Sustaining Life

FROM SOIL MICROBIOTA TO GUT MICROBIOME

EDITOR'S NOTE: This piece contains excerpts from a talk at Beyond Pesticides' 35th National Pesticide Forum, "Healthy Hives Healthy Lives, Healthy Land: Ecological and Organic Strategies for Regeneration" by David Montgomery, PhD, a McArthur Fellow, professor of geomorphology at the University of Washington, and author of several books, including *Growing a Revolution*, *The Hidden Half of Nature*, and *Dirt*. Rachel Carson in her book *Silent Spring* wrote, "By their very nature, chemical controls are self-defeating, for they have been devised and applied without taking into account the complex biological systems against which they have been blindly hurled. The chemicals may have been pretested against a few individual species, but not against living communities." In this vein, Dr. Montgomery, in this talk, brings modern scientific understanding to one of the most critical public health and environmental issues of the modern era—how complex microbial or biological systems that Ms. Carson identified are essential to the health of the soil microbiota and the gut microbiome in humans. Dr. Montgomery's complete talk can be viewed on Beyond Pesticides' YouTube channel at *bp-dc.org/Forum17*.

Pesticides disrupt critical microbial communities that support plants and people

DAVID MONTGOMERY, PhD

Thank you all for coming to the Forum, and for the invitation to talk to you today. I'm a geologist by background. My wife Anne Biklé, co-author on the book *The Hidden Half of Nature: The Microbial Roots of Life and Health*, which I'll be talking about today, is a biologist. Why would people like us, who were trained to study in the more traditional natural history disciplines of things we can actually pick up, look at, see, and feel for ourselves, write a book about microbes? This was very much a collaborative effort, as you'll see as I go through what it is that we learned along the way.

A BONAFIDE SCIENTIFIC REVOLUTION

The real message is that the way we understand the microbial world has been going through a revolution in thought, which Anne and I think is akin to a genuine bonafide scientific revolution. The way that we are now thinking about how microbial communities interact with plants and with people—and are central to their health and well-being—is completely shifting the way that we have thought about and looked at how we interact with the microbial world. This has fundamental implications, we argue, for both agriculture and medicine, which relate to the themes that you all are very interested in, in terms of the application of broad spectrum biocides as routine measures. As we got into researching this book about the stars of the microbial world, and their interactions not only with each other, but with other organisms, we realized that a big-scale change is occurring in the way that we think about our relationship to nature—that is centered in the microbial and microscopic world.

INTERACTING WITH MICROBIAL COMMUNITIES

The title of our book, *The Hidden Half of Nature*, is actually meant to be taken literally. If we look at the range of scales—

moving up by factors of ten from down at the nanometer scale of DNA up to the scale (the meter scale) that we live in, you will notice that the boundary between the microscopic world, the invisible world, and the visible world lies halfway through the scale. There is as much of a range in size in the microscopic world of nature as there is in the world of nature that we know, from the size of amoebas up to humans. If you actually weighed all the microbes on this planet, and you compared that to the weight of all the plants and animals on this planet, they are about equal. There are about a nonillion microbes on this planet. (A nonillion is a one followed by 30 zeros.) If you took all the bacteria, all the microbes in the world, and laid them end to end (it takes 50 thousand of them just to go around my thumb), they would reach the nearest star and back. In other words, microbes, if they ever got organized, could actually get off this planet before we could.

So, how is it that we came to actually recognize and get interested in the microscopic world? Well, it may seem like a bit of a *non sequitur.* We bought a house in Seattle and it came with an old growth Seattle lawn. It was a lawn planted in 1918. Nothing much had been growing there after that, and I thought it was a perfectly fine lawn. The dog liked to chase balls on it, and I got to get the graduate students over for cookouts once a year. But my wife is a gardener and viewed this as her garden to-be. One of the main reasons we bought this house was that she wanted to actually transform the property from something other than that lawn. So, when we pulled off the lawn, we discovered that we actually had this incredibly rich, dark, fertile soil. Uh, no! We had glacial till.

Seattle is a town that was overrun by a glacier that scraped off bits of British Columbia, bulldozed it down to where we live in Seattle, and then overran it with a mile-high pile of ice. That pile was about three times the height of the space needle, if you are looking for scale. It was basically nature's concrete. We did not find a single worm in the soil when we pulled that lawn off. There were no macroscopic life forms. Now, I'm sure there were some microbes in there, but we will get back to that a little later. We realized that we did not have soil. We had dead dirt.

Now, when you think about what it is that actually makes for rich, fertile soil, it is the marriage of geology and biology. You would think that people like Anne and I would have understood this. But, I did not think to dig a soil pit in our yard when we bought the house, and neither did she, so we were faced with this when we started to try to turn that yard into a garden. We realized that we had the geology—we had all those bits of Canada that had been scraped down our way—but we did not have the biology. The organic matter content in our soil and our area when we started was less than one percent. This led us—I should say more correctly it led Anne—to think that what we really needed to do was add a lot of organic matter to the yard. She started what we call in the book her "organic matter crusade," which meant going to every place that we could get organic matter, bringing it in, putting it on as compost or mulch in the yard, and trying to rebuild our soil.

THE ORGANIC MATTER CRUSADE

At the time, I was writing a book about the way that agricultural practices had destroyed civilization after civilization by degrading their soil, and it was a revelation to me as to how fast you could actually revive soil. It was happening right under my nose, in my own yard, as Anne was indulging in her grand experiment of bringing life back to the yard. The soil pit that we actually ended up digging in the yard about five years into her organic matter crusade had wood chips and the mulch that she was layering on the surface of the soil and glacial till down at the bottom—she was not a digger, she was a composter and a mulcher. The plant roots go down to the till and then go sideways. They are not going down into the till. Nevertheless, we found about two inches of halfway decent soil that formed in about five years.

If you actually look at geological literature, at how fast soils form, you get rates that are measured in tenths of a millimeter a year. Here, we have two inches in five years. This was not from breaking rocks down to form more soil—it was forming good soil out of the geology that was already there by adding the biology. It started me thinking: What if the key to soil restoration is not the way a geologist usually thinks about it, in terms of making more soil from rocks, but it is actually turning the stuff at the surface into more of a fertile soil by adding the biology?

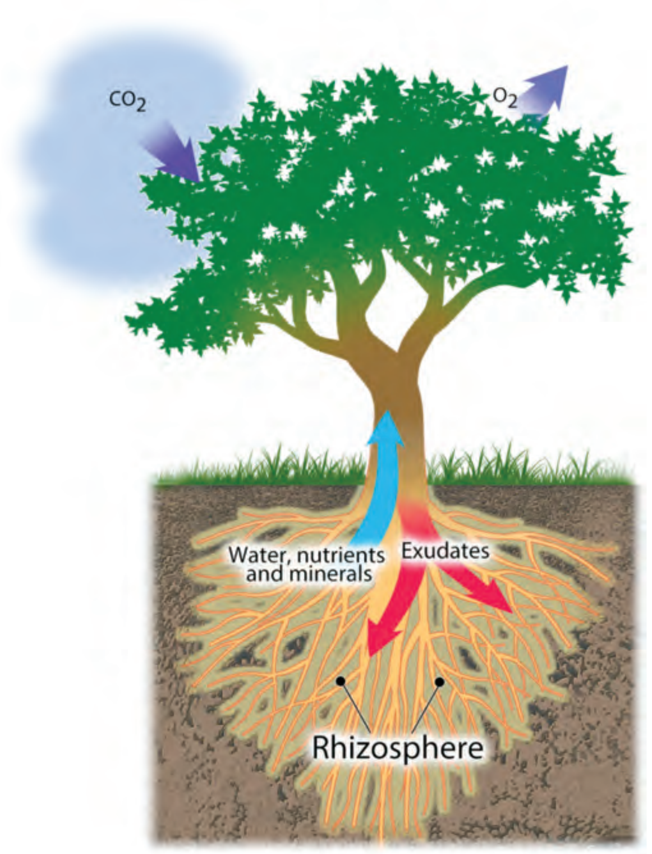
We were cycling organic matter into this underground ecosystem and started us on this view of a completely different relationship of the natural world to human societies.

The change in our soil transformed the yard above ground too. We ran into an explosion of plant life. What happened? Why was this organic matter crusade, adding dead material to the surface of the soil, leading to an explosion of life, both above and below ground? Basically, that compost that we were adding at the surface was being consumed by microbes, bacteria, and fungi, the smallest creatures in the soil food web, which were then being consumed by larger creatures, which are consumed by larger creatures. We were cycling organic matter into this underground ecosystem in ways that led us to learn things that frankly quite surprised us and started us on this view of a completely different relationship of the natural world to human societies.

One of the things that Anne and I both noticed when she started her composting and mulching activities is that we would lay a good bed of mulch down in the fall and it would be virtually gone come the spring. Initially, we were starting to think, "Is somebody coming into our yard at night and taking all our good stuff?" No. It turns out, actually, that our neighbors are quite happy to have us go rake up their leaves and bring them back to our yard. But, still, this stuff was disappearing and breaking down. We were good enough scientists to realize it was not just disappearing. It was being transformed.

The microbial life—the bacteria and fungi—were the things primarily responsible for that transformation, and they turned out to be very nutrient rich—rich in nitrogen, rich in phosphorus, and rich in the micronutrients that all life forms need. Why? Well, because they are breaking down organic matter that used to have those nutrients—used to be living matter. When nematodes and microarthropods can graze on and consume these smaller creatures, it comes out later in a transformed state that can be fairly good fertilizer. I like to think of them as tiny livestock that are manuring the soil from the inside out. We are adding all that organic matter to the yard, basically feeding our grazing animals, which are then in turn being grazed. That is essentially building up the nutrient levels in the soil through a two-step soil-food web.

FIGURE 1: **Rhizosphere Rich with Life**



Source: David Montgomery

To be honest, to a geologist, that was not completely new thinking—that is systems thinking we are fairly accustomed to. But we started to look into and learn things that really quite surprised me. They center on what happens in the rhizosphere, that zone around the root system of a plant that is incredibly rich with life. It is one of the most life-dense zones on the planet, and it started us thinking: "Why is that?"

THE RHIZOSPHERE: A BIOLOGICAL BAZAAR

I was quite surprised to learn that roots are actually two way streets. When I took soil science a few decades ago in graduate school, I was basically taught that plant roots were like straws. They bring up water and the nutrients contained in them that have been derived from rocks into plants. It turns out that plants actually push out into their soil up to 30 or 40 percent of the carbon and the carbon-rich compounds that they manufacture with their monopoly on photosynthesis. They will push that stuff out of their roots and into the soil. Why would a plant do that? How many of you take 30 to 40 percent of your income and just go throw it on a street corner somewhere? If you think about it in those terms, it is an utterly irrational thing for a plant to do. And yes, I know plants do not have brains, but they do communicate. Why would plants be essentially pushing out such nutritious material, what Elaine Ingham, PhD (U.S. Soil Microbiologist, founder of Soil Foodweb, Inc.) likes to call the equivalent of cakes and cookies, into the soil? It is to feed the life that is living in the rhizosphere. Why would a plant do that, and maintain that over the entire history of plants? If you go back and look at the very first plant fossils 400 million years ago, they have mycorrhizal fungi intertwined with their roots. This has been going on as long as there have been plants. Why would they do that? Well, it is not because most of the microbes are pathogens. That would be an evolutionary dead end. It is because they are feeding life forms in the soil that provide benefits to the plants. So, Anne and I learned to see the rhizosphere, this life-dense zone around the roots of plants, as what we call a biological bazaar, where microbes and plants trade nutrients, metabolites, and exudates.

If you blow up the area around the root or root hair of a plant, what is happening is in the rhizosphere. There is a high concentration of bacteria and mycorrhizal fungi connecting with the plants. Most of those exudates that come out of the plant roots make it only a millimeter or centimeter out into the soil before they are consumed. They get rapidly eaten, and what happens to things that get eaten? They get transformed into metabolites, the byproducts of some living organism. Those bacteria are pushing out into the soil, in their metabolites, things like plant growth promoting hormones. They are helping to dissolve the materials out of the soil and get them back into the plant. Why would bacteria make plant growth hormones? This is like one kingdom of organisms creating something to help another. It is a classic example of a symbiotic relationship. The plants are helping to feed the microbes, the microbes are helping to nurture the growth, and, it turns out, the health of the plants. Mycorrhizal fungi, reaching out into the soil, are going out and excavating things like phosphorus, manganese, or iron from the soil, bringing it back, and trading it to the plant in exchange for a cut of the photosynthetic harvest.

When Anne and I learned this, we were really quite surprised that these kinds of relationships that have developed in the rhizosphere seem to be every bit as complex and evolutionarily fine-tuned as the relationships between plants and pollinators above ground. But we have not known about that because they are occurring in this invisible world, a microscopic world, and they are happening below ground. It is sort of the double hidden nature of the hidden half of nature. We were even more surprised when we started looking into some of the other aspects of the relationship between plants, their roots, and the microbes living in the rhizosphere. For example, when some insect herbivores snack on your favorite plant, or a crop, that plant will push exudates out into the soil that are tailored to feeding the growth of very particular microbes or microbial communities, which will then produce very particular exudates that are taken back up by the plant and can produce compounds that taste bad to that particular insect. This is a really fined-tuned evolutionary relationship. This kind of thing is why Anne and I ended up writing *The Hidden Half of Nature*. It is utterly fascinating. Thirty years ago, we did not understand most of the mechanisms. We did not have the technology to actually study the connections, and to establish that symbiosis is not just wishful thinking. The modern science that has been coming out in the last couple of decades has nailed these relationships as cutting edge science, even though they are very similar, in terms of their broad implications, to some of the things Sir Albert Howard and Lady Eve Balfour (principal figures in the early organic movement) were proposing in the 1930s and 1940s. The science is finally catching up with some of the insights of the early pioneers of organic agriculture.

THE SOIL BODY CONNECTION

What does this mean in terms of how we think about plant health and plant diet? Anne and I have defined something we like to call the "fertilizer diet"—if you provide a plant with most of the macronutrients that it needs (the nitrogen, phosphorus, potassium [NPK]) that you usually find on the label of a synthetic fertilizer bag) those plants will not put as much energy into creating an extensive root system, and they turn into what we like to call "couch potato crops." The fertilizer diet provides plants with the stuff they need for growth. However, the system that they rely on to promote their health and their defensive capabilities requires micronutrients and metabolites that the microbes in the soil produce. When you feed them a heavy diet of macronutrients, they do not invest in their root system to put the exudates out into the soil to recruit the microbes that make the beneficial microbial compounds. They are getting a heavy dose of macronutrients and a light dose of beneficial microbial metabolites.

On the other hand, plants grown in soils that are rich in organic matter will grow extensive root systems, put out lots of exudates, and essentially recruit microbial allies. That is a recipe for plant health. What does that soil life diet look like? It turns out it looks a lot like the kind of thing that Anne did to our yard. In adding our composted coffee grounds (we have a surplus of them in Seattle), our leaves and woodchips, we were basically bringing back the biology to feed the subsurface biology that is the other half of fertility in fertile soils.

SOIL, HUMAN IMMUNE SYSTEM, AND GUT MICROBIOME

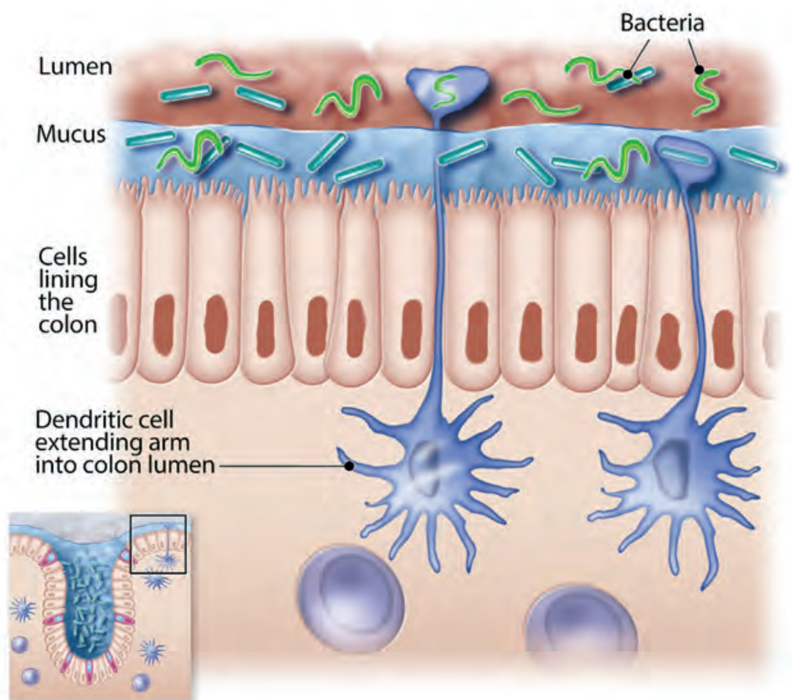
We watched the transformative effects on both the life in our yard and the development of our soil, but we got thrown a curve ball. We were starting to think that the microbial world is this really neat, symbiotic world in terms of what was happening in our yard, and then Anne was diagnosed with microbial-caused cancer. This was a very serious event in our lives, obviously, and thankfully now she has just passed her five-year anniversary of being cancer-free. So it is an episode that we hope is well and truly behind us. That episode started Anne thinking very strongly about what it is that actually supports health, and, particularly, the human immune system. Because, with an event like cancer in your life, you start thinking about what are the things that we can do to really bolster the effectiveness of our immune system to try and make sure we do not have any future episodes along those lines. So, while we were thinking of the microbial world as this incredibly symbiotic thing, this curve ball reminded us that not all microbes are on our side. There are very bad microbes in this world, and it led us into thinking about the human microbiome and its relationship to our immune system.

This is an area of science that has been exploding. If you graph the numbers of publications on the human microbiome since 2000, you will notice an exponential growth curve that keeps going up. The numbers of papers and interest in the human microbiome have obviously exploded in the last couple of years, and this led Anne and me to look into the relationship between the human immune system and human health. This has led to something that I never thought I would ever be doing, which is standing in front of an audience and talking about the human colon.

GASTROENTEROLOGY AND SOIL SCIENCE

A little geography here. Looking at a cross section of the colon, the lumen is the center. It turns out that most of the human immune system—some 80 percent of our immune cells—occur in the lining of the colon just outside the colon wall. The colon is also where 80 percent of our microbiome lives. What is our microbiome? It is the indigenous and endemic microbial community that lives on and within us. When we started looking into immunology journals and we started to run across wording that talked about the mucus layer that lines the lining of our colon as an exudate that your colon wall cells produce and push out into the lumen, we started recognizing a very similar set of terms in both the gastroenterology literature and in the soil literature. Why is it that our colon lining would be producing exudates that actually support and feed a fair number of the microbes in our microbiome? It is starting to sound a little bit like what plants do. To basically understand the connection to the human immune system, we have to dive in to what is happening across our colon lining. It turns out that your colon lining is one cell thick; one cell separates the inside of us from the outside of us. If we look at a cross section from the lumen down into the inside of our colon wall, there is this mucus layer, and there are microbes living both in the lumen and the mucus.

FIGURE 2: **Human Colon: Immune System and Microbiome**



Source: David Montgomery

Immune cells, called dendritic cells, are like shape-shifting amoebas. They can extend an arm, stick it between the cells that line your colon, go out into the lumen or the mucus, and grab a sample of something. They bring that sample back inside and share it with T-cells, which are other cells in our immune system. Those dendritic cells will sample those microbes, bring their pieces (antigen) back, and show them to the T-cells. T-cells are essentially major players in our immune system, but they are inactive most of the time. Each T-cell is tailored for a very particular antigen. When the dendritic cell brings the antigen to the T-cell, the T-cell gets activated. The dendritic cell sampling of the microbes in our colon and colon lining activate T-cells in two different ways. We are used to thinking about our immune system as a system that goes after pathogens and kills them, kind of like a paramilitary organization living within us. But, it turns out that there are two kinds of T-cells that get activated by this mechanism. Certain microbes, when they get sampled, activate T-cells that trigger inflammation. Other T-cells, when they get triggered, quell inflammation (they are anti-inflammatory). In the classic way of thinking about our immune system, we just think about them as things that would trigger inflammation, because inflammation is the process through which our body does remodeling. It takes out cells we do not want, but like all remodeling projects, there is always incidental damage. You do not want inflammation to be happening all the time. If you do not need inflammation to be combating some kind of malady, you want inflammation to be turned off. This idea that the regulation of our immune system, to quell inflammation, is dictated in part by microbes that are living in our gut, is a completely new way of looking at the immune system, and it also leads us to a completely new way of thinking about and looking at what we eat.

If you look at what has changed over the course of the 20th century, in terms of infectious and chronic diseases, there is a relationship here that we are going to try to get at the heart of. If we look at what has happened in terms of infectious diseases since the Second World War, they have really dropped dramatically. Why? Well, obviously, antibiotics came into play in that era. There were great increases in public sanitation during that same era as well, and the development of vaccines and their widespread use. Infectious diseases have gone through the floor in the last couple of generations. At the same time, rates of chronic disease have gone through the roof. So, what is happening with that? There is a hypothesis that researchers in the microbiome world have been investigating that is in great part based on that sort of teeter-totter balance of our pro- and anti-inflammatory immune cells and that relates to what is happening in our gut. That hypothesis can be framed as questions: Are we missing some of our microbes? Have the microbial communities in our gut changed enough that the puppeteers, if you will, that have been running our immune system, are actually misfiring, or getting bad information?

Diseases Associated with Microbiome

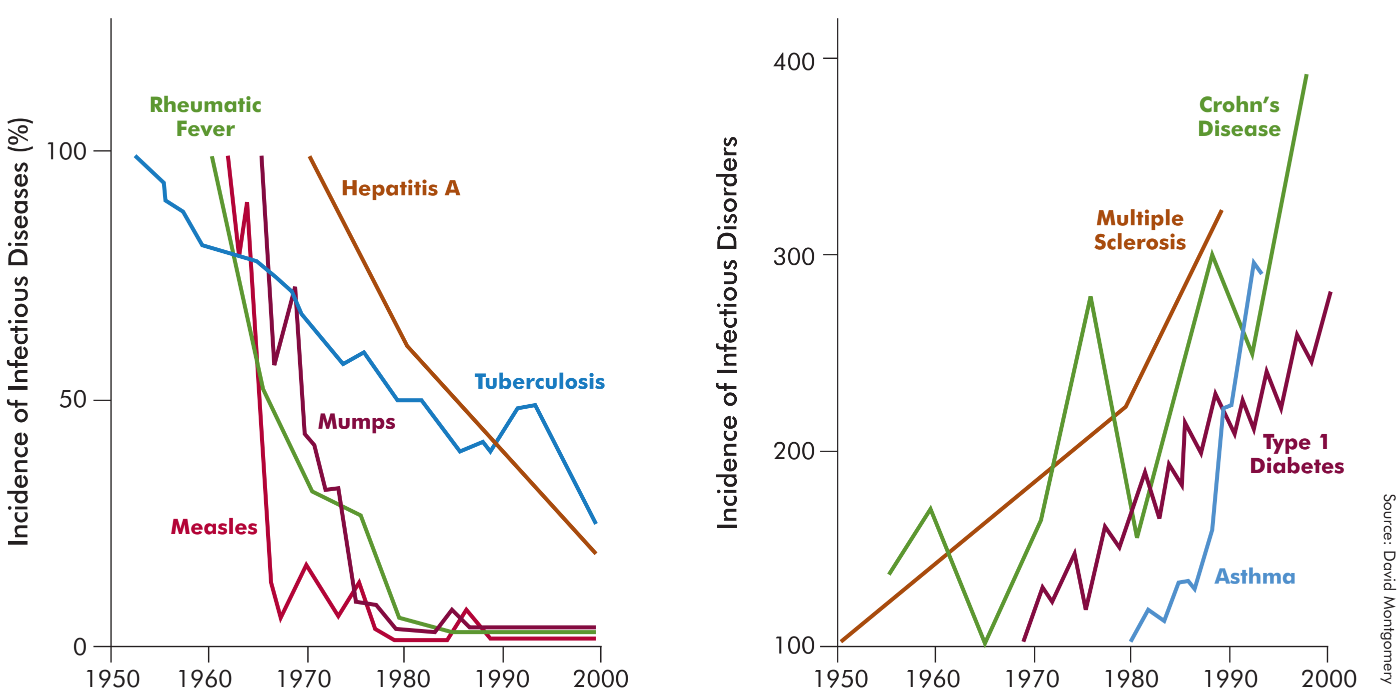
Allergies, Asthma, Autism, Bacterial vaginosis, Cardiovascular Disease, Certain cancers, Crohn's Disease, Depression, Inflammatory Bowel Disease, Leaky Gut Syndrome, Multiple Sclerosis, Obesity, Type 1 and Type 2 Diabetes, and Parkinson's.

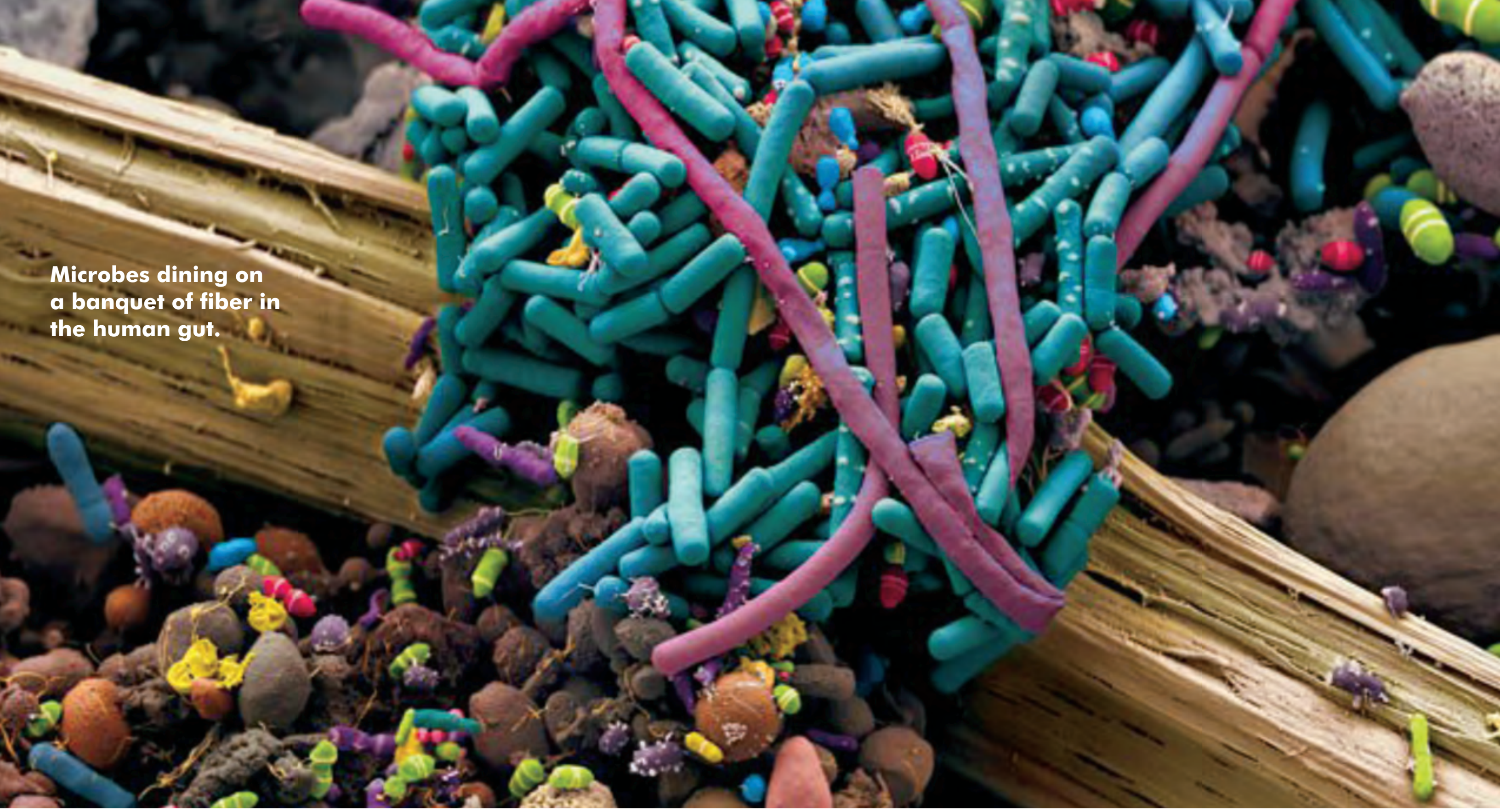
Think about our immune system not so much as a police force, but more as an intelligence arm. Have we been getting bad intelligence for the last few decades, in terms of what our bodies should do in relation to inflammation? This is a hypothesis that is being pursued by many researchers around the world. There is a whole bunch of maladies (see box)—and I notice that there is an article that came out a couple days ago that added Parkinson's to the list—for which causal links are starting to be established. Every one of these diseases is one in which people have hypothesized and demonstrated correlative effects, and some of them have demonstrated causative effects.

THE 20TH CENTURY DIET

What might have happened to our microbiome that could have led to such serious proposals to investigate the idea of very widespread effects? Well, what about what we eat? We know about changes in antibiotics after the Second World War, and how that might affect the human microbiome should not be much of a mystery. Broad spectrum antibiotics kill microbes broadly. What about what we eat? To understand the connection of diet with the human microbiome, we need to think a little bit about the human digestive track. I'm going to take you on a field trip through the human digestive track, and we are going to start at the stomach, where there are hardly any bacteria (1 to 10 per milliliter of fluid). It is an incredibly acidic environment. What happens there? Well, things are supposed to be dissolved. So, food will come in, and we start to dissolve it. In the small intestine, we have the enzymes to break down and absorb things like proteins, simple sugars, and fats. They will get absorbed in the small intestine, and there are more microbes there than there are in the stomach. It is not until you get down to the colon that we start getting numbers in the hundreds of millions to trillions of microbes. Most of our microbes are living in our colon. And, like all organisms, they need to eat. Most of

FIGURE 3: **Inverse Relation between the Incidence of Prototypical Infectious Diseases (left) and the Incidence of Immune Disorders (right) from 1950 to 2000.**





Microbes dining on a banquet of fiber in the human gut.

those microbes are eating whatever does not get absorbed by us through our digestive tract. That tends to be whole plant foods (complex carbohydrates).

What do those microbes living in our colon do with those whole plant foods that get down there with those complex carbohydrates? They ferment them. We basically have an on-board fermentation tank called our colon. And, the microbes living within it are essentially living off of the part of our diet that actually makes it down to what we like to think of as the tranquil grazing pastures for the microbes in our colon.

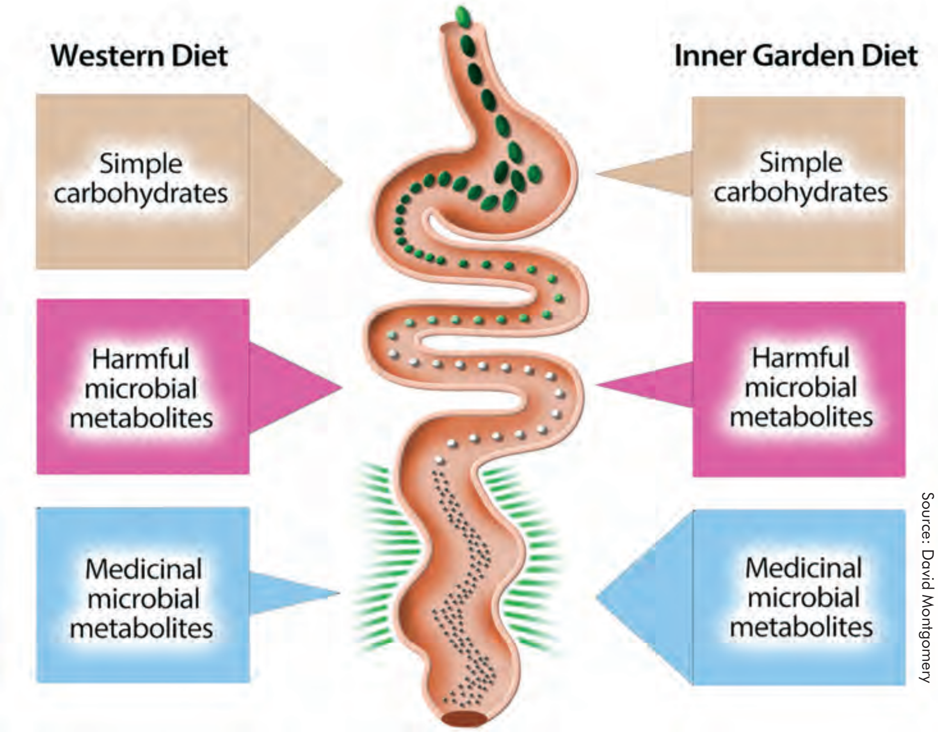
So, what happens if we have a diet that does not have much in the way of complex carbohydrates? We are basically starving what is down in your colon. What has happened to the human diet in the last 100 years or so in the developed world? Well, we have changed our carbohydrate consumption. If you look at total carbohydrate consumption in grams per day from 1910 to 1997, you will notice that we had a high carbohydrate consumption but a high fiber content. What is another word for complex carbohydrates? Fiber! That is what your doctor or nutritionist would call them. So, carbohydrates come in simple forms, as simple sugars, and as complex carbohydrates, or fiber. We had a high carbohydrate, high fiber diet early in the 20th century, and a lot of changes happened during the century. Late in the century, the carbohydrate component of our diet went back up, so that it is about the same as it was early in the 20th century—but the form is different. We're eating simple sugars, not complex carbohydrates. Any why is that? Well, two-fold. The processing of grains has greatly reduced the complex carbohydrates in our diets, and there has also been a great increase in simple sugars being added to everything.

A photograph of microbes dining on a banquet table of fiber in the human gut (see above) could just as easily be a photograph from the garden. The message that I want to convey is that there are really strong parallels in what is happening in terms of the relationship between the microbial world out in agricultural fields and in the garden, and within the garden of our own gut. How does this matter to our own health? I'll try to drive it home here. We have all these different fiber sources, they get into our colon, consumed by the microbiota within our colon, our microbiome, and then produce their own metabolites. A lot of them produce fatty acids, like acetate, butyrate, and propionate.

I am going to focus just on butyrate. Why? Well, what feeds the cell lining of our colon wall? Most of the cells in our body are fed by our blood. Our colon lining gets most of its energy from the butyrate that is produced by microbes living in our gut. Those microbes depend on a diet of fiber. If they do not get enough butyrate, the gaps between the cells start to grow because the cells shrink, and, as you might imagine, it is would not be crazy to posit that this might be linked to something called leaky gut. So, what happens when dendritic cells sample that butyrate, bring the antigen back, and show it to the T-cells? It activates T regulatory cells. Those are the kind of T-cells that quell inflammation, and that basically block an inflammatory response. Here we have all the pieces connected between our diet and the inflammatory response in our bodies, and the way our immune system is working and mediated greatly through the role that microbial metabolites play in our gut.

Where does this leave us in terms of thinking about the human diet? Well, if we think about what is happening with

FIGURE 4: **Western Diet vs. Inner Garden Diet**



The Western diet is heavy on simple carbohydrates and light on medicinal microbial metabolites. An Inner Garden Diet is light on simple carbohydrates and heavy on medicinal microbial metabolites.

the western diet, it is rich in simple carbohydrates. We are getting a lot of stuff that is being absorbed in our bodies into the small intestine, but we are really not putting a whole lot of fiber down into the colon, so we are getting a low dose of these medicinal microbial metabolites. Butyrate is just one of many compounds that the microbiota in our colon are actually making. There are estimates that 30 to 40 percent or more of the metabolites—of the compounds circulating in our blood—are metabolites from microbes in our colons. We like to think of our microbiota, our microbiome, as microbial alchemists. They are transforming that fiber into beneficial metabolites. On the other hand, if we think about something that Anne has termed the "inner garden" diet— and she got to name it because she is the gardener—it can include modest simple carbohydrate consumption. It also produces a lot of medicinal microbial metabolites—things that could actually be very useful in preventive medicine.

We need to think about our microbial crew, or the microbiomes of both plants and people, in terms of protecting, restoring, and cultivating the beneficial microorganisms that are key elements of those communities.

So, what does an "inner garden" diet look like? It contains a lot of whole plant foods, some kind of a protein source, and unprocessed whole grains as a great source of fiber. The key thing, and the thing that transformed our diet after we did this research, was thinking that we really need to feed our microbes first. I now think, after I have fed my microbes enough of a whole plant food based diet, I can go have dessert, or I can have a burger, or whatever I want to go eat. The idea of prioritizing the feeding of our microbial crew is actually really crucial for health. This understanding led Anne and me to the revelation that transformed the way that we framed and wrote *The Hidden Half of Nature*.

THE PARALLELS: SOIL HEALTH AND THE HUMAN GUT

When we started writing *The Hidden Half of Nature*, we thought we were writing a book about restoring soil and restoring our yard, and we ended up devoting half of it to the human microbiome. Why? Well, when you look at these two systems, the human gut and the root system (rhizosphere of a plant), you realize that they are very similar, but inside out. You take your colon and turn it inside out, and it is not all that different from the root system of a plant; do the opposite, and you get kind of the same thing. This is in terms of how the microbial communities in those organs are actually interacting to promote the health of the host. They are basically assisting with nutrient acquisition. The microbes in the soil are really helping to bring micronutrients and some major nutrients into plants, while the microbes in our body help facilitate nutrient transfer across our colon wall. The role of microbial metabolites, promoting the health of both plants and people, has become very clear in the literature in the last few decades. The parallels, when you get into it, are actually quite striking.

HUMAN IMMUNITY AND PLANT DEFENSE

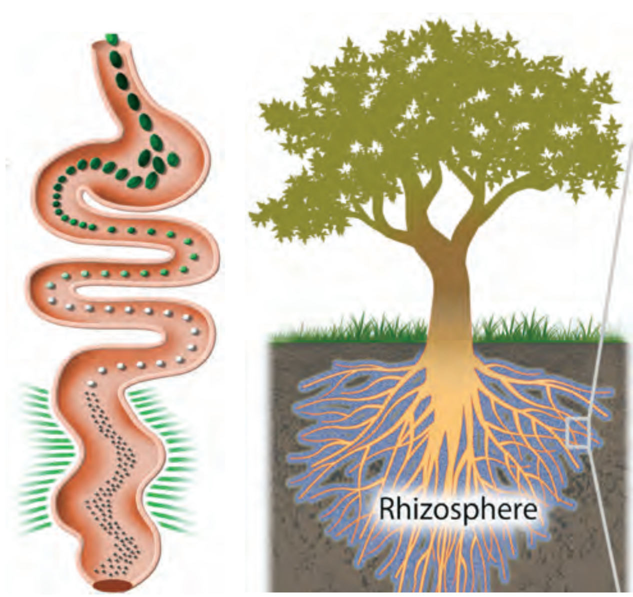
The other parallels are in terms of immunity and plant defense. The defense system of our bodies and the defense system of plants are different. After all, we can move around and we take nature inside of us, whereas a plant is stuck outside and cannot move around in nature. The role of

> *We really need to think about avoiding the routine use of broad-spectrum biocides, because if we use a broad spectrum biocide, we are taking out all the beneficial organisms, as well as the pests and pathogens.*

microbial communities and their metabolites in supporting plant defense and our own immune systems are actually strikingly parallel. What does this essentially mean for thinking about our relationship to the natural world? Well, first of all, it means that we need to think about our microbial crew, or the microbiomes of both plants and people, in terms of protecting, restoring, and cultivating the beneficial microorganisms that are key elements of those communities. That has clear implications for both medical and agricultural practices.

In case you want to convey to somebody the essence of what I am talking about, in terms of all these microbes, we have boiled the book down to six words for you, which should be fairly easy to remember. It's basically, "Mulch your soil—inside and out."

FIGURE 5: **The Root is the Gut (inside-out)**



Nutrient Acquisition
Microbial Metabolites
Immunity and Defense

Source: David Montgomery

STOPPING BIOCIDES THAT KILL INDISCRIMINATELY

There is also another really big implication of the realization of the fundamental role of microbial community ecology in the health of both plants, and therefore crops, and people. We really need to think about avoiding the routine use of broad-spectrum biocides, because if we use a broad spectrum biocide, we are taking out all the beneficial organisms, as well as the pests and pathogens. We have thought about microbes for a little over a hundred years now, in terms of germ theory, as being bad—we need to keep them off of us, and we need to sanitize our world. But we actually have been learning very recently about how the science is very misguided. That is not to say that antibiotics or even pesticides should never be used—what is absolutely clear in my mind is that the idea of relying on them as our routine front line applications in both agriculture and medicine makes absolutely no sense in light of the modern science that has been revealing these intricate and highly involved relationships between the microbial communities and the health of plants and people.

My book, *Growing a Revolution,* focuses on how we can apply some of these ideas in agriculture, how we can turn one kind of soil into another kind of soil, depending on how we actually farm the land. If you are interested in soil and its relationship to human societies and the broader ecological world, and how to restore soil, I refer you to my book *Dirt,* part of my trilogy. *Dirt* talks about the role in which farming practices have destroyed soils over the course of history, and continue to do so under modern conventional agriculture. *The Hidden Half of Nature* talks about the nature of the microbial world in terms of what really makes for fertile soil. The *Growing a Revolution* is about how to actually fix the problem—because it turns out that I think we actually could restore fertility to the world's agricultural soils shockingly fast if we put our minds to it and completely changed our agricultural practices.

I'd like to thank you all very much.

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