentrations, subsoil horizons contribute to more than half of global soil carbon stocks (6).

An analysis of 2,700 soil profiles in global databases revealed the percentage of organic carbon in the top 20 cm - relative to the first metre - averaged 33%, 42%, and 50% for shrublands, grasslands and forests, respectively (6)

By subtraction, if 42% of the carbon in the top metre of grassland soils is in the 0-20cm increment, then 58% is in the 20-100cm increment.

In short, deep carbon matters.

There is a need to reassess the shallow sampling depths used for calculating soil carbon stocks, particularly in light of the evidence for the responsiveness of deep soil carbon to changes in land use and vegetation.

Pasture management effects on ‘deep carbon’ in New Zealand

Research into carbon dynamics in New Zealand’s pastoral soils has revealed soils are not necessarily in ‘steady state’ with respect to carbon, as had previously been believed. This is particularly so for ‘deep carbon’.

Progressive enrichment of over 200% of the carbon in the 40-100cm increment a well-studied New Zealand soil under stable pastoral management, across samplings in 1959, 1974 and 2002 (7) indicated deep carbon is more reactive than was once considered.

In their paper entitled ‘*Large losses of soil C and N from soil profiles under pasture in New Zealand during the past 20 years’,* Schipper and colleagues recorded soil carbon losses averaging 21 tonnes per hectare (21 tC/ha) in the top one metre of soil at 31 sites on flat to rolling pastoral land in New Zealand (8). These losses were associated with an intensification of land use and commonly extended to depths of one metre or more (8). The average soil carbon loss of 1 tC/ha/yr (8) equates to a cumulative loss of 50 t/ha of soil carbon over a 50 year period.

A subsequent study involving the analysis of 83 sites, found that significant amounts of soil carbon were lost where dairy cattle grazed flat land (9). In contrast, carbon levels improved under drystock grazing on hill country, while no significant changes to soil carbon were observed under drystock grazing on flat land or under tussock grasses in high country.

Andisols - inherently fertile volcanic soils once thought to be protective of soil carbon - lost similar amounts of carbon to other soil orders under intensive dairying (9). In other words, the changes in the level of soil carbon were management related rather than a function of soil type.

One of the key findings to emerge was that the largest soil carbon losses in the intensively managed dairy soils occurred in the 20-80cm increment of the soil profile, while the improvements to hill country grazed by dry stock were most evident in the 30-60cm increment (9).

It is unfortunate to see losses in soil carbon occurring in soils under intensively managed dairy pastures in New Zealand, a country blessed with vast tracts of inherently fertile land. Dairy pastures are predominantly composed of shallow-rooted, short-lived ryegrass and clover mixes that tend to be grazed very short.

Low plant diversity and inadequate root architecture contribute to poor soil function and low rates of carbon sequestration, particularly at depth. Vertical root distribution has a large influence on the deep sequestration of carbon (6,10). Carbon exuded by the roots of actively growing plants can build soil as deep as roots can go.

Dairy systems also receive higher fertiliser inputs than drystock systems, particularly with respect to N (9). Schipper *et al*. noted fertiliser N applications in dairy systems were in the order of “50-150 kgN/ha/yr” [equivalent to 100 to 300 kg urea per hectare] while drystock pastures “tended to receive no urea” (9).

The extraordinary power of plant diversity

Plant diversity is the cornerstone of a world-wide revolution in agriculture that is completely rewriting everything we thought we knew about soils, plants and animals.

Comparisons of low-input high-diversity pastures with high-input low-diversity pastures in many parts of the world indicate yields are either comparable - or higher - in low-input high-diversity systems and soil carbon sequestration is significantly higher.

A German experiment in which fertiliser rates of 0, 100 and 200 kg N/ha/yr were applied to 78 experimental grassland communities of increasing plant species richness (1, 2, 4, 8 or 16 species; with 1 to 4 functional groups) showed higher diversity was a more important factor for pasture yield than nitrogen fertiliser (11).

High-diversity plots (4 functional groups and 8 or more species) also accumulated 21.8% more carbon compared with low-diversity plots (1, 2 or 4 plant species) (12). Increased carbon storage was due to increased rhizosphere carbon inputs in the more diverse plant communities (12).

Research undertaken in Ireland and Switzerland has shown yield advantages of up to 50% for perennial pastures containing four functional groups compared to monocultures (13). Similarly, an eight-year study undertaken in the south of England found that species-rich pastures averaged 43% higher herbage yield than species-poor pastures (14). Regression analysis indicated the variation in herbage yield was related to differences in the number of non-leguminous herbs, suggesting the increased yield of species-rich pastures reflected the greater range of life forms present (14).

In a 12-year field trial in Minnesota, multi-species swards with asynchronous growth traits significantly increased soil carbon to one metre depth (10).

As well as increasing soil carbon and improving soil function, multi-species crops and pastures provide habitat and food for insect predators. Recent research has shown that as the diversity of insects in crops and pastures increases, the incidence of insect pests declines, avoiding the need for insecticides (15).

The Carbon Capture Farm

Understanding the importance of where carbon is stored and how we might enhance the processes contributing to stable carbon storage is fundamental to the future productivity of New Zealand's agricultural industries. The capture and storage of deep soil carbon will require the restoration of above- and below-ground diversity of plants and microbes.

Two simple steps for carbon capture and storage at depth

i) Incorporate as much pasture diversity as possible, particularly deep-rooted warm- and cool-season herbs and a variety of grasses.

ii) Replace high-analysis N fertiliser and water-soluble P with biology-friendly products to enhance the innate capacity of soil microbial communities to fix atmospheric nitrogen and solubilise phosphorus, two of the key components of humic polymers. Microbial processes are integral to the long-term storage of carbon. The humification process is inhibited by the application of high-analysis N and/or P.

Pasture basics

Optimum function of multi-species swards is achieved when there are four functional groups (grasses, legumes, tall herbs, short herbs) with at least two species from each. We need to start thinking of pastures as 'herblands' rather than 'grasslands'. Maximum benefit will be derived from deep-rooting species of non-leguminous herbs high in secondary plant compounds, with asynchronous patterns of growth. The greater the spread of photosynthesis over the year the greater the potential for soil carbon storage as well as enhanced animal performance. Check the roadsides at different times of the year for an indication of which plant families are best adapted to growing in your region.

Microbes matter

Multi-functional soil and plant microbial communities drive productivity, provide protection from pests and diseases and increase plant tolerance to abiotic stresses such as frost and drought (16, 17). But as Louis Pasteur famously said “Le microbe n’est rien, le terrain est tout.” (The microbe is nothing, the terrain is everything). It is up to us to create a soil environment that favours beneficials over opportunists. That applies to the human microbiome as well. Indeed, human and soil microbiomes are linked (18).

A biostimulant applied at planting will assist the core microbiome of the germinating seed to form beneficial relationships with resident soil microbes. Seeds must not be treated with insecticide or fungicide. Placing high analysis N and/or water-soluble P on or near seeds, or indeed, in contact with soil, limits microbial diversity and is not recommended. Regular application of low rates of a blend of biological stimulants, plus a protein hydrolysate when needed, will support photosynthesis and increase root depth and root exudation, enhancing the functioning of the soil microbiome and improving soil carbon storage at depth. Microbial community assemblages are the key determinant of whether carbon inputs are respired from soil as carbon dioxide or stabilised in soil as humus. The simplest way to monitor the benefits or otherwise of the biostimulants you are using is by measuring Brix. Brix levels will also be reflected in animal performance.

Grazing management

Strategic grazing (only 30% - 50% leaf removal at each graze during the growing season) combined with adequate recovery should ensure that high-diversity multi-species swards never need replacement. Root biomass, root depth and deep carbon accrual will increase over time - as will animal production. The energy, mineral and trace element content is higher in the top half of the plant. Animal performance is maximised by skimming pasture in a ‘flash graze’, leaving adequate photosynthetic material for rapid recovery. The less taken out in each graze period, the sooner stock can return.
It has been calculated that by removing no more than 50% of the leaf area during each graze, up to 60% more forage can be produced in a growing season (19).

Conclusion

Ecologically sound agricultural production based on above- and below-ground biological diversity can assist New Zealand meet emission reduction targets, through the creation and storage of deep soil carbon.

The Kyoto Protocol, which relates only to carbon sequestration the 0-30cm increment of topsoil, completely overlooks the ‘sequestration of significance’ in the 30-100cm increment. Deeply sequestered carbon is more chemically stable than topsoil carbon and also alleviates subsoil constraints, improving farm productivity and enhancing hydrological function.

The costs involved in converting current high-input low-diversity short-term forages to low-input species-rich multi-functional perennial pastures would be minimal in comparison to the benefits. An appropriately managed diverse pasture sward should remain productive and continue to sequester deep soil carbon almost indefinitely.

Although carbon is rapidly sequestered in fast-growing trees, it is also rapidly returned to the atmosphere after harvest, resulting in no net sequestration in harvested plantations. In contrast, deeply sequestered soil carbon can remain for millennia.

Providing support for farmers to develop and implement a whole-farm approach to enhancing the sequestration of deep, stable soil carbon would be more beneficial to the New Zealand nation than attempting to store carbon in short-rotation pine forestry.

Literature cited

1. Manley, B. and Evison, D. (2017). Quantifying the carbon in harvested wood products from logs exported from New Zealand. *New Zealand Journal of Forestry,* 62(3):36-44.
2. Lucas, D. and Burrows, L. (2019). Radiata pine plantations – a band-aid to nowhere**.** https://pureadvantage.org/news/2019/09/11/radiata-pine-plantations-a-band-aid-to-nowhere/
3. Global Forest Coalition (2020). 15+ years of REDD. Has it been worth the money? https://globalforestcoalition.org/wp-content/uploads/2020/09/REDD-briefing.pdf
4. Salinger, J. and Desjardins, R. (2019). Why a 'two-basket' emissions approach to climate change is hot air**.** https://www.nzherald.co.nz/opinion/news/article.cfm?c_id=466&objectid=12219776
5. Riedel, K. and Lassey. K (2008). Detergent of the atmosphere. *Water & Atmosphere,* 16(1) 2008. https://niwa.co.nz/sites/niwa.co.nz/files/import/attachments/detergent.pdf
6. Jobbagy, E. G. and Jackson, R. B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, 10: 423–436.
7. Baisden, W. T. and Parfitt, R. L. (2007). Bomb ^{14}C enrichment indicates decadal C pool in deep soil? *Biogeochemistry* 8: 59-68. doi: 10.1007/s10533-007-9101-7
8. Schipper, L. A., Baisden, W. T., Parfitt, R. L., Ross, C., Claydon, J. J. and Arnold, G. (2007). Large losses of soil C and N from soil profiles under pasture in New Zealand during the past 20 years. *Global Change Biology* 13: 1138–1144. doi: 10.1111/j.1365-2486.2007.01366.x
9. Schipper, L. A., Parfitt, R. L., Ross, C., Baisden, W. T., Claydon, J. J. and Fraser, S. (2010). Gains and losses in C and N stocks of New Zealand pasture soils depend on land use. *Agriculture Ecosystems and Environment,* 139: 611-617. doi: 10.1016/j.agee.2010.10.005
10. Fornara, D.A. and Tilman, D. (2008). Plant functional composition influences rates of soil carbon and nitrogen accumulation. *Journal of Ecology,* 96: 314-322. doi.org/10.1111/j.1365-2745.2007.01345.x
11. Weigelt, A., Weisser, W. W., Buchmann, N. and Scherer-Lorenzen, M. (2009). Biodiversity for multifunctional grasslands: equal productivity in high-diversity low-input and low-diversity high-input systems. *Biogeosciences*, 6: 1695-1706, doi:10.5194/bg-6-1695-2009
12. Lange, M. *et al.* (2015). Plant diversity increases soil microbial activity and soil carbon storage. *Nature Communications,* 6:6707 doi: 10.1038/ncomms7707
13. Haughey, E. *et al.* (2018). Higher species richness enhances yield stability in intensively managed grasslands with experimental disturbance. *Scientific Reports*, 8: 15047. doi: 10.1038/s41598-018-33262-9
14. Bullock, J.M., Pywell, R.F. and Walker, K.J. (2007). Long-term enhancement of agricultural production by restoration of biodiversity. *Journal of Applied Ecology*, 44: 6-12. DOI: 10.1111/j.1365-2664.2006.01252.x
15. Lundgren, J.G and Fausti S.W. (2015). Trading biodiversity for pest problems. *Science Advances,* 1(6). doi: 10.1126/sciadv.1500558
16. Gopal, M. and Gupta, A. (2016). Microbiome selection could spur next-generation plant breeding strategies. *Frontiers in Microbiology*, 7: 1971. https://doi.org/10.3389/fmicb.2016.01971
17. Rout, M.E. and Southworth, D. (2013), The root microbiome influences scales from molecules to ecosystems: The unseen majority. *American Journal of Botany*, 100: 1689-1691. doi:10.3732/ajb.1300291
18. Blum, W., Zechmeister-Boltenstern, S., and Keiblinger, K. M. (2019). Does soil contribute to the human gut microbiome? *Microorganisms*, 7: 287. https://doi.org/10.3390/microorganisms7090287
19. Gerrish, Jim (2015). Wasting grass. Iowa Beef Center. https://www.youtube.com/watch?v=7X_Bz91zWOw

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WEBINAR Q&A

Ag@Otago – Christine Jones Seminar

From Stephen Crawford to Everyone: 04:47 PM
Does it matter what is in the plant mix with the 4+ plant types?

Christine's reply: Soil microbes function most effectively as diverse consortia and are best supported by plants with asynchronous functional traits. Research from around the world indicates the most rapid soil-building occurs when there are four functional groups (grasses, legumes, tall herbs, short herbs) and two to four species from each group. The non-leguminous herbs are critical for both feed conversion efficiency and soil carbon storage.

Think of grasses as weeds that are very tolerant of defoliation. They make great lawns and playing fields. Ruminants can survive on grass but they don't thrive. Grasses have low nutritional value compared to non-leguminous herbs. Offer livestock a choice between grass or a multi-species sward and they will choose the multi-species sward every time. The issue is that they will want to graze it into the ground. Hence the grazing of diverse pastures requires a higher order of management.

The second phase of the Irish SmartGrass project was re-named SmartSward when the researchers realised it was not about grass. The grasses are only there to provide some structure. A rising plate meter will tell you little, if anything, about forage quality.

The choice of species for your multi-species sward will of course be influenced by enterprise, soil type, rainfall, minimum and maximum temperatures etc. My visits to South Otago have been exceedingly brief, so not really sure what grows there, but my best bet (from a distance) would be ….

Grasses: Prairie grass, cocksfoot
Legumes: Red clover, white clover (+ maybe lucerne? sanfoin? birdsfoot trefoil?)
Tall herbs: Chicory, yarrow
Short herbs: Plantain, burnet, meadow parsley, sorrel, evening primrose

It's hard to know just how much diversity is required but I'd suggest the first two species listed in each category are probably the most important. That combination would give you eight tried and tested species from four functional groups. If it was possible to add in some of the others it could prove worthwhile. A nurse crop of oats, barley and linseed may prove beneficial during establishment. Also, annual flowers such cosmos, cornflowers and vetch are highly nutritious and attract beneficial insects. Perhaps these could be established in areas that can be protected from grazing while flowering?

Pasture quality is more about functional diversity and feed conversion efficiencies than biomass. By way of analogy, a small plate of herbs will provide far more nutrition for a person than a mountain of lettuce - and having eight different kinds of herbs in the mix would be better than just one.

In regards to the number of pasture species required to provide maximum benefit, it seems logical to think that at some point functional redundancy should occur. However, there are data suggesting it gets better the more species in the mix - even up to 60!!

North Island beef producers have achieved markedly improved liveweight gains when they increased the pasture diversity from 12 to 24 species, but I'm not sure whether that was a time factor or a diversity factor. That is, were the 24 spp. sown in the same fields as had originally contained 12 spp? If so, could the observed response simply be a carryover effect. Soils improve rapidly under multi-species pastures. The only way to tell would be the have a split-paddock with 12 spp. on one side and 24 spp. on the other.

Research funds might be better expended answering that question than breeding new varieties of shallow-rooted short-lived ryegrass that contribute little to animal nutrition and even less to soil health.

The only thing we know for certain about pasture diversity is that anything less than four functional groups is inadequate (i.e. the majority of New Zealand's current pastures).

From Tim Blackler to Everyone: 04:57 PM
Silica and carbon building is there a relationship? Does aluminium toxicity inhibit sequestration of C at the outset? Chemical residues and limitations on carbon sequestration? Rattan Lal, JSWS 2014 on 'Societal Value of Carbon' talks about need for N, P, S to build carbon. Does nutrient cycling in animals (provided the grazing management is right) supply ample nutrients to meet this need through dung & urine? If so, does the nutrient need to be present in at least some sort of optimal level in the soil or because we are exporters will we always need to supply nutrient removed? OR, assuming in is the parent material and microbial activity is optimal, can we just continue to tap into this going forward?

Christine's reply: Silicate minerals constitute around 90% of the earth's crust but I'm not aware of any relationship between silica and carbon. You would need to ask a geologist.

The aluminium story is interesting. It is definitely part of the carbon story but I need to talk about the carbon part first.

The figures quoted by Rattan Lal are for the **decomposition** of organic matter. Decomposition is a catabolic pathway in which complex forms of organic matter such as plant residues are broken down into smaller and smaller components. If the carbon to nitrogen ratio (C:N ratio) is too high in a product such as wheat straw, for example, lack of nitrogen will slow the decomposition process and hence nitrogen may need to be added.

On the other hand, the liquid carbon pathway is anabolic. It begins with simple sugars exuded by plant roots. During the humification process the carbon is polymerised to form complex and highly stable carbon compounds. In the liquid carbon pathway, the N, P and S incorporated into humic polymers are activated through soil biological processes. They do not need to be added.

So where do the N, P and S come from? The atmosphere is 78% dinitrogen. There are literally thousands of species of soil bacteria and archaea able to convert atmospheric N to plant available forms - provided plants exude sufficient carbon to support them. That's why it's important to optimise photosynthesis through pasture diversity and appropriate grazing management. If N fertilisers have been used, N-fixing microbes will not be prevalent. It takes around three years for their numbers to increase to sufficient levels for N to be dropped totally out of the system. During transition N should never be applied to soil, as it inhibits the natural N-fixing process. It can however be applied as a foliar if plants appear N-deficient. The safest form of N is a protein hydrolysate, such as fish. If you need a quick fix, ammonium sulphate is a better option than urea. But remember, applying soluble N will drop Brix levels and reduce the rate of root exudation, so only use it if you have to. Never use N to increase the 'amount' of pasture, as it will simply be empty calories. Stock will perform better on short, nutrient dense pasture than taller pasture pumped up with N. It may look better but its not.

What about P and S? These are only required in very small quantities. The biological processes activated by root exudates are sufficient to supply the amounts needed. If water-soluble P is applied to soils it will inhibit these natural pathways. Remember, over 97% of the P in soils is <u>not</u> in a plant available form and will <u>not</u> show up on a soil test. The only safe way to asses P status is through plant tissue tests.

In some locations - especially those distant from the coast - levels of available S can be low, in which case there is no harm in applying a small amount.

Where does aluminium fit into this story?

Humus is an organo-mineral complex. That is, it is composed of carbon plus minerals. Humic polymers are 58-62% C, 6-8% N, 1-2% P and 0.8-1.5% S. That adds to around 70%. The other 30% of the humic molecule is mostly iron and aluminium. If humus is breaking down, aluminium will be released into solution. If humus is forming, aluminium will be taken out of solution and safely sequestered.

In other words, levels of available aluminium rise as carbon levels fall and levels of available aluminium fall as soil carbon levels rise.

Does animal dung and urine provide the N and P needed for humification? No. As explained above, the availabilities of N and the P are increased through the activation of microbial processes supported by plant root exudates. However, appropriate grazing management is required to optimise the exudation process. And because animals and soils have co-evolved, soil microbes respond to signals from shed animal hair, saliva, dung and urine, all of which stimulate soil biological activity and indirectly increase the availability of N and P.

Do we need to replace the minerals exported in product? No. The minerals removed in farm products are a tiny fraction of the total amount present in soil. A standard soil test - even a test of totals - is a very poor indicator of what is actually present. X-ray diffraction (XRD) is the only method that provides a full mineralogical analysis of the soil. A tissue test is the best indicator of whether those minerals are actually getting into the plants.

Again, pasture diversity and appropriate grazing management are the best means to ensure the soil microbiome is receiving the energy it needs to activate the biological processes that underpin the availability of essential minerals and trace elements - and of course, increase the level of stable soil carbon. All are linked.

To return to your question re Rattan Lal, the application of high rates of water-soluble N and/or P reduces root exudation, inhibiting the biological processes necessary for the acquisition of minerals and trace elements, resulting in mineral-deficient plants and animals. Rattan Lal was recently awarded the $250,000 World Food Prize. In previous years the award has gone to Monsanto, Syngenta and the European Federation of Biotechnology (genetically modified crops). I would suggest you view Lal's comments re the need for fertiliser through that lens.

From Alan to Everyone: 05:00 PM
We keep hearing about NZ soils having high carbon levels compared to the rest of the world. What is your definition of a high carbon soil, what % carbon? What is the potential of our soils if we grow our soil horizon to say 1 metre?

Christine’s reply: The total carbon storage capacity of soil is determined by a combination of factors including vegetation type, clay content, temperature and rainfall. In general terms, carbon storage capacity increases in the presence of deep-rooted plants growing in functionally diverse communities that support the microbial assemblages necessary for humification. The speed with which carbon levels can be increased (provided diverse plant communities are in place) is enhanced in soils with a high clay content, adequate levels of soil moisture and moderate temperatures.

In comparison to many other regions of the world, New Zealand soils are ideally suited to the storage of soil carbon, at least in a physical sense. However, this capacity is currently limited by the presence of shallow-rooted plants on much of the land used for agricultural production. Further, because soil carbon sequestration is a microbially-driven process and is intrinsically linked to other microbial processes such as free-living nitrogen fixation and phosphorus solubilisation, the application of high rates of synthetic fertilisers in New Zealand limit the potential for additional carbon storage.

The other factor to consider in regards to soil carbon is that it is the direction of change, rather than the absolute amount, that matters in biological terms.

Around 6 million hectares of wheat are grown on the West Australian sandplains where Total Organic Carbon (TOC) levels are commonly less than 1%. Where farmers have increased this to 2% the enhanced productivity and resilience to climatic extremes is incredible. Yet in many regions of the word, 2% soil carbon would be considered woefully inadequate.

Irrespective of the starting point, if carbon levels are trending down, levels of organic nitrogen, mineral and trace element availabilities, soil porosity and structure will decline. If carbon levels are trending up, levels of organic nitrogen, mineral and trace element availabilities, soil porosity and structure will improve.

In terms of carbon capture and storage, the amount of CO2 removed from the atmosphere for a 1% increase in soil carbon will be the same whether the change is from 1% to 2% or 8% to 9%. But we need to consider more than the percentage change. The depth at which the additional carbon is sequestered is extremely important. If soil carbon can be increased at depths below 20cm it is far more likely to be stable. Below 30cm would be even better. Soil carbon can be sequestered as deep as roots can go. I’ve seen chicory roots 2 metres in length, so there’s no reason why carbon could not be sequestered at that depth.

Because New Zealand has ideal temperature and moisture conditions for soil carbon sequestration, the potential for NZ agricultural soils to sequester carbon at depth when sown to deep-rooted pasture species is enormous.

From Shengjing to Everyone: 05:02 PM
In these deep soil studies, did they talk about what is causing loss of this deep soil C? Assuming they are not cultivated sites.

Christine’s reply: Carbon can be lost from depth for several reasons, including over-application of high analysis fertilisers, low diversity pastures, plant species with shallow roots and grazing pastures too short and too frequently. Most NZ dairy pastures get a tick in every box.

From Ross Hyland to Everyone: 05:06 PM
Huge promotional push globally around hydroponic and vertical urban farming. After your talk, surely such food will be virtually of zero value nutritionally. Comment please CJ

Christine’s reply: The issue with hydroponics is that because nutrients are taken up in solution, the uptake is passive. In other words, the plants just sit there and drink (sound appealing?) but don't get any say in what they're drinking (maybe not so appealing). If you lace the concoction with poison, they'll take it up. You get the picture.

Of course, substances normally considered to be 'poisons' will not knowingly be added to hydroponic systems producing vegetables for human consumption. But to my mind, nitrate, a commonly used fertiliser, is a poison. Nitrate is a carcinogen at 2ppm and will be present in the water and in green leafy vegetables grown hydroponically at much higher concentrations than that. Why do people apply nitrate to plants? Because they grow faster. In a hydroponics system you can grow larger, leafier veggies the more nitrate you apply. But larger and leafier does not necessarily mean more nutritious.

In a biologically active soil, the transfer of nutrients to plants is mediated by the plant-microbe bridge. Plants will signal to microbes for what they need, then exchange liquid carbon for those nutrients in a barter system. If the plant has to 'pay' it will only 'buy' what it requires, hence everything will be in balance. If the soil is microbially active, nitrogen compounds can be transferred to plants in the organic form (mostly as amino acids) and there is no need for any nitrate to be present at all.

In a hydroponics system, in addition to 'unwanted' ingredients such as nitrate, there will also be many things missing. Trace elements such as selenium and iodine are classic examples. They are not used in hydroponic systems but are essential to human health.

From Greg to Everyone: 05:08 PM
Can you explain the difference between Organic Matter% and Total Carbon% tests, what is best?

Christine’s reply: Organic ‘matter’ is essentially the decomposed remains of something that was once living - such as plants, insects or animals - or decomposed manure. Hence it will be comprised of all the elements we observe in living things - carbon, nitrogen, oxygen, hydrogen, calcium, magnesium, potassium, sulphur and so on.

Because it is an extremely heterogeneous product, it is not possible to accurately measure how much ‘organic matter’ is in soil. The standard test for estimating SOM used to be the Walkley Black method, which determines the 'dichromate-reducible' materials. Under some circumstances (eg if the soil contains high concentrations of reduced iron or manganese, or is highly saline) it is possible for Walkley Black to only be around 85% accurate.

Most labs these days will measure Total Carbon (by combustion) which is much simpler, cheaper and more reliable than Walkley Black. Then they will multiply the carbon percentage by 1.72 to obtain an estimate of ‘organic matter’. Why 1.72? Because organic matter is usually around 58 to 62% carbon. Using the 58% value provides a conservative estimate.

Again, it is only an estimate. It would be far less confusing for everyone if ‘organic matter’ estimates were not included in soil test reports.

What we really need to know is how much total carbon is in soil. This is determined by loss on ignition and is a much more accurate measurement than Walkley Black.

The only issue is that total carbon includes inorganic carbon (such as carbonates from the application of lime). If we want to know how much of the carbon in soil came from the atmosphere - and how the amount of carbon sequestered is changing over time - the soil sample needs to be treated with acid to drive the carbonates off, prior to combustion to determine the organic carbon content.

The other important consideration is that humified carbon formed anabolically via the liquid carbon pathway is very different to decomposed organic matter. Humus begins its journey as simple carbon compounds exuded from plant roots, which are polymerised through microbial processing. To call this material ‘organic matter’ would be misleading, as it can remain stable for millennia, whereas ‘organic matter’ decomposes. ‘Organic matter’ is more correctly referred to as ‘labile carbon’ and is mostly in the surface layers of the soil.

The term ‘organic matter’ needs to be deleted from soil test reports. If everyone talked in terms of Total Organic Carbon (TOC) it would simplify matters enormously.

From Sam Lang to Everyone: 05:09 PM
Thanks Christine! Do you still think we need to wean off N inputs over 2-3 years, or with high quality biostimulants/inoculants like SPICE/Johnson-Su can we support plant microbiome adequately from day 1 and go cold turkey?

Christine’s reply: It depends on the context. Are you meaning monoculture crops and pastures or highly diverse systems? Diversity replaces fertiliser. If a cover crop or pasture contains four functional groups with a minimum of two species from each, then a biostimulant should be all that is necessary to assist germinating seeds form a good relationship with resident soil microbes. From there, quorum sensing will come into play and nitrogen should be fixed as needed. The nitrogen may not show up on a soil test as it will be taken up by plants at the same rate as it is being fixed. However, it will show up in tissue tests.

In the above situation, you would not want to be putting high analysis N or P anywhere near the seeds. However, if a farmer is trying to reduce nitrogen inputs on monoculture crop or pasture then the natural N-fixing microbes will not be present and a biostimulant is not going to replace them. In the absence of plant diversity, natural N-fixers will take three years to build up to sufficient numbers for N to be dropped out of the system.

It is relatively easy for livestock producers to diversity the forage on offer as the benefits for animal health and soil building far outweigh the cost of the seed. Not quite so simple in a crop production scenario, unless the crop is for silage or hay. To increase the diversity of soil microbial communities in seed or grain production systems, farmers may need to experiment with relay cropping, interseeding, intercropping and/or multi-species covers. It’s possible that some N will always be needed in low diversity crops, but only protein hydrolysates and/or ammonium sulphate should be used - and of course it goes without saying that biostimulants on seed, in furrow and as foliars will help enormously.

From Hamish to Everyone: 05:14 PM
What biostimulants are proven to work well mixing with seed down the drill?

Christine’s reply: Autoinducers produced in microbially rich fermentation environments populated by facultative anaerobes such as lactobacillus are the most effective at stimulating the seed’s core microbiome. Autoinducers will be present in products such as fermented seaweed, vermiliquid, KNF and compost extracts. These products all make great seed dressings. All you need is the cold-water extract, which contains the autoinducers. No need to make an oxygenated ‘brew’ which skews the population to aerobes and reduces microbial diversity. Home gardeners can obtain a cold-water extract of cow manure by simply soaking it in a bucket. The cow has already fermented the forage in its rumen.

There are many excellent off-the-shelf biostimulants available. Information on how and when to apply, plus the recommended rates of application, will be on the product label.

Irrespective of which biostimulant you choose, dilute solutions are best. Biochemical ‘signalling molecules’ are more potent in parts per trillion than parts per million. Frequent applications at low rates when plants are actively growing are more effective than less frequent applications at higher rates. It is also beneficial to combine several types of biostimulant to increase the diversity of signalling molecules. To combine three products, for example, you would use each at one-third the recommended rate.

From Stephen Crawford to Everyone: 05:18 PM
When you say use no fertiliser, are you talking about N or all fert?

Christine’s reply: I’m only referring to water-soluble high analysis N and/or P (urea, anhydrous ammonia, MAP, DAP, superphosphate etc). An excess of other elements such as potassium can interfere with soil balance, but does not inhibit root exudation to the same extent as water-soluble N and P. The reason N and P are problematic is that plants have evolved intricate mechanisms to obtain these essential elements and their ready availability creates a chain reaction with many negative consequences. For a start, root exudation is reduced, as the plant does not need to support natural N-fixing and P-solubilising bacteria in the rhizosphere. When root exudates are reduced, soil structure declines. No amount of fertiliser can overcome soil compaction. By attempting to alleviate nutrient deficiencies in low diversity pastures we’ve caused a raft of soil function, animal health and environmental issues.

Provided there is sufficient diversity in the forage base, the microbes will take care of all the plant’s nutritional needs as well as provide protection from pests and diseases and increase plant resilience to environmental stresses. Sounds almost too good to be true, but farmers around the world are discovering the extraordinary power of diversity in many and varied cropping, horticultural and pastoral situations. If we look to the natural world, we see biodiversity is the cornerstone of productivity. So why not get with the strength? Complex systems are self-organising. Therefore what we need to aim for in agriculture and horticulture is the reinstatement of sufficient complexity for the system to manage itself. All we need to add is seed - and some biostimulants to help things along.

From Simon Inkersell to Everyone: 05:22 PM
Is there a test or what is the best way to measure nutrient levels in feed. Or do we have to stick with the DM, ME and protein measures?

Christine's reply: Using a refractometer to measure Brix will give you the best indication of feed value. You can calibrate your taste buds to the refractometer provided you know the pasture has not been sprayed. There was a reason old-timers tasted the grass. These days most of it tastes like cardboard, so it's not surprising the cows complain.

Animal performance will be greatly enhanced if pastures are Brixing above 12 (measured on a sunny afternoon). If Brix levels are falling short of that, you need to review pasture composition, fertiliser program and grazing management. The application of high analysis N and/or P fertilisers will reduce Brix levels as well as shortening plant roots. Heavy grazing will do the same. As mentioned elsewhere in this document, most of the energy and nutrients are in the recently emerged leaves, hence animal liveweight gains and fertility are higher if only the top half of the plant is grazed. 'Flash grazing' deepens plant roots, increases total biomass production and increases Brix levels.

From prem maan to Everyone: 05:30 PM
Have you looked at deep inverse tillage?

Christine's reply: With all due respect to the well-meaning researchers investigating this technique, I cannot understand why one would want to expend huge amounts of fossil fuel turning soil upside down. The carbon buried in inverse tillage is labile surface carbon formed through the decomposition of organic matter. It is not humus. It is not stable. The organic matter will continue to decompose, albeit more slowly, after inversion. Inverse tillage is not a long-term solution.

My understanding of the research being undertaken into inverse tillage in New Zealand is that following soil inversion, the area is sown to a monoculture ryegrass pasture. The presence of shallow-rooted fertilised ryegrass is the primary reason soil carbon is only accumulating in the 0-15cm increment of the soil profile. Turning soil upside down does not solve the problem. Only a change in pasture composition can do that.

The sequestration of deep, humified carbon requires a diversity of deep-rooted plants and their microbial assemblages. Once a multi-species sward has been established it should never need replanting, provided it is managed appropriately - and deep soil sequestration should continue indefinitely.

Multi-species swards can be established on all land classes, whereas inverse tillage has limited applicability. A change in pasture composition would be in everyone's best interests …. microbes, plants, animals, people and the environment.

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