Reference: Dr Christine Jones. Acres USA Eco Farming daily.

SOIL RESTORATION: 5 CORE PRINCIPLES

By Christine Jones

Soil restoration is the process of improving the structure, microbial life, nutrient density, and overall carbon levels of soil. Many human endeavors — conventional farming chief among them — have depleted the Earth to the extent that nutrient levels in almost every kind of food have fallen by between 10 and 100 percent in the past 70 years. Soil quality can improve dramatically, though, when farmers and gardeners maintain constant ground cover, increase microbe populations, encourage biological diversity, reduce the use of agricultural chemicals, and avoid tillage.

Soil restoration begins with photosynthesis.

THE POWER OF PHOTOSYNTHESIS

Imagine there was a process that could remove carbon dioxide (CO_2) from the atmosphere, replace it with life-giving oxygen, support a robust soil microbiome, regenerate topsoil, enhance the nutrient density of food, restore water balance to the landscape, and increase the profitability of agriculture. Fortunately, there is. It's called photosynthesis.

In the miracle of photosynthesis, which takes place in the chloroplasts of green leaves, CO_2 from the air and H_2O from the soil are combined to capture light energy and transform it into biochemical energy in the form of simple sugars.

These simple sugars — commonly referred to as photosynthates — are the building blocks of life. Plants transform sugar into a great diversity of other carbon compounds, including starches, proteins, organic acids, cellulose, lignin, waxes, and oils.

Fruits, vegetables, nuts, seeds, and grains are packaged sunlight derived from photosynthesis. The oxygen our cells and the cells of other living things utilize during aerobic respiration is also derived from photosynthesis.

Significantly, many of the carbon compounds derived from the simple sugars formed during photosynthesis are also essential to the creation of well-structured topsoil. Without photosynthesis there would be no soil. Weathered rock minerals, yes… but no fertile topsoil.

THE PLANT-MICROBE BRIDGE

It comes as a surprise to many that over 95 percent of life on land resides in soil, and that most of the energy for this amazing world beneath our feet is derived from plant carbon. Exudates from living roots are the most energy-rich of these carbon sources.

In exchange for 'liquid carbon,' microbes in the vicinity of plant roots — and microbes linked to plants via networks of beneficial fungi — increase the availability of the minerals and trace elements required to maintain the health and vitality of their plant hosts (1,2).

Bruce Tainio: Amending Soil Microbial Life, from the 2005 Eco-Ag Conference & Trade Show. (1 hour, 2 minutes) Listen in as the popular agronomist explains how to feed the microbial life in your soil, and develop optimal microbial biodiversity. Microbial activity also drives the process of aggregation, which enhances soil structural stability, aeration, infiltration, and water-holding capacity. All living things — above and below ground — benefit when the plant-microbe bridge is functioning effectively.

Sadly, many of today's farming methods have severely compromised soil microbial communities, significantly reducing the amount of liquid carbon transferred to and stabilized in soil. This creates negative feedbacks all along the line. Over the last 150 years, many of the world's prime agricultural soils have lost between 30 and 75 percent of their carbon, adding billions of tons of CO_2 to the atmosphere (3).

The loss of soil carbon significantly reduces the productive potential of the land and the profitability of farming. Soil degradation has intensified in recent decades — around 30 percent of the world's cropland has been abandoned in the last 40 years due to soil decline (4). With the global population predicted to peak at close to 10 billion by 2050, the need for soil restoration has never been more pressing. Soil dysfunction also impacts human and animal health.

NUTRIENT DEPLETION IN OUR FOOD

Over the last 70 years, the level of every nutrient in almost every kind of food has fallen between 10 and 100 percent. This is an incredibly sobering fact. An individual today would need to consume twice as much meat, three times as much fruit, and four to five times as many vegetables to obtain the same amount of minerals and trace elements available in those same foods in 1940.

Dr. David Thomas (5,6) has provided a comprehensive analysis of historical changes in food composition from tables published by the Australian Medical Research Council, the Ministry of Agriculture, the Ministry of Fisheries and Foods, and the Food Standards Agency. By comparing data available in 1940 with that in 1991, Thomas demonstrated a substantial loss in mineral and trace element content in every group of food he investigated.

The nutrient depletion summarized in Thomas' review represents a weighted average of mineral and trace element changes in 27 kinds of vegetables and 10 kinds of meat:

5. **Mineral Depletion in Vegetables** (1940-1991; average of 27 kinds of vegetables):

Copper – declined by 76%
Calcium – declined by 46%
Iron – declined by 27%
Magnesium – declined by 24%
Potassium – declined by 16%

6. **Mineral Depletion in Meat** (1940-1991; average of 10 kinds of meat):

Copper – declined by 24%
Calcium – declined by 41%
Iron – declined by 54%
Magnesium – declined by 10%
Potassium – declined by 16%
Phosphorus – declined by 28%

Significant mineral and trace element depletion was also recorded in the 17 varieties of fruit and two dairy products tested over the same period (5). The mineral depletion in meat and dairy reflects the fact that animals are consuming plants and/or grains that are themselves minerally depleted.

In addition to the overall decline in nutrient density, Thomas found significant changes in the ratios of minerals to one another. Given that there are critical ratios of minerals and trace elements for optimum physiological function, it is highly likely that these distorted ratios have an impact on human health and well-being (5).

RESTORING NUTRIENT DENSITY TO OUR FOOD

It is commonly believed that the significant reduction in the nutrient density of today's chemically-produced foods is due to the dilution effect. Dilution occurs when yields rise but mineral content falls. Significantly, though, vegetables, crops, and pastures grown in healthy, biologically active soils do not exhibit these compromised nutrient levels.

Only in rare instances are minerals and trace elements completely absent from soil. Most of the "deficiencies" observed in today's plants, animals, and people are due to soil conditions not being conducive to nutrient uptake. The minerals are present in the soil but are simply not plant-available. Adding inorganic elements to correct these so-called deficiencies is an inefficient practice. Instead we need to address the biological causes of dysfunction.

Around 85 to 90 percent of plant nutrient acquisition is microbially-mediated. The soil's ability to support nutrient-dense crops, pastures, fruits, and vegetables requires the presence of a diverse array of soil microbes from a range of functional groups. The majority of microbes involved in nutrient acquisition are plant-dependent. That is, they respond to carbon compounds exuded by the roots of actively growing green plants. Many of these important groups of microbes are negatively impacted by the use of "cides" — herbicides, pesticides, insecticides, and fungicides.

In short, the functioning of the soil ecosystem is determined by the presence, diversity and photosynthetic rate of actively growing green plants — as well as the presence or absence of chemical toxins.

But who manages the plants and the chemicals? You guessed it… we do.

Fortunately, consumers are becoming increasingly aware that food is more than a commodity (7). It is up to us to restore soil integrity, fertility, structure, and water-holding capacity — not by applying Band-Aids to the symptoms, but by better managing our food production systems.

THE SOIL CARBON SINK

Soil can function as a carbon source — adding carbon to the atmosphere — or a carbon sink — removing CO_2 from the atmosphere. The dynamics of the source/sink equation are largely determined by land management.

Over the millennia a highly effective carbon cycle has evolved, in which the capture, storage, transfer, release, and recapture of biochemical energy in the form of carbon compounds repeats itself over and over. The health of the soil and the vitality of plants, animals, and people depends on the effective functioning of this cycle.

Technological developments since the Industrial Revolution have produced machinery capable of extracting vast quantities of fossil fuels from beneath the Earth's surface as well as machinery capable of laying bare large tracts of grasslands and forests. This has resulted in the release of increasing quantities of CO_2 into the atmosphere while simultaneously destroying the largest natural sink over which we have control.

The decline in natural sink capacity has amplified the effects of anthropogenic emissions. Many agricultural, horticultural, forestry, and garden soils today are a net carbon source. That is, these soils are losing more carbon than they are sequestering.

The potential for reversing the net movement of CO_2 to the atmosphere through improved plant and soil management is immense. Managing vegetative cover in ways that enhance the capacity of soil to sequester and store large volumes of atmospheric carbon in a stable form offers a practical and almost immediate solution to some of the most challenging issues currently facing humankind.

The key to successful soil restoration and carbon sequestration is to get the basics right.

FIVE PRINCIPLES FOR SOIL RESTORATION

1. **Green is good — and year-round green is even better**

Photosynthesis draws hundreds of billions of tonnes of CO_2 from the atmosphere every year. The impact of this reduction was dramatically illustrated in a stunning visualization released by NASA in 2014 (8). The movement of carbon from the atmosphere to soil — via green plants — represents the most powerful tool we have at our disposal for the restoration of soil function and reduction of atmospheric CO_2.

While every green plant is a solar-powered carbon pump, it is the photosynthetic capacity and photosynthetic rate of living plants (rather than their biomass) that drive the biosequestration of stable soil carbon. Photosynthetic capacity is the amount of light intercepted by green leaves in a given area (determined by percentage of canopy cover, plant height, leaf area, leaf shape and seasonal growth patterns).

On agricultural land, photosynthetic capacity can be improved through the use of multi-species cover crops, animal integration, multispecies pastures, and strategic grazing. In parks and gardens, plant diversity and mowing height are important factors. Bare soil has no photosynthetic capacity. Bare soil is also a net carbon source and is vulnerable to erosion by wind and water.

Photosynthetic rate is the rate at which plants are able to convert light energy to sugars. It is determined by many factors, including light intensity, moisture, temperature, nutrient-availability and the demand placed on plants by microbial symbionts. The presence of mycorrhizal fungi, for example, can significantly increase photosynthetic rate. Plants photosynthesising at an elevated rate have a high sugar and mineral content, are less prone to pests and diseases, and contribute to improved weight gains in livestock.

Photosynthetic rate can be assessed by measuring Brix with a refractometer. An increase of around 5 percent in global photosynthetic capacity and/or photosynthetic rate would be sufficient to counter the CO_2 flux from the burning of fossil fuels, provided the extra carbon was sequestered in soil in a stable form. This is feasible. On average, global cropland is bare for around half of every year (9). If you can see the soil, it is losing carbon!

Both photosynthetic capacity and photosynthetic rate are strongly impacted by management. Leading-edge light farmers are developing innovative and highly productive ways to keep soil covered and alive, while at the same time producing nutrient-dense food and high-quality fiber.

Grazing Management

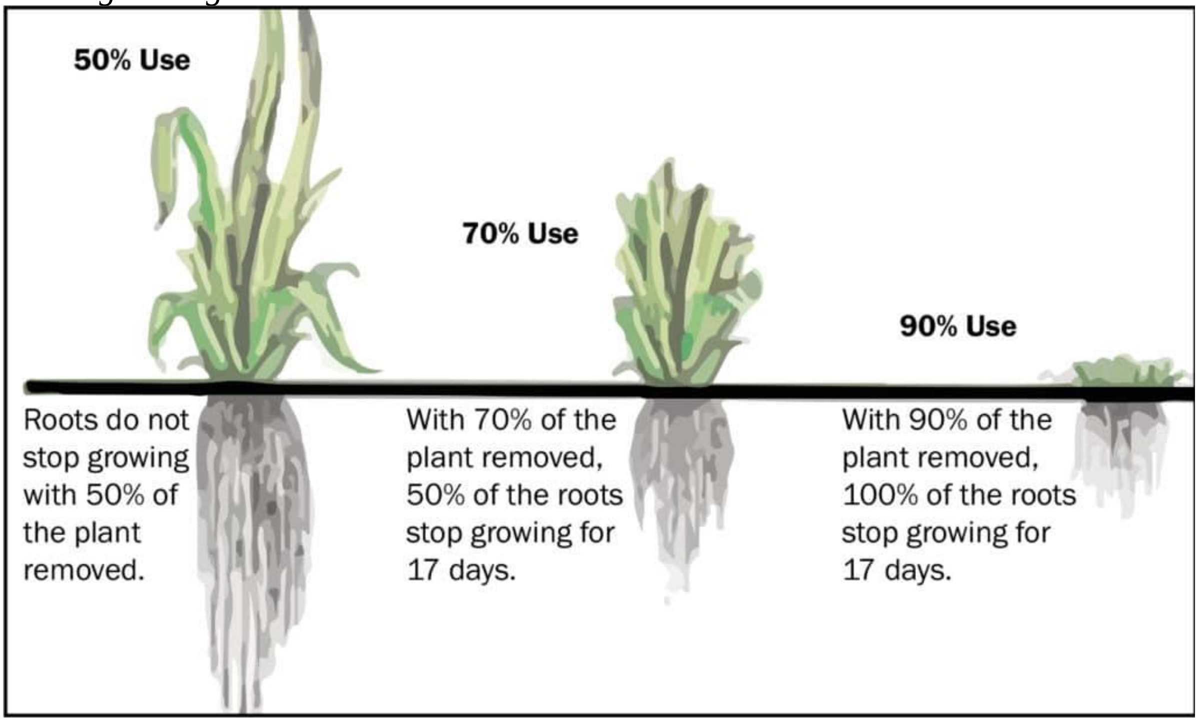

Figure 1: Growth of both tops and roots is significantly impaired if more than 50 percent of the green leaf is removed in a single grazing event.

This topic requires far more space than is available, but it is vitally important that less than 50 percent of the available green leaf be grazed (see figure above). Retaining adequate leaf area reduces the impact of grazing on photosynthetic capacity and enables the rapid restoration of biomass to pre-grazed levels. Over a 12-month period, significantly more forage will be produced — and more carbon sequestered in soil — if pastures are grazed tall rather than short.

In addition to leaf area, pasture height has a significant effect on soil building, moisture retention, nutrient cycling, and water quality. To maintain photosynthetic capacity (and to ensure rapid recovery) it is highly beneficial to remove livestock from a pasture before you can see their feet.

Regenerative grazing can be extremely effective in restoring soil carbon levels deep underground. The deeper the carbon, the more it is protected from oxidative and microbial decomposition. The sequestration of most significance is that which occurs below 30 cm (12).

Crop Production

Increasingly sophisticated machinery and a plethora of “cides” have provided the means for the planet’s rapidly expanding population to create bare ground over billions of acres, dramatically reducing global photosynthetic capacity. Reduced levels of photosynthesis have in turn resulted in reduced carbon flow to soil, significantly impacting soil and landscape function and farm productivity.

Organic carbon holds between four and 20 times its own weight in water. This means that when carbon levels are depleted, the water-holding capacity of the soil is significantly compromised. Low water-holding capacity results in poor structural stability when soils are wet and reduced plant growth when soils are dry.

One of the most significant findings in recent years has been the improvements to infiltration, water-holding capacity, and drought-resilience when bare fallows have been replaced with multi-species covers. This improvement has been particularly evident in lower rainfall regions and in dry years (13).

1. **Microbes matter**

   A healthy agricultural system is one that supports all forms of life. All too often, many of the life-forms in soil have been considered dispensable. Or, more correctly, they have not been considered at all.

   The significance of the plant-microbe bridge in transferring and stabilizing carbon in soil is becoming increasingly recognized. The soil microbiome is now heralded as the next frontier in soil restoration research.

   One of the most important groups of plant-dependent soil-building microbes are mycorrhizal fungi. These extraordinary ecosystem engineers access water, protect their hosts from pests and diseases, and transport nutrients such as organic nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, iron, and essential trace elements including copper, cobalt, zinc, molybdenum, manganese and boron — all in exchange for liquid carbon. Many of these elements are essential for resistance to pests and diseases and climatic extremes such as drought, water-logging, and frost.

   When mycorrhizal symbiosis is functioning effectively, 20-60 percent of the carbon fixed in green leaves can be channelled directly to soil mycelial networks, where a portion is combined with biologically-fixed nitrogen and converted to stable humic compounds. The deeper in the soil profile this occurs the better. Humic polymers formed by soil biota within the soil matrix improve soil structure, porosity, cation exchange capacity, and plant growth.

   Soil function is also strongly influenced by its structure. In order for soil to be well-structured, it must be living. Life in the soil provides the glues and gums that enable soil particles to stick together into pea-sized lumps called aggregates. The spaces between the aggregates allow moisture to infiltrate more easily. Moisture absorbed into soil aggregates is protected from evaporation, enabling soil to remain moist for longer after rain or irrigation. This improves farm productivity and profit.

   Well-structured soils are also less prone to erosion and compaction, and they function more effectively as bio-filters.

   Sadly, many of the microbes important for soil function have gone missing in action. Can we get them back? Some producers have achieved large improvements in soil health in a relatively short time. What are these farmers doing differently? They diversify.

1. **Diversity is indispensable**

   Every plant exudes its own unique blend of sugars, enzymes, phenols, amino acids, nucleic acids, auxins, gibberellins, and other biological compounds, many of which act as signals to soil microbes. Root exudates vary continuously over time, depending on the plant's immediate requirements. The greater the diversity of plants, the greater the diversity of microbes, and the more robust the soil ecosystem.

The belief that monocultures and intensively managed systems are more profitable than diverse biologically based systems does not hold up in practice. Monocultures need to be supported by high and often increasing levels of fertilizers, fungicides, insecticides, and other chemicals that inhibit soil biological activity. The result is even greater expenditure on agrochemicals in an attempt to control pests, weeds, diseases, and the fertility issues that ensue.

The natural grasslands that once covered vast tracts of the Australian, North American, South American, and sub-Saharan African continents — plus the "meadows" of Europe — contained several hundred different kinds of grasses and forbs. These diverse grasslands and meadows were extremely productive prior to simplification through overgrazing and/or cultivation.

Figure 2: Triticale monoculture (left) suffering severe water stress while triticale sown with other species (right) is healthy. In addition to triticale, the "cocktail crop" contains oats, tillage radish, sunflower, field peas, faba beans, chickpeas, proso millet and foxtail millet.

Innovative farmers are experimenting with up to 70 different plant species to see which combinations perform best for soil restoration. Some grain and vegetable producers are setting aside up to 50 percent of their cash crop area for multi-species diverse soil primers. They believe the benefits far outweigh the costs. It has been reported that two full seasons of a multispecies cover can perform miracles in terms of soil health. Mixtures of peas with canola, clover or lentils with wheat, soybean and/or vetch with corn, and buckwheat and/or peas with potatoes are becoming increasingly common.

The integration of animals into cropland can also be extremely beneficial. This doesn't need to be complicated, though. Something as simple as including one or two companions with a cash crop can make a world of difference.

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

An aspect of plant community structure that is gaining increased research attention is the presence of 'common mycorrhizal networks' (CMNs) in diverse pastures, crops and vegetable gardens.

It has been found that plants in communities assist each other by linking together in vast underground super-highways through which they can exchange carbon, water and nutrients (16,17). CMNs increase plant resistance to pests and diseases (18), enhance plant vigor, and improve soil health.

In my travels I've seen many examples of monocultures suffering severe water stress while diverse multi-species crops beside them remained green (see photo above).

In mixed-species plantings, warm-season grasses (such as sorghum and maize) are the most generous 'givers' to soil carbon pools, while broadleaf plants benefit the most from the increased availability of nutrients. In livestock production systems, animal health issues linked to lack of plant diversity (and hence animal nutrition) can often mean the difference between profit and loss.

1. **Chemical use can be dangerous**
   Living soils can significantly improve the mineral cycle. Researchers have shown, for example, that mycorrhizal fungi can supply up to 90 percent of plants' nitrogen (N) and phosphorous (P) requirements (20). In addition to including companions and multi-species covers in crop rotations, maintaining a living soil often requires reducing the application of high-analysis synthetic fertilizer and other chemicals.

Profit is the difference between expenditure and income. In years to come we will perhaps wonder why it took so long to realize the futility of attempting to grow crops in dysfunctional soils, relying solely on increasingly expensive synthetic inputs.

No amount of NPK fertilizer can compensate for compacted, lifeless soil with low wettability and low water-holding capacity. Indeed, adding more chemical fertilizer often makes things worse. This is particularly true for inorganic N and P.

An often-overlooked consequence of the application of high rates of N and P is that plants no longer need to channel liquid carbon to soil microbial communities in order to obtain these essential elements. Reduced carbon flow has a negative impact on soil aggregation and limits the energy available to the microbes involved in the acquisition of important minerals and trace elements. This increases the susceptibility of plants to pests and diseases.

Inorganic Nitrogen

The use of high-analysis N fertilizer poses a significant cost to both farmers and the environment. Only 10 to 40 percent is taken up by plants, which means that 60 to 90 percent of applied N is lost through a combination of volatilization and leaching.

It is often assumed that nitrogen only comes from fertilizer or legumes. But all green plants are capable of growing in association with nitrogen-fixing microbes.

Even when N fertilizer is applied, plants obtain much of their N from microbial associations.

Farmers experimenting with yearlong green farming techniques are discovering that their soils develop the innate capacity to fix atmospheric nitrogen. If high rates of N fertilizer have been used for a long time, though, it is important to wean off N slowly, as free-living nitrogen-fixing bacteria require time to re-establish.

Another of the many unintended consequences of the use of nitrogen fertilizer is the production of nitrous oxide in water-logged and/or compacted soils. Nitrous oxide is a greenhouse gas with almost 300 times the global warming potential of carbon dioxide.

Inorganic Phosphorous

The application of large quantities of water-soluble P, which is found in fertilizers such as in MAP, DAP, and superphosphate, inhibits the production of strigolactone, an important plant hormone. Strigolactone increases root growth, root hair development, and colonization by mycorrhizal fungi, enabling plants to better access phosphorous that is already in the soil. The long-term consequences of the inhibition of strigolactone include destabilization of soil aggregates, increased soil compaction, and mineral-deficient (e.g. low selenium) plants and animals.

In addition to having adverse effects on soil structure and the nutrient density of food, the application of inorganic water-soluble phosphorus is highly inefficient. At least 80 percent of applied P rapidly adsorbs to aluminium and iron oxides and/or forms calcium, aluminum, or iron phosphates. In the absence of microbial activity, these forms of P are not plant-available.

It is widely recognized that only 10-15 percent of fertilizer P is taken up by crops and pastures in the year of application. If P fertilizer has been applied for the previous 10 years, there will be sufficient P for the next 100 years, irrespective of how much was in the soil beforehand. Rather than apply more P, it is more economical to activate soil microbes in order to access the P already there.

Mycorrhizal fungi are extremely important for increasing the availability of soil P. Their abundance can be significantly improved through cover crops, diversity, and appropriate grazing management.

1. **Avoid aggressive tillage**

Tillage may provide an apparent quick-fix to soil problems created by lack of deep-rooted living cover. Repeated and/or aggressive tillage increases the susceptibility of the soil to erosion, though. It also depletes soil carbon and organic nitrogen, rapidly mineralizes soil nutrients (resulting in a short-term flush but long-term depletion), and is highly detrimental to beneficial soil-building microbes such as mycorrhizal fungi and keystone invertebrates such as earthworms.

The increased oxidation of organic matter in bare soil from tillage, coupled with reduced photosynthetic capacity, not only adds carbon dioxide to the atmosphere but may also contribute to falling levels of atmospheric oxygen.

CONCLUSION

All food and fiber producers — whether grain, beef, milk, lamb, wool, cotton, sugar, nuts, fruit, vegetables, flowers, hay, silage, or timber — are first and foremost light farmers.

Since the Industrial Revolution, human activities have sadly resulted in significantly less photosynthetic capacity due to the reduced area of green groundcover on the Earth’s surface. Human activity has also impacted the photosynthetic rate of the groundcover that remains.

Our role, in the community of living things of which we are part, is to ensure that the way we manage green plants results in as much light energy as possible being transferred to — and maintained in — the soil battery as stable soil carbon. Increasing the level of soil carbon improves farm productivity, restores landscape function, reduces the impact of anthropogenic emissions, and increases resilience to climatic variability.

It is not so much a matter of how much carbon can be sequestered by any particular method in any particular place, but rather how much soil is sequestering carbon. If all agricultural, garden, and public lands were a net sink for carbon, we could easily reduce enough CO_2 to counter emissions from the burning of fossil fuels.

Everyone benefits when soils are a net carbon sink. Through our food choices and farming and gardening practices we all have the opportunity to influence how soil is managed. Profitable agriculture, nutrient-dense food, clean water, and vibrant communities can be ours… if that is what we choose.

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Soil ecologist Dr. Christine Jones works with innovative farmers and ranchers to implement regenerative land management practices that enhance biodiversity, nutrient cycling, carbon sequestration, productivity, water quality, and community and catchment health. She launched Amazing Carbon (www.amazingcarbon.com) as a means to share her vision and inspire change. In 2005, Dr. Jones held the first of five "Managing the Carbon Cycle" forums to promote the benefits of soil carbon. Over the past decade she has gained international recognition as a speaker. She was also the keynote speaker at the 2017 Acres U.S.A. Eco-Ag Conference & Trade Show in Columbus, Ohio, and taught a course on restoring diversity to agricultural soils during Eco-Ag University.

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Literature cited:

1. Jones, C.E. (2008). Liquid carbon pathway. Australian Farm Journal, July 2008, pp. 15-17.

2. Kaiser, C., Kilburn, M. R., Clode, P. L., Fuchslueger, L., Koranda, M., Cliff, J. B., Solaiman, Z. M. and Murphy, D. V. (2015), Exploring the transfer of recent plant photosynthates to soil microbes: mycorrhizal pathway vs direct root exudation. New Phytologist, 205: 15371551. doi:10.1111/nph.13138.

3. Lal, R., Follett, R.F., Stewart, B.A. and Kimble, J.M. (2007). Soil carbon sequestration to mitigate climate change and advance food security . Soil Science, 172 (12), pp. 943-956. doi: 10.1097/ss.0b013e31815cc498

4. Pimentel, D. and Burgess, M. (2013). Soil erosion threatens food production. Agriculture 2013 , 3, 443-463; doi:10.3390/agriculture3030443

5. Thomas, D.E. (2003). A study of the mineral depletion of foods available to us as a nation over the period 1940 to 1991. Nutrition and Health, 17: 85115.

6. Thomas, D.E. (2007). The mineral depletion of foods available to us as a nation (1940-2002) a review of the 6th Edition of McCance and Widdowson. Nutrition and Health , 19: 21-55.

7. Latham, J. (2016). Why the food movement is unstoppable. Independent Science News. https://www.independentsciencenews.org/health/why-the-food-movement-is-unstoppable/

8. Miller, P. (2014). Stunning NASA visualization reveals secret swirlings of carbon dioxide. https://www.nasa.gov/press/goddard/2014/november/nasa-computer-model-provides-a-new-portrait-of-carbon-dioxide/
9. Siebert, S.; Portmann, F.T.; Döll, P. Global Patterns of Cropland Use Intensity. (2010). Remote Sensing, 2 (7), 1625-1643; doi:10.3390/rs2071625
10. Voth, K. (2015). Great "Grass Farmers" Grow Roots. National Grazing Lands Coalition.
11. Crider, F.J. (1955). Root growth stoppage resulting from defoliation of grass. U.S. Department of Agriculture Technical Bulletin 1102, 23 p. babel.hathitrust.org
12. Jones, C.E. (2011). Carbon that counts. New England and North West Landcare Adventure 16-17 March 2011. amazingcarbon.com
13. Weller, J. (2015). Testimony to House of Representatives Committee on Agriculture bipartisan subcommittee on Conservation, Energy and Forestry hearing on the Benefits of Promoting Soil Health in Agriculture and Rural America.
14. Natura, H. (undated). Illinois Native Plant Guide. Root systems of prairie plants. nrcs.usda.gov
15. Lundgren, J.G and Fausti S.W. (2015). Trading biodiversity for pest problems. Science Advances 1(6). doi: 10.1126/sciadv.1500558
16. The Plant Guy (2012). Plant Social Networks- is this why companion planting & inter-cropping work?
17. Walder, F., Niemann, H., Natarajan, M., Lehmann, M.F., Boller, T. and Wiemken, A. (2012). Mycorrhizal networks: Common goods of plants shared under unequal terms of trade. Plant Physiology , 159(2): 789797. doi: 10.1104/pp.112.195727
18. Johnson, D. and Gilbert, L. (2014). Interplant signalling through hyphal networks. New Phytologist, 205(4): 1448-1453. doi: 10.1111/nph.13115
19. Kelly (2014). Who knew? Cover crop cocktails are commune hippies.
20. Smith, S.E, Read, D.J. (2008). Mycorrhizal Symbiosis, 3rd Edition. Academic Press.

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