Future Directions international

INDEPENDENT STRATEGIC ANALYSIS OF AUSTRALIA'S GLOBAL INTERESTS

Strategic Analysis Paper

6 July 2020

Soil Carbon Restoration: Can Biology do the Job? Part Three

Jack Kittredge,
Policy Director North East Organic Farming
Edited by Christopher Johns
Research Manager, *Northern and Rural Australia Research Programme*

Key Points

- Bare soil oxidises carbon, while plants protect it. Green plants form a barrier between air and soil, slowing the process of carbon emission.
- Studies report that the organic cropping systems with the highest levels of carbon restoration are those practising no-till while adding organic matter to the soil.
- Cover crops are essential in any organic strategy to reduce or eliminate tillage, control weeds, and build soil carbon.
- Concerns exist about raising large numbers of ruminant animals because in the process of digestion, they give off greenhouse gas. It is only when ruminants are away from biologically active soil or water, such as in feedlots, however, that ruminant emissions can be of concern.
- Increasing soil carbon builds aggregates which, in turn, enables soil to hold water, thus providing reserves to plant roots. This capacity to retain water also reduces the risk of erosion and can result in improved crop quality and yield.

Summary

In this, the third and final part of Jack Kittredge's paper, he firstly asks the question: what practices do we need to use to build and keep carbon in our soil? He then discusses, in detail, the soil management practices that will enhance and maintain soil carbon. He then describes the advantages of building organic matter in the soil in addition to of removing carbon dioxide from the atmosphere. To conclude the article, the author states that if we wish to survive, we have no alternative but to restore carbon to the soil and that it can be done through biology. It uses a process that has worked for millions of years. Anyone who manages land can

follow these simple principles and restore carbon to the soil while renewing our atmosphere and agricultural soils.

Analysis

How Can We Restore Soil Carbon?

As soil scientists learn more about the components and microbial processes that form humus, we will have a better understanding of how to assist its creation. But there is evidence suggesting that building soil organic matter is not just a job of adding organic matter to your soil. That will create a thriving microbial community and can make crops flourish. But to build long term carbon, you need to do more.

What we need to know is: what practices do we need to use to build and keep soil carbon in our soil?

Keep Soil Planted. Probably the most important single lesson is that bare soil oxidises carbon, while plants protect it. Green plants form a barrier between air and soil, slowing the process of carbon emission by microbes. Erosion by wind and water is also a major enemy of soil carbon, and growing plants are your best protection against erosion. Finally, plants not only protect soil carbon but also add to it through their power of photosynthesis. Put simply, every square foot of soil that is left exposed, whether it is between rows of crops, because you are tilling up a field, or have just harvested a crop and are leaving the land to fallow, reduces your carbon bank account.

Practices like winter vegetation to cover the soil and under-sowing with legumes and cover crops are important so that after the crop is taken there is a productive cover to increase soil carbon, protect against erosion, feed soil organisms and increase aggregation. (Azeez)

Minimise Tillage. One of the most difficult carbon restoration practices for organic growers to adopt is to reduce tillage. Since organic growers do not use herbicides, tillage of the soil is their major weapon against weeds. But tillage does several detrimental things. First, it stirs up soil and exposes it to the air, oxidising the carbon in the exposed soil. Second, tillage rips up and destroys the hyphae of mycorrhizal fungi, the microbes responsible for much of the symbiosis that is so important for plant vigour and increased exudation of liquid carbon. Their hyphae are the delicate network strands that permeate the soil and carry water and nutrients to plant roots. Studies report increases in fungal biomass at all sites where tillage is reduced. (Six) Third, the complex soil aggregates that have been built up of microbial exudates to protect important chemical transformations such as nitrogen fixing and carbon stabilization will be ruined by tillage. Fourth, tillage tends to destroy the pore spaces in the soil that are vital for holding air and water, which enable microbial vitality. Finally, tillage itself often involves equipment that is powered by fossil fuels, releasing greenhouse gases in their operation.

Studies report that the organic cropping systems, with the highest levels of carbon restoration, are those practicing no-till and adding plenty of organic matter, such as cow manure, to the soil. (Khorramdel) Critics of tillage report that even one tillage operation after several years can result in loss of most of the carbon built up during that time. (Lal 2007)

There are some studies that report that the soil carbon gains of no-till are not distributed deeply through the soil profile, but rather occur mostly near the surface. This is a problem, they suggest, because the best chance for humus formation and long-term carbon stabilization seems to be deeper in the soil, closer to clay and minerals to which the carbon can bond to resist oxidation. They also argue that the kind of soil organic matter produced under no-till management is only incorporated in the sand/soil fraction of the soil near the surface and is easily oxidised upon eventual disturbance. (Azeez)

Some studies that point to the shallowness of organic matter build-up under no-till, however, also report a slow deepening of soil organic matter after 10 to 15 years under the system, presumably because of both decreased organic matter decomposition and long term soil mixing by larger soil organisms. (Powlson)

There are several systems and devices that are currently being designed for organic growers to reduce tillage. Planters are available that open the soil only enough for the seed or seedling to be deposited and close it right up again afterward. Roller-crimpers have been designed which roll over and crimp a long-stemmed cover crop before flowering, killing it but not disturbing the soil. The market crop is then planted right into the stubble of the cover. Doubtless many other good ideas for enabling organic farmers to fight weeds while not disturbing the soil will be developed. There is certainly a need for more progress on this front.

An alternative method of controlling weeds is the use of mulch to prevent light from reaching them. The simplest mulches to apply are sheets of plastic. Their production, however, usually requires fossil fuels and removal can be difficult and time consuming. Mulching with organic materials such as hay or shredded crop residue adds decomposing organic matter to the soil and builds carbon, but in biologically active soils it requires continual additions of material which can be costly and time-consuming. The primary drawback to mulching, however, is that it does not take carbon from the atmosphere and fix it into the soil via photosynthesis, as living plants do.

Cover Crops. Cover crops are essential in any organic strategy to reduce or eliminate tillage, control weeds and build soil carbon. Ideal candidates for cover crops can be killed (by frost, mowing or crushing) before flowering, so they do not produce seeds and become weeds themselves. Their photosynthesis is an important source of soil carbon while living, and their biomass becomes available after they die. Legumes are important in the cover crop mix, as are deep-rooted plants like annual ryegrass or cereal rye that bring nutrients from deep in the soil and add nitrogen and carbon back to those lower levels.

Besides increasing soil carbon, cover crops reduce nitrogen leaching and discourage wind and water erosion. They improve soil structure, increase water infiltration and reduce evaporation. They also provide higher levels of lignin than most cultivated crops, thus supporting mycorrhizal fungal growth and fungal products such as glomalin that promote soil particle binding. (Rodale, Azeez)

Diversity and Crop Rotation. One of the keys to supporting the microbial life in the soil is to encourage diversity. One principle of nature seems to be that the more biodiversity there is in a system, the healthier and more resilient it is. This is also true when building soil carbon. (Lal 2004) Below ground, biodiversity enables every microbe to fill a niche in the food web – fungi, algae, bacteria, earthworms, termites, ants, nematodes, dung beetles, etc. Above ground, monocultures invite pests and disease where crop diversity keeps infestations from growing and spreading. This applies to both crops and to cover crops, which should contain many plants of different types – broad leaf and grass, legumes and non-legumes, cool and warm weather, wet and dry. No matter what the conditions, some should be able to thrive and photosynthesize. "Cocktail cover crops" are mixes of many varieties of cover crop seed and are now available for purchase to guarantee biodiversity.

Crop rotations also help benefit biodiversity. Rotations with continuous cover crops eliminate the need for fallow periods to refresh the land and increase the activity of soil enzymes. Microbial biomass is larger when legumes are included in the rotation. (Six)

Grazing ruminants are also a common way for organic farms to improve soil organic matter levels. The grazing itself promotes the growth, then sloughing off, of grass roots -- which provides carbon to feed hungry soil microbes. Pastures and perennial systems, if properly managed, can show rapid increases in organic matter. Animal manure is one of the most valuable products of the small mixed farm, rich as it is in both carbon and the living microbes that inoculate soil with biological diversity.

Reduced Use of Chemicals. The use of synthetic agricultural chemicals is destructive of soil carbon. Toxins like pesticides are lethal to soil organisms, which play a crucial role in enhancing plant vitality and photosynthesis. Fertilizers have also been shown to deplete soil organic matter. In the Rodale Institute's Compost Utilization Trials using composted manure with crop rotations for ten years resulted in carbon gains of up to 1.0 ton/acre/year. The use of synthetic fertilizers without rotations, however, resulted in carbon losses of 0.15 ton/acre/year. (LaSalle)

The Morrow Plots at the University of Illinois were the site of one of the longest running controlled farm trials in history. Researchers analysed data from 50 years in which fields on which a total of from 90 to 124 tonnes of carbon residue per acre had been added, but which also used synthetic nitrogen fertilization. Those plots lost almost 5 tonnes of soil organic matter per acre over the trial period. (Khan)

One suggested cause of the negative impact of synthetic fertilizer on soil carbon is the fact that it tends to reduce the size and depth of plant roots since it is concentrated in a shallow layer at the soil surface rather than spread throughout the soil as would be nutrients from legumes, minerals or other natural sources. (Azeez) Another reason might be the impact on the plant of absorbing ammonium ions which causes it to release hydrogen ions, which acidify the soil. (Hepperly) A third possibility is that the availability of free nitrogen causes the plant to exude less liquid carbon to obtain nitrogen from microbes. If you have been using synthetic nitrogen fertilizers, however, and want to stop doing so it may be wise to cut back gradually over three or four years because it will take time for nitrogen-fixing bacteria to build up in your soil. Stopping cold turkey may result in disappointing yields the first year. (Jones SOS)

Pasture. As noted earlier that proper pasturing is a highly effective method of agriculture to restore soil carbon. A recent study of land converted from row cropping to management intensive grazing showed a remarkable carbon accumulation of 3.24 tons/acre/year. This is in the range of deep-rooted African grasses planted to savannas in South America that achieved rates of 2.87 tons of carbon/acre/year. (Machmuller)

Part of the efficiency of pastures at fixing carbon is probably related to the fact that several grasses use the C4 photosynthetic chemical pathway, which evolved separately from the more usual C3 pathway. Particularly adapted to situations of low water, high light and high temperature, C4 photosynthesis is responsible for some 25 to 30 per cent of all carbon fixation on land, despite being used by only 3 per cent of the flowering plants. (Muller)

Some people are concerned about raising large numbers of ruminant animals because in the process of digestion they employ bacteria in their rumen that give off methane, a greenhouse gas that the animal then exhales. In an ecological setting this is no problem as methanotrophic bacteria, which live in a wide variety of habitats and feed solely on methane, will quickly metabolize it. In fact, after the Deepwater Horizon oil spill in the Gulf of Mexico, some 220,000 tons of methane bubbled to the surface but were quickly consumed by an exploding population of methanotrophic bacteria. It is only when ruminants are away from biologically active soil or water, such as in feedlots or on soil to which synthetic chemicals have been heavily applied, that ruminant methane emissions can be of concern. (Jones SOS)

Forests. Converting degraded soils to forest use has been proposed to enhance soil carbon. As with other plants, the rate of forest soil carbon restoration depends on climate, soil type, species and nutrient management. The studies we have found on soil carbon in forests generally show modest gains in soil carbon or, in some cases, a net loss. (Lal 2004) There are some, however, that suggest proper management of woody plants can also deliver sizeable soil carbon gains. (Quinkenstein) Also, reforestation can lead in other ways to climate moderation and water cycle restoration.

Biochar. The potential for use of charred residues to enhance soil fertility, while restoring carbon to the soil, has recently gained a lot of attention. Pointing to the terra preta soils of the Amazon, anthropogenic dark earths enriched with char more than 800 years ago, proponents cite the high fertility these soils even today. Other char-containing soils are Mollisols, grassland derived soils extensive in North America, the Ukraine, Russia, Argentina and Uruguay that produce a significant portion of global grain harvests. The char in these soils has been attributed to grassland fires that occurred long ago. The actual chemistry of these char residues has only recently been investigated. Their stability and fertility may be related to protective habitats their internal spaces provide for microbes, or to char's molecular structure, which creates a large cation exchange capacity (ability to hold ions of minerals needed for plant nutrition). (Mao)

Although biochar has not been extensively studied, researchers suggest that biomass carbon converted to biochar can sequester about 50 per cent of its initial carbon in the soil for long periods, leading to a more stable and long-lasting soil carbon than would be the case from direct land application of uncharred carbon. (Dungait)

Of course, any conversion of carbon to biochar must involve a life cycle assessment concerning the source of the carbon, its land use implications, and the energy of processing and applying it. There are some indications, however, that biochar is a good way to confer additional stability to labile, or easily broken down, organic matter in soil. (Powlson)

Benefits of Restoring Carbon to Soil

The advantages of building organic matter in your soil are not limited to removing carbon dioxide from the atmosphere.

Water. Increasing soil carbon builds aggregates, which in turn act as sponges to enable soil to hold water, thus providing reserves to plant roots in times when precipitation is low and a ready sink to soak up excess in times when it is high. This capacity to retain water also reduces the risk of erosion and can result in improved crop quality and yield. Some growers believe that companion plants or a cover crop will use up all available water or nutrients. To the contrary, supporting soil microbes with a diversity of plants improves the crop's nutrient acquisition and water retention. (Jones SOS)

Interestingly, since the 1930s the mean maximum and minimum water levels of the Mississippi River have gotten more extreme – flood levels are higher and low river levels are lower. This happens because the water cannot infiltrate the soil as it should. With good infiltration some water supplies plant production and some flows slowly through the soil to feed springs and streams which bring a long-lasting base flow to river systems. But if groundcover is poor, soil aggregation diminishes, and water cannot infiltrate well. Thus, in floods water runs along the surface and erodes soils, and in droughts there is no supply retained in the soil for either plants or maintaining flow to springs and streams. (Jones SOS)

Fungal Dominance. Scientists are finding that a high ratio of fungi to bacteria in soil is very important to plant production. You can tell if you have such a ratio by the aroma of a handful of soil – if it is mushroomy, not sour. It is the fungi that seek out and supply water and nutrients to plant roots as needed. Unfortunately, most of our agricultural soils are bacterially dominant, rather than fungal dominant. But practices that avoid bare soil, do not till, use cover crops of many species, and encourage high density but short duration grazing with significant rest periods are moving soil toward fungal dominance.

Better Crops. Plants, just like animals, have evolved complex defences against enemies. Their mechanisms are many, and clever. Some avoid detection by adopting visual defences such as mimicking other plants or camouflaging themselves. Some make attack difficult by putting on armour such as thick cell walls, waxy cuticles, or hard bark. Some deter predation by use of thorns, spines, or sticky gum-like exudates. Many synthesize secondary metabolites to prevent attacks chemically (poisons, repellents, irritants, or even volatile organic compounds that attract the enemies of the plant's predator). (Wink) Plants also engage in symbiotic relations with bacteria that can inhibit local pathogens and thus defend plants against attack.

Such abilities, just as is the case with immune systems in animals, are strongest when the plant is healthy. That health is optimal when the needs of the plant for sunlight, nutrition, water, oxygen, and carbon dioxide are fully met. Of course, that happens best in healthy soil with a high carbon content and a diverse and large population of microbes. Those conditions can lead to crops with nutrient density, resistance to pests and diseases, more antioxidants and longer shelf life. (Gosling, Wink, Reganold)

Plants that are not held back by disease or predation and have their nutrient needs met are going to thrive and give abundant yields. Also, healthy plants biosynthesize more of the volatile molecules and higher metabolites that produce the flavours and aromas of food crops. Restoring carbon to soils is a way to benefit all: farmers with larger yields, gardeners with tastier crops, and consumers with healthier food.

Conclusion.

Using biology to restore organic matter to soils and stabilise it is not only beneficial to those who manage land and crops but is also vital to our society. We have taken too much carbon from the soil, burned it, and sent it into the atmosphere as carbon dioxide. Even were we to stop burning fossil fuels tomorrow, the greenhouse gases already released will continue to raise global temperatures and set free more harmful gases many years into the future.

If we want to survive, we really have no alternative but to restore carbon to the soil. That this can be done through biology, using a method that has worked for millions of years, is exciting. Farmers, gardeners, homeowners, landscapers -- anyone who owns or manages land -- can follow these simple principles and not only restore carbon to the soil but help rebuild the marvellous system that nature has put in place to renew our atmosphere while providing food, beauty and health for all creation.

Sources

AAAS, American Association for the Advancement of Science, (2014) What We Know: The Reality, Risks, and Response to Climate Change.

Albrecht WA, (1938) Loss of Soil Organic Matter and Its Restoration, Yearbook of Agriculture, USDA.

Amundson R, Berhe AA, Hopmans JW, Olson C, Sztein AE, Sparks DL, (2015) Soil and human security in the 21st century, Science, 348, 1261071.

Azeez G, (2009) Soil Carbon and Organic Farming, UK Soil Association, http://www.soilassociation.org/LinkClick.aspx?fileticket=SSnOCMoqrXs%3D&tabid=387 .

Cairney JWG, (2000) Evolution of mycorrhiza systems, Naturwissenschaften 87:467-475.

Comis D, (2002) Glomalin: Hiding Place for a Third of the World's Stored Soil Carbon, Agricultural Research, http://agresearchmag.ars.usda.gov/2002/sep/soil .

Coumou D, Rahmstorf S, (2012) A decade of weather extremes, Nature Climate Change, Vol. 2, July 2012, pages 491-496.

Dungait JAJ, Hopkins DW, Gregory AS, Whitmore AP, (2012) Soil Organic Matter turnover is governed by accessibility not recalcitrance, Global Change Biology, **18**, 1781-1796.

EPA Office of Atmospheric Programs, April 2010, Methane and Nitrous Oxide Emissions From Natural Sources.

FAO, Organic matter decomposition and the soil food web, http://www.fao.org/docrep/009/a0100e/a0100e05.htm .

Gosling P, Hodge A, Goodlass G, Bending GD, (2006) Arbuscular mycorrhizal fungi and organic farming, Agriculture, Ecosystems and Environment 113 (2006) 17-35.

Hepperly PR, (2015) Sentinels of the Soil, Acres USA, June, 2015.

Hoorman JJ, Islam R, (2010) Understanding soil Microbes and Nutrient Recycling, Ohio State University Fact Sheet, SAG-16-10.

IFOAM (2012) Submission from IFOAM to the HLPE on Climate Change and Food Security, 10/4/2012.

Jansa J, Bukovská P, Gryndler M, (May, 2013) Mycorrhizal hyphae as ecological niche for highly specialized hypersymbionts – or just soil free-riders? Frontiers in Plant Science, Volume 4 Article 134.

Jastrow JD, Amonette JE, Bailey VL, (2006) Mechanisms controlling soil carbon turnover and their potential application for enhancing carbon sequestration, Climatic Change 80:5-23.

Jones C, SOS (2015) Save Our Soils, Acres USA, Vol. 45, No. 3.

Jones C, (2015) unpublished letter to an Ohio grazer, June 2015 and to author, July 2015.

Khan SA, Mulvaney RL, Ellsworth TR, Boast CW, (2007) The myth of nitrogen fertilization for soil carbon sequestration, Journal of Environmental Quality; Nov/Dec 2007; Vol 36.

Khorramdel S, Koocheki A, Mahallate MN, Khorasani R, (2013) Evaluation of carbon sequestration potential in corn fields with different management systems, Soil and Tillage Research 133 25-31.

Kirkby CA, Kirkegaard JA, Richardson AE, Wade LJ, Blanchard C, Batten G, (2011) Stable soil organic matter: A comparison of C:N:O:S ratios in Australian and other world soils, Geoderma 163 197-208.

Lal R, (2004) Soil carbon sequestration to mitigate climate change, Geoderma 123 (2004) 1-22.

Lal R, Follett RF, Stewart BA, Kimble JM, (2007) Soil carbon sequestration to mitigate climate change and advance food security, Soil Science 0038-075X/07/17212-943-956.

LaSalle TJ, Hepperly P, (2008) Regenerative Organic Farming: A Solution to Global Warming, Rodale Institute, https://grist.files.wordpress.com/2009/06/rodale_research_paper-07_30_08.pdf .

Machmuller M, Kramer MG, Cyle TK, Hill N, Hancock D, Thompson A, (2015) Emerging land use practices rapidly increase soil organic matter, Nature Communications 6, Article number 6995.

Mao JD, Johnson RL, Lehmann J, Olk DC, Neves EG, Thompson ML, Schmidt-Rohr K, (2012) Abundant and stable char residues in soils: Implications for Soil Fertility and Carbon Sequestration, Environmental Science and Technology, 46, 9581-9576.

Meléndrez M, (2014) The Journey to Better Soil Health, unpublished paper presented to the First International Humus Expert's Meeting, Kaindorf, Austria, January 22 and 23, 2014

Muller A, Gattinger A, (2013) Conceptual and Practical Aspects of Climate Change Mitigation Through Agriculture: Reducing Greenhouse Gas Emissions and Increasing Soul Carbon Sequestration, Research Institute of Organic Agriculture, Switzerland.

NASA, (2008) Target Atmospheric CO_2: Where Should Humanity Aim? Science Briefs, Goddard Institute for Space Studies.

NOAA (National Oceanic and Atmospheric Administration), What is Ocean Acidification? http://www.pmel.noaa.gov/ .

Nichols K, Millar J, (2013) Glomalin and Soil Aggregation under Six Management Systems in the Northern Great Plains, USA, Open Journal of Soil Science, Vol 3, No. 8, pp. 374-378.

NSIDC, (2015) Methane and Frozen Ground, National Snow and Ice Data Center, https://nsidc.org/cryosphere/frozenground/methane.html .

Ontl TA, Schulte LA (2012) Soil Carbon Storage, Nature Education Knowledge, 3(10):35.

Peterson TC, Stott PA, Herring SC, Hoerling MP, (2013) Explaining Extreme Events of 2012 from a Climate Perspective, Special Supplement to the Bulletin of the American Meteorological Society, Vol. 9, No. 9.

Powlson DS, Whitmore AP, Goulding WT, (2011) Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false, European Journal of Soil Science, **62**, 42-55.

Quinkenstein A, Böhm C, da Silva Matos E, Freese D, Hüttl RF, (2011) Assessing the carbon sequestration in short rotation coppices of *Robinia pseudoacacia L*. on marginal sites in northeast Germany, in Carbon Sequestration Potential of Agroforestry Systems: Opportunities and Challenges, 201, Kumar BM and Nair PKR (editors) Advances in Agroforestry 8.

Reganold JP, Andrews PK, Reeve JR, Carpenter-Boggs L, Schadt CW, Alldredge JR, Ross CF, Davies NM, Zhou J, (2010) Fruit and soil quality of organic and conventional strawberry agroecosystems, PLos One 5(10): 10-1371, Oct 6, 2010.

Rodale (2014) Regenerative Organic Agriculture and Climate Change: A Down-to-Earth Solution to Global Warming, www.rodaleinstitute.org .

RSC (Royal Society of Chemistry), Rate of Photosynthesis: limiting factors, http://www.rsc.org/learn-chemistry/content/filerepository/CMP/00/001/068/Rate%20of%20photosynthesis%20limiting%20factors.pdf .

SAPS (Science and Plants for Schools), Measuring the rate of photosynthesis, (2015) http://www.saps.org.uk/secondary/teaching-resources/157-measuring-the-rate-of-photosynthesis .

Six J, Frey SD, Thiet RK, Batten KM, (2006) Bacterial and fungal contributions to carbon sequestration in agroecosystems, Soil Science Society of America Journal 70:555–569.

Timmusk S, Grantcharova N, Wagner EGH, (2005) Applied and Environmental Microbiology, Nov. 2005, P. 7292-7300

Velivelli SLS, (2011) How can bacteria benefit plants? Doctoral research at University College Cork, Ireland, published in *The Boolean.*

Walker TS, Bais HP, Grotewold E, Vivanco JM, **(2003)** Root Exudation and Rhizosphere Biology, Plant Physiology vol. 132, no. 1, 44-51.

Wink M (1988) Plant breeding: importance of plant secondary metabolites for protection against pathogens and herbivores, Theor. Appl. Genet. (1988) 75:225-233.

*****

Any opinions or views expressed in this paper are those of the individual author, unless stated to be those of Future Directions International.

Published by Future Directions International Pty Ltd.
80 Birdwood Parade, Dalkeith WA 6009, Australia.
Tel: +61 8 9389 9831 Fax: +61 8 9389 8803
E-mail: cjohns@futuredirections.org.au
Web: www.futuredirections.org.au