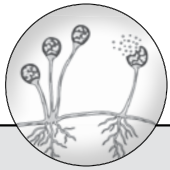


CHAPTER 1

Introduction

WHAT DO YOU SEE when you look at the surface of a leaf?

The surface is mostly smooth, but it can have some bumps on it and some leaves are quite hairy. The color is mostly green, although yellow and red also concur on garden plants. You might even see an insect or two crawling across the leaf, but other than that, there is not much activity.

Your perspective of that leaf is very wrong because you are using macro eyes. They just don't see the details very well. If you look at the leaf with a microscope, you suddenly see a whole new world that is full of millions of organisms. Some are stationary and others are speeding along. Admittedly, speeding along at microscopic levels is actually quite slow.

Not only do you see many individual organisms, but you also see many different types of organisms. Some, like viruses, are extremely small and can't be seen even with a light microscope. In contrast, others are relatively huge, multi-celled organisms. Even shapes vary a lot. You'll see spheres, long rods, and undefined blobs. Some are whipping hair-like appendages around to help them motor along.

The colors are fabulous. Some are clear with almost no coloration, but many have shades of blue, green, red, and violet. Their surfaces also vary a lot, and scientists use this texture to help with identification.

It might seem like an idyllic environment. All natural and cozy, but it is anything but. Microbes are constantly fighting for food and space. Small ones are eaten by larger ones, who get eaten by even larger ones. These guys don't even fight fairly and use all kinds of chemical weapons to destroy each other.

This is one very complex society, and to be honest, scientists are just starting to understand it.

The most common microbes are bacteria, and a gram of fresh leaf, the weight of a paperclip, may harbor as many as a hundred million of them.

Let's dig a little deeper. Scrape off all of the surface microbes so that we can see the leaf. Under a microscope, the surface no longer looks smooth. It is mountainous with all kinds of valleys, cracks, and holes. These are perfect places for microbes to hide.

If you look a little closer at the holes, you will find some very large ones, the stomata. The plant uses these to absorb carbon

Surface of a coleus leaf

dioxide and expel excess oxygen, water, and other gases. The microbes take full advantage of these and crawl right inside the leaf. Some spend their whole life inside leaves.

Once inside the plant, microbes can even enter plant cells. Some of these are very beneficial to plants, who actually send out chemical signals to attract them. Others, like viruses, can be quite harmful.

A leaf is covered in thousands of different microbes. Some are beneficial, some are neutral, and others are harmful pathogens. This book is all about these microbes and their interaction with plants and each other.

Why Learn About Microbes?

Why learn about microbes when you could be learning how to care for plants? Would that not make you a better gardener? Perhaps, but one thing I have learned after gardening for many years is that learning about plants only takes you so far. There are just too many plants to study. I have learned that if you take the time to understand the underlying basis of nature, growing any plant becomes easy.

Microbes are vital to plant growth. They help plants get nutrients from soil and dead organic matter. They cover every square inch of the plant, including leaves, stems, flowers, fruits, and even the roots. Some are beneficial to plants, others are pathogens ready to kill the plant, and many play a neutral role. But even these neutral actors are critical for soil structure, soil nutrient levels, and plant health.

Understanding the interaction between plants and microbes is as important as learning how to water your plants or how to situate them correctly for the right amount of light. You can't see the microbes, but they are everywhere, and everything you do in the garden affects them and in turn your plants.

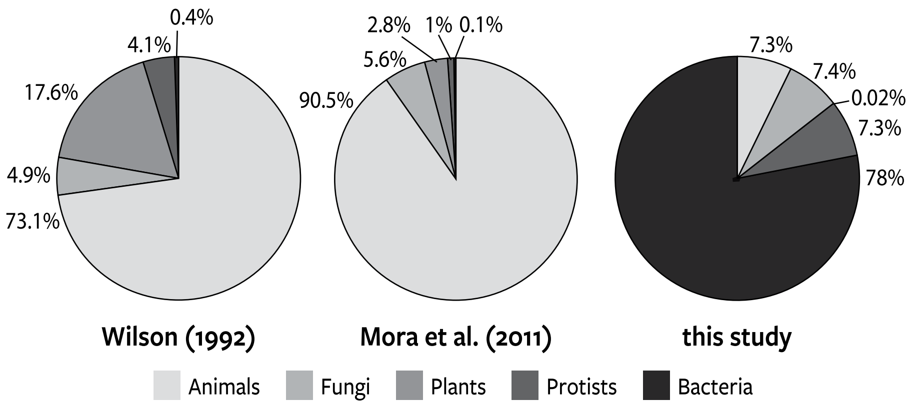
As we travel down the road of understanding, you will learn about microbes that plants farm to get more nitrogen. Plants also allow microbes to "pollinate" flowers so that they end up in seeds to help future generations fight bacterial infections. Special fungi attach themselves to roots to extend the plant's reach in soil, making it easier to find nutrients.

Plant-available phosphate is a rare resource in soil, and microbes collect it for plants. Nitrogen-fixing bacteria take nitrogen gas from the air and convert it to a form plants can use. But did you know that it is the plant that initiates and manages these associations? Plants actively manipulate the microbe community around themselves.

Gardeners become obsessed with plant diseases, and microbial pathogens are certainly important. What is more surprising to me is that most diseases are preventable, not by direct actions of the gardener but by the activity of invisible microbes in and on the plants.

How many species of living things inhabit earth? That seems like a simple question, but we still don't know the answer because most species have not yet been identified. We have named around 1.5 million of them. About two thousand new native plants are discovered every year. There are many spots on earth that have never been botanized, so the number is certain to grow.

The largest gap in our understanding of organisms is with microbes. Their small size and visible similarities make it very difficult to identify species. It is only now with the help of DNA analysis that we are starting to appreciate their numbers.



Pie of Life: Relative number of species on earth. Credit: John J. Wiens et al.[1]

Armed with new DNA data, scientists have developed a new estimate of life on earth that is between one and six billion species. These results are still quite speculative, but they are changing our understanding of our world. The "Pie of Life" charts show how our estimates have changed over time. The latest estimate shows that microbe species dominate (70–90 percent) of the planet.

Terms Used in This Book

Science is full of weird terms, but it is critical to know these terms in order to understand the underlying meaning. I have kept technical terms to a minimum, but a few are important for gardeners to know.

Plant Spheres

Scientists have defined specific microbe ecosystems as spheres. I have used the terms phyllosphere and rhizosphere in this book:

- anthosphere—area around a flower
- carposphere—area around a fruit
- phyllosphere—area around leaves and stems
- rhizosphere—area around roots

Epiphytes and Endophytes

An epiphyte is an organism that grows on the surface of a plant. Orchids are a good example of this. The term is also used to describe microbes that grow on plants.

An endophyte is an organism that lives inside a plant. Endophytic microbes are found in all parts of a plant, including the seeds.

Strain VS Species

The terms genus and species are used to identify a particular organism and they work very well for larger organisms such as animals and plants. Microbes add an extra complication because they mutate very quickly and they can easily exchange pieces of DNA. For any given species, there can be numerous variations and rather than identifying each one as a new species, scientists tend to call them strains. Strains are different enough to be identifiable but not different enough to warrant a species designation.

Facultative Anaerobe

All organisms require energy to live and those living in an oxygen-rich environment, like most animals and plants, use oxygen to make an energy molecule called ATP—the energy battery of living things. Such organisms are called aerobic.

Some organisms, mostly microbes, live in an oxygen-poor environment and get their energy through fermentation. These are called anaerobic.

There is a third class of organisms called facultative anaerobes. These guys will get their energy using ATP when oxygen is plentiful but can switch to fermentation when the oxygen level drops. Yeast is a facultative anaerobe, as are bacteria such as *Staphylococcus* spp., *Escherichia coli,* and *Salmonella.*

This ability to live in both environments makes it easier for them to survive as conditions change. You might recognize *E. coli* as a common gut bacteria that grows in our intestine, which is a low-oxygen environment, but it also lives in soil and on leaves, which are high-oxygen environments.

Many gardeners make the mistake of thinking that pathogens only exist in anaerobic conditions, but all three of the above-mentioned bacteria can cause disease and infection.

Eukaryotes and Prokaryotes

The cells of all living organisms can be divided into one of two categories: eukaryotic and prokaryotic.

Eukaryotes are organisms that have eukaryotic cells, which are the basis of all multicellular organisms including animals, plants, and fungi. These cells have well-defined organelles inside their cells. Examples include the nucleus that contains the DNA or RNA, the endoplasmic reticulum, which is used to synthesize proteins, lipids, and steroids, and the mitochondria, which produces energy.

How do you remember which is which? Simple. You are a complex organism and therefore a "Youkaryote."

Beneficial VS Effective Microbes

These two terms are used a lot in gardening discussions and are often misused. They are not the same thing.

Beneficial Microbes

Most academic discussions are just about microbes, but gardeners and manufacturers of products like to use the term "beneficial microbes." By definition, these are microbes that are beneficial to plants and include anything that is not a pathogen. Even if a microbe does not help a plant directly, it usually helps indirectly by providing nutrients to soil, or competing with pathogens.

The term *beneficial* does not really tell you much about the microbe, except that it is not a pathogen. Ignore this term on product labels—it is just marketing gibberish.

Effective Microbes

The term *Effective Microorganisms* (EM) was first used by Dr. Teruo Higa to describe a combination of about eighty different microbes that were capable of improving the decomposition of organic matter. He developed the idea that the right combination of "positive microbes" would improve any media, including soil. The initial product was called EM-1, which contained three groups of microbes: yeast, photosynthetic bacteria, and lactic acid bacteria.

Since the introduction of EM-1, many other formulations have been produced by a variety of manufacturers. When you buy a product containing EM, you are buying a combination of microbes that the manufacturer considers important.

Fertilizer

Most gardeners use the term *fertilizer* to refer to synthetic fertilizer, but once you understand that the nutrients from both synthetic fertilizer and organic fertilizer are identical, you realize that both will have the same effect on plants and microbes. It is the amount of added nutrients that is key, not the type.

In this book, I use the term fertilizer to refer to both synthetic and organic fertilizer. If it is important to differentiate between the two, I'll call them synthetic fertilizer and organic fertilizer, with the latter referring to a wide range of products including manure, compost, blood meal, etc.

Miscellaneous Terms

Bulk Soil—the soil outside of the rhizosphere, which includes most of the garden soil.

Microbiome—the microorganisms in a particular environment, such as the surface of a leaf (the leaf microbiome) or the inside of your gut (the gut microbiome).

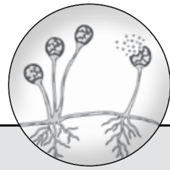
Mineralization—the conversion of organic matter to inorganic minerals (i.e., the creation of minerals/nutrients).

Immobilization—the conversion of inorganic minerals to organic matter (i.e., minerals become incorporated into organic molecules).

Abiotic—nonliving factors such as moisture level, temperature, and soil type.

Symbiont—an organism that is very closely associated with another, usually larger, organism. This larger organism is called a host.

Micrometer (µm)—a useful unit for measuring size in the microbe world. One inch equals 25,400 µm. One cm = 1,000 mm = 10,000 µm.



CHAPTER 2

The World Under a Microscope

Microbes by the Numbers

YOU CAN'T SEE THEM or touch them but microbes exist in vast numbers. It has been suggested that the number of bacteria on earth is 5,000,000,000,000,000,000,000,000,000,000. This is five million trillion trillion, or 5×10^{30}.

To make it easier to understand this large number, consider just one gram of soil. That is the weight of a single paper clip, or the amount of soil under your fingernails after an hour of gardening.

The table of microbes shows some of the most common microbe categories and their respective numbers in one gram of garden soil.

	Size (μm)	Rate of Reproduction	Number/g of soil	biomass (g/m²)
Bacteria	1–10	20 minutes	10^9	40–500
Actinomycete	1–2	varies	10^8	40–500
Fungi	2–10 wide 5–50 long	varies	10^7	100–1,500
Algae	1–2	24 hours–4 weeks	10^6	1–50
Protozoa	10–100	4–8 hours	10^5	> 2,000
Nematode	300–5,000	30 days	10^4	varies
Virus	0.03			
Human hair	40–70			

Microbe Number and Biomass in the top 6 inches of soil, adapted from Hoorman 2010.[2]

It contains a billion bacteria and a million fungi. There can even be more than a thousand nematode worms.

The right-hand column is the biomass (total weight of the organism). You will note that although there are fewer fungi in soil, their mass can actually be larger than that of bacteria. In general, mass equates to biological activity. Organisms with a larger mass eat more, use up more oxygen, produce more CO_2, and have higher amounts of waste. Mass affects the ecosystem more than the number of individual organisms.

These numbers are so large they are hard for us to understand, so this might help: the microbes in one acre of soil weigh the same as two cows.

Microbes Are Important to Plants

Plants can be grown in hydroponic conditions where they are supplied with fertilizer, water, and light. This is a very protected environment where pests and diseases are restricted and closely controlled, but even here plants have microbes on them.

In nature, microbes replace the protected environment of a greenhouse. They cycle nutrients and feed the plants. They improve soil conditions so that water is more readily available, and they protect plants from disease.

You are not just growing plants. You are growing a whole microbial community that in turn helps you take care of the plants.

Plant Growth-Promoting Microorganisms

Plant growth-promoting microbes (PGPM) are organisms that are beneficial to plants. This is a very general definition and as such includes many of the microbes discussed in this book. The benefits include:

- nitrogen fixation
- production of plant hormones such as auxins, gibberellins, and cytokinins
- synthesis of vitamins and antibiotics

- mineral solubilization
- degradation of toxins

An interesting example of PGPM are the 538 yeast strains found under chestnut trees. Seventy-seven of them synthesize indole-3-acetic acid (IAA), with fifteen producing high levels. IAA is the main hormone (an auxin) in plants and it regulates several important processes including growth, cell division, tissue differentiation, apical dominance, and responses to light, gravity, and pathogens. Roots are very sensitive to IAA levels. In addition to helping the trees grow better, the yeast also provides antifungal protection.

Many gardeners have used IBA, a synthetic form of IAA, as a rooting hormone on cuttings.

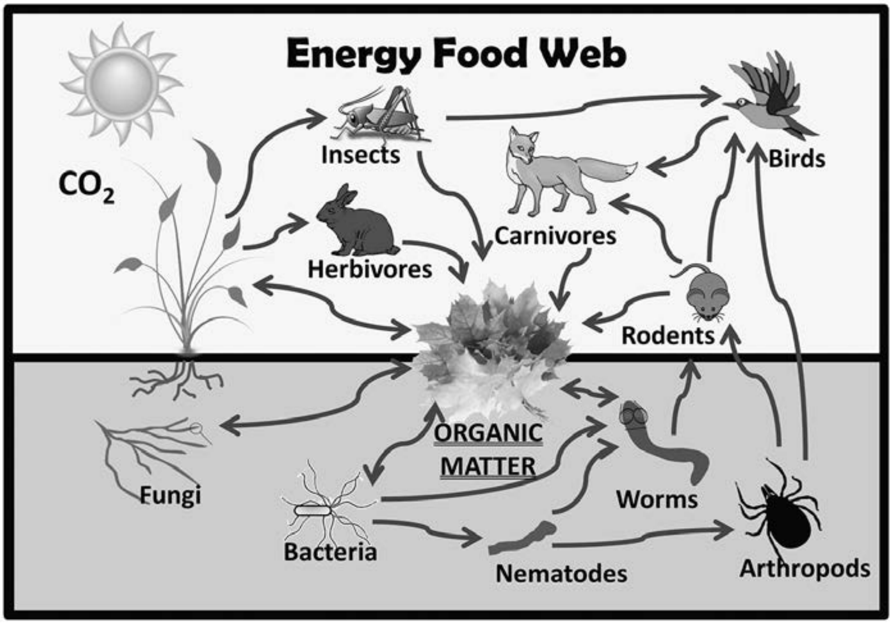
Energy Food Web

All living organisms require a source of energy. The ones that can use the sun as an energy source are called autotrophs, and those that use carbon compounds are called heterotrophs. A few bacteria that get their energy from minerals are also called autotrophs.

Plants, algae, and a few specialized bacteria, such as cyanobacteria, are autotrophs that can produce their own carbon food using photosynthesis. They use the energy of the sun to convert CO_2 from the air into energy-rich compounds containing carbon.

Heterotrophs can't make their own food. They get their energy needs met by eating organisms that contain compounds such as sugars, fats, and carbohydrates. We get our energy from these carbon compounds.

The Energy Food Web diagram shows how carbon moves from plants to most other life forms. Carbon is passed from one to the other as each life form consumes its food. When an organism dies, the organic matter is used by microbes as their energy source and they in turn become the food source for larger heterotrophs. The carbon moves from organism to organism until it again becomes dead organic matter and the cycle repeats all over again. The key point here is that all of the carbon energy originates with the autotrophs: the plants and algae.



If the energy food web continued as I have described it, the amount of organic carbon compounds on earth would be continually increasing, but that is not what happens. As organisms extract the energy out of the food, they produce CO_2 through a process called respiration. Animals get rid of excess CO_2 by breathing it out. Plant roots also respire and expel CO_2. A significant amount of CO_2 is also created during composting as microbes digest the dead organic matter.

The Reality of Composting

When we throw an apple core on the ground it decomposes. If we put the same apple core on a pile, we call it composting. I prefer using the term composting because gardeners are more familiar with it but from a chemical perspective, both processes are identical.

Composting starts with the raw materials. These are normally organic materials that you would easily recognize. An apple core, a banana peel, a dead tomato plant, grass clippings, and some newspaper. You can recognize each of these input materials because they are relatively large.

If you look at these materials on a cellular level, you would see a lot of small details. The stem of the tomato plant has xylem and phloem tubes which are surrounded by epidermis (outer skin). The inside of a leaf has an intricate structure of different layers. Everything is made up of cells, which have their own internal organs.

Now let's look at this more closely on a molecular level. Everything is made out of complex molecules. Big proteins containing thousands of atoms. DNA strands that are huge. Complex starches and oils are made from long chains of atoms.

The difference between a live tomato plant and a newly dead one on a molecular level is zero. There has been virtually no decomposition in that dead tomato plant, and under a microscope it looks just like a live plant.

Now let's jump ahead to the end of the composting process. All of the familiar structures of the plant are gone. The cells have all been broken apart. A lot of the large molecules have been decomposed. Proteins are now small amino acids and some of these have even been converted to free nitrate molecules that plants can use. Large starch molecules are now simple sugars. Plants don't use these sugars, but microbes use them to grow, and in the process release nutrients that plants can use. In short, composting converts all of the large molecules into small molecules that can be used by plants and microbes.

Composting is all about creating an ideal environment for microbes. Supply them with the right temperature, nutrients, moisture, and oxygen and they will do all the work for you. For full details of the process see my book *Compost Science for Gardeners*.

Nutrient Cycling

Nutrient cycling is the process that makes nutrients available to all life forms. Small and large animals get their nutrients by digesting food, but what about organisms that can't eat, such as plants and most microbes? They can only feed on free-floating nutrients, and the decomposition of dead organic matter is the main source of these.

All living organisms require a range of nutrients to survive, but the two most critical nutrients for all life are carbon and nitrogen. Earth has lots of carbon in the form of CO_2, so plant growth is not limited by carbon. However, in order for plants to use CO_2 they need a matching amount of nitrogen, and since nitrogen levels are low, it is nitrogen that limits plant growth. Nitrogen is also the growth limiting nutrient for most animals.

The air we breathe is 80 percent nitrogen gas, but it needs to be converted into other chemical forms before plants or animals can use it. These other forms of nitrogen are made available in soil in a number of ways:

- decomposition of special minerals
- lightning
- decomposition of organic matter
- addition of fertilizer
- nitrogen fixation

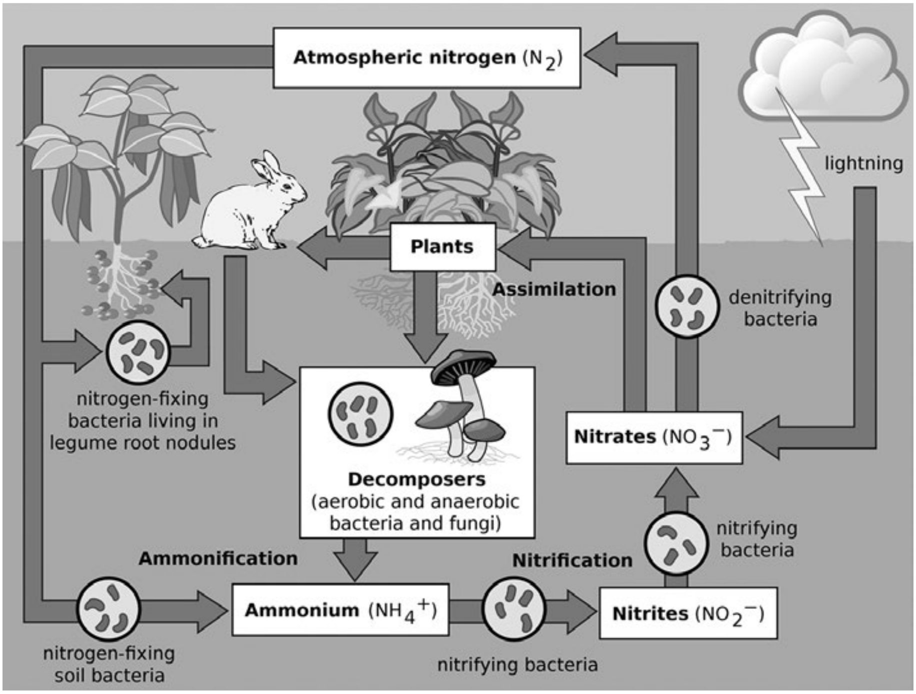
Lightning converts atmospheric nitrogen into nitrogen oxides (NO and NO_2), which can then be converted into ammonium and nitrate ions by microbes. This is an important process, but it is not a significant source of soil nitrogen.

Fertilizer plays an important role in agriculture, but it is of limited value for native plants.

Organic matter is made in a couple of different ways. As organisms die, their bodies become part of soil organic matter and since microbes do not live very long, they contribute a lot of this material. Organisms that eat others produce some type of waste material—animal and microbe poop—and this adds more organic matter. It all goes through a composting process to release nutrients.

A decomposed one-hundred-pound sample of organic matter produces the following:

- 60–80 lb. carbon dioxide, which gets released into the atmosphere
- 3–8 lb. living microbes



Nitrogen Cycle. Credit: commons.wikimedia.org/wiki/File:Nitrogen_Cycle_2.svg

- 3–8 lb. dead microbes
- 10–30 lb. humus

Organic matter is mostly carbon and oxygen with some hydrogen and nitrogen and very small amounts of phosphorus and sulfur. The amount of other nutrients is even smaller.

Carbon-to-Nitrogen Ratio of Microbes

If you have done some composting, you will know that the right carbon-to-nitrogen (C:N) ratio speeds up the process. The reason for this is that the bacteria and fungi doing the composting need a particular C:N ratio to live, and this is true of all life forms.

The ideal starting C:N ratio for compost is 30:1, thirty times as much carbon as nitrogen. As CO_2 is released during the composting process the ratio falls to 20:1, which is ideal for the microbes.

Each type of organism has a required internal C:N ratio based on their biochemistry. Bacteria tend to be around 5:1 (range of 3:1 to 10:1). Fungi are around 10:1, with protozoa and nematodes having a ratio of 8:1.

The fact that bacteria have a low carbon-to-nitrogen ratio is critical to nutrient cycling and plant growth. When protozoa and nematodes eat bacteria, they consume too much nitrogen relative to the carbon. The excess is excreted as ammonium and nitrate, which can be used by plants and other bacteria.

Building Healthy Soil

As a gardener, you probably dream about black gold—that really nice black crumbly soil. It is great garden soil because it drains well, contains lots of air, and it has many larger channels that are

Microbe Myth: Sterile Soil Exists

Lots of people talk about sterile soil either purchased in a bag or heat treated in the oven. Sellers even put the word "sterile" on their product. The reality is that gardeners never have sterile soil.

Bagged soil may be heat treated to kill pathogens and weed seeds, but the product is not packed using sterile conditions.

You can try to sterilize soil in an oven, but you need a temperature of 212°F (100°C) for thirty minutes to do that. Some people try to use temperatures higher than this, but that can cause soil to become phytotoxic due to soluble salts, such as manganese.

Once soil is sterile, it is impossible for a gardener to keep it sterile. As soon as you open the bag or take it out of the oven, microbes settle on the soil. The plant pot you use is not sterile, nor are your hands or the plant you are potting up.

Is it important to have sterile soil? It will become clear from this book that plants grow better in nonsterile soil. There is no point in trying to sterilize soil, except maybe to kill weed seeds, and that is not a big issue for potted plants.[3]

perfect for root growth. This type of soil is due to a process known as aggregation where sand, silt, and clay are cemented together into larger clumps known as aggregates. This process is described fully in *Soil Science for Gardeners.*

What causes soil aggregation? There are a number of factors, but microbes play a key role. They produce chemical slimes that help stick soil particles together. Soil with more microbes has better aggregation and better nutrient cycling. Microbes are the key to healthy soil.

Microbes Can Harm Plants

So far, I have painted a very rosy picture about microbes and how they help plants, but as all gardeners know, they can also cause diseases that harm plants.

Plants are stationary and are prone to any pathogen that happens to land on them or bump into their root system. They do have an innate immune system that helps defend against some attacks, but this is not their entire defense mechanism.

A big part of their defense is provided by the beneficial and neutral microbes that cover them. These form a protective shield around the plant, both above and below ground. Some of these microbes are known to antagonize pathogens, and others produce substances that are toxic to specific pathogens. Most of these microbes are just taking up valuable space and resources so that pathogens can't gain access to the plant.

From a gardener's perspective, it might appear as if healthy plants suddenly get a disease. Roses get black spot or a lilac gets powdery mildew. And who can forget the late blight that killed all of your tomatoes last year. The reality is that these pathogens have been on the plant long before you saw any symptoms.

Initially, a pathogen invasion doesn't do much damage and the plant can deal with it. You won't even see a problem. In some cases, a point is reached where the fight between plant and pathogen swings in favor of the pathogen. It then grows and multiplies and symptoms start to appear.

Microbe Myth: Don't Compost Infected Plant Material

Gardeners hate diseases and they will do just about anything to prevent them. Common advice tells you not to compost infected plant material. Instead, remove leaves that show any powdery mildew or black spots and discard them in the garbage. Maple trees get a common disease called tar spots (round black spots), and gardeners are warned not to compost these leaves for fear of spreading the disease.

This sounds like good advice, but in most cases, it's not.

As you learn more about microbes, you will realize that they are everywhere and they travel long distances using air currents. By the time you see white mildew or black spots, the pathogen is everywhere. It's on all the green healthy leaves, the bark, and the ground. Removing a few leaves that show the symptoms will make no difference.

There is also no issue with composting these leaves. The fungal spores are already all over the compost pile and the garden soil so you might as well get some value from the leaves. By fall, every leaf in the garden has some kind of pathogen growing on them. Even discarding every single leaf will have a limited effect on disease next year. Unless everyone in town collects all the leaves with tar spots on them and discards them properly, you will have tar spots next year. They are unsightly but do little harm to the plant.

There are exceptions to this rule, and that is the reason it is important to understand the disease you are dealing with. Viruses are very deadly, and infected plants should be removed and put in the garbage.

Black knot fungus affects mostly Prunus plants (plums, cherries, etc.) and forms black growths on the branches. These growths release spores in early spring. If you remove and discard the growth before then, you will have fewer outbreaks of the disease. The wood from some very contagious diseases such as verticillium wilt in trees should also be discarded.

The key is to identify the problem, understand the problem, and then take appropriate action.

Powdery mildew is a good example of this. Its spores are everywhere, even early in the season. It does very little to the plant until conditions are right, and then it starts to grow. Gardeners usually don't spot it until it is quite far along its development cycle. It is important for gardeners to understand this when they are thinking about treatments and especially preventative options. By the time you see it, it is probably too late.

Gardeners Affect Microbes

A lot of what microbes do happens without much involvement on your part, but you can have a direct impact on them. You can make them happy and prosper, or you can make their life difficult and even kill them. Here are some dos and don'ts for the garden.

Compaction

Most microbes have a similar biochemistry to that of animals and in particular they need to have access to oxygen. The oxygen in soil is supplied by the air that fills the channels between soil particles. Ideal soil has about 25 percent air, which provides plenty of oxygen and more importantly provides a way to dilute the buildup of CO_2.

Compaction reduces the size of the air channels, squeezes air out, reduces oxygen levels, and increases CO_2 levels.

Tilling

Small microbes such as bacteria are not affected very much by tilling, but the larger fungal hyphae are physically damaged.

There are also chemical effects. Tilling introduces more oxygen into the upper soil layer, which in turn speeds up the decomposition of organic matter. In the past this was considered to be a negative effect on soil health, but recent studies have shown that although carbon levels do drop in the top six inches of soil, they actually increase below that level. Tilling does not change the total amount of organic matter in soil. Since most soil microbes live in the top few inches of soil, tilling does decrease populations in the topsoil.

Spraying Pesticides

Spraying pesticides on soil can harm the microbe community, although it is important to understand that every chemical will have a different effect. It is quite incorrect to lump all synthetic chemicals into one group and say they all harm microbes.

For example, glyphosate, the active ingredient in Roundup, has very little effect. When sprayed on soil, it sticks very tightly and is mostly unavailable. We now know that certain microbes use glyphosate as a food source, and decompose it into benign compounds. That explains its short half-life in soil.

Other pesticides persist in soil and we don't really understand how many of these affect microbe populations, but it is almost certain that some will be harmful.

What happens when you spray a pesticide onto leaves? Leaves are covered with microbes that protect the plant from pathogens. Does the pesticide harm these communities? We actually know very little about this for most products.

A few studies have looked at this, and in general it seems that most chemicals will disrupt the microbe community on leaves. Some are harmed, but others seem to prosper. What is clear is that the natural community is affected and any such change may lead to increased disease.

So far I have been talking about synthetic pesticides, but everything I have said also applies to household products. When you spray your dish soap solution on leaves, it appears to do very little damage, but that is because you can't see the microbes and the changes don't happen right away. Soap or any other so-called safe products will affect the microbe community and can lead to a higher level of disease.

Soil Moisture

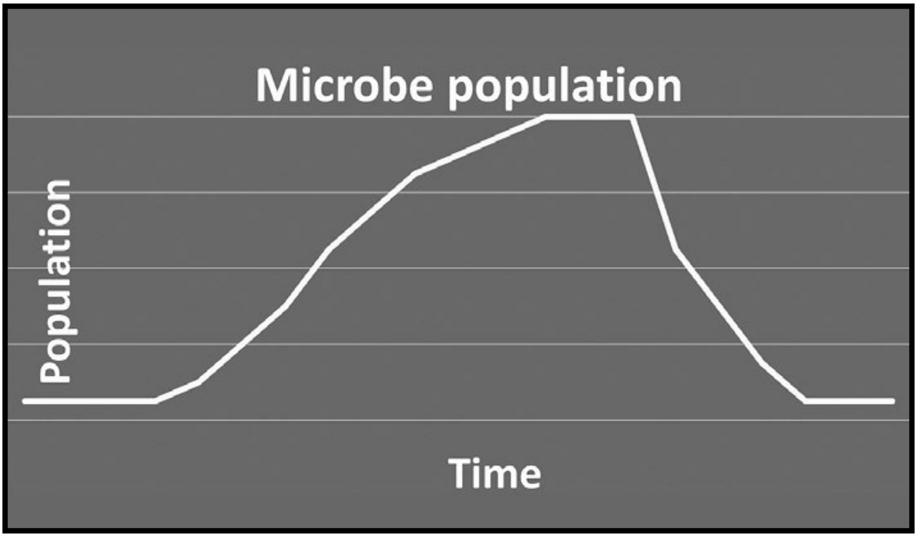
Almost all of the soil microbes in this book live in the soil water. They need moisture to stay hydrated, and many travel along with the water as it moves through the soil. As the soil dries out, they either die or go into a type of hibernation state known as dormancy. Maintaining a good moisture level is critical for keeping microbial populations healthy.

Microbe Food

Microbes need to eat, and their favorite food is organic matter. They eat each other and they eat dead and decomposing matter. Some can engulf whole organisms, but most just excrete enzymes that digest nearby material so it can be absorbed. Added mulch, an annual layer of compost, and even fall leaves provide food for your microbes.

Some gardeners think they can increase microbe populations by adding "magical" products such as molasses, which is mostly sugar that microbes love. The problem is that it does not last very long. When molasses is added to soil, the food resource suddenly increases, which causes a population explosion. Soon the sugar runs out and microbes start dying. The dead become food for the living, at least for a while. Soon the food runs out and the population returns back to the level that existed before the molasses was added.

This does provide some minor benefit to soil, but it's quite small. It is much better to add other forms of organic matter that take months or even years to decompose and the best of these is



Change in microbe population after adding molasses or other sugar sources.

compost. Which compost is best? This video will explain that to you: https://youtu.be/aONjPeJ-2vM

How Do Microbes Move Around?

Some microbes have appendages that can drive them forward, but most rely on other forces for this such as moving water, air currents, insects, and even gardeners moving soil and plants around. Many fungi form small, lightweight spores that travel great distances on air currents. The molds and powdery mildews can travel many miles to get to your garden.

A lot of pathogens use insects as carriers. Aphids carry all kinds of diseases from plant to plant. Malaria is caused by microorganisms that belong to the genus *Plasmodium* and are moved from host to host by mosquitoes. Many microbes are sticky and become stuck to anything larger that moves: mammals, birds, insects, and even earthworms.

You might think that earthworms like eating organic matter, but the real reason they chomp down on leaves and other debris is to ingest microbes—their favorite food. Microbes also live in their gut and help with the digestion process. What comes out of the end of the worm is a pile of partially digested organic matter and a whole lot of microbes that have just been transported from one place to another.

Some bacteria have flagella, which are a kind of propeller that spins around and moves the organism forward. Others use whips and hairs to propel them.

How do they know where they are going? Some just move in random directions, hoping they go the right way, but many follow chemical signals similar to the way a dog follows a scent.

Bacteria don't have a real body odor, but they release metabolites that do have a scent, and they have a sense of smell. They can detect the smell of ammonia, an important source of nitrogen. This sense of smell has also been detected in fungi and slime molds.

Bacteria can sense nutrients, and will move toward them. Fungi are attracted to chemicals produced by plant roots. Pathogens can "smell" their prey. Movement can be quite deliberate either toward a scent or away from it.