THE MAGIC OF HEALTHY SOIL
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March 6, 2021

Forgive me if I repeat myself, but healthy soil has so much to teach us about life on this planet, any discussion of soil health is bound to circle around to the same fundamental life principles again and again. Undisturbed healthy soil (and I should point out there's precious little undisturbed healthy soil left in this world) is quite simply the most highly evolved, intricately self-organized ecosystem on Earth, the ideal model, if fully appreciated, for a healthier, more productive, more sustainable human ecosystem. The intelligence with which healthy soil mediates the production of photosynthetic energy, the foundation of all life on this planet - intelligence residing primarily in the genes of the soil microbial community – currently exceeds our human understanding. Soil microbiologists are only beginning to plumb the depths of soil microbial intelligence. Soil microbial intelligence, it turns out, is a highly sustainable intelligence. Human intelligence, it turns out, is not. Today humans represent the greatest threat to the world's soil in its 500-million-year existence. This past century, conventional farming, deforestation, climate change, and human population overshoot have destroyed about two-thirds of the healthy soil microbiome around the world. The rest is expected to be rendered economically unproductive in another 30 to 60 years. After that, ten or eleven billion humans will need a new planet.

Let me give you one example of the intelligence I'm referring to. This occurs when a healthy seed comes in contact with healthy soil. A healthy seed carries within it what is called a core microbiome, a collection of microbes it got from its parent plant and parent soil. These microbes, in addition to helping protect the ungerminated seed are ready and waiting to work with the next common mycorrhizal soil network the seed comes in contact with. A common mycorrhizal soil network is a healthy soil's combined internet and Amazon Prime distribution system connecting and coordinating the resources of a large volume of soil. The seed knows from its core microbiome which way is up to the light and down to water and nutrients – so it doesn't waste energy sending roots and shoots off in random directions. The core microbiome keeps the seed from germinating until the temperature has been high enough for a long enough time and enough moisture is available. When the seed puts out a root, the common mycorrhizal network in healthy soil, consisting of thousands of miles of fungal hyphae, or

microscopic hollow tubes in each square yard of topsoil, connecting all the plant roots in the network, senses the new root's presence, seeks it out, and makes a permanent connection with it, in effect saying "Welcome to the neighborhood – we've got everything you'll ever need – water, minerals and nutrients of every kind, growth hormones, energy from healthy plants of numerous species nearby, thousands of species of beneficial microbes, and signals from the network to let you know if there are any pests or diseases in the network, in which case we'll help you switch on the correct genes to protect yourself. We'll keep you supplied and informed from a volume of soil ten thousand times larger than your own roots can reach. Whatever you need, we'll make sure it'll be there, from many meters away if necessary. All you have to do is, as your leaves start photosynthesizing, weep about forty percent of that photosynthate out of your roots into the common network to help keep us all fed and informed. Your photosynthate contains biochemical signals about everything important going on inside and around you. We'll make sure those signals are properly interpreted and that there is a timely and appropriate response if needed. Welcome aboard, new green plant. You are the foundation of all life on this planet. We are here to help you fulfill your mission."

Compare this to a seed from a depleted conventionally cropped soil, whose core microbiome is all but missing. Such a seed may not know up from down, wet from dry, or cold from hot. It's not protected from frost or drought. When it does sprout a root, its signal is weak or defective and the common mycorrhizal network often doesn't recognize it – it might just as well be another piece of rock or detritus needing to be decomposed. Whatever nutrients and water the seedling can access immediately adjacent to its own root are all it's ever going to get from the soil. The same is true of a seed that has been drenched with N or P fertilizer or coated with an insecticide. Even if there is a functioning common mycorrhizal network in the soil, and there often isn't, it won't recognize a chemically treated seed. That seed is a foreign object. It's on its own. If the farmer doesn't feed it, spray it, and water it regularly, like any house plant, it weakens and dies.

Something I have been saying for years now bears repeating. Earth's civilized human carrying capacity the second half of this century in a post-carbon world in which we have run out of cheap oil, will depend entirely on how many acres of farmland we have regenerated to full microbial health the first half of this

century. By year 2100, Earth's sustainable human population could be anything from a few hundred million barely civilized survivors eking out a meager subsistence from depleted soils if we continue pursuing conventional agriculture, to as many as four to six billion of us living a reasonably civilized life if we start universally applying what we are learning about soil health. The well-being of any civilization depends on an abundance of agricultural production. Frankly, I don't really want six billion neighbors, but civilization's future numbers and material quality of life will depend substantially on how we manage our soils this next three decades. If we do successfully regenerate the world's soils, it will open up a range of choices and opportunities for choosing what kind of civilization we want, and hopefully remind us of a lesson our petrochemical culture seems to have forgotten, that there is inevitably a tradeoff between human numbers and material quality of life. Our choices must be conscious and rational, informed by an understanding of the evolutionary imperatives all ecosystems operate under. A basic understanding of evolutionary imperatives is key to making survivable choices for our future. These imperatives boil down to the fact that all ecosystems impose physical limits, that those resources are best utilized by biologically diverse communities, fully communicating internally, equitably sharing common resources, and working mutually for the common good.

The basic strategies of successful evolution that persist to this day were fully established 500 million years ago when soil first began to form on land. Evolution in soil is all about soil microbes acting in ways beneficial to plant communities to ensure a consistent supply of photosynthetic energy to themselves through plant root exudates, and what's good for soil microbes and photosynthesis turns out to be good for the entire global ecosystem, including humans. The awareness is gradually becoming clearer, especially for soil microbiologists, that we humans have an existential stake in the well-being of Earth's soil microbiome and its support of photosynthesis, the source of all life on Earth, which we happen now to be destroying faster than it can regenerate itself. Only about half the photosynthesizing leaf tissue is left today of what nature provided us a brief 10,000 years ago.

Evolution is best described as change through time. Whether we're talking about animal, plant, or microbe, the genes controlling how they grow and what they do in their lives are reproduced anew with each new generation, and in bacteria that's about once every twenty minutes. Because gene reproduction is

occasionally inaccurate, genetic anomalies or mutations accumulate over time. While the overwhelming majority of these mutations are either neutral and have no effect, or harmful and are eliminated because they can't compete, the few that result in an ecological benefit, for example more efficient capture of solar energy, or more efficient transfer of that energy to herbivores, those are likely to survive longer. Which leads us to our most important evolutionary imperative. For 3.5 billion years, the most important contributor to evolutionary success – or ecological sustainability – is when a variety of different organisms (we call that biodiversity) living in communities and interacting together (we call that symbiosis) and slowly working out mutual benefits (we call that mutualism), out-reproduce and outlast organisms and communities that don't work together as well or as fully. The more effectively such organisms work together cooperatively or complementarily, the longer they and their communities are likely to last in evolutionary time. The longer they last, the more ways they discover to work together. It's a virtuous cycle. Equitably sharing and supporting one another in diverse, mutualistic communities is the first among many lessons from the evolution of soils we humans would do well to consider practicing more purposefully in our own communities. With luck and dedication, if we don't kill ourselves first, someday we humans could be as smart as dirt.

Now, I want to talk specifically about ecosystem health as a product of evolution

There are those who claim that evolution has no preferred direction, that mutations are random and that life is as likely to devolve as to evolve. I counter with the remarkably complex workings of undisturbed, healthy soil, the most ancient and venerable ecosystem on our planet, which has survived every challenge an unpredictable universe has thrown at it over hundreds of millions of years, yet it survived and continued to grow in complexity. The progressive elaboration of mutually supportive biological complexity in ecosystems is inevitable, in my understanding as a student of evolution. Evolution is constantly experimenting with ways to enhance the flow of solar energy through Earth's ecosystems, typically by elaborating the number of pathways through which that energy can flow. The greater the energy flow through any ecosystem, the more structural and functional complexity it can sustain, the smaller steps and more paths that energy can take, providing the ecosystem a more stable, more predictable, more resilient and longer-lasting existence. The fact that energy flow

fosters complexity is true whether we're talking about the long-term flow of solar energy from photosynthesis or our brief but soon-to-be-ending fling with petrochemical energy. The average American today has the equivalent of about 100 chemo-electro-mechanical energy slaves doing our bidding at the flip of a switch or the press of an accelerator. Every calorie of food on an American plate today is subsidized on average by a dozen calories of petrochemical energy. This recent economic complexity, now only about 200 years old in the modern human ecosystem, will not last beyond the middle of this century when oil and gas become too expensive for most of their current uses, particularly for producing cheap food. The extent to which humanity's current huge numbers can be sustained depends entirely on how soon we get serious about regenerating our soils. The well-being of any civilization is a direct function of the productivity of its soils.

Below ground, a high-functioning ecosystem evolves in the direction of all ecosystems, one of increasing symbiotic mutualism, organisms living together in ways that benefit one another, all ultimately in the service of photosynthetic energy. The largest number of mutualistic interactions on Earth are microbial, not surprising since they had three and a half billion years head start on us, have an average generation time of twenty minutes against our twenty-five years, outnumber us six sextillion to one (that's a 6 with 20 zeroes after it), and can swap genes among themselves and with other species as casually as we swap conversation.

Humans have a great deal to learn from soil microbes. It is their ancient and intricate mutualistic symbiotic interactions that are so amazing when we look closely at all they accomplish collaboratively with no hands, eyes, ears, brains, tractors, or smart phones. Evolved mutualistic collaboration among diverse participants in stable communities is hands down the most important mechanism contributing to evolutionary success - or longevity - or sustainability, and this is just as true for advanced social species like humans as it is for soil organisms.

Conflict and competition, on the other hand, disrupt both ecosystem stability and evolutionary longevity. Nature has evolved numerous strategies to keep conflict under control, the same basic strategies that work for controlling diseases, predation, and pest infestation. These mechanisms rely on symbiotic relationships evolved over millions of years. They make sure the good guys

outnumber the bad guys, use most of the resources for themselves, and keep a number of predatory "police" organisms around to keep the bad guys under control.

But, photosynthesis is key. Anything that disrupts or inhibits the natural flow of photosynthetic energy through ecosystems is, by definition, unhealthy, and detrimental to ecosystem productivity. Conventional farming today, characterized by gratuitous soil disturbance, chemical biocides, elimination of biodiversity, and months of bare soil fallow every year is the most ecologically unhealthy enterprise in civilization's current repertoire. But this isn't new with modern society. Inept soil management has been involved in more failed civilizations in human history than have wars. Let me cite now a list of currently diminished human ecosystem functioning resulting from our current chronic soil mismanagement: more severe floods, deeper longer-lasting droughts, more destructive hurricanes and tornados, fewer wildlife and pollinators (half the world's wildlife has been eliminated in the last 40 years, and I recently heard that 75% of our insect population has been lost in the last 30 years. Western bumblebees have been reduced 93% in the last twenty years … but to continue with my list), less dependable rainfall and deteriorating climate, failing crops, depleted soils, less nutritious food, more hunger, and declining public health, leading to throngs of homeless refugees and civil unrest (as witness the Arab Spring ten years ago. The abandoned, lifeless soils of Syria's once-fertile crescent, the cradle of civilization, are said to be only twenty years ahead of California's central valley. San Francisco could easily become the next Damascus when the central valley starts to empty out. Since the start of the Green Revolution fifty years ago, one-third of the world's cropland has been abandoned as economically unproductive in large part *because* of the green revolution, and the world is now losing farmland at the rate of 25 million acres every year, almost equal to all the farmland in Illinois each year - but to complete my list of diminished human ecosystem function), in the not too distant future, as farm productivity falls, a failed global civilization is becoming a distinct possibility. The bare farm soil we see so regularly here in the Midwest, on which photosynthesis is entirely missing, is as unhealthy and counterproductive as land can possibly be, and human society inevitably reflects the health of its soils. When soil is not covered with green plants, it is dying. When soil is tilled or fertilized or sprayed to get rid of weeds and pests, it is being actively killed. Conventional agriculture, on balance, is progressively killing every acre it touches. We are in the middle of, and

responsible for, Earth's sixth mass extinction, with extinction rates thousands of times faster than natural rates of extinction. Can humans avoid the same fate we are inflicting on the global ecosystems that spawned us as a species? What will it take to guarantee our survival?

Continuous yearlong photosynthesis from highly diverse plant communities is the be-all and end-all of global ecosystem health, and of human health as well. 'Weeds' may be the bane of a conventional farmer's existence, but 'weeds' are nature's early warning and first responders to ecosystems in which photosynthesis has been compromised. 'Weeds' like cockleburs, dandelions, and thistles should be appreciated, not eliminated. They are nature's way of restoring photosynthesis to damaged plant communities. Left to run their course in a diverse plant community, these unwelcome sentinels quickly give way to more desirable species. Weeds are simply doing their best to keep the world alive. As a survivor of Non-Hodgkins Lymphoma, I suggest we not glyphosate them. The ideal way to control weeds is to maintain a diverse year-round 100% ground cover of plants you prefer, to suppress the plants you'd rather not see.

Now let's look specifically at what is a healthy soil?

A healthy soil is the essential underground infrastructure of a high-functioning ecosystem in much the same sense a major city is essential infrastructure for a high-functioning civilization. It is a repository of evolved intelligence that coordinates and catalyzes the ecosystem's productivity. A healthy soil, whose workers are the myriad microbes living within it, is constructed of weathered rock particles and organic materials glued into a stable, intricate, purposeful architecture of soil aggregates. These soil aggregates are suffused with life-giving humus manufactured by soil microbes from plant root exudates. This intricate but sturdy soil infrastructure holds plants firmly upright so they can capture light, while insulating life belowground from extremes of heat or cold. Its detailed architecture allows for the abundant simultaneous storage, easy retrieval, and movement of water, air, nutrients, plant roots, pheromones or signaling molecules, heat, and all the various soil organisms that distribute photosynthetic energy flow throughout the ecosystem.

Healthy soil, functioning as it should – as it evolved to function before humans started messing it up - needs no synthetic irrigation, fertilization, tillage, weed-,

pest-, or disease control. It can already do all of that on its own without our help. The intelligence in a soil microbial community is amazing. Sensing what is occurring all around it, turning genes on and off, both its own and others, it coordinates and directs the complex sequence of interactions, both above- and below-ground, that guarantee maximum ecosystem productivity despite a highly variable environment. Rather than eliminating "weeds" because we once thought they took water and nutrients away from REAL crops, we should be encouraging carpets of functionally diverse plant species to outcompete the weeds and to serve as companion crops into which we plant our cash crops, trusting a healthy soil ecosystem to nurture both simultaneously. A major focus of agricultural mechanical research in the organic and regenerative community should be how most efficiently to grow and harvest cash crops in the presence of full-cover companion crops.

What is the magic of microorganisms?

The workings of microbial evolution constitute the closest thing to real magic in the ecological world. One supposedly simple common human gut microbe, *Bacteroides thetaiotaomicron,* for example, can produce 260 different enzymes for breaking down complex carbohydrates. Each higher order organism, an individual person like you, for example, is, in essence, a large, complex, highly coordinated community of microorganisms. In Earth's evolutionary progression, before individual microbes combined to form multi-cellular organisms, they were already highly evolved through billions of years of trial-and-error. Each bacterium had a cell wall with a selectively permeable membrane that was exquisitely responsive to the myriad substances floating around in its growth medium, able to sense chemicals as dilute as a few parts in a trillion. This allowed it to actively usher inside its cell body those things that could be used as food or building materials. It sensed and resisted the entry of harmful materials. The membrane actively expelled wastes and poisons, while it kept inside what should be kept and protected. It signaled its presence biochemically to other microbes and sensed the presence of others, including other species, knowing when there were enough signals of the right kind to switch on or off their own genes or someone else's genes for a coordinated response.

One of the earliest evolved capabilities of microbes when they started invading other cells and one another, was to manipulate the host's genome for the

invading microbe's advantage. Viruses, about which we know next to nothing, do the same thing in even greater numbers. Fortunately, the majority of successful invaders that have survived, actually confer an advantage or provide a benefit, some have even become essential or obligate. Antibiotics unfortunately kill them all, good and bad. Nature's preferred immune strategy is to keep enough good guys around to monopolize the resources and hold the bad guys down. When that doesn't work, there are usually a small number of predatory organisms available to neutralize the troublemaker. It is becoming increasingly clear that the first line of defense against ill health or guarantor of good health in humans is a healthy, nutrient-dense, diet giving the advantage to your good microbes, and nutrient-dense food can only come from microbially healthy soil.

So-called simple bacteria evolved so many remarkable capabilities. At least five of these microbial specialists, the oxidizers, the fermenters, those able to move about on their own, the photosynthesizers, and the nitrogen-fixers subsequently managed to ingest one another in various combinations without digesting them or compromising their function, eventually forming symbiotic multi-cellular collaborations that were able to reproduce and survive as individual whole complex organisms through time. You are the result of one such very complex microbial collaboration. Like every plant and animal in the world, you are embedded in a world of microbes. You are constructed of and coated with microbes. Microbes are embedded in you. Some of these microbes are able to switch your genes on and off to maintain your physical and mental health just as they switch their own genes on and off to accomplish their own specialized functions and to aid in their own survival. You are an intricately coordinated community of microbes, each of them doing individually pretty much what microbes have always done for billions of years, but collectively they add up to the musician, artist, farmer, or student your microbes let you think of as you.

And now I should say a few words about the magic of biodiversity

Evolution isn't mysterious or magic. Things that work well tend to last. The better they work, the longer they last and the more important a part of the ecosystem they become. Things that don't work as well are crowded out of existence by things that work better. Biodiversity is one of the things that confers more benefits than almost anything else in nature. Biodiversity represents a pool

of options from which nature can select as needed when conditions change. It's a guarantee of survival.

Eastern Australia is an area consisting of mile after mile of monocultured wheat. It is also an area of sparse and unpredictable rainfall. Some years they get a wheat crop and some years they don't. In recent years when the wheat crop fails, verdant green stripes of healthy wheat eight or ten feet wide can be seen in a grid pattern across the otherwise brown landscape. These are former fence lines that were removed and converted to wheat crop in recent years as farms consolidated and the farming equipment became larger and more automated. For decades, before the fences were removed, these fence line strips were not tilled, planted, or sprayed, unlike the cropped areas. Whatever random wheat seeds and assorted species of weeds found their way there grew year-round, undisturbed. Year after year, root exudates from these diverse, photosynthesizing weeds built up a healthy soil underneath, creating strips of a highly diverse soil microbiome. The nutrient status and moisture holding capacity of those fence line strips was significantly higher than the rest of the field. In dry years now, these fence-line strips don't experience the same drought as the rest of the field. Their soil moisture and temperature are perfectly fine, thank you. But this advantage will only last for a few more years. The green stripes are doomed to fade, victims of conventional farming practices.

There are countless examples around the world now, of people experimenting with cover crops where they plant one or two, occasionally three, species together and they too often either fail outright or at least disappoint, but where eight, ten, or twenty species of the appropriate species diversity are grown together, they produce abundant, lush growth from exactly the same climatic inputs. What we are learning is that at some level of diversity in a plant community, the microbes reach a quorum and genes are switched on to activate the underground mycorrhizal network in ways that make everything in the network grow profusely. We know some of those bacteria produce plant growth hormones when switched on.

To coordinate the complex underground microbial symphony of a healthy soil, a plant community's roots are all interconnected by an internet of mycorrhizal fungal hyphae you've heard me refer to as the common mycorrhizal network, a network consisting of tens of thousands of miles of microscopic hollow tubes in

each cubic meter of soil mysteriously capable of moving things in two directions simultaneously in the same tube, if that is called for. This network is able to transport water and nutrients and signaling molecules from remote locations throughout the soil to wherever they are needed to support photosynthesis. Research makes abundantly clear now that, even with identical amounts of leaf tissue present, the more plant species diversity is present, interconnected by a common mycorrhizal network, the more plant biomass is produced per acre, the more nutritionally dense with vitamins, minerals, and micronutrients that biomass is, the more organic carbon it builds into the soil, and the more resistant the community is to pests, diseases, drought, and freezing, the very essence of ecosystem health. For every harmful species of bacterium, insect, or fungus, there are hundreds or thousands of beneficial species ready to take resources away from the bad guys. Destroying the soil's common mycorrhizal network, which unfortunately always kills more good microbes than bad microbes, is the principal reason tillage, biocides, bare fallow, and set-stock grazing are so destructive of agricultural soils, grow so many weeds, and foster so many diseases and pests.

Here I should interject that nature never farms without animals, and humans shouldn't either. Whether you eat them or keep them as pets is your choice. But you absolutely need them to grow the healthiest soil and plant community. Grasses and prairie plants coevolved for the last 55 million years with grazing animals. Grazing stimulates photosynthesis and plant growth as an adaptive response to tissue tearing and trampling as well as to the saliva, dung, and urine that is deposited. For thousands of years, farming experts have praised the virtues of manure for maintaining soil health. Adding cover crops and grazing animals to conventional cropping systems results in increased crop yields, plus meat, wool, egg, and dairy production from livestock, all at little or no cost for irrigation, synthetic fertilizer, or chemical biocides. Adding managed grazing can as much as double the rate of carbon accumulation and humus production in soil as compared to regenerative practices without livestock.

How healthy a soil is can be easily and inexpensively measured. The most direct measure of soil health is soil organic matter testing using loss-on-ignition analysis which tells you what percent of the soil's weight is organic matter. In simple terms, a certified lab incinerates a dried soil sample in a very hot oven until it stops losing weight and calculates what percent weight it loses. For any soil type

in the American midwest, the more SOM, the healthier the soil, the more nutrient-dense its produce, the more ecosystem services it is providing and, I would add, the more farmers should be paid for growing it. A healthy soil is a public utility of overwhelming value to society. Soil organic matter is unquestionably the world's most valuable crop. Those who grow and steward it should be properly compensated. Conventional farmers, I stress, do not grow carbon into their soils. They deplete it. It is interesting to note that, no matter the crop feeding it, SOM has the same chemical structure and composition and provides the same ecosystem services everywhere in the world. The techniques to grow it and test it, just like the practices that destroy it, are also the same everywhere in the world. Soil organic matter testing should become a world-wide standard for all ranchers, farmers, gardeners, and landscapers. It is said that you can't manage what you don't measure. Universal SOM testing could revolutionalize agriculture.

The best *indirect* measure of soil health is Brix (B-R-I-X) testing which tells you both how rapidly a plant was photosynthesizing before it was harvested and how abundantly a soil microbiome was providing it nutrients. A Brix test measures the concentration of dissolved sugars, minerals and micronutrients in plant, fruit, or vegetable sap. I often BRIX the vegetables and fruits I buy. Farmers market food is definitely the most nutrient-dense.

If every rancher, farmer, gardener, and landscaper in the world adopted these two simple tests, soil organic matter on an annual basis at the end of the growing season, and a BRIX measure of the produce, and if consumers insisted on seeing these metrics wherever farm products are sold, human health would take a quantum leap forward in a very short time.

There is no good reason to test for conventional soil fertility, N, P, and K in a healthy soil. A diverse community of soil microbes will provide all the fertility you need. Soil fertility and health will be faithfully indicated by the two tests I recommend – soil organic matter and BRIX.

Finally I want to talk about the magic of post-carbon agroecosystems

Anticipating the world's looming shortage of affordable oil and natural gas in the next few decades, given their centrality to conventional food production today, by

the second half of this century we are going to have to learn all over again how to survive on an all-natural local agriculture – which means natural rainfall without artificial irrigation, natural fertility without synthetic fertilization, and natural tillage by indigenous soil fauna, particularly earthworms and beetles. As luck would have it, climate change is also mitigated by these very same farming practices. As quickly as possible, we need to permanently – year-round - re-green all the world's farmland, but we can't do that effectively until we restore dependable regional rainfall, about half of which we have eliminated by deforestation and inappropriate farming practices. That can only be accomplished by rebuilding the soil-carbon sponge (meaning its soil organic matter which is now about two-thirds depleted), by restoring the world's forests (similarly depleted), restoring its wooded field borders and woodlots (about 90% depleted), and by restoring and diversifying our soil microbial communities. Doing so will restore evapotranspiration (which is the water vaporized into the atmosphere through the leaves of actively photosynthesizing plants). Evapotranspiration feeding regional precipitation and replenishing a restored soil-carbon sponge, is not only the ideal irrigation system, it is Earth's most effective evaporative cooling system, able to cool the planet much more quickly than reducing carbon dioxide emissions.

Here, I need to explain further. Water that is evaporated from the soil surface but not transpired through a plant, goes into the atmosphere as haze, just water vapor and a load of heat. And there it stays. Hazes are nature's most oppressive greenhouse gases for trapping heat. Water vapor controls 90% to 95% of atmospheric heat dynamics, while carbon dioxide controls only ten or eleven percent. But, water transpired by healthy plants, trees in particular, deliver a third substance to the atmosphere of great importance to the hydrologic cycle. In addition to water vapor and heat, a bacterium growing abundantly on leaf surfaces, *Pseudomonas syringae* being the most common, is transpired into the air along with the transpired moisture and heat. This symbiotic bacterium serves as a condensation nucleus in the upper atmosphere uniquely capable of causing millions of haze droplets to coalesce or condense into water droplets large enough to form clouds and eventually large enough to fall as rain or snow. You'll be hearing more about bioprecipitation in the future. The coalescence of haze water particles into larger droplets releases their heat back to space leaving highly cooled water droplets that eventually grow large enough to fall back to earth. Forests and woodlands, both because they have a higher leaf area index than

grasslands, and because of their greater concentrations of *Pseudomonas* bacteria, are about twice as effective at producing evapotranspiration and rain or snow as are grasslands. But this is all dependent on their getting moisture from a fully regenerated soil-carbon sponge. Grasslands, of course, don't NEED as much rain as woodlands or they wouldn't remain grasslands, but they could certainly use more dependable rain than they are getting around the world today. To most quickly cool the planet and avoid runaway climate change, we should be planting trees and regenerating the soil carbon sponge in our farm and ranch soils with singular urgency.

In the post-carbon era, assuming we regenerate our soils, food will again become both more nutritious and tastier. The U.S. has long spent about twice as much per person on health care as the average OECD (Organisation for Economic Cooperation and Development) nation, yet we have the worst health statistics of them all. This is because of the Standard American Diet (or S-A-D). To get the same minerals, vitamins, and micronutrients today from our food as we got in 1940, we would have to eat twice as much meat, three times as much fruit, and four to five times as many vegetables. Taste, of course, declines with mineral and micronutrient depletion. It will be refreshing to reacquaint ourselves with the taste of nutrient-dense foods again, many of us for the first time. Only healthy soil can bring out the remarkable differences in taste between heritage species, bred for taste, and garden variety species bred for reasons other than taste, such as growing season, plant height, uniformity, water efficiency, pest resistance, stem thickness, and so on. Grown in depleted soils, even heritage species taste like cardboard. It will be especially beneficial healthwise to be rid of the toxic chemical, hormonal, and antibiotic condiments now seasoning our conventionally grown food.

For my final thought, prior to WWII, farm families were able to keep nearly three fourths of their gross farm income after expenses, and rural communities were thriving. Input suppliers and service providers at the time got about a quarter of gross farm income. Everyone prospered equitably. In the last two decades, corporate chemical suppliers and farm service providers have taken 98% of gross farm income and in some years more than 100%, for products guaranteed to both progressively kill soil and burden farmers with unsupportable debt. This is called "more-on" agriculture, referring to putting more chemicals on to make things better. Better for whom is regrettably clear and it's not for farmers. Bankruptcies

and suicides are at all-time highs in the U.S. farm community today. Absentee landlords knowing nothing about farming are becoming the norm and turning their thumbs down on investing in soil health. Non-owner tenant farmers, whose leases may or may not be renewed from year to year, have little incentive to invest in land improvements. Our rural communities, and now, sadly, our farmers, are dying right along with our soils.

That will change only when farm families own their own land again, giving them a compelling incentive to improve farm profits and practices. This has been shown repeatedly throughout the history of world land ownership. The progressive impoverishment of farmers and their loss of land ownership is an inevitable part of the arc of history for urbanized, feudalistic or capitalist societies that don't appreciate or understand the myriad benefits responsible farmers can actually provide. If I were King, all farmland would be confiscated and redistributed to the families farming it under the condition they agree to adopt regenerative farming practices. We would pay them to transition from high-input "more-on" agriculture to a more natural, ecological way of farming. We would pay them for every ton of carbon they sequester. Nature spent 3.5 billion years evolving the most productive soil ecosystem ever to exist, one requiring no help from humans. Today's farmers need to learn to work with nature, not against it. Corporate chemical agriculture, and, I would add, most Agricultural Extension agronomists, have taken us in exactly the wrong direction this past 75 years. This intentionally unnatural direction has devastated the world's soils, not to mention human health, and turned its produce into cardboard. The closer we can reproduce what nature so painstakingly created, the closer we will get to the holy trinity that evolution provided us of microbially healthy soils, delicious nutrient-dense foods, and microbially healthy animals and people. The soil microbial community will do all this for us at very little cost if we just feed it a year-round highly diverse organic plant diet, restore the trees and woodlots (and we're going to need lots and lots of woodlots for home heating and cooking when affordable oil and all the wooden porch railings and wooden house trim are burned up), bring back grazing animals to our farms, and plant in our fields, our flower beds, our orchards, and our former suburban lawns lots of compost, vegetables, herbs, fruits, grains, nuts, flowers, cows, chickens, pigs, sheep and goats for our own consumption, then stand aside and let the soil do what it already knew how to do successfully for millions of years before profit-seeking humans came up with a different idea.