INTERVIEW

SOS: Save our Soils

Dr. Christine Jones Explains the Life-Giving Link Between Carbon and Healthy Topsoil

To the pressing worldwide challenge of restoring soil carbon and rebuilding topsoil, the Australian soil ecologist Dr. Christine Jones offers an accessible, revolutionary perspective for improving landscape health and farm productivity. For several decades Jones has helped innovative farmers and ranchers implement regenerative agricultural systems that provide remarkable benefits for biodiversity, carbon sequestration, nutrient cycling, water management and productivity. After a highly respected career in public sector research and extension, in 2001 Jones received a Community Fellowship Award from Land and Water Australia for "mobilizing the community to better manage their land, water and vegetation." Three years later she launched Amazing Carbon as a means to widely share her vision and inspire change. Jones has organized and presented workshops, field days, seminars and conferences throughout Australia, New Zealand, South Africa, Zimbabwe, Europe, the United States and Canada. Last year, she gave presentations to American organizations and institutions as diverse as Arizona State University, NRCS, Pennsylvania No-Till Alliance, the Massachusetts chapter of Northeast Organic Farming Association (NOFA), San Luis Valley Soil Health Group and the Quivira Coalition. In 2015 Jones' personal commitment to make the biggest possible impact globally will take her to Alberta, Saskatchewan, Manitoba, Ontario, Kansas, New Mexico, California, Florida, Costa Rica and South Africa, as well as many regions within Australia and New Zealand. In early March she travels to Western Australia, 2,500 miles from her home, to hold the first in a series of Soil Restoration Farming Forums, in which 11 farmers will receive monetary awards for reversing soil deterioration in dryland cropping systems through intercropping with perennial warm season grasses.

Dr. Christine Jones

Interviewed by Tracy Frisch

ACRES U.S.A. You've written that the most meaningful indicator for the health of the land and the long-term wealth of a nation is whether soil is being formed or lost. Yet there's a widespread belief, actually dogma, that the formation of soil is an exceedingly slow process. Even some organic researchers accept that idea. You describe the formation of topsoil as being breathtakingly rapid.

DR. CHRISTINE JONES. People have confused the weathering of rock, which is a very, very slow process, with the building of topsoil, which is altogether different. Most of the ingredients for new topsoil come from the atmosphere – carbon, hydrogen, oxygen and nitrogen.

ACRES U.S.A. Why have many soil scientists denied the phenomenon of rapid soil-building?

JONES. Because they do their research in places where it's not happening, where the carbon is running down and the soils are deteriorating. We need to measure carbon on farms where soil-building is occurring and see what the farmers and ranchers are doing to make that happen.

ACRES U.S.A. The process of fixing carbon in the soil seems to be the crux of your work. You describe a cycle with carbon in three phases: as a gas, a liquid and a solid.

JONES. The issue we're facing is that too much of the carbon that was once in a solid phase in the soil has become a gas. That could be dangerous for the human species. Climate change is just one aspect. Food security, the nutrient density of food and the water-holding capacity of the soil are also very potent reasons for keeping carbon in a solid phase in the soil.

ACRES U.S.A. Your term "liquid carbon" is such a brilliant phrase. It has really helped me conceptualize the carbon cycle. What do you mean by it?

JONES. Liquid carbon is basically dissolved sugar. Sugars are formed in plant chloroplasts during photosynthesis. Some of the sugars are used for growth and some are exuded into soil by plant roots to support the microbes involved in nutrient acquisition.

ACRES U.S.A. I remember bringing up the idea of leaky roots in a conversation with you and you laughed.

JONES. At first people thought "leaky" roots were defective. Exuding carbon into the soil seemed such a silly thing for plants to do! Then it became recognized that some of the exudates were phenolic compounds with allelopathic effects, important in plant defense. Of course we now know that plant roots exude a vast array of chemical substances, all based on carbon, to signal to microbes and to other plants. But perhaps the most significant finding, at least from a human perspective, is that the flow of liquid carbon to soil is the primary pathway by which new topsoil is formed.

ACRES U.S.A. All of which revolves around the concept of a plant-microbial bridge?

JONES. In order for carbon to "flow" to soil, there has to be a partnership between plant roots and the soil microbes that will receive that carbon. Somewhere between 85 to 90 percent of the nutrients plants require for healthy growth are acquired via carbon exchange, that is, where plant root exudates provide energy to microbes in order to obtain minerals and trace elements otherwise unavailable. We inadvertently blow the microbial bridge in conventional farming with high rates of synthetic fertilizers or with fungicides or other biocides.

ACRES U.S.A. Are you observing an increased awareness of the significance of biological processes?

JONES. There is a lot more energy generated through biological processes than through the burning of fossil fuels. Most life-forms obtain their energy either directly or indirectly from the sun, via the process of photosynthesis. Plants are what we call autotrophs. That is, they feed themselves by combining light energy with CO_2 to produce biochemical energy. As heterotrophs, we obtain energy by eating plants or eating animals that ate plants. In effect, we're running on light energy too. Even microbes in a compost heap are obtaining energy by breaking down organic materials originating from the process of photosynthesis.

ACRES U.S.A. You distinguish between organic matter formed by the decomposition of manure, crop residues or other carbonaceous materials – and humus – which is generated via a building-up process. I think a lot of times that is misunderstood.

JONES. It's a really important distinction, but it's often overlooked. In order to obtain the energy that is contained in cellulose, lignin, starches, oils, waxes or other compounds formed by plants, microbes have to break this material down – the same as we do when we digest starches or proteins or anything else of plant or animal origin. We breathe out more CO_2 than we breathe in, because as we utilize the energy we obtain from the assimilation of food, our cells release CO_2. The decomposers in the soil are doing exactly the same thing – breaking down organic materials and releasing CO_2. These processes are catabolic. Conversely, the formation of humus is an anabolic process, that is, a building-up process. Rather than sugar being the end point, sugar is the start point. Soil microbes use sugars to create complex, stable forms of carbon, including humus.

ACRES U.S.A. How would you define humus?

JONES. Humus is an organo-mineral complex comprising around 60 percent carbon, between 6 and 8 percent nitrogen, plus phosphorus and sulfur. Humic molecules are linked to iron and aluminum and many other soil minerals, forming an intrinsic part of the soil matrix. Humus cannot be "extracted" from soil any more than wood can be "extracted" from a tree.

ACRES U.S.A. You frequently mention mycorrhizal fungi in your work. What makes them so special?

JONES. Much of the initial research into mycorrhizal fungi was related to the uptake of phosphorus. Phosphorus is a highly reactive element. As soon as there's any free phosphorus floating around in the soil, including whatever we may add as fertilizer, it becomes fixed. In other words, it forms a chemical bond with another element like iron or aluminum or calcium, making it unavailable to plants. But certain bacteria produce an enzyme called phosphatase that can break that bond and release the phosphorus. Once released, the phosphorus still has to be transported back to the plant, which is where mycorrhizal fungi come in. As our analytical techniques have became more sophisticated, we've realized that mycorrhizal fungi also transport a wide variety of other nutrients, including nitrogen, sulfur, potassium, calcium, magnesium, iron and essential trace elements such as zinc, boron, manganese and copper. In dry times they supply water. Mycorrhizal fungi can extend quite a distance from plant roots. They form networks between plants and colonies of soil bacteria. Plants can communicate with each other via messages sent through these networks. Mycorrhizal fungi are both the highway and the Internet of the soil.

ACRES U.S.A. How can something so important be overlooked?

JONES. Much of the agricultural research undertaken in pots in glass houses is fundamentally flawed. Soil is homogenized to remove background noise, that is, to make the soil in all the pots similar at the outset. The blending process breaks up the hyphae of mycorrhizal fungi. In some trials the soil is also sterilized to eliminate any microbial activity that could interfere with the treatment being assessed. And often the soil has been stored for a long time prior to the experiments, which means most of the soil organisms have died. In such an environment, plants are likely to respond to applied fertilizer, as they have no other means to obtain nutrients. Similarly with field trials, if the soil has been cultivated or bare fallowed, mycorrhizal fungi will not be there in sufficient quantities for effective carbon flow and nutrient acquisition. In healthy, biologically active soils, we do not see a response to synthetic nitrogen or phosphorus fertilizers. If anything, the use of these is counterproductive.

ACRES U.S.A. I've learned from you that plants colonized by mycorrhizal fungi can grow much more robustly even though they're giving away as much as half of the sugars that they make in photosynthesis through their roots.

JONES. That's correct.

ACRES U.S.A. So we have this system characterized by abundance and generosity, and that's really different from the way we are used to thinking about growing crops.

JONES. The point that's often missed is that a mycorrhizal plant photosynthesizes much faster than a non-mycorrhizal plant of the same species growing right next to it. The plant is able to give half its energy away and still grow stronger because of the symbiotic relationship with the fungus. It doesn't cost the plant anything to photosynthesize faster. It's just using sunlight more efficiently. Remember, plants are autotrophic.

ACRES U.S.A. And sunlight is free.

JONES. CO_2 is free too. If a plant photosynthesizes faster it's going to have higher sugar content and a higher Brix level. Once Brix gets over 12, the plant is largely resistant to insects and pathogens. High-Brix plants have formed relationships with soil microbes able to supply trace elements and other nutrients that the plant needs for self-defense, for its immune system. When plants are able to produce high levels of plant-protection compounds, the insects go elsewhere.

ACRES U.S.A. We tend to think that minerals in the soil are scarce because most of them are not in a form available to plants.

JONES. A soil test will only tell you what is available to plants by passive uptake. The other 97 percent of minerals – made available by microbes – will not show up on a standard test. By looking after the microbes in the soil we can increase the availability of a huge variety of minerals and trace elements – most of which are not even in fertilizers.

ACRES U.S.A. We always hear the story about fields that were continuously cropped or hayed for 30 years where the soil is so exhausted that we have to add a lot of nutrients or we can't grow a thing.

JONES. The problem is that we interrupt carbon flow with the way we farm. Cultivating the soil and using chemical fertilizer and pesticides break up the mycorrhizal networks. If plants can obtain nitrogen or phosphorus easily, they will stop pumping carbon into the soil to support their microbial partners. It's taken a while for people to realize that plant root exudates are not only important for nutrient exchange, but also essential for the maintenance of topsoil. If carbon is not flowing to soil via the liquid carbon pathway, soil deteriorates. Carbon is needed for soil structure and water-holding capacity as well as for feeding the microbes involved in nutrient acquisition. When soil loses carbon, it becomes hard and compacted. The differences in infiltration and moisture retention between high- and low-carbon soils are dramatic. Planetary stocks of fresh water are declining alarmingly. More efficient water use is going to be absolutely critical to the survival of our species. Making better use of water requires improved soil structure – which in turn requires actively aggregating soils. If aggregates are breaking down faster than they're forming, the water-holding capacity of soil can only deteriorate.

ACRES U.S.A. How can we tell if a soil has good aggregation?

JONES. Dig a hole and take a handful of soil. Squeeze it gently and release. If the soil is well aggregated, it will look like a handful of peas. If the soil remains in hard chunks that don't break easily into small lumps, then it isn't well aggregated.

ACRES U.S.A. What processes are going on inside of a soil aggregate?

JONES. The aggregate is the fundamental unit of soil function. A great deal of biological activity takes place within aggregates. For the most part, this is fueled by liquid carbon. Most aggregates are connected to plant roots, often to very fine feeder roots, or to mycorrhizal networks unable to be detected with the naked eye. Liquid carbon streams into the aggregates via these roots or fungal linkages, enabling the production of glues and gums that hold the soil particles together. If you gently lift a plant from healthy soil, you'll find aggregates adhering to the roots. The moisture content is higher inside a soil aggregate than on the outside, and the partial pressure of oxygen is lower on the inside than on the outside. These important properties enable nitrogen-fixing bacteria to function. When aggregates aren't forming – because of cultivating the soil or using chemicals or having bare soil for six months or more with no green plants – crops are not able to obtain sufficient nitrogen. The tendency is then to add fertilizer nitrogen, exacerbating the situation. The application of large quantities of inorganic nitrogen interrupts carbon flow to soil, further reducing aggregation.

ACRES U.S.A. It sounds like a vicious cycle.

JONES. Yes, the more N applied, the more soil structure deteriorates and ironically, the less N is available to plants. You'll rarely see a nitrogen-deficient plant in a healthy natural ecosystem. When I was driving home yesterday I noticed yellow, nitrogen-deficient pastures on many of the dairy farms I passed. But in the area between the fence and the road, where no fertilizer had been used, the grasses were a lovely dark green.

ACRES U.S.A. We are familiar with Rhizobium bacteria and their relationship with legumes. What should we know about free-living nitrogen fixing bacteria?

JONES. From an agricultural perspective the most important of the free-living nitrogen-fixing bacteria are associative diazotrophs – so-called because the atmospheric nitrogen that they fix occurs as di-nitrogen (N_2) and associative because, like mycorrhizal fungi, they require the presence of a living plant for their carbon. These bacteria live in close proximity to plant roots or are linked to plant roots via the mycorrhizal highway.

ACRES U.S.A. Isn't our knowledge of these organisms pretty recent?

JONES. The reason we know so little about associative diazotrophs is that most cannot be cultured in the lab. This applies to most species of mycorrhizal fungi as well. As bio-molecular methods for detecting microbes in the soil become more sophisticated, we're realizing there is a lot more life – and a lot more species – than we thought. It has become obvious that there are thousands of different types of bacteria and archaea that can fix nitrogen. The Haber-Bosch process, by which we manufacture nitrogen fertilizer, is a catalytic reaction requiring enormous amounts of energy. Yet microscopic bacteria in the rhizosphere or within plant-associated aggregates can fix nitrogen simply using light energy from the sun, transformed to biochemical energy during photosynthesis and channeled to soil by plant roots.

ACRES U.S.A. I'm a little confused because I understood that there is a difference between mineral nitrogen and organic nitrogen.

JONES. That's correct. Nitrogen-fixing bacteria produce ammonia, a form of inorganic nitrogen, inside soil aggregates and rhizosheaths. Rhizosheaths are protective cylinders that form around plant roots. They're basically a bunch of soil particles held together by plant root exudates. You can easily strip them off with your fingers. Within these biologically active environments the ammonia is rapidly converted into an amino acid or incorporated into a humic polymer. These organic forms of nitrogen cannot be leached or volatilized. Amino acids can be transferred into plant roots by mycorrhizal fungi and joined together by the plant to form a complete protein. On the other hand, inorganic nitrogen applied as fertilizer often ends up in plants as nitrate or nitrite, which can result in incomplete or "funny" protein. This becomes a problem in cattle if it turns up as high levels of blood urea nitrogen (BUN) or milk urea nitrogen (MUN). Nitrates cause a range of metabolic disorders including infertility, mastitis, laminitis and liver dysfunction. There is also a strong link between nitrate and cancer. In some places in the United States it is not safe to drink the water due to excessive nitrate levels. Milk can also have nitrate levels above the safe drinking standard, but people happily consume it, not realizing it's unhealthy.

ACRES U.S.A. These are great points. How dependent is the world on the application of synthetic nitrogen?

JONES. Farmers around the world collectively spend about $100 billion per year on nitrogen fertilizer. I'm greatly inspired by the multi-species cover crop revolution in the United States. Leading-edge farmers like Gabe Brown, Dave Brandt and Gail Fuller are showing it's possible to maintain or even improve crop yields while winding back on fertilizer. These farmers are light years ahead of the science. They're building soil, improving the infiltration of water, increasing water holding capacity and getting fantastic yields. They have fewer insects and less disease. The carbon and water cycles are fairly humming on their farms.

ACRES U.S.A. I want to get your recipe for transforming terra-cotta tile into chocolate cake – that is, turning hard, compacted soil into loose, fragrant soil teeming with life.

JONES. There isn't a "recipe" as such for maintaining soil aggregates (the starting point for chocolate cake). It's really just a set of guiding principles. Soil becomes like a terra-cotta tile when aggregates break down. Hard, compacted soil sheds water. The amount of effective rainfall is dramatically reduced. It's also much harder for plant roots to grow in poorly aggregated soil. The first rule for turning this around is to keep the soil covered, preferably with living plants, all year round. In environments where the soil freezes, it's still important to maintain soil cover with mulch or a frost-killed cover crop or better still, a frost-hardy cover that will begin to grow again as soon as spring arrives. Microbes will go into a dormant phase over winter and re-activate at the same time as the plants. In regions with a hot, dry summer, evaporation is enemy number one. Bare soil will be significantly hotter and lose more moisture than covered soil. Aggregates will break down unless the soil is alive. Aggregation is absolutely vital for moisture infiltration and retention.

ACRES U.S.A. OK, so that's one.

JONES. Point two is to maximize diversity in both cover crops and cash crops. Aim for a good mix of broadleaf plants and grass-type plants and include as many different functional groups as possible. Diversity above ground will correlate with diversity below ground. Third, avoid or minimize the use of synthetic fertilizers, fungicides, insecticides and herbicides. It's a no-brainer that something designed to kill things is going to do just that. There are countless living things in soil that we don't even have names for, let alone an understanding of their role in soil health. It's nonsense to say biocides don't damage soil! In Australia many farmers plant seeds treated with fungicide "just in case." They're actually preventing the plant from forming the beneficial associations that it needs in order to protect itself. After a few weeks of crop growth, they will then apply a "preventative" fungicide, which also finds its way to the soil, inhibiting the soil fungi that are essential to crop nutrition and soil building. The irony is that plants are then unable to obtain the trace elements they need to fight fungal diseases. We see many examples of crops grown biologically that are rust-free, side-by-side with rust infected plants in neighboring fields where fungicides are being used. There is an analogous situation with human health. Not that long ago the cancer rate was around one in 100. Now we're pretty close to one in two people being diagnosed with cancer. At the current rate of increase, it won't be long before nearly every person will contract cancer during their lifetimes. Cancer is also the number one killer in dogs. Isn't that telling us something about toxins in the food chain? We're not only killing everything in the soil, we're also killing ourselves – and our companion animals. Is that what we want for our future?

ACRES U.S.A. Are you a cancer survivor?

JONES. Yes, I am, which is basically why I do what I do. But I don't say a lot about that because if you start your talk with "we're all going to die from cancer unless we change," people tune out. It's too threatening. Most of us have lost loved ones through cancer.

ACRES U.S.A. You say it's not just the toxins in our food that are the problem, but the use of biocides – chemicals that kill living organisms – which reduce the nutrient content of food. And you attribute that nutrient reduction to the inhibition of the plant-microbial bridge.

JONES. Spot on. If the plant-microbe bridge has been blown, it's not possible for us to obtain the trace elements our bodies need in order to prevent cancer – and a range of other metabolic disorders. Cancer is not a transmissible disease. It's simply the inability of our bodies to prevent abnormal cells from replicating. To date, the response to the cancer crisis has revolved around constructing more oncology units, employing more oncologists and undertaking more research. The big breakthrough in cancer prevention will be in changing the way we produce our food.

ACRES U.S.A. We have plenty of evidence from meta-studies that the nutrient content of produce grown organically tends to be higher than produce grown chemically. We also have documentation of steep declines in nutrient content in a number of foods over the last century.

JONES. Yes, we're getting a double whammy. We're ingesting chemical residues, but not the trace elements and phytonutrients we need for an effective immune response. Plants need trace elements, like copper and zinc, to make these phytonutrients. But the trace elements will not be available in the absence of an intact microbial bridge.

ACRES U.S.A. You've talked about the pressure on farmers to have tidy farms and uniformity in their fields. It seems like one of the problems you're identifying is a faulty understanding of what it means to farm well and to be a good farmer. What are some of the qualities that farmers think they should have that get in the way of building healthy soil?

JONES. I must admit that in the early '90s, when I first started going onto farms that were using holistic planned grazing, I was a bit shocked to see the number of weeds popping up. These weeds would have been sprayed under the former management regime, but the ranchers were saying, "Don't worry. We have to pass through this weedy stage. If we spray weeds, we create bare ground and the weed seed that's there means the weeds simply come back." There's a saying, "the more you spray weeds, the more weeds there will be to spray." It's oh so true! Continually reverting to bare ground creates more problems than it solves. Those ranchers knew some weeds had deep roots that bring up nutrients. Leaving them there meant better quality plants would eventually be able to grow in the improved soil and replace the weeds. That is exactly what happened. Over the last 60 years we've tried – and failed – to control weeds with chemicals. One of the exciting things about the multi-species cover crop revolution that's underway in the United States is that the greater the variety of plant types you use, the more niches you fill and the less opportunities there are for weeds. Cover-crop enthusiasts are experimenting with 60 or 70 different species in their mixes. I see the trend to polyculture as the most significant breakthrough in the history of modern agriculture. Even so, the first time you see a multi-species cover or a cash crop grown with companion plants, you might think, "Wow, that looks untidy" because we're not used to it. It takes a little while to realize that having all those different plants together is really beneficial. Somehow we have to change the image of what a healthy field looks like so that when people see bare ground or a monoculture, they recognize it's lacking – and that this is not a good thing.

ACRES U.S.A. What sort of response are the cover crop pioneers receiving?

JONES. They're seeing fantastic results. The trouble is they are not getting the accolades they deserve. This is slowly beginning to change. NRCS, in particular, are being exceptionally supportive of these leading-edge farmers. Cover cropping is now generating a huge amount of interest. Recently I visited Brendon Rockey, a young potato farmer in the San Luis Valley of Colorado. Brendon has increased irrigation efficiency 20 percent through the use of cover crops. There is increasing worldwide recognition of the fact that multi-species cover crops improve soil-water relationships.

ACRES U.S.A. Right, another aspect of that abundance.

JONES. If there is a bare fallow between crops – or bare ground between horticultural plantings such as grapes – soil aggregates break down. As a result, water cannot infiltrate as quickly. It remains closer to the surface and evaporates more readily. Lack of aggregation also renders the soil more prone to wind and water erosion. We have this fear that if we grow companion plants or a cover crop, they're going to use up all the water and nutrients. We have to realize that by supporting soil microbes, a diversity of plants actually improves nutrient acquisition and water retention.

ACRES U.S.A. In the transition period from a chemically intensive system where you don't have a functioning plant-microbial bridge, what are some kinds of practices that farmers can use?

JONES. Sometimes when farmers realize the importance of soil biology they immediately stop using fertilizers and chemicals. This is not necessarily a good thing. It takes time for soil microbial populations to re-establish. If the soil is dysfunctional, chances are the wheels will fall off when fertilizers are pulled. If there is a failure, farmers will revert back to what they know ... chemical agriculture. You have to wind back *slowly* and accept that it's going to take time to transition. The key to getting started is to experiment on small areas. It's a matter of dipping a toe in the water. Include some clovers or peas with your wheat, or vetch with your corn – just on one part of the field. This reduces the risk. When farmers see that they've gained rather than lost yield – and that the crop looks healthier – they will be inspired to try a larger area and a greater variety of companion plants next time. Another option is to plant a multi-species cover crop on part of the land that would normally be devoted to a cash crop. You're exceptionally lucky in the United States in that a lot of farmers are experimenting with cover crops now. Once the diversity ramps up, the ladybirds and lacewings and predatory wasps appear and the need for insecticides falls away. And after heavy rain, it's obvious that water has infiltrated better in the parts of the field where the cover crops were. Gradually the changes become an integral part of farming – an exciting part, in fact. Experimentation and adaptation become the norm, rather than conformity. Confidence builds, as ways to restore healthy topsoil become firsthand knowledge.

ACRES U.S.A. What about fertility?

JONES. It's important to cut back on chemical fertilizers slowly. If you've been using loads of synthetic nitrogen, then free-living nitrogen-fixing bacteria won't be abundant in your soil. An easy way to transition is to reduce the amount of nitrogen applied by around 20 percent the first year, another 30 percent the next and then another 30 percent the year after. At the same time as reducing fertilizer inputs it's absolutely vital to support soil biology with the presence of a wide diversity of plants for as much of the year as possible. Another way to gradually reduce fertilizer inputs is to use foliar fertilizers rather than drilling fertilizer under the seed. Foliar-applied trace minerals can also help during transition. These can be tank-mixed with biology-friendly products such as vermi-liquid, compost extract, fish hydrolysate, milk or seaweed extract. Whichever path you choose to support soil biology, the overall aim is for soil function to improve every year. The overuse of synthetic fertilizers will have the opposite effect.

ACRES U.S.A. You mentioned the longest-running field experiment in North America that found that high nitrogen depletes soil carbon?

JONES. The Morrow Plots are the oldest continuously cropped experimental fields in the United States. A team of University of Illinois researchers investigated how the fertilization regimes that were commenced in these plots in 1955 affected crop yields and soil carbon and organic nitrogen levels. They discovered that the fields that had received the highest applications of nitrogen fertilizer had ended up with less soil carbon – and ironically less nitrogen – than the other fields. The researchers concluded that adding nitrogen fertilizer stimulated the kind of bacteria that break down the carbon in the soil. The reason there is less nitrogen in the soil even though more has been applied is that carbon and nitrogen are linked together in organic matter. If carbon is decomposing, then the soil will also be losing nitrogen. They decompose together.

ACRES U.S.A. That's fascinating. Tell me about David Johnson and what he is finding in his research at New Mexico State University.

JONES. Dr. David Johnson is based in Las Cruces, south of Albuquerque. He has discovered that the ratio of fungi to bacteria in the soil is a more important factor for plant production than the amount of available nitrogen or phosphorus. Sadly, in most of our agricultural soils, we have far more bacteria than fungi. The good news is that farmers use multi-species cover crops, companion crops, pasture cropping and other polycultures – and the ranchers who manage their perennial grasses with high density short duration grazing accompanied by appropriate rest periods – are moving their soils toward fungal dominance. When you scoop up the soil, it has that lovely composty, mushroomy sort of smell that indicates good fungal levels. Oftentimes agricultural soils have no smell or a smell that is a bit sour. Fungi are important for soil carbon sequestration as well as nutrient acquisition. The formation of humus, a complex polymer, requires several catalysts, including fungal metabolites.

ACRES U.S.A. That is a really interesting insight. I would like to get some perspective on soil degradation. You've written about how lush and green Australia's landscape was at the time of European settlement in the early 1800s, land that's now desertified. How do your readers react?

JONES. They have a particularly hard time believing that the southern and southwestern parts of Australia supported green plants during our hot, dry summers. It's fortunate that some of the first European settlers kept journals. George Augustus Robinson, who was the Chief Protector of Aborigines, kept a daily journal for several years. Robinson was a keen observer. He made sketches of the landscape as well as describing it. In summertime when it was over 100 degrees and without rain for months on end, Robinson noted green grass and carpets of wildflowers everywhere he looked. Sadly, we don't know what many of these plants were because we no longer have wildflowers in some of the colors he recorded.

ACRES U.S.A. Could you reconstruct what happened to destroy all this lush, diverse vegetation?

JONES. European colonists brought boatloads of sheep which rapidly multiplied. In England you could have sheep in continual contact with the grass and it didn't matter greatly because it nearly always rained. Australian weather tends to oscillate between drought and flooding rain and the English weren't used to that. By the late 1800s there were many millions of sheep in Australia, grazing the grasslands down to bare earth in the dry periods. When it rained, the unprotected soil washed away. The river systems and wetlands filled with sediment. We're now farming on subsoil. We've lost around 2 to 3 feet of topsoil across the whole country. The original soil was so well aggregated that aboriginal people could dig in it with their bare hands. The first Europeans to arrive in Australia talked about two feet of black "vegetable mold" that covered the soil surface. Today our soils are mostly light-colored. The use of color to describe soils only came into being after the carbon-rich topsoil had blown or washed away. It's not an uncommon story. Just about every so-called civilized, developed country in the world has lost topsoil by one means or another. In the States you had your Dust Bowl, created by tillage. Restoring the health of agricultural soils will require more than learning how to minimize soil losses. We need to learn how to build new topsoil, and we need to learn how to do it quickly.

ACRES U.S.A. I read that in Australia, using the so-called best management practices of stubble retention and minimal tillage, wheat production results in the loss of 7 kilograms of soil for every kilogram of wheat harvested. Is it still that bad?

JONES. Yes, probably worse. I have documented evidence of 20 tons of soil per hectare per year being lost through wind erosion. The average wheat yield in Australia is very low, around 1 ton per hectare. We lose massive amounts of soil to achieve it. The current situation is not sustainable.

ACRES U.S.A. How much of Australia's farmland would have to increase soil carbon to offset your country's carbon emissions?

JONES. It would require only half a percent increase in soil carbon on 2 percent of our agricultural land to sequester all Australia's CO_2 emissions. Our emissions are low in relation to our land area because we have a relatively small population.

ACRES U.S.A. Do you have any idea worldwide how much farmland would have to be managed differently to increase soil carbon sufficiently to reverse global climate change or offset greenhouse gases?

JONES. Agriculture is the major land use across the globe. According to the FAO there are around 1.5 billion hectares of cropland and another 3.5 billion hectares of grazing land. Currently much of that land is losing carbon. No doubt there will be – and indeed there already have been – endless arguments about how much carbon can be sequestered in soil. In my view it's not a matter of how much but how many. The focus needs to be on transforming every farm that's currently a net carbon source into a net carbon sink. If all farmland sequestered more carbon than it was losing, atmospheric CO_2 levels would fall at the same time as farm productivity and watershed function improved. This would solve the vast majority of our food production, environmental and human health problems. I'm disappointed to see that articles are still being published in internationally recognized peer-reviewed soil science journals – as recently as 2014 – downplaying the potential for carbon sequestration in agricultural soils. Predictably, these articles fail to mention plant roots, liquid carbon or mycorrhizal fungi. Many scientists have confused themselves – and the general public – by assuming soil carbon sequestration occurs as a result of the decomposition of organic matter such as crop residues. In so doing, they have overlooked the major pathway for the restoration of topsoil. Activating the liquid carbon pathway requires that photosynthetic capacity be optimized. There are many and varied ways to achieve this. I have enormous respect for the farmers and ranchers who have done what the experts say can't be done. If we have a future, it will be largely due to the courage and determination of these individuals.

ACRES U.S.A. You initiated the Australian Soil Carbon Accreditation Scheme (ASCAS). I'm quite impressed that one person started something like that.

JONES. I launched ASCAS in 2007 out of frustration that the federal government wasn't doing anything to reward innovation in land management. I wanted to demonstrate that leading-edge farmers could build carbon in their soils and be financially rewarded for doing so. But my attempts were blocked at every level, including being subjected to public ridicule. I suspect much of the resistance stemmed from the fact that Australia was importing over $40 billion worth of farm chemicals and policy-makers saw that as a big business. They realized that in order to build soil carbon, farmers would need to reduce chemical use. There were other issues too. Australia ratified the Kyoto Protocol nine months after the launch of ASCAS. Under Kyoto Protocols, the issuance of carbon credits requires adherence to the 100 year rule, which basically means that any payment for soil carbon must be registered on the land title and the money refunded if for any reason the carbon levels fall over the ensuing 100 years. Then there's the additionality rule, which states farmers cannot be paid for changes in land management that they would have made anyway, or that result in higher profits.

ACRES U.S.A. You said this story has a good ending.

JONES. Despite the roadblocks, I felt it was important that soil restoration pioneers be recognized. Late last year we decided to discard the original ASCAS model and start afresh. On March 19, 2015, almost eight years to the day after we launched the ASCAS in 2007, our patron Rhonda Willson will present 11 Soil Restoration Leadership Awards at a farming forum in Dongara, Western Australia. It's a fitting conclusion that these awards be presented in the International Year of Soils.

ACRES U.S.A. What changes did your Soil Restoration Leaders make in order to improve soil function?

JONES. The agricultural region of Western Australia experiences an extremely hot, dry summer. Winters are cool and moist, although not as moist as many farmers would like. Innovative ranchers have been planting summer active grasses at the end of winter when there is sufficient moisture for germination, despite 'expert' opinion that it's too hot and dry in summer for anything to grow. Perennial grasses have incredibly deep root systems and form mycorrhizal associations that help them survive. The grasses soon create their own microclimate. It's an absolute delight to see these patches of green in an otherwise parched landscape. It helps us understand how the countryside encountered by the first European settlers was able to remain green over the summer.

ACRES U.S.A. At the People's Climate March in New York City, a large contingent of vegan activists carried signs blaming cattle as a major cause of global warming. What are your thoughts on targeting ruminants for greenhouse gas emissions?

JONES. There were more ruminants on the planet 200 years ago than there are now, but we've gone from free-ranging herds to animals in confinement. That changes everything. Firstly, we're growing feed for these animals using fossil-fuel intensive methods and secondly, confinement feeding creates a disconnect between ruminants and methanotrophs. Methanotrophic bacteria use methane as their sole energy source. They live in a wide variety of habitats, including surface soils. If a cow has her head down eating grass, the methane she breathes out is rapidly metabolized by methanotrophs. There's an analogous situation with termites. Termites produce methane during enteric fermentation, as happens in the rumen of a cow. But due to the presence of methanotrophic bacteria, methane levels around a termite mound are actually lower than in the general atmosphere. In nature, everything is in balance. After the disastrous Deepwater Horizon oil spill in the Gulf of Mexico, the ocean was bubbling with not only oil, but also methane. To the astonishment of scientists monitoring the spill, populations of methanotrophic bacteria exploded and consumed an estimated 220,000 metric tons of methane gas, bringing levels back to normal.

ACRES U.S.A. When we talk about the consequences of the increased extreme weather associated with climate change, like devastating floods and droughts, all too often we neglect to consider how better land management can reduce their impacts.

JONES. With weather events becoming more extreme our farming systems need to be more resilient. Again, this is where having carbon sequestered in soil to maintain aggregate stability and improve infiltration is vitally important. If we look at flooding on the Mississippi, for example, we see that the mean maximum and mean minimum water levels from the early 1800s to the present show an increasing perturbation since the dust bowl era of the 1930s. That is, the highs are becoming higher – floods are more severe – and the lows are getting lower – the river doesn't 'run' as much as it used to. This boom-bust situation is due to inappropriate land management. If soil is in good condition, water infiltrates rapidly and is held in the soil profile. Some of this water is used for plant production and some will move downward through the soil to replenish the transmissive aquifers that feed springs and small streams, enabling year-round, moderated base-flow to river systems. If groundcover is poor and soil water-holding capacity is low, rapid run-off not only leads to flooding in lower landscape positions, but also takes a lot of topsoil with it. These days it's not just soil, but a heap of chemicals too – which end up in the Gulf of Mexico.

ACRES U.S.A. Causing the Dead Zone?

JONES. Yes. The consequences are enormous. And when the flood is over, the river level drops because the transmissive aquifers haven't been recharged.

ACRES U.S.A. Is adding compost to the soil sufficient to turn things around?

JONES. Compost is certainly a fantastic product, but compost alone is not enough. It will eventually decompose, releasing CO_2. However, the application of compost to appropriately grazed pastures or polyculture crops can increase plant growth and photosynthetic rate, resulting in more liquid carbon flowing to soils. Diverse microbial populations – particularly fungi – supported by the compost, can aid in humification, improving soil structure, water-holding capacity and nutrient availabilities. On large agricultural holdings such as we have in many parts of Australia, it is not economically viable to spread compost. However, compost extract, which is simply the chemical signature of compost, can prove highly beneficial. The use of natural plant or seaweed extracts as biostimulants is a relatively new but rapidly expanding area of R&D and farmer-adoption worldwide. The advantage of biostimulants is that they function at very low rates of application – milliliters per hectare – as opposed to a product such as compost which needs to be applied in tons per hectare. These products stimulate soil biota and enhance plant root function. The proliferation of roots is quite obvious when you dig in the soil. There can also be rapid improvements in soil structure.

ACRES U.S.A. Your orientation is extraordinary. I'm wondering if at a certain point in your life, the way you saw the world underwent a radical change.

JONES. I've always been in tune with natural rhythms. I grew up in a little log cabin in what Australians call the bush. Here in the States you might call it wilderness. On one side of our cabin there was a big lake. An estuary joined the lake to the ocean, so there was water on three sides. The fourth side was a forest filled with all kinds of intriguing plants and animals. I was very much a child of the earth. My dad said I had my own veggie patch when I was only two. By that stage I could also apparently catch more fish than him. I just seemed to know where the fish would be and what they wanted to eat and what time of day they would be feeding. I was unaware that humans over-consume resources and pollute the environment until we moved to the city when I was about eight years old. I cried myself to sleep every night because, for me, it was paradise lost.

ACRES U.S.A. Did you study soils because you loved to grow things?

JONES. At school I became very interested in economics and planned to do an economics degree. Out of the blue I was offered a scholarship to study textiles. My first full-time job after graduation involved research into the parameters of wool that affect processing performance. Unless wool fibers have an even diameter all the way along their length – and high tensile strength – they break easily and are difficult to spin into yarn. Wool quality is influenced by pasture quality, which in turn is affected by soil quality. In a roundabout way I became interested in the linkages between soil health, plant growth and animal production. I undertook a Ph.D. in soil biochemistry to better understand how plants communicate with soil microbial communities. There haven't really been any light-bulb moments; it has been an ongoing process of discovery, finding the miraculous in the common.

For more information about Dr. Christine Jones visit *www.amazingcarbon.com*.