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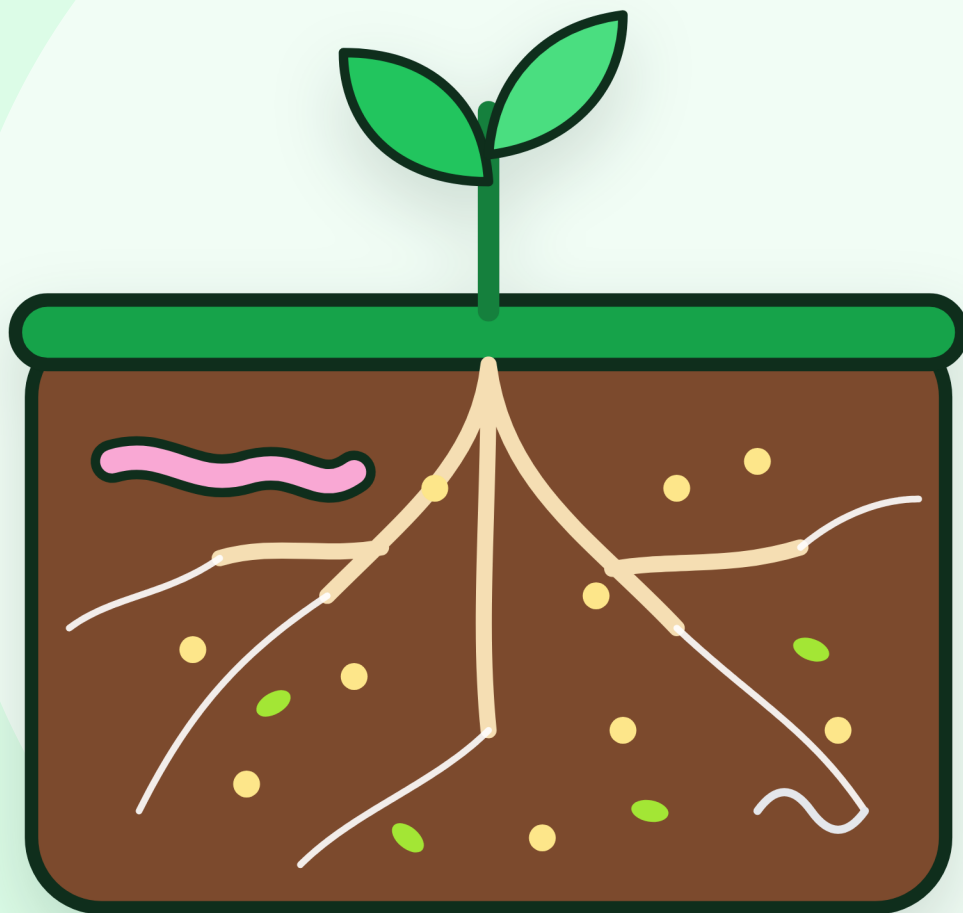
FREE SAMPLE

Part 1 of Grow Like a God

What is the soil food web, and who really feeds your plants?



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tonight*



Free Sample: Part 1 of Grow Like a God

What is the soil food web, and who really feeds your plants?

BY MAX SIDOROV

INSIDE THIS GUIDE

Why a “Web” and Not a “Chain”?	3
A Beautiful World Underground	3
Invisible Life	4
The Journey of Organic Matter: From Leaf to Humus	5
From Bare Ground to Ancient Forest: The Four Stages of Soil Life	7
Who Really Feeds the Plant	11
Why Grasses Have Bacteria and Trees Have Fungi	15
Notes	19

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Pick up a pinch of healthy garden soil, about the size of a coin. What do you see? Dark, crumbly earth that smells like a forest after rain. Now look at it under a microscope. That one pinch can hold hundreds of millions of bacteria, even a billion, plus thousands of other tiny creatures.¹ Fungi, protozoa, rotifers, nematodes, microarthropods and, if you're lucky, a tiny enchytraeid (a potworm, a small white cousin of the earthworm). And they don't just live side by side. They're connected. They eat, make, release, build and protect.

This is the **soil food web**.

● Why a “Web” and Not a “Chain”?

In school we learn about food chains: “The grasshopper eats the grass, and the bird eats the grasshopper.” Underground, things are messier. There's no neat line that runs from A to Z.

The soil food web is more like the internet. Each point links to many others, and everything is connected. So connected that we, the top predators at the peak of the food pyramid, depend on single-celled bacteria living somewhere in the ground. The bacteria have no idea they're helping us. They just like the sugar from the roots. But they are the hidden cushion that all life above ground rests on.

There's no top and no bottom in this web. Carbon and nutrients travel along countless paths, from root to microbe to predator and back to the root.

Think of the soil less as a bag of chemicals and more as the digestive system of the land. Once you see it that way, you're already halfway to understanding it.

● A Beautiful World Underground

The soil has plenty of heroes besides bacteria and fungi. Let's sort them into three groups. But remember: none of them works alone. They all depend on one another.

Group One: Decomposers and Miners

Bacteria are the speed champions. Near busy roots, a bacterial population can renew itself in less than a day.² They pull the nutrients they need out of the soil by breaking down rock particles and dead organic matter.

Fungi are masters at breaking down tough materials such as cellulose, lignin (the woody part of plants) and chitin, and at freeing up nutrients.³ Their white threads, called hyphae, run through the soil and bind crumbs of soil together into clumps called aggregates.⁴ In healthy soil, these threads can add up to tens of meters in a single gram.⁵

Group Two: Predators and Grazers

These are the **protozoa** (single-celled hunters such as amoebae, flagellates and ciliates) and the **nematodes** (tiny worms, most too small to see). They can't eat root exudates, the sugars and other compounds that roots leak into the soil. Instead, they hunt bacteria and fungi. When a protozoan eats a bacterium, it releases the extra nitrogen as ammonium (NH_4^+), a form plants can take up through their roots.^{6,7} Without these predators, much of that nitrogen would stay locked inside the bacteria.

Group Three: The Engineers

Earthworms and **enchytraeids**. They swallow soil along with its bacteria, fungi and bits of organic matter. Their gut secretions bring the soil closer to neutral pH as it passes through,⁸ and their castings come out packed with microbes, which speeds up the release of nutrients that plants can use.⁹ You could call earthworms the digestive tract of the soil.

● Invisible Life

How Many Are Down There? (Numbers That Take Your Breath Away)

In **healthy, living soil** (forest soil, say, or an old field left to rest), here are the numbers:

- **Bacteria:** One gram of soil (roughly a teaspoon) holds **100 million to 1 billion** bacteria.¹ At the high end, that's more than the number of people in the United States and Canada put together, in a single spoonful.
- **Fungi:** The fungal threads in that same gram can stretch **tens of meters**.⁵ Add up all the threads under one hectare, and they could circle the Earth at the equator many times over!

Bottom line: The fungi alone on our planet outweigh all the animals several times over.¹⁰ Much of that life is under your feet. It isn't just "dirt." It's the digestive system of all the land on Earth.

Organism	Number in 1 gram
Bacteria	100 million – 1 billion ¹
Fungal threads (hyphae)	tens of meters or more ⁵
Protozoa (amoebae, flagellates)	up to 1 million ¹¹
Nematodes	up to 100 in farm soil, several hundred in forest soil ¹²
Rotifers and other microscopic animals	up to about 40 in the top layer of forest soil ¹³

Now multiply that by the number of grams in your garden bed. In the top layer of soil (15–20 cm, or 6–8 in) on one hectare (2.5 acres):

- **Bacteria:** about 2 tonnes of living bacteria (roughly a ton per acre, about the weight of two cows).¹⁴

- **Fungal threads:** The top 15 cm (6 in) of a hectare weighs roughly 2,000 tonnes. So even at just 1 meter of thread per gram, the threads laid end to end would run about 2 million kilometers. That's about 50 times around the equator. In rich soils with tens of meters per gram, it's hundreds of times.⁵

In one hectare of healthy soil, there are enough fungal threads to wrap around the Earth at the equator again and again.

And that's not counting the worms, insects, mites and millipedes. One square meter (11 sq ft) of good soil can hold **up to 200 earthworms or more**.¹⁵ Together, a healthy worm population can pass the whole top 15 cm (6 in) of soil through their bodies in 10 to 20 years.¹⁶

All of this is an army that works 24/7, with no paycheck, no days off and no breakdowns.

We Know Only a Tiny Fraction

Here's the catch. Classic microbiology grows bacteria in Petri dishes, but most soil bacteria simply won't grow in the lab.¹⁷ Scientists estimate that less than 1% of the microbes seen under the microscope in soil have ever been grown and studied.¹⁸ With the classic methods, we only ever meet the small part of this world that adapts easily to lab life.

This idea is key to understanding the soil food web. We're trying to understand a hugely complex system while seeing only the tip of the iceberg. The bacteria that can't be grown in the lab make up this hidden mass. They do vital but poorly understood jobs: they break down organic matter, build soil structure and work with plants. Once you realize how little our old tools could see, the focus shifts. Counting species matters less than understanding how they work together.

This hidden majority keeps the system in balance. New DNA-based methods are opening up a whole unexplored world. One early study found about 4,000 different kinds of bacteria in a single soil sample.¹⁹

But let's stop for a minute and take in just how much we don't know.

How much is still a mystery? Imagine how many hundreds of thousands of kinds of bacteria and fungi live beneath our feet, unnamed and unstudied, yet doing work the whole planet relies on.

We're standing at the door of a "black box" that hides the factory of life. And here lies the central conflict of our time. Harsh chemical farming works on the idea of "wipe out everything that lives" and treats soil as a dead growing medium. We take a different path. Our mission is not to destroy but to bring back to life. By feeding these unknown but vital bacteria and fungi, and by rebuilding the links of the soil food web, we can bring about a real change. We can grow food that is truly alive.

This isn't just farming. It's a return to the roots of our existence.

• The Journey of Organic Matter: From Leaf to Humus

Organic matter gets into the soil in many ways: fallen leaves, dead roots, grass clippings, manure, compost, straw, root exudates, and the dead bodies of microbes and worms. Along the way it passes through several stages, and each one matters for fertility.

First Stop: Fresh Residues

It all starts with things you can recognize. A leaf is a leaf. Grass is grass. A root is a root. They still have their shape and color. They hold sugars, starch, proteins, cellulose and water, everything microbes love most.

This is the easiest, fastest food for soil life. Bacteria and fungi pounce on it. They tear molecules apart, release energy, use it to build their own bodies, multiply, die, and get broken down in turn. At this point, the soil is having a real feast.

Fresh organic material is like a hot lunch for the soil. It arrives, it gets eaten, and it gives energy to the whole system.

This stage lasts from a few days to a few months. It depends on moisture, temperature, oxygen, what the residues are made of and how active the microbes are.

Second Stage: Organic Matter After the First Breakdown

Once the easiest, tastiest parts are gone, what's left is the stuff that didn't break down right away. It's a coarser, tougher mass: cell walls, lignin, waxes, tannins, chitin from dead fungi, and the remains of microbes.

By now it no longer looks like a leaf or a bit of straw. It turns shapeless and dark brown. It still holds a lot of energy, but that energy is hard to get at.

This is where a new cast takes the stage: the specialists in tough compounds. Fungi (especially the mushroom-forming group called basidiomycetes), actinomycetes (thread-forming bacteria that give soil its earthy smell) and slow-growing bacteria. They're in no hurry. Their job is to patiently chew through the toughest molecules and free up what the first eaters left behind.³

This isn't lunch anymore. It's digesting the toughest stuff. The work is hard and slow, but without it the next stage can't happen.

Third Stage: The Birth of Humus

Humus is the finish line. It's what the whole process was for.

Humus is organic matter that has been through the furnace of microbial processing and come out tough and long-lasting.

For a long time, scientists thought humus was a special kind of giant, nearly eternal molecule. Newer research shows it isn't. Humus is the most broken-down, most processed part of soil organic matter, and it still breaks down, just slowly. What makes it last for decades or even centuries is protection: it sticks to clay and mineral particles and hides inside soil crumbs where microbes can't easily reach it.^{20,21} Along the way it glues soil particles into crumbs, holds water, binds minerals, feeds plants and stores carbon.

Humus smells like earth. It's black, soft and crumbly. Under a microscope it looks like a sponge: a huge inner surface that holds on to water and nutrients like a magnet.

Most important of all, humus is a reserve. A reserve of carbon, of life, of future harvests. Soil rich in humus can bounce back on its own. Soil without it is fragile, and fertilizer alone can't make up for what's missing.

A Conveyor Belt You Must Never Stop

These three stages aren't separate events. They're one continuous conveyor belt.



Organic matter enters the soil all the time. As long as it keeps coming, all three stages run at once. In one spot things are just starting to break down. In another the tough stuff is being digested. Somewhere else humus is building up.

But the conveyor can break. Stop adding organic matter, and the food runs out, the microbes dwindle and the process grinds to a halt. Cut off the air, and the first stage slows down, the second never starts and humus stops forming. Add chemicals that kill microbes, and you cut every thread at once.

Soil fertility is the speed at which organic material turns into humus. The faster and better this process runs, the stronger and healthier your land will be.

What This Means for You

Understanding this journey is the key to managing your soil.

- **You can't make humus directly.** All you can do is supply the raw materials and set up the conditions for nature to make it.
- **The more varied the organic residues,** the more balanced the diet for the whole web.
- **The longer organic matter stays on the surface or in the top layer,** the more naturally it breaks down.
- **The less you disturb the soil,** the more smoothly all three stages work together.

Your role isn't that of a plowman, a chemist or a gardener in the old sense. Your role is that of a **conductor**. You set up the conditions, set the rhythm and supply the materials. The heavy lifting is done by soil life.

• From Bare Ground to Ancient Forest: The Four Stages of Soil Life

When you look at an abandoned field overgrown with orache (a weedy relative of spinach), dandelions and quackgrass, you may see a "mess." Nature sees an **orderly sequence**. Nature hates empty space. Each step prepares the soil for the next one.

This is called **succession**, the natural process by which land heals itself. Once you understand it, you'll stop fighting "weeds" and start working with them as allies.

A note on the numbers below. The fungal-to-bacterial ratio (F:B ratio) compares the weight of fungi in the soil to the weight of bacteria. Soil labs measure some of these ratios, but most of the stage-by-stage values below come from the soil food web model taught by soil biologist Dr. Elaine Ingham. Treat them as a

rough guide, not exact targets. Real soils vary a lot. Field studies do back up the overall direction: on bare ground left behind by a retreating glacier in Washington State, the soil community shifted from bacteria-dominated to fungus-dominated as plants moved in over the decades.²²

Stage 1. The Bacterial Field. Bare Ground and the First Settlers

On bare, disturbed ground, whether it's a plowed field, an empty lot after construction or bare clay, there's very little life. There's almost no organic matter, no humus, and fungi have little to live on.

The first plants that can survive here are **weeds and other annuals**. They live fast, so they can grow and set seed while the soil is still poor. Many of them lean mostly on bacteria.

The F:B ratio at this stage: **about 0.1 : 1 or lower** (in other words, ten or more times as many bacteria as fungi, by weight).

Who arrives first? Bacteria and annual "weeds."

- Bacteria are the toughest. They don't need complex organic matter. They can live on the simple sugars that plant roots release.
- Annuals (orache, chickweed, dandelion, wild mustard) sprout in no time. Their roots are shallow, but they release sugars into the soil and feed the bacteria.

What happens at this stage:

- Bacteria multiply and start breaking down whatever is there.
- Grass roots loosen the top layer, opening the first channels for water and air.
- Plants die back, leaving organic matter on the surface.

This isn't "fertility" yet. This is "starting the engine."

Stage 2. Organic Matter Builds Up. Humus and Worms

Every year the plants die and fall to the ground. Bacteria and worms eat them. The organic matter slowly turns into **humus**, the dark, long-lasting material that holds moisture and feeds the soil.

Little by little, the plants live longer. **Perennial grasses** move in. They need slightly more stable soil. The F:B ratio rises to **about 0.5 : 1 to 1 : 1** (bacteria and fungi are now nearly equal).

Then come **crops** (corn, sunflowers, tomatoes and so on). Productive farm soils run at about **1 : 1** or a little lower.²³

Who arrives: Earthworms, millipedes and the first saprophytic fungi (fungi that feed on dead material).

What happens:

- Humus builds up, and the soil darkens.
- Structure appears: the soil turns crumbly and full of pores.
- Moisture lasts longer.
- Perennial grasses take over, and they grow more roots.

This is the “building up savings” stage. Organic matter turns into fertility.

Stage 3. The Fungi Arrive. Shrubs Appear

Fungal spores are present in almost every soil. But fungi need food and peace to thrive. Once there's enough coarse organic matter and the soil is left undisturbed, they finally take hold. Fungi aren't “invaders.” They come in to handle the last, toughest stage of processing.

Who arrives: Saprophytic fungi, which break down coarse material (branches, stems, the roots of perennials), and more mycorrhizal fungi (fungi that partner with living roots).

Shrubs need more soil structure and more fungi to bind soil crumbs together and gather phosphorus.

F:B ratio: roughly **5 : 1 – 10 : 1** in the soil food web model.

What happens:

- Fungal threads run through the top layer, binding soil particles together.
- Shrubs appear: currants, viburnum, serviceberry, hazel. Their roots partner with fungi.
- The soil stops drying out, and annual weeds give way to perennials.

This is a transition stage. Bacteria and fungi start working together, and the soil becomes “alive” in the full sense of the word.

Stage 4. Forest. A Fungal Ecosystem

When enough humus has built up and the shrubs have made shade and a sheltered microclimate, the trees arrive. Apples, pears, oaks, nut trees. Under trees, the soil needs to be loose, moist and well structured.

Who arrives: Mycorrhizal fungi that live in partnership with tree roots.

F:B ratio: In broadleaf forests (oak, maple, beech), about **5 : 1 – 10 : 1**. In conifer forests (pine, spruce, fir), **100 : 1 or more**.²⁴

And finally, **old conifer forest** that hasn't been touched for hundreds of years. Here the fungal-to-bacterial ratio can reach **1000 : 1**.²⁵ The soil under a forest like that is full of fungal threads, with bacteria scattered through it.

What happens:

- The fungal network becomes the backbone of the whole food supply.
- Trees feed the fungi sugars, and the fungi supply the trees with phosphorus, water and micronutrients.²⁶
- The soil becomes a stable, self-renewing system.
- The forest needs no help from us. It feeds and protects itself.

This is the finale. A forest is one of the most resilient forms of life on land.

Weeds are not the enemy. They're the first construction crew to show up on an empty lot. They make organic matter. Next come the worms, which turn that organic matter into humus. Then the fungi arrive and tie everything together into one web. Only then come the trees, at the top of this pyramid. If you plant

an apple tree in bare clay, you're skipping three stages. If you work with nature, you're simply speeding up its own process. Don't fight weeds. Use them as a tool. They're your allies on the road to the forest.

Why Is That?

Because **fungi build soil**. Their threads run through the ground, glue particles into crumbs and create pores for air and water.²⁷ Fungi break down tough organic matter: lignin (in bark and wood) and cellulose.²⁸ Without fungi, the forest would drown in its own fallen leaves and wood.

Bacteria are the fast-moving army. They work best on simple sugars. Weeds release simple sugars, so they suit fast bacteria. An oak releases more complex compounds, so it suits slow, powerful fungi.

Succession table (F:B ratio, rough guide)

Ecosystem stage	Examples	Fungi : bacteria ratio
Bare ground / disturbed soil	After construction, plowing, fire	0.01 – 0.1 : 1
Early annuals	Orache, chickweed, shepherd's purse	0.1 – 0.3 : 1
Grasses and perennial grasses	Quackgrass, fescue, clover (early on)	0.5 – 1 : 1
Row crops	Corn, sunflowers, tomatoes	about 1 : 1 ²³
Shrubs	Currants, raspberries, wild roses	5 – 10 : 1
Young trees	Birch, aspen, willow (broadleaf)	about 5 – 10 : 1 ²⁹
Mature trees	Oak, beech (broadleaf); pine (conifer)	5 – 10 : 1 broadleaf; 100 : 1 or more conifer ²⁴
Old growth	Old conifer forest, 200+ years	100 – 1000 : 1 ²⁵

What This Means for Gardeners and Farmers

Everything.

- If you plant **tomatoes** in soil with an old-forest ratio (1000:1 in favor of fungi), they'll grow poorly. They need more bacteria. The soil is too "fungal."
- If you plant **blueberries** (a woodland berry that likes fungal soil) in a freshly tilled bed with a 0.1:1 ratio (bacteria in charge), they'll struggle. They need fungi.³⁰
- If you dig or till the ground under an apple tree, you tear up the fungal threads and push the soil back toward bacteria.³¹ Apple trees don't like that. That's why many organic orchards avoid tilling.

How can you tell?

You can send a soil sample to a lab that checks soil life under a microscope. Or you can look at what's growing. Gardeners have long read weeds as clues. Treat them as hints, not proof: one or two weed species don't diagnose a soil on their own, but a whole patch of plants that like the same conditions tells you more.³² In the author's experience:

If your plot has orache and chickweed, you likely have bacterial soil (early succession).

If it has nettles and goutweed, it's likely in transition.

If it has horsetail and sorrel, the structure is probably poor and there are few fungi.

If it has moss and wood sorrel, it's closer to forest soil, more fungal.

The Irony of Modern Farming

Decades of plowing, herbicides and heavy synthetic fertilizer push many fields toward a **bacterial state**, with few fungi left.^{31,33,34} Yet most farm crops, corn and wheat included, rely on partnerships with mycorrhizal fungi.³⁵ Then farmers wonder why they need so much fertilizer.

Fungi aren't being put back. And without fungi you lose soil structure, a big share of the plant's phosphorus supply and stored carbon in the soil.

Fertilizer alone won't fix that. Those fields need their fungi back. The good news is that fungi start returning quickly: in a Dutch study of 26 former farm fields, fungal biomass rose within the first two years after cultivation stopped.³⁶

● Who Really Feeds the Plant

For a long time we thought of the plant as a self-made provider. A root reaches down, finds a bit of clay or sand, sucks the minerals out of it, and that's that.

That's what the textbooks said. That's what we learned in school. But it's only a small part of the story.

Three Great Discoveries

1. The fungus-root (mycorrhiza): discovered in 1885

German biologist **Albert Bernhard Frank** was studying tree roots. He noticed something strange: the roots were wrapped so tightly in fungal threads that you couldn't tell where the root ended and the fungus began.

Frank coined the word "**mycorrhiza**" (from the Greek *mykes*, fungus, and *rhiza*, root).³⁷ He proposed that this was no accident but a partnership that helps both sides: the fungus helps the root get water and minerals, and the root pays in sugar.

At first, much of the scientific world opposed him.³⁸ How could a fungus help a tree? Fungi were known for rotting things and living as parasites!

Frank died in 1900, long before his idea was fully accepted.³⁹ Over the following century, researchers found that most land plants, roughly 80% of plant species or more, form mycorrhizas. That includes nearly all trees and most grasses, crops and shrubs.⁴⁰

Today we know forests as we see them depend heavily on mycorrhizal fungi. The fungi gather phosphorus from places roots can't reach and pass it to the tree in exchange for sugar.²⁶ One major review estimated that these fungi, together with nitrogen-fixing bacteria, supply up to 75% of the phosphorus plants take up each year, and in temperate and northern forests up to 80% of their nitrogen.⁴¹

2. Nitrogen-fixing bacteria: discovered in 1888

In 1886–88, German scientists **Hermann Hellriegel** and **Hermann Wilfarth** showed that legumes with root nodules take nitrogen from the air, and that they need something living in the soil to do it.⁴² Then, in 1888, Dutch microbiologist **Martinus Beijerinck** isolated the bacteria from legume root nodules. These bacteria do something remarkable: they turn nitrogen gas from the air (N_2) into ammonia (NH_3), which the plant can use.⁴³

Before this work, people thought legumes somehow enriched the soil on their own. Hellriegel and Wilfarth showed it took a living partner, and Beijerinck found it: bacteria. He named them *Bacillus radicicola* (“dweller in the root”). A year later, Frank gave the group the name we still use, *Rhizobium*.⁴⁴

Today a whole genus of bacteria, *Beijerinckia*, carries Beijerinck’s name.

3. The plant pays in sugar: proven in the 1950s–80s

Researchers such as the Swedish scientists **Melin** and **Nilsson**, the British ecologist **David Read** and their colleagues showed, in a series of clever tracer experiments, what Frank had suspected all along. British botanist **Jack Harley**, who co-wrote the standard textbook *Mycorrhizal Symbiosis* with Sally Smith in 1983, helped pull the evidence together.

- In 1953, Melin and Nilsson fed a nitrogen compound carrying a traceable label to a fungus. The label turned up inside the pine seedlings the fungus was attached to. Nutrients really were flowing from fungus to tree.⁴⁵
- Later, plants were given carbon dioxide with radioactive carbon (C^{14}). The labeled sugar moved down into the roots and then out into the fungal threads.⁴⁶
- In 1984, Read’s team showed that this labeled carbon could even travel through the fungal network from one plant to another.⁴⁷

The circle was complete. The plant feeds the microbes sugar. The microbes help feed the plant minerals.⁴⁸

The most striking part is how much the root relies on its partners. Roots do some mining of their own. They release acids and enzymes and change the pH right around them, and grasses even make their own iron-grabbing compounds.^{49,50} But on their own, roots mostly take up water and nutrients that are already dissolved and ready to use, a bit like a drinking straw. Fungal threads and microbes reach much farther and unlock much more.

So who does most of the mining?

Bacteria and Fungi.

They’re the main miners of the underground world. They release acids, enzymes and special molecules (siderophores, “iron hooks”) that pry nutrients out of clay, sand and rock.⁵⁰

- nitrogen (from the air and from organic matter)
- phosphorus
- potassium

- calcium
- magnesium
- iron
- sulfur
- and a dozen more micronutrients

Without bacteria and fungi, much of these minerals would stay locked inside rock crystals for a very long time.

So what does the plant do?

The plant does what bacteria can't: it catches sunlight and turns it into sugar.

And that sugar is the paycheck bacteria and fungi earn for mining the periodic table for the plant. Grain crops send 20–30% of the carbon they capture below ground, and pasture grasses 30–50%.⁵¹ Much of that builds and runs the roots themselves. But a real share leaks out into the soil to feed microbes. Not because plants are generous. Because otherwise the bacteria and fungi won't come. Once they've moved in around the roots, they live on that sugar and gather what the plant needs, in a kind and beautiful partnership.

A simple list: who mines what

Nutrient	Who mines it for the plant
Nitrogen (N)	Bacteria (nitrogen fixers, ammonifiers)
Phosphorus (P)	Mycorrhizal fungi and special bacteria (phosphate mobilizers)
Potassium (K)	Bacteria (potassium mobilizers) ⁵²
Calcium (Ca)	Fungi (hyphae leach it out of particles) ⁵³
Magnesium (Mg)	Bacteria and fungi (break down crystals)
Iron (Fe)	Bacteria (release siderophores, "iron hooks")
Sulfur (S)	Sulfur bacteria
Copper, zinc, manganese	Fungi and bacteria (crack open minerals)

What Can the Plant Do on Its Own?

Less than you might think. On its own, a plant can:

- 1. Drink water** and the nutrients already dissolved in it. Yes, roots can do that.
- 2. Catch carbon dioxide.** Through its leaves, with the help of the sun.
- 3. Make sugar.** That's photosynthesis.
- 4. Get a little nitrogen from the air.** But only if it's a legume, and even then only with the help of bacteria living in the nodules on its roots.

For almost everything else, it leans heavily on bacteria and fungi.

Every Plant Has Its Own Team

This is where it gets beautiful.

Each plant species gathers its own particular mix of bacteria and fungi around its roots.⁵⁴ The tomato strikes a deal with one group. The apple tree with another. The birch with a third.

They don't choose on purpose, of course. It's how things worked out over millions of years of evolution. Each plant's root exudates draw in the microbes that suit it, so the crowd around a tomato's roots is different from the crowd around an oak's. Gardeners often put it this way: each plant hires the miners it needs most.

Just as every restaurant has its own head chef.

When you plant something in sterile soil (or in a pot of store-bought potting mix with no life in it), it goes hungry, even when there are plenty of minerals around. There's no army of miners to unlock that food.

What Science Says

Sergei Winogradsky, one of the founders of soil microbiology, and the scientists who followed him learned to study soil microbes where they live, not just in lab dishes. Later, Dr. Elaine Ingham and her colleagues counted fungi and bacteria directly under the microscope. Ingham found that annuals and row crops tend to favor bacteria-rich soil, while trees and perennials favor fungus-rich soil.⁵⁵ Her model set rough targets. For tomatoes, about 0.5–1 (slightly more bacteria). For apple trees, about 5–10 (fungi clearly in charge). If you find 0.1 under a birch, something such as tilling or fungicides has likely damaged the fungal network.

In *Teaming with Microbes*, Jeff Lowenfels and Wayne Lewis champion compost tea (a liquid brewed from compost) as a way to put microbes back into tired soil. Many growers swear by it, and there is research on their side. A review of the experimental evidence found that compost teas sprayed on plants can suppress some plant diseases, with results that depend a lot on the compost used and how the tea is brewed.⁵⁶ Controlled trials are still few and results vary, which is why good compost and careful brewing matter so much.⁵⁷ Treat it as a promising experiment in your own garden, not a guaranteed fix.

Flip Your Thinking

Here's the main thing to remember from this chapter:

The plant doesn't feed itself from the soil alone.

Bacteria and fungi help feed it.

And the plant pays them in sugar.

We thought the plant was a lone hero. It turns out it's the mayor of a city. It runs things, organizes, sets up the conditions. But the coal is dug by little invisible miners underground.

• Why Grasses Have Bacteria and Trees Have Fungi

This is one of the most important questions in practical gardening and farming. The answer shapes what you plant, how you feed it and how you heal your soil. It all comes down to **feeding strategy and pace of life**.

One honest note first. This is a useful simplification, not an iron law. Most grasses and crops also partner with mycorrhizal fungi.⁴⁰ What changes is the balance: fast plants lean more on bacteria, and slow, woody plants lean more on fungi.

Bacteria (the “Fast and Many” strategy):

- **What they are:** Tiny single cells.
- **How they eat:** They release enzymes straight into the water around them. They need **dissolved food** (sugars, simple amino acids).
- **Speed:** In the lab, some bacteria divide every 20 minutes or so. In real soil, a bacterial population turns over in days to weeks, and near busy roots in under a day.⁵⁸ Their numbers jump the moment there’s moisture and warmth.

Fungi (the “Far and Thorough” strategy):

- **What they are:** Many-celled threads (hyphae) that grow like a spiderweb.
- **How they eat:** They push into solid materials (rock particles, bark, plant fibers) and absorb nutrients through their thread tips. They don’t need a film of water to live in the way bacteria do; they need **contact**.
- **Speed:** They grow more slowly. Fungal biomass in soil turns over up to ten times more slowly than bacterial biomass, over weeks to months,⁵⁹ and a fungal network can spread over large areas and last for years.

Grasses (and all annual plants) evolved to lean on a **bacterial** environment.

- Grass has a fibrous root system that looks a bit like a scrub sponge. Most of it sits in the top layer of soil, about 30 cm (12 in), though some roots go much deeper.⁶⁰
- Grass grows fast and pumps **simple sugars** into the soil (root exudates such as glucose, fructose and sucrose). This is perfect food for bacteria.

Grass’s main request: “I need fast NITROGEN to grow green leaves!”

Bacteria are champions at turning organic matter into nitrogen plants can use, and they do it fast. That’s why grass teams up with bacteria in the rhizosphere (the thin zone of soil right around the roots). Bacteria multiply quickly, break down organic matter and release nitrates (NO_3^-), the form of nitrogen most grasses and row crops prefer.⁶¹

Trees (and perennial shrubs) evolved to lean on a **fungal** environment.

- A tree has deep roots and a long life. It needs to draw water and phosphorus from deep down and to deal with **hard food** (leaf litter, wood, rock).

- Trees can't replace their roots every year the way grass does. So they "hire" fungi. Fungal threads grow through solid particles and reach farther than a root ever could.
- **The tree's main request:** *"I need PHOSPHORUS and MOISTURE, and I need to make it through the winter."*
- Fungi supply phosphorus and water, and the plant pays them in sugars and **fats (lipids)**. Research shows that plants feed fatty acids to their mycorrhizal fungi, which can't make their own.^{62,63}

Tree roots release **more complex compounds** that suit fungi. Fungi slowly break down tough organic matter (lignin, cellulose) and gather phosphorus, potassium and micronutrients from minerals. In forest soils, most nitrogen stays in the ammonium form (NH_4^+), and many trees, especially conifers, take up ammonium more readily than nitrate.^{64,65}

The Bottom-Line Contrast

Grass feeds bacteria so they'll quickly cook it a nitrogen "lunch" while the sun is high.

A tree feeds fungi so they'll build an underground "pipeline" for water and phosphorus that lasts for years.

Root Exudates

A plant doesn't decide, "I want bacteria" or "I want fungi." It simply releases what it releases, and the microbes follow the scent on their own.⁵⁴

Type of plant	What the roots release	Which microbes they attract	Why
Grasses (cereals, annuals)	Simple sugars (glucose, fructose, sucrose)	Bacteria	Bacteria eat simple sugars fast and release nitrates
Trees, shrubs, perennials	Complex organic acids, polyphenols, tannins	Fungi	Fungi slowly break down complex organic matter and mine minerals

What this means in practice

1. **If you have a lawn or a vegetable garden** (grasses, annuals), your goal is to boost **bacterial** activity. Add compost rich in bacteria, don't dig deep, and use fast cover crops (mustard, phacelia).
2. **If you have an orchard** (trees, shrubs), your goal is to boost **fungal** activity. Add fungal compost (such as Johnson-Su compost), mulch with bark, sawdust and wood chips (that's fungal food), and don't plow or dig.
3. **If you have a mixed plot**, create zones. Vegetable beds are bacterial. The root zones around tree trunks are fungal.

Cheat sheet

Feature	Bacterial soil	Fungal soil
Who dominates	Bacteria	Fungi
Typical plants	Grasses, cereals, annuals, vegetables	Trees, shrubs, perennials

Feature	Bacterial soil	Fungal soil
Root exudates	Simple sugars	Complex acids, tannins
Form of nitrogen	Nitrates (NO_3^-)	Ammonium (NH_4^+)
pH	Bacteria do best near neutral (about 6.5–7.5) ⁶⁶	Fungi tolerate a wide pH range; fungal soils are often, but not always, more acidic
Best mulch	Grass, straw, crop tops (fast organics)	Bark, wood chips, sawdust (slow organics)
Fungi : bacteria ratio	<1:1	>1:1 (up to 1000:1)

But Why Did It Evolve This Way?

That's a question worth a million years of evolution.

Grasses live fast and bright. Annual grasses have to grow, set seed and die in one season. They need **fast food**: nitrates, which bacteria deliver right away. Simple sugars from the roots attract bacteria, the bacteria provide nitrates, and the grass grows and sets seed. All in 3–4 months.

Trees live slow and long. They can't count on quick bursts. They need a **stable, long-term environment** that doesn't dry out, overheat or swing in pH. Fungi help create that kind of environment. Their threads bind the soil into crumbs, hold water and gather minerals year after year. A tree is in no hurry. It builds its body over decades.

Grass is a sprinter. A tree is a marathon runner. Different strategies, different chemistry, different partners.

Why Trees Chose Fungi and Grasses Chose Bacteria (Speed vs. Reliability)

Here's how the two partnerships compare side by side:

Feature	Bacteria (allies of grasses)	Fungi (allies of trees)
Speed of work	Very fast (hours to days).	Slow (weeks to years).
What they deliver	Fast nitrogen (for green leaves).	Many minerals, mainly phosphorus, plus water and zinc (for the trunk, bark and winter). ⁶⁷
How they hand it over	Bacteria release nutrients into the soil when they die or are eaten. The grass helps itself.	The fungus connects directly with the root and trades nutrients right at the root cells.
What the plant pays	Simple sugars (quick energy).	Sugars and fats (long-lasting energy).
Attitude to digging	Love it! Dig the soil, add oxygen, and the bacteria boom.	Hate it! Dig the soil, tear the fungal threads, and the fungus suffers. ³¹

The Irony of Modern Gardening

Many gardeners put **nitrogen fertilizer** under their trees, thinking they're helping. But heavy nitrogen tends to shrink the mycorrhizal fungi a tree depends on. One large review found nitrogen fertilizer cut mycorrhizal fungi by about 15% on average.⁶⁸ Over time, ammonium-based fertilizers also make soil more acidic.⁶⁹ The tree leans more and more on the gardener's fertilizer. The gardener adds more. And the cycle repeats.

The right approach: each group of plants has its own ecosystem and its own set of bacteria and fungi. Our job is to give each plant access to this extraordinary life and the chance to connect with it.

• Notes

Each number matches a small number in the text. A source used more than once keeps the same number.

1. Tugel, A. J., Lewandowski, A. M., & Happe-vonArb, D. (Eds.). (2000). *Soil Biology Primer*. Soil and Water Conservation Society. Gives 100 million to 1 billion bacteria per teaspoon of productive soil.
2. Rousk, J., & Bååth, E. (2011). Growth of saprotrophic fungi and bacteria in soil. *FEMS Microbiology Ecology*, 78(1), 17–30. <https://doi.org/10.1111/j.1574-6941.2011.01106.x> Reports bacterial turnover of 12–19 hours in the rhizosphere and days to weeks in bulk soil.
3. Floudas, D., et al. (2012). The Paleozoic origin of enzymatic lignin decomposition reconstructed from 31 fungal genomes. *Science*, 336(6089), 1715–1719. <https://doi.org/10.1126/science.1221748> White-rot fungi are the main decomposers of lignin.
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