The Carbon Sequestering Garden

Gardening for the Planet While Growing Some of the Best Food Possible

By Allison Houghton

NOFA MASS
Northeast Organic Farming Association

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Massachusetts Chapter, Inc.

www.nofamass.org

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Introduction
Gardening for the Planet

Whatever takes place each day in this world beneath our feet has wide-ranging influences on some of the great issues of our time – pollution, nutrition and health, global warming, and preservation of biodiversity.

— James B. Nardi,
author of *Life in the Soil*

Minding your own patch of this planet by nurturing your soil and building humus (sequestering atmospheric carbon) is the ultimate win/win. It benefits the gardener, the garden and this practice regenerates the precious medium that sustains us all. In fact, it may be your most powerful contribution to the greatest challenge we will ever face.

— Graeme Sait

In the course of history, there comes a time when humanity is called to shift to a new level of consciousness, to reach a higher moral ground. A time when we have to shed our fear and give hope to each other. That time is now.

— Wangari Maathai

The impact of climate change is daunting, but we have a strong ally in the world beneath our feet. The soil, quiet as it might seem from the surface, is full of organisms living and dying, unlocking and storing nutrients and carbon, breaking down pollutants, and purifying water. These microorganisms are producing slimes and glues and residues that create soil structure and help it resist extremes, such as flooding or drought or compaction. When the soil is functioning at its full capacity, it is like a carbon-rich sponge that rebounds from stress, resists erosion, and buffers extremes.

Every plant, growing slowly and steadily from the soil, is an active participant in the soil ecosystem, fueling much of the biological activity happening underground. Plants actively capture carbon from the air as CO_2 through photosynthesis to produce sugars for themselves, and pump a portion of these sugars (liquid carbon) out through their roots in a symbiotic relationship with the microbiology. Some of this liquid carbon goes on to become the glues that build soil structure, creates humus (the substance that makes the soil dark, crumbly and rich), and builds the soil's water-holding capacity.

When you look out at your garden, what do you see? You might see soil or exposed dirt, grass, garden vegetables, mulch, weeds, maybe some trees or shrubs. You might see insects (or hear them buzzing to and fro), or see evidence of them in holes in the leaves of your trees and veggies. Take a look. Take a moment to observe what's out there.

Now take another look, specifically at the soil. Is it dark and crumbly, dusty and tan, or compacted and grey? Would you describe the soil in your garden as alive, sweet-smelling, and healthy? Or is it inert, compacted, and tired? Soil health is defined by the National Resources Conservation Service (NRCS) as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans". Soil, in this context, is so much more than a growing medium for your plants. When we make the shift to thinking of soil as a living ecosystem full of life, we understand it has a measure of health that can change. As gardeners, we have the unique capacity to work with the health of this ecosystem, and actively build the soil, capture carbon, hold more water and air, all while growing some of the best tasting, nutritious food we possibly can.

The many relationships and processes happening in the soil are complex and incredible, but the principles for building soil health (and consequently soil carbon) are

relatively simple. NRCS's Soil Health division broke them down to four general principles

Although there are many creative ways gardeners can build up the soil and sequester carbon (which we'll explore in this booklet), these overarching principles can be helpful to keep in mind as a guide for better land health.

1. Minimize or avoid chemical, physical and biological stressors. Completely eliminate or avoid the use of artificial pesticides and fertilizers, which are chemical stressors that can actively destroy soil life, destabilize and degrade soil structure, and halt soil carbon building processes. Manual tilling and breaking up the soil is an example of a physical stress that (especially when done regularly and deeply) will destroy microbial communities including the long fragile strands of fungi, which take a long time to rebuild. Drought, wind, and extreme cold or hot temperatures can also stress soils and soil life, especially if the surface of the soil is exposed to the elements. Protect your soil, and manage it more by disturbing it less.

2. Use plant diversity to increase soil diversity. Plants have the unique ability to influence and direct soil biodiversity through the soil biodiversity at their roots. In fact each type or family of plant can influence a separate, unique community of microorganisms. With one type of plant in the garden, you will get a specialized microbial community associated with that plant. Add 14 different types of plants to your garden, and the diversity increases dramatically. Using both annuals and perennials, rotating annuals, interseeding or undersowing a variety of plants in your garden: these are all ways to improve diversity aboveground that in turn promote diversity and resilience belowground.

3. Keep living roots in the soil year round to feed your soil. Maintain living plant roots in the soil year round or for as much of the year as possible. Remember that plant roots provide the fuel that soil microbes need to thrive**.** Perennial plants (those that remain alive for several years without having to be reseeded) are an excellent choice for doing this. Planting groundcovers, cover crops, or strips of grass at the edges or pathways, or in between annual vegetable plants can also be creative ways to feed the soil microbial community and maintain the flow of root exudates (liquid carbon) into the soil for as much of the year as possible.

4. Keep the soil covered as much as possible. Even if you can't cover the soil with living plants, try to cover any bare soil to protect it from loss of carbon to oxidation, temperature extremes, erosion, rainstorms, and drying out. Mulches such as shredded leaves, hay, cardboard, compost, and wood chips are all ways to keep the soil covered while also adding organic matter to the garden.

In this book we will explore the many ways you can garden for the planet and work within an ecosystem to create a thriving and productive garden that sequesters carbon. But remember climate change is not just about rising carbon levels in the atmosphere. It is about land health, water, and life on all levels. It is about social justice, human health, security, sea level rise, the fate of biodiversity of the planet (including ourselves), affordable food and water access, the stability of communities and governments as well as economies and ecosystems – climate change affects them all. And although, no one garden on its own can tackle the mighty forces at play in our world today, each garden *does* exist within a neighborhood, a community, a watershed, an ecosystem, and a world. Just like a tiny tomato seed from your garden, it is hard to fully realize the potential for the many fruits and thousands upon thousands of future seeds, you can grow simply by planting it.

Chapter One
Getting Started

Soil is literally alive. It is full of bacteria, fungi, algae, protozoa, nematodes and many, many other creatures. In a teaspoon of healthy soil, in fact, there are more microbes than there are people on earth.

— From *Soil Carbon Restoration: Can Soil Biology Do the Job* by Jack Kittredge

Upon this handful of soil our survival depends.

— Sanskrit text, 1500 BC

In addition to the principles mentioned in the introduction (minimize soil stressors, encourage plant and soil diversity, maintain living roots in soil year round, and keep soil surface covered), here are some overarching practices to help you get started and help maximize your efforts in creating a thriving and carbon-sequestering garden!

Practice Organic Management

One of the most important steps you can take to ensure that your garden and backyard can maintain a thriving and diverse soil ecosystem capable of sequestering carbon and building land health is to avoid all synthetic pesticides and fertilizers. These products are most notably used on lawns, but can also be prevalent in the garden as well. While most people might recognize that fungicides, herbicides and other pesticides negatively affect soil life, it is less well known that synthetic, water-soluble fertilizers also have an equally devastating impact on soil life, structure, and capacity to build organic matter and sequester carbon. When plants begin receiving nutrients directly in liquid form, they stop exuding the all-important soil-building sugars through their roots that feed the microbial community around them. These fertilizers, particularly chemical nitrogen and phosphorous, can break down soil structure, create acidic conditions that drive away earthworms and other soil organisms, while actively shutting down the ability of soils to sequester carbon and build organic matter. Many of the nutrients in these fertilizers will leach out of the soil, not only wasting money for the gardener who bought them, but also polluting waterways and often stripping other nutrients like calcium out of the soil as they go.

Instead, practice prevention to get your system in balance and boost its natural defenses. Start by promoting a thriving and diverse soil ecology by building up the soil food web with good organic matter, compost and mulches, inoculating the soil with beneficial soil life, and developing a thriving and diverse plant community. Choose smart methods that will combat pests and disease and effectively stop them in their life cycle rather than using broad spectrum sprays or fixes that often inadvertently make the problem worse over time. Some examples might include introducing or supporting habitat for natural predators such as frogs, birds, and predatory insects, rotating your crops, ensuring good airflow and drainage for crops. Choose organic sprays and fertilizers when needed or work the soil ecology to build soil nutrition and resilience. Find a good reference guide to help identify strategies for dealing with specific pests or diseases such as *The Organic Gardener's Handbook of Natural Pest and Disease Control.* Building health, resilience and high quality production of the land is a process that will continue to develop over time.

Get a Soil Test

It is very important, especially for those in urban or heavily industrialized areas who are interested in starting a garden, to get a soil test before getting started to check for lead and other heavy metals. Lead is of particular concern in city soils, along highways, and

near old buildings -- mostly from leaded gasoline and lead paints that were only regulated in earnest a few decades ago. And although lead contamination is a serious concern for gardeners, the practices that build soil carbon also limit lead's impact in the soil, on the plants, and ultimately on human health. By covering the soil, building soil biology, adding plenty of organic matter, and making sure the soil is not highly deficient in essential nutrients, you can lessen or even negate lead's impact on your soils. Plants do not preferentially take up lead, but will if the soils are poor, nutrient deficient, and low in organic matter. If the lead levels in your soil are high, however, or in rare cases extremely high, be prepared to take the recommended precautions, or avoid growing edible crops entirely.

Every soil testing laboratory has a slightly different set of methods and techniques for taking soil tests. The method each lab uses to give you results on soil nutrients will depend on the types of tests the lab uses to evaluate the soil sample. If you are evaluating your soil over time, stick with the same soil testing lab and their recommended sampling strategies to ensure consistency of results. For more information on a few specific labs, see the resources section.

Correct Nutrient Deficiencies

When working with depleted or degraded land, often there are nutrient deficiencies that affect not only the plants growing in those soils, but also the soil structure and its ability to hold water and air as well as a thriving biology. Even with a garden that has had compost applied to it for years, nutrient deficiencies or imbalances can show up that impact the health of the plants, their quality, and the overall nutrient density of the garden produce. A thriving soil biology can access nutrients that may not even show up on a soil test and build fertility over time to high levels. By taking the time to rebalance and remineralize the soil at the outset, however, you give the microbes a head start by giving them the nutrients and the "house" or soil structure they need to thrive. In New England, for example, our soils are prone to certain deficiencies due to our rainfall patterns, the age of our soils, and the parent rock materials that created them. Correcting these deficiencies can help your garden and the soil biology blossom (quite literally) in a way you may not have seen before.

Remineralizing the soil is about balance. There are many further resources, including consultants, that can help you navigate this complex but important topic. There are a few main points that are important to impart however.

Which nutrients are important?
For many years gardeners have been told that nitrogen, phosphorous and potassium ("NPK" on fertilizer labels) and pH are the most important things to monitor and adjust in the garden. But our understanding of the soil has come a long way – we now realize that *many* nutrients are equally important for plant health, not just these three, and the balance of these nutrients will ultimately help determine the proper pH balance of the soil. Calcium, for example, is crucial for building cell walls, transporting nutrients into the plant, and fruit formation. Magnesium is absolutely required for chlorophyll production, while sulfur is essential for synthesizing proteins and ultimately creating compounds that help protect the plant from disease and develop flavor. The more we learn, the more we realize that micronutrients such as zinc, boron, silicon and copper are also key to plant health and function. Although they are needed in only tiny amounts, they are no less important to both plant and soil biology.

Balancing Major Cations (Ca, Mg, K, Na). When you first get a soil test, take a look at your major cations (positively charged nutrients), specifically Calcium (Ca), Magnesium (Mg), Potassium (K), and Sodium (Na). All are essential for plant growth. Less well known is the fact that their ratios in the soil impact soil health and structure. For example, the ratio between Ca and Mg in the soil can sometimes dictate how "tight" or "loose" a soil is. In New England soils, for instance, we often have Ca deficiencies that not only limit plant growth, but also produce soils that are tight, compacted, have a low pH, and have difficulty absorbing water. There are several models for soil cation balancing, but many agree that a good ratio among Ca: Mg: K: Na is 68:12:4:2. To compare this ratio to that in your soil, look at the "base saturation" values in a typical soil test.

Addressing Anion Deficiencies (S, B). Two common anion (negatively charged particles) deficiencies in New England soils are sulfur (S) and boron (B) as they are harder for soils to "hold" and thus easily leach out of our soils in the rain. Boron, for example, is needed in very small amounts in the soil, but is essential for proper uptake of a host of other essential nutrients, proper seed set and pollen viability, and proper root and leaf tip growth. Symptoms of a boron deficiency are hollow stems in broccoli or hollow hearts in potatoes, tiny beets or small broccoli heads, and shriveled or stunted new growth in tips of leaf growth. But be careful not to over apply! Boron is an essential nutrient, but needed in very small quantities in the soil. Another way to keep anions like boron and sulfur in the soil is to build soil humus, which can hold both cations (+) and anions (-), unlike clay particles which can only hold positively charged nutrients. Consequently, depleted soils often need anions to be restored, at least initially, but sometimes repeatedly in areas of frequent rainfall and low organic matter.

Consider Nitrogen and Phosphorous. Nitrogen and phosphorous are both essential for plant growth; however, many gardens often have excesses of both these nutrients. Nitrogen is difficult to measure in the soil, so many laboratories no longer test for it. Phosphorous is often found in very high levels in garden soils from large amounts of compost and manures added over time. Excesses in both these nutrients can cause pest and disease problems as well as run-off from your land into waterways, even from organic sources. If your land is degraded or depleted, very sandy or clayey, you may need these essential nutrients. Soil biology is an excellent ally in both fixing nitrogen and solubilizing phosphorous to make it more available to plants. Other excellent methods for building up depleted levels of nitrogen and phosphorous in soils that may need them are composted manures, rock phosphates, seed meals, and planting nitrogen-fixing plants like clovers, peas and beans. Remember that an active soil biology will also help hold these nutrients in the soil and prevent nutrient run-off once you add them back in.

Address Micronutrients and Trace Elements. Micronutrients, like boron (B), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), silicon (Si), molybdenum (Mo), cobalt (Co), and selenium (Se), among others, are needed in small quantities in the soil, and yet they are just as essential to plant function as the major nutrients. The more we learn about plant health, pest/disease resilience, and even human health, the more micronutrients and trace elements are added to lists as important or even essential. Make sure there is a good supply of these micronutrients in the soil as well as an active soil biology to help make these nutrients readily available to your plants, and also ultimately to you as well.

Micronutrients needed for plant health are also crucial for human health.
Photo from the International Year of Soils by the Food and Agriculture Organization of the United Nations in 2015.

How to Apply Needed Nutrients?
When adding minerals to your soil, there are two main approaches to consider. The first way you can choose to correct specific deficiencies is by adding these nutrients in pure forms directly through mineral supplements. This approach is especially useful for correcting major nutrient deficiencies such as calcium, magnesium, or phosphorus. When using this approach with micronutrients and trace elements, be sure to always add pure minerals with a carbon source like compost or humates to help hold them in the soil and also buffer their effects.

The second method is adding amendments that are a rich source of a broad spectrum of micronutrients and trace elements. In a garden with many soil variations, different types of plants, and tiny microclimates, this is probably the best way to ensure your garden is getting what it needs. Amendments that include a broad range of trace minerals include sea minerals, ancient seabed or volcanic deposits, local rock dust (especially from volcanic or granite quarries), azomite, greensand, wood ash, and kelp, as well as rock phosphates. Compost is a great additive, especially for adding organic matter to build soil structure and adding a healthy dose of soil biology, but compost can only be as good or as diverse in nutrition as the materials that are used to produce it. To make a nutrient-rich garden compost, use as diverse a range of materials as you can, and consider adding sources of micronutrients directly to the compost pile. If you are deficient in major nutrients, consider adding these directly to the compost pile to ultimately be incorporated into the garden. See compost section in Chapter 3 for more ideas.

Actively Build Soil Structure

You may have to deal with heavily compacted, poor or compacted soils in your yard. If you do, one of the best ways to address the problem is to add organic matter to build soil structure. Organic matter can be a great way to stimulate biological activity, feed soil microbes, and begin building soil structure.

For bare or exposed soils that are quite compacted, you might also need to initially aerate the soils by breaking through any hardpan, crust, or compaction layer to allow air, water, roots and consequently soil life to more effectively reach these deeper levels. A broadfork, pitchfork, or similar tool can be a great way to loosen up or crack through these impenetrable layers. Consider using an intensive gardening method to loosen the soil such as John Jeavon's double digging method outlined in his book *How to Grow More Vegetables* listed in the resource section.

In the long run, soil biology could ultimately do the job of loosening the soil bit by bit, very slowly over time, wearing down these compacted layers and ultimately breaking through. However, by initially improving air and water flow in the soil, you can give the biology an even greater head start. Once you are past the difficult initial stages of breaking through serious compaction and getting the soil biology established (building both organic matter content and soil structure in the process), you will want to change tactics and practice minimally disturbing the soil biology that you have so carefully helped to foster.

Consider Your Weeds

Weeds can indicate the condition of your soil. Weeds are tenacious, deep-rooted, fast spreading and fast growing. They are often nature's first layer of defense for covering bare or damaged soils. Think about where you see weeds: in compacted soils, ground that is constantly disturbed, on construction sites and waste piles. If your soil is deficient in certain micronutrients, certain weeds may be present that specifically hyperaccumulate or concentrate these very nutrients over time – it is nature's way to try and correct (very slowly!) certain soil mineral deficiencies in the topsoil. Dandelions, for example, have deep taproots and often grow in soils that are compacted and deficient in calcium, such as lawns treated routinely with chemical nitrogen fertilizer (which, ironically, strips calcium out of the soil). By remineralizing your soil, preventing unnecessary disturbance like tillage or leaving the soil bare, you can not only reduce weed pressure, but speed up the natural processes the weeds are trying to fulfill.

You might also reconsider the negative associations we have with many common weeds. Dandelions, docks, amaranth, lamb's quarters, chickweed, and purslane, for example, are common weeds. Some have strong medicinal and nutritional qualities that rival or even surpass our intensely cultivated lettuces, spinaches, and salad greens. Chickweed, for example, is high in vitamin C and A. Purslane is a natural source of omega 3 fatty acids, containing more than some fish oils. Lamb's quarters can rival spinach in a whole host of nutrients including calcium and important B vitamins. And all parts of the dandelion are edible (flowers, leaves, roots), supporting important liver and digestive function in the body. If you decide to forage or take advantage of the amazing health benefits of your weeds, be sure to first take a soil test to make sure you aren't harvesting from contaminated soils.

Reconsider the weeds in your yard as allies, and think about working alongside these plants by taking some time to understand more about what they are telling you about your soil. Are they trying to cover bare spots, break through hardpans and compacted layers, or restore the organic matter content to your overly disturbed land? See the resource section for more information on this topic including the book, *Weeds and What They Tell*.

Chapter Two
Add Life in the Soil

Our collective future pivots on many people coming to understand that soil fungi matter. That plant ecosystems must be respected. That soil stewardship is our highest calling.

— Michael Philips,
Mycorrhizal Planet

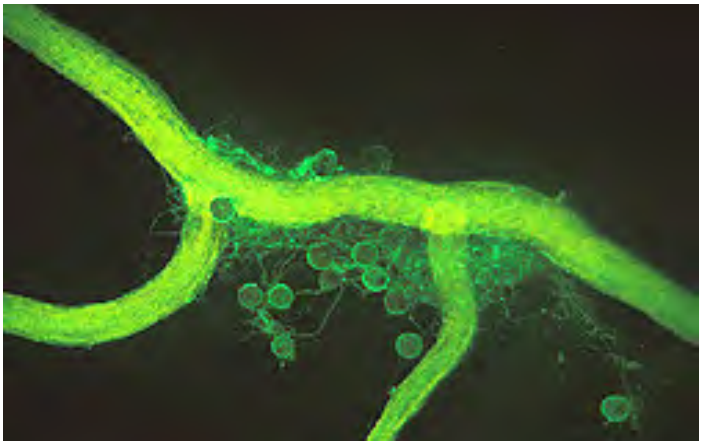
Essentially, all life depends upon the soil ... There can be no life without soil and no soil without life; they have evolved together.

— Charles E. Kellogg,
USDA Yearbook of Agriculture, 1938

There are many beneficial organisms that live in the soil from bacteria, fungi, protozoa, arthropods, nematodes, earthworms, and even small animals. Engage with this tiny workforce in your yard, support them, and find ways to add or cultivate them into your soil.

How they interact with each other, the soil, and the plants around them, are the keys to building soil carbon and land health. These microbes can solubilize certain nutrients like phosphorus and calcium, capture atmospheric nitrogen from the air and fix it in the soil, trigger or support an immune response in your plants to prime them to fight off pests and disease, or deliver complex chemical compounds your plants may not be able to access or manufacture on their own. Soil microbes assist or accelerate the creation of soil humus (a more stable form of carbon formed within soil aggregates), exude carbon-rich slimes and glues that build soil structure, as well improve the speed and quality of the composting process.

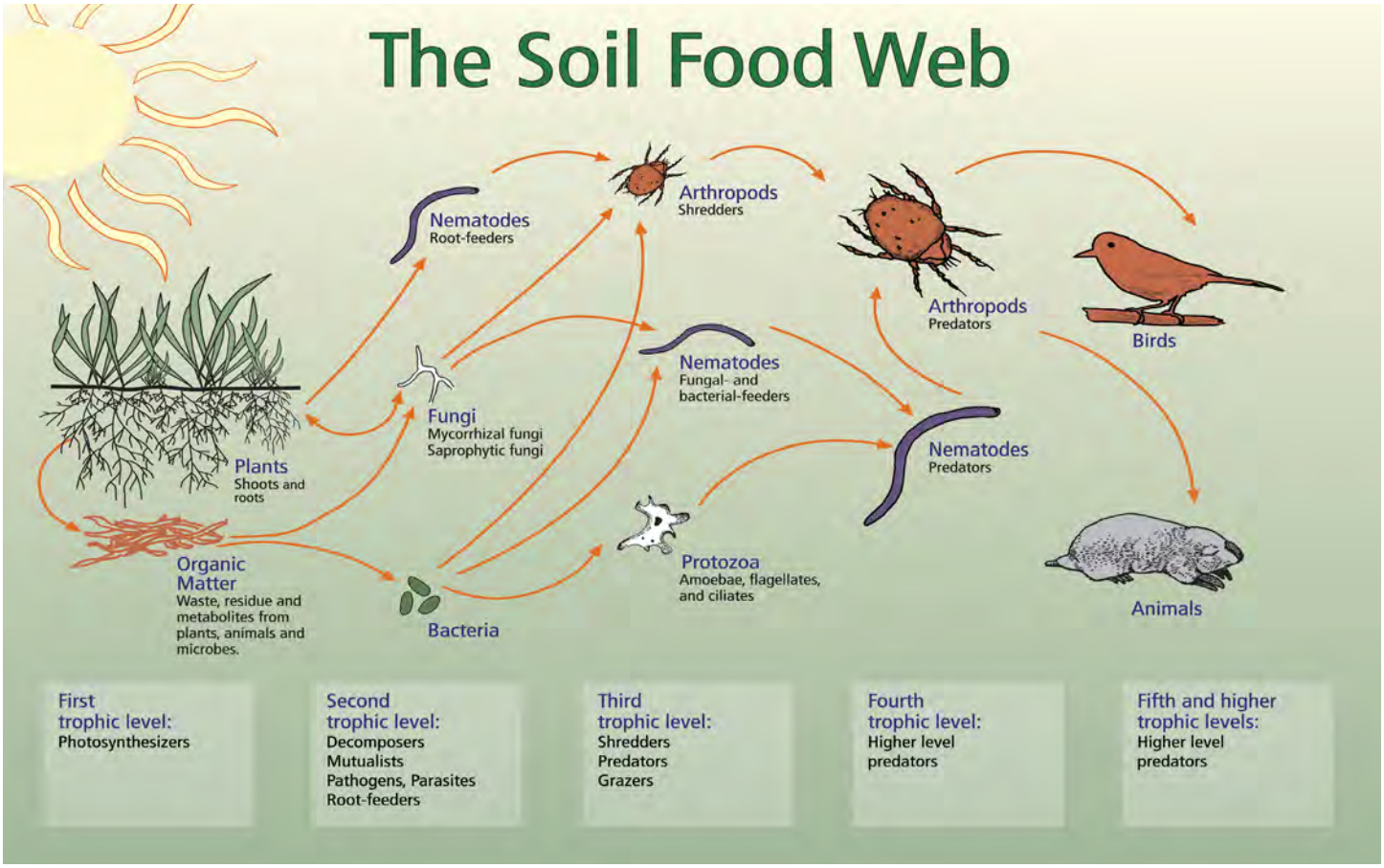
One example of a beneficial soil organism is mychorrizal fungi. These amazing fungi partner with the many types of plant roots to get access to the supply of root exudates, which they need but cannot produce on their own. These fungi connect the plant to their own complex networks, bringing back nutrients and moisture the plant couldn't possibly access with its own roots. Mycorrhizal fungi can literally "mine" tiny rock particles in the soil for nutrients in exchange for the carbohydrate exudates (liquid carbon). These nutrients are otherwise completely inaccessible to plants and in their insoluble form, will not even show up on most soil tests.



Glomalin (only recently discovered by scientists in 1996) is a strong, carbon-rich glue exuded by mycorrhizal fungi into the soil. Glomalin appears to help the fungi stabilize itself over long distances, carry water and nutrients, and build soil structure. Photo credit: Sara Wright, USDA Agricultural Research Service.

Adding or cultivating beneficial microorganisms in your soil is one way to support the amazing soil food web, and with it, soil carbon-building processes, to make your garden and land thrive. These organisms do occur naturally in soils or can eventually find their way to your yard (if not already present), but by adding them directly or specifically cultivating them, you can ensure that you have the diversity you want in your soils. This can be an especially good strategy to give degraded, compacted or overly disturbed soils a head start by ensuring they have the biology they need.

Adding beneficial microorganisms can be a great way to directly improve soil health, but don't forget to also maintain



Picture of the soil food web from the USDA's Natural Resources Conservation Services "Soil Biology Primer"

that biology by remembering soil health principles including fostering a diverse plant community aboveground to support diversity belowground, keeping the soil surface covered, and maintaining living roots in the soil for as much of the year as possible. Here are a few ideas for adding beneficial microorganisms to the soil.

Nitrogen-fixing Inoculants

This inoculant is added to the seeds of nitrogen-fixing plants (think legumes such as peas, beans, and clover). The bacteria attach to the roots as the seeds germinate and form nodules that fix atmospheric nitrogen. This is probably the best known inoculant and is the one most commonly used by large-scale growers. Although the bacteria in the inoculant is often naturally occurring in soils, the inoculant can be an inexpensive way to ensure you are getting the soil benefits of nitrogen-fixing plants, especially if your soil is actively cultivated, depleted, or heavily compacted.

Microbial and Mycorrhizal Inoculants

Many beneficial fungal and microbial inoculant mixes are becoming available on the market. If you are looking for a general beneficial inoculant, find a mix that has as diverse a range of species as possible, including both endo- and ecto-mycorrhizae. Some of these inoculants will be in a form to treat seeds directly (1 lb inoculant can treat up to 100 lbs of seeds), some can be mixed into water and applied to plants, added to transplants or bare root transplants, added to potting mixes, or used to enhance the composting process. Be aware that the mixes will be different depending on the application.

Indigenous Microorganisms

Consider collecting microorganisms yourself from the diverse environments around you. A very simple way to do this is to take some

soil from the base of a thriving plant of the same variety that you are growing and place it at the base of the one you are planting. For example, a robust old apple orchard could be a good source for beneficial organisms for your young fruit tree saplings. You could also try following the Korean Natural Farming method for collecting indigenous micoorganisms and try inoculating cooked rice with forest microbiology to either add directly to the garden or to further culture in a compost pile to spread more broadly throughout the garden. See resources for more information on Korean Natural Farming methods.

Ramial Wood Chips

The leaf buds and young twigs of trees are full of nutrients preparing for new tree growth, and when chipped into a mulch, provide a slow-release of these important nutrients as well as being a thriving environment for mycorrhizal fungi. The chipped wood from mostly the bark, buds, branches and twigs, as opposed to wood chips mainly from the trunk of a tree, are called ramial wood chips, and are a great mulch for the yard and garden. Choose hardwood tree species, if possible, to ensure the white mycorrhizal fungi thrives as compared to the yellow or orange fungal threads you would see from wood chips made of conifers or softwood tree species. These chips are excellent sources of slow release nutrients for orchards, shrubs, and garden vegetables, as well as a carbon-rich food for symbiotic mycorrhizal fungi.

Compost Tea

Another method of adding a blend of beneficial microorganisms to your garden to stimulate biological activity in the soil and improve plant growth is applying compost tea. A compost tea brewer can be as simple as a 5-gallon bucket filled with water, actively aerated with a fish-tank style air pump with a bag of high quality compost suspended in the water (much like a large tea bag). Compost teas are usually brewed for 1-3 days, depending on the microbiology you are trying to culture. Often sugars or other "microbial stimulants" are added to the tea to ensure the right concentrations of the beneficial microbes and boost their populations. Compost teas can be an effective way to add microorganisms that may be missing from your soil food web, cycle nutrients, build organic matter, or improve plant health and growth over a large scale with relatively little effort.

A compost tea should never smell "bad", and it will take a fair amount of skill to confidently brew a batch of a useful product. It also must be actively aerated to ensure the right proportion of aerobic, beneficial microbes to your soils. These teas are not the same as the herbal brews or ferments that are sometimes used as homemade fertilizers. There are many resources available to help guide you along the way, including *The Compost Tea Brewing Manual* by Dr Elaine Ingrahm, a chapter on compost tea in *Teeming with Microbes*, and also many other resources connected with local compost tea suppliers, plant nurseries, and garden supply centers.

If you are serious about brewing a high quality compost tea, you might also consider getting a microscope to verify you are getting a healthy diversity of the right blend of beneficial organisms. Several books, consultants, and other resources exist to help guide you to get to learn and recognize the tiny creatures you will observe. Get to know what numbers of bacteria, protozoa, fungi, and nematodes you can expect to see in a single drop of good quality compost tea. See resource section for more information.

Chapter Three
Building up Soil Organic Matter

The soil is the great connector of lives, the source and destination of all. It is the healer and restorer and resurrector, by which disease passes into health, age into youth, death into life. Without proper care for it we can have no community, because without proper care for it we can have no life.

— Wendell Berry,
The Unsettling of America: Culture and Agriculture

Adding organic matter to the soil can be a great way to stimulate biological activity in the soil food web and begin to build both soil structure and soil carbon. Organic materials like compost and mulch will directly feed the carbon-hungry soil food web. Some of these carbon sources will not be stored for the long-term in the soil as they may cycle quickly through the soil food web as they are ingested, respired and even be oxidized back to the atmosphere (this is especially true for soils that are left bare or actively disturbed). Some of these carbon sources you add to the soil, however, will eventually go to build soil structure and stable soil carbon or humus, stimulate the soil biology, and increase the overall organic matter content of your soil over time.

Compost and mulches are examples of direct ways to add organic matter to the soil, and can be ways to manage the fertility, keep the soil surface covered, and manage soils more (such as weed suppression with mulches) by disturbing the soils less. Living plant ground covers can also be a way to build up soil organic matter as the plants fuel a complex microbiology at their roots that stimulate the microbiology and soil carbon-building processes deeper within the soil. Biochar, a stable carbon-rich soil amendment, can be another way to help add carbon and foster a carbon-building soil food web in soils. It can be especially useful in supporting soil biology in a compacted, degraded or heavily disturbed landscape.

Compost

Composting is a powerful tool to help rebuild soils and introduce lots of soil life that can help with soil-building practices. If a soil is depleted or degraded, compost is an excellent tool to jumpstart the life in the soil that is responsible for making stable humus. Although there are many strategies for making compost, the basics are to combine a balance of "brown" or carbon-rich materials (such as cardboard, shredded leaves, straw, woody stems, sawdust) with "green" or nitrogen-rich materials (such as grass clippings, food scraps, coffee grounds, animal manures, weeds, and pruned garden plants). One way to do this is to make alternating layers of "brown" and "green" materials as you build the pile. Another method many gardeners use is to have a steady supply of easy to store, dry "brown" materials such as shredded leaves or straw and incorporate a hefty handful or two every time you add a handful of greens. Here are some creative ways to enhance the effectiveness of your compost pile.

Use a Diversity of Materials
Diversify the materials you add into your compost pile to ensure you are getting a wide range of mineral nutrients and "food sources" for your microorganisms. Be creative with new ways to incorporate carbon and nitrogen into the pile. Kelp or seaweed collected after a storm, coffee grounds from a local cafe, mushroom "waste" leftover from growing mushrooms, cover-crop clippings, and wood ash from the fireplace are all examples of materials that can add a diversity to your finished compost.

Many commercial composting processes add lime to their compost to maintain a pH optimal for effective decomposition. Calcitic lime also has the added benefit of providing a

bioavailable form of calcium to the garden – a mineral nutrient essential to effective plant functioning and one that is often deficient in many garden soils across New England. A healthy sprinkling of agricultural lime added to each layer, or added occasionally if the pile is built more slowly, is best. Avoid dolomitic lime unless you also have a magnesium deficiency in your soil.

Boost your Compost's Nutrient-Holding Capacity
Add materials such as clay that have a high cation exchange capacity (CEC): the ability to hold onto lots of soil nutrients. Add a clay source directly to the pile to help it stabilize and hold onto nutrients longer. An example is colloidal clay rock phosphate, which will also give your compost more phosphorous, calcium, and a range of trace nutrients. You could also consider "mining" your own clay reserves if you have a subsoil clay layer. Many subsoils have clay layers that have much higher CEC levels than the surface topsoil, making it an excellent compost additive and nutrient stabilizer. Biochar also will increase your compost's CEC and maintain moisture as well as provide tiny pore spaces for beneficial microorganisms to live.

Add Trace Minerals
Incorporate a diverse range of materials to get trace nutrients into your soil. Good examples are rock dusts, especially from volcanic or igneous rocks, sea minerals, kelp meal or seaweed, and ash from a wood-burning fire place. When they go through the composting process these nutrients and materials are gradually broken down by the soil biology and made more bioavailable to your plants when you apply them to the garden. If you are remineralizing your soil with pure blends of micronutrients, adding them to the composting pile before adding them to the garden is a good way to buffer their release, and a way to ensure a more consistent, effective availability in the soil.

Add Finished Compost or Manure
A great way to speed up the composting process is by adding in soil-building microorganisms present in a previously finished compost pile. Adding animal manure from a local farm or backyard pen can also be a great way to speed up the composting process by giving a healthy dose of nitrogen to the pile. If you have a lot of carbon-rich materials in the compost, manure could be just the material you need to get the compost cooking.

Build Compost with a Diverse Soil Food Web
Depending on how you manage your compost pile, you can encourage a bacterially or fungally dominant pile. Both have benefits. To make a diverse compost, rich in a wide variety of beneficial bacteria, fungi, nematodes, micro-arthropods, protozoa, and earthworms, you will need to provide a diverse range of materials and environments for these organisms to thrive as the compost is being built.

Many composts tend to be bacterially dominant. Bacteria are excellent digestors of many of the ingredients that go into the pile, can thrive in high disturbance environments (such as when compost is turned), and are the ones responsible for a compost pile "heating up." They also cycle and unleash a wide range of nutrients as they grow, feed, and die. Bacteria are crucial components of the soil food web and for plant health.

You can also experiment with several methods to help encourage more fungi in your compost, which encourage long term carbon building process. Some of these methods are incorporating a diverse range of carbon-rich food sources (fungi are the ones who ultimately break down plant lignin in woody materials), keeping the compost pile relatively shallow, cool, and both moist (this could happen after the hot bacterially dominant phase), and maintaining a low-disturbance environment (i.e. minimal turning of the pile).

Two interesting strategies you might try for building a fungally dominant compost are using Korean natural farming methods to build a compost inoculated with indigenous microbes, and building a backyard Johnson Su Bioreactor. Additionally, if you are curious about your success in encouraging a thriving soil food web in your compost, consider getting a bio-assay of your compost to get a full food web analysis and rating. See the resources at the end of this chapter for more information on each of these options.

Mulches

Mulches are a great way to keep the soil covered and provide the hungry soil life with a source of organic matter to keep the biology active and thriving. An active soil biology can quickly incorporate mulches (even wood chips), sometimes within a single season. Here are a few mulch ideas.

Wood Chips
Wood chips added onto the surface of the soil not only feed the soil below, but also suppress weeds and encourage beneficial fungi. Healthy, biologically thriving soils can easily digest wood chips in a few months. However if your soils are light, sandy or nutrient-poor, be particularly mindful not to incorporate or mix the wood chips into the soil, as that can cause the soil to "seize up" as it tries to pull nitrogen from the surrounding area to digest the wood chips. Leave the wood chips on the surface so microbes can access the carbon source as they need it. You might even consider putting a layer of compost down first, then mulching with wood chips if your soil is particularly nutrient poor.

This strategy of layering compost and wood chips is also an excellent one for building soil rapidly. It can be particularly useful in urban areas to build directly on a hard surface like cement or asphalt or underlying subsoil where the topsoil has been stripped away. One effective strategy for dealing with some invasive or unwanted plants is to cut them to the ground, put down a thick layer of cardboard and apply a layer of wood chips on top at least six inches thick (or more) to thoroughly smother any regrowth. Over time the chips will break down and leave you with a rich soil.

Straw and Hay
Straw and hay are light, easy-to-apply soil covers. They also make excellent food for soil biology and can break down quickly. Spread them along a newly planted bed and to allow seedlings to grow through a lightly mulched layer. Or incorporate the mulch more thickly around transplants or in pathways to keep the soil surface covered and suppress weed growth.

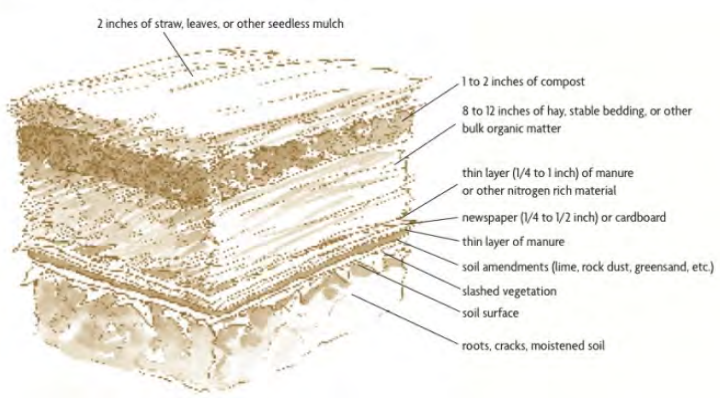
Alfalfa hay, though more expensive than regular straw or hay because of its higher protein content, is an excellent biological stimulant. Alfalfa hay is good at encouraging protozoa, the tiny soil microbe that is a favorite food of earthworms and a predator of soil bacteria. By eating bacteria, protozoa help unlock important soil nutrients, shift the carbon-to-nitrogen ratio in the soil, and help to create a more diverse micro-landscape. Highly disturbed soils often are more bacterially dominant (as opposed to fungally dominant) as bacteria are the fastest producers and can recolonize quickly after a deep disturbance like tilling or drought. By introducing protozoa and keeping the soil surface covered, you are helping encourage succession and diversity in the soil to eventually build to a more stable soil structure that also includes beneficial fungi.

Leaves
There is often an abundance of leaves in the fall that have been collected from yards and parks. Consider incorporating this resource as mulch to your yard. Leaves can be incorporated either whole or pre-shredded to your yard and garden as a mulch. Shredded leaves are sometimes preferable in the garden and compost as they incorporate into the soil more quickly and are easy to spread between plants. Whole leaves, on the other hand, can take a long time to eventually break down, making them an effective weed suppressant soil cover and as well as providing a protective layer for overwintering pollinators and predatory insects, many of which disguise their cocoons among fallen leaves.

Many leaves collected from a roadside crew will come pre-shredded. If your leaves are not pre-shredded and you would like to shred them, there are several options to break them down. Spread them over a driveway or walkway, and then drive, lawn mow, or trample over them until they are the consistency you want. Feed the leaves directly into a small chipper to shred. Put leaves in a loose chickenwire enclosure or empty, open-ended compost bin and use a weed-whacker to "blend" them, much like you would use an immersion blender in a pot of soup to puree it. Connect with a local town, company or recycling center and ask if they can dump either whole or shredded leaves at your garden or request. This is often more successful in exchange for a small fee or barter of some kind.

Other Mulch Options
Many other materials add cover to the soil as well as providing a food source to be slowly tapped by the microbial community underground. Be creative with "waste" streams. Some ideas may include: leftover substrate from mushroom production (rich in nutrients and enzymes that can assist in breaking down certain pollutants), cocoa hulls, cardboard (earthworms seem to especially love the moist environment under cardboard), corn stalks, spent grain from microbrewers, or a cover crop cutting.

Sheet Mulching
Sheet mulching (also sometimes referred to as "lasagna gardening") is a method of gardening using layers to rapidly build soil. It can be a great way to build high quality soil on top of an existing garden, lawn, or even on top of a hard, impermeable surface such as an asphalt driveway or parking lot. Some examples of layers you could include: newspaper, cardboard, finished compost, shredded leaves, an upturned layer of sod, grass clippings, soil mineral amendments, straw, shredded paper, manure, and wood chips. Ideally, it involves using existing materials you can access easily and that you can "reinvest" into your landscape.



This is one example of how you can do "sheet mulching" with local materials from Toby Hemmingway, author of Gaia's Garden.

Materials to Avoid
Black walnut, eucalyptus, and sunflower seed hulls are all examples of materials that produce naturally occurring compounds that can inhibit certain plant growth. Avoid using mulches that are made up solely of or contain large amounts of these materials. Black walnut, for example, is known for its detrimental effect on nightshades (tomatoes, peppers, potatoes), but can also inhibit growth on other garden plants. Also be cautious when using grass clippings or other garden waste if you suspect that is has been heavily treated with chemical pesticides.

Cover Crops

Cover crops are commonly used on farms in between crop plantings to cover soil in the off-season, build soil structure, fix nitrogen, make soil nutrients more available, protect soil from erosion, suppress weeds, pests or disease, and build soil carbon. As a gardener, you, too, can also use cover crops with great results! To maximize your success with cover crops in a small space, however, it's important to know how best to manage them to avoid having them overwhelm your garden or become your top weed. In the following section, we will review the three main things to know before you start with cover crops (how to plant, maintain, and kill them), common cover crop profiles, and some creative ways you as a gardener can use cover crops in your landscape.

How to Plant, Maintain, and Kill Your Cover Crops!

Cover crops are generally pretty easy to **plant**. Often sprinkling or broadcasting the seed over the surface of the soil is enough, similar to how you would plant grass seed. To maximize germination and prevent animals and birds from eating your seeds, however, lightly rake or cover them with a sprinkling of soil or compost. You can seed cover crops anywhere you have bare earth: between or under existing garden crops (such as tomatoes, corn, or kale) or in rows or pathways. Or you can grow them mid-season in between the harvest of one crop and the planting of another on a freshly prepared garden bed.

Most cover crops are very **low-maintenance**, and will need little water or support during growth. When seeding them, try to time the planting, whether in spring, summer, or fall, just before a good rain (or consider watering them in) to help ensure consistent and even germination. When planting in the fall, be sure to plant early enough before a frost (at least 4 weeks) to help your plants get established. One easy way to extend the duration of a cover crop and keep the growth to a manageable height during the growing season is to mow them back. For grasses you might even considering mowing them several times to delay flowering and seed head formation.

Even though it may sound counterintuitive, a very important last step to making cover crops a success in your garden is know how to **kill them**. For annual cover crops or crops that will not survive the winter, it is fairly straightforward: either remove or cut them down to ground level just at flowering before they form seeds or let them "winter kill." For perennials and crops that are hardy enough to survive the winter (which has benefits to you as a gardener), you need more of a strategy to terminate them. One technique is to first mow or cut the crop low with a scythe or set of shears, let them dry out for a day or two, then actively disrupt the roots either by incorporating them into the soil with a garden hoe, solarizing them with a plastic sheet (a common no-till strategy) or using dark colored landscape fabric to block light and smother regrowth. If possible, wait 2 to 3 weeks before planting seeds (you can plant transplants directly) after you have incorporated cover crop residue into the soil, giving the residue a chance to break down.

Profiles of Common Cover Crops

There are many varieties of cover crops you can use in your garden. Here are just a few "profiles" of commonly-used cover crops you might choose for your garden. To choose what works best for your site, consider what time of year you have available to plant cover crops and what benefit you want from them: do you want them to prevent oxidation of soil, suppress weeds, increase soil organic matter content, fix nitrogen, or break up a hardpan?

Buckwheat. An excellent, warm weather cover crop that germinates easily in warm soils in early summer, buckwheat grows quickly (up to 2 feet tall), has little white flowers (which pollinators love) in as little as 30 days, is easy to kill, and suppresses weed growth. Buckwheat easily outcompetes weeds, and can be a good first "crop" to grow in an area you have just cleared of invasive weeds. To kill, cut it low to the ground at or just after peak flowering before seeds set or pull plants out manually (buckwheat is very easy to hand pull). Let plants dry on the surface of the soil as green mulch, add them to the compost pile, or chop up to be incorporated into the soil with a hoe.

Barley. A fast-growing grain that is often planted late in the summer, barley builds soil structure, and captures excess nutrients (such as nitrogen not used by a drought stricken garden or lawn in summer) from the soil, which could otherwise leach from the soil in fall and winter. It generally winter kills (assuming our winters are cold enough), and so provides a good mulch cover for the soil in winter and a "food" for hungry soil microbes first thing in the spring. If we have a warm winter or a hot spell that makes barley look like it is going to seed, simply mow or cut it back to help delay seed formation.

Clover. Plant clover in spring when the night-time temperature is above 40 degrees or in late summer or fall. Clover is a great living mulch, fixes nitrogen, and can help solubilize phosphorus locked up in the soil with the help of the soil microbial community. Dutch or New Zealand white clover, for example, is a low-growing perennial clover that can be established in permanent pathways or in rows between vegetable and fruit plantings as it tolerates being trampled. Like most clover, it can be helpful to mow it every so often to keep it from getting too tall or spreading ever so slowly into your garden. Red clover is a biennial tall pink or purple-headed clover that backyard animals and pollinators love, as is crimson clover, a more tender clover than can "winter kill" in New England, but will readily reseed itself if given the chance. Crimson clover has a strikingly brilliant red flower and can be a great choice planted underneath orchard trees or between rows of highbush blueberries, or can be paired with other tall cover crops such as rye, barley or oats. Crimson clover can also be undersown in vegetable beds with brassicas (like kale or broccoli) or other tall annual vegetable crops.



From left to right: New Zealand or Dutch White clover, Red Clover, and Crimson Clover.

Daikon Radish. Daikon radish, also known as tillage or forage radish is an annual cover crop that can be used to break up hardpans or compacted soils with roots that can extend as much as 3 feet deep in 60 days under the right soil conditions! It can also suppress weeds and readily improve the organic matter content of the soil. Not only are they also an excellent food, but as the radishes grow, they are very effective at naturally outcompeting weeds. In fact, when planted in the fall, the "weed suppression" effect can last through the following spring

season long after the radishes have died back. To prepare a completely weed-free, no-till-style bed for the spring, plant a stand of daikon radish in August or early September. When left to overwinter their leaves die back and protectively cover the surface of the soil for part of the winter while their deep root systems "melt" into the ground, leaving perfect holes in the ground for the early spring planting with no bed prep needed. If you are really thinking ahead, you might choose to sow the daikon radish seeds in rows, in the same spacing you hope to use for your spring crops such as onion starts. Holes left by deep-rooted daikon radishes can also help with drainage and deep water infiltration in winter and early spring.

Left: Daikon radish tops in fall. Right: Holes left by daikon radish in spring. Photo from Joel Gruver, Western Illinois University.

Hairy Vetch. A nitrogen-fixing legume with purple flowers, hairy vetch needs to be planted in late summer or early fall to get a good start on winter. With fairly winter-hardy roots, vetch will typically come back in spring, so it is important to think through how to terminate it and use it strategically. Vetch can be cut back around flowering in the spring just above the roots where it can be left to dry in place. It is an excellent option for building soil, protecting the soil in winter, fixing nitrogen, and growing your own mulch to benefit spring and summer crops. It can also be planted in early spring and is popular in combination with rye.

Rye. Rye comes in two types. Ryegrass is an annual that is a good quick-growing crop that will winter kill, while cereal or winter rye is a biennial that builds an excellent root system and needs to be terminated in the spring. Winter rye is one of the few cover crops that can get planted right up to the first frost date because it germinates well in cold weather, prompting the quote "it's never too late to plant a cover crop". Both types of rye provide a strong root system, which make them an excellent option for building soil and preventing erosion over the winter – even though the annual rye dies back, the residues remain to hold the soil in place. Winter rye, however, can be difficult to terminate in spring, especially if the stalks are allowed to grow tough as they get older later in the spring. Despite its challenges, cereal rye can be an excellent winter forage green for backyard chickens. In fact, leaving chickens on a planting of rye for extended periods of time can be a great way to kill it in preparation for spring or summer planting. Rye can also help suppress parasitic root nematodes and can be grown for all or part of the season to significantly reduce their numbers. Ryegrass is a good option for pathways and can be easily maintained with regular mowing.

Left: Ryegrass (less hardy annual). Right: Winter or Cereal Rye (hardy perennial) forming seed heads in spring

Oats and Peas. Oats and field peas get established best in cool weather, and are an excellent soil building duo that can be planted in the fall, around 6-10 weeks before the first fall frost date. They can last through winter until the spring (especially if you have cold hardy peas), provide great winter soil cover, fix nitrogen, and increase the soil's organic matter content. Plan to terminate the crop just as the peas begin to flower in the spring in time for spring and summer planting. This combination can also be planted early in the spring.

Creative Ways to Use Cover Crops in the Backyard

There are many excellent cover crops that you can use in your own backyard, but there is no need to be limited to how cover crops are traditionally planted on a farm scale.

For instance, try eating your cover crops by planting edible varieties such as fava beans, peas shoots, bush beans, daikon radish, spinach, kale, radish, milky oats (green oat seedheads used as a gentle medicinal tea), young grass shoots or turnips, all of which are an excellent addition to the garden or your plate.

Underseeding or interseeding cover crops below pre-established crops in your garden is another way to keep soil covered, maintain soil moisture, and not sacrifice your planting space to a non-edible crop. As a loose rule of thumb, just make sure your main crop is about 1/3 of the way through it's days to harvest before sowing cover crop seed to ensure your main crops have a good head start. Some examples might include: clover under kale, nitrogen-fixing vetch below corn, or heat-loving buckwheat in between rows of summer or winter squash.

Grow your own mulch by planting cover crop like oats, rye or barley which can be cut just before going to seed and laid directly on the ground or dried to be added as a garden mulch at a later time in the garden. Once dried these materials also add an excellent source of carbon to the compost heap.

Lastly, you could also try planting a cocktail of cover crops or mixing blends of many different types of cover crop seeds to increase soil microbial biodiversity belowground by increasing plant diversity aboveground. Studies through the USDA with Brazilian agronomist Dr. Ademir Calegari showed that using cover crops blends with at least five different plant families (they used grasses, cereals, legumes, brassicas and members of the beet family) made a dramatic improvement in soil structure and increased the release of beneficial compounds from these plants' roots into the soil. There seemed to be a unique synergistic benefit that only appeared when the complete diversity of plant families was used. You can even create cocktail cover crop blends that can be cut when young and eaten like a salad. See resources for the wide range of cover crop options available.

Biochar

Biochar is a powerful soil amendment that is produced by burning carbon materials at very high heat in the presence of very little oxygen. Biochar is different from the charcoal or wood ash in a fireplace or barbeque pit in that the process captures and reignites the off-gases of the burning process to burn at an even higher temperature, effectively capturing carbon in a very stable form. The burning process is called pyrolysis. Biochar has a complex microstructure that can hold water and air, and can host (and protect) a thriving community of soil microbes.

The most widely recognized example of biochar in agriculture is from the Amazon rainforest, where native peoples used it for centuries to enrich and build up the relatively poor jungle soils – they were able to support millions of inhabitants in a thriving agricultural system that continued to build up (rather than degrade) soil fertility each year. This soil is known as "terra preta", and even today, although no longer produced on a wide scale, is highly prized for its fertility and thriving microbiology.

Biochar can be made from "waste products" such as branch trimmings, woody crop residue, or invasive species removal and returned as a carbon-rich amendment to the soil. Prepared properly, biochar can boost crop yields, improve soil structure, and improve the soil's nutrient-holding capacity. Improperly prepared, however, it can stunt plant growth and negatively affect soil life in the short term. Here are some tips for preparing biochar for optimal performance. See resource section for more information!

Ensure Enough Moisture
When freshly made, biochar can be very dusty and dry and even repel water initially. Make sure you add enough water to avoid dust and make it easier to handle, but don't waterlog it so much that air is not available for beneficial aerobic microbes to colonize. The consistency should be such that it holds together loosely or in soft clumps if you try to squeeze a handful in your fist.

Use a Variety of Particle Sizes
Depending on where you get your biochar or if you make it yourself, you might need to crush it to ensure you get a wide spectrum of particle sizes. This is easier to do if you moisten the char first and helps you avoid either losing the valuable small-particle dust in the wind or breathing it in. Smaller particles have better surface area and by crushing large pieces you enhance the biochar's ability to have exposed pore spaces which can hold water, provide homes for soil life, and hold onto nutrients. Some biochar will come to you pre-crushed so you may not need this step.

Add Minerals
Biochar, like organic matter in the soil, has an enormous capacity to hold positively- and negatively-charged nutrients, making biochar an excellent medium for holding nutrients in the soil (especially micronutrients or trace elements referenced in Chapter 1) that might otherwise wash away. This unique capacity, however, also means that biochar can effectively suck or absorb nutrients from the soil initially if applied in its raw form. That is why adding mineral blends and trace nutrients to biochar is a great way to not only to incorporate the nutrients slowly and safely into the soil community, but also to prevent the potentially negative, initial impact of raw biochar on the soil.

Add Soil Life
Lastly, after biochar is hydrated, crushed and remineralized, make a point of ensuring you add life to it before adding it to your soil. You could do this in a number of ways either by adding an inoculant (as referenced in Chapter Two) or incorporating your biochar into your compost pile before applying it. The soil life will work with the nutrients and help make them more "bioavailable" for plants and also proliferate in the tiny pore spaces available in the biochar. That way, when you apply biochar to your garden or yard, you are delivering an amendment that is teeming with life and holds a balance of air and water, and a soil biology that is more than ready to work with the plant community to exchange valuable soil nutrients for plant sugars – a win-win solution for everyone involved.

Chapter Four
Capture Every Drop of Water

On a very basic level the key is carbon-rich soil. Often, what is considered a water scarcity problem is really an inability-to-keep-water-on-the-land problem... It's an amazing sponge. When we lose that sponge, we have landscape degradation.

— Judy Schwartz, author of
Water In Plain Sight:
Hope for a Thirsty World

Building carbon in your soil prepares the land to receive rainwater like a sponge. At the same time, keeping moisture in the soil helps the soil-carbon-building process. In the soil, water and carbon go hand in hand. How effectively your land captures rainwater can be an indirect measure of how well you are building organic matter, establishing a stable soil biology, and creating stable soil carbon. Conversely, your organic matter is a predictor of how well your soil will capture and hold water.

Building organic matter in the soil builds capacity for the soil to hold water. Complex carbon is the glue that holds together soil particles and bridges soil structure, creating the millions of stable pores that make the soil sponge-y. Good soil structure has many millions of pore spaces of varying size for simultaneously holding water and maintaining air and living space for soil biology.

According to NRCS, with every 1% increase in organic matter, an acre of land will be able to hold 20,000 more gallons of water. If the average yard were 1/5 of an acre, then a 1% increase in organic matter would mean that a yard can absorb and hold roughly 4,000 more gallons of water – the equivalent of 72 standard 55-gallon rain barrels! In other words, the yard would be able to infiltrate (absorb, pulling the water down into it's structure) and store a more intense rainfall than it could previously.

A resilient soil structure will act as a sponge, absorbing water quickly while keeping its structure intact, and staying moist for longer into the next dry spell. As New England will likely continue to experience drier weather interspersed with heavier rains, this resilient soil structure is even more important. In the summer of 2017, for example, one Boston rainstorm dropped close to 2 inches in a single hour, triggering flash flood warnings and washing away much valuable topsoil. Two inches of rain over the average yard is equivalent to just about 10,000 gallons of water. If the yard has a soil organic matter content of say, 2% (not uncommon), then it could, in theory, hold up to 8,000 gallons of the 10,000 that fell. However, if the yard is sloped, the soil is already saturated, and/or the soil is bare, the water will run off the surface with little time to soak in. However, if the soil organic matter is even slightly higher and the soil surface is protected with living plants or mulch, the land will have more capacity to absorb water like a sponge, absorb it more quickly, and prevent the resulting erosion and possible flash flooding.

Make it your goal to slow down and capture every drop of water that falls in your yard and protect any bare soil from the powerful (and surprisingly destructive) impact of raindrops. This chapter shows many creative ways we can work with water to build soil carbon, fuel microbial life, protect our soils and waterways from being overwhelmed in heavy rain events, and create a healthier, more resilient garden.

Rain barrels

Rain barrels are a great way to store water physically on your land for later use, especially runoff from a roof or other structure. If you are beginning with a soil that has very low organic matter (and consequently low water-holding capacity),

consider rain barrels or other water-holding tanks to temporarily hold more water on site – water, which might otherwise leave the site as runoff or through drainpipes during a rainstorm. This will give the soil more time to absorb the rain, and you more time to help build up the organic matter content in your soil. Many city and town governments as well as local watershed associations provide resources and recommendations for people in their regions, often including subsidies for acquiring rain barrels.

The Mt. Auburn Cemetery in Watertown, MA collects the majority of its water for irrigation from rain barrels off of the roof of its greenhouse. Each barrel is connected to the next via plastic tubing. This means when one rain barrel is full, it overflows into the next barrel, and then the next. It's a clever system for capturing a large amount of rainwater for later use. Photo from Paul Kwiatkowski at Mount Auburn Cemetery.

Mulches and Ground Covers

Mulches and plants used as living ground covers are very helpful in protecting the soil from the impact of rain. Rain drops hit bare ground with a surprising amount of force, dislodging and washing away soil particles, destroying the structure at the surface, and creating a crust that can become less permeable to water infiltration over time. The soil can thus become more compacted as the soil dries more quickly and oxidized more carbon into the atmosphere. Mulches and living ground covers diffuse the intense impact of rain and prevent erosion. Straw, hay, corn stalks, leaves, cocoa hulls, and wood chips not only keep the soil surface protected during a heavy rainstorm, but can also become saturated themselves, and hold moisture at the surface for extended periods of time after a rain. Both mulches and living plant covers will increase organic matter content over time, further increasing your soil's ability to absorb more water more quickly. Gravel, pea stones, and rocks will not increase organic matter, but can still be a valuable protection for soil in places which might get extra heavy flow during rainfalls, such as under the eaves of roofs, mouths of gutters, or the edges of buildings.

If you find you have soil that has been left uncovered, bare, and has developed a crust from repeated battering by rain, wind, and sun, consider reseeding it by making your own clay seed balls (sometimes called "seed bombs") with a technique popularized by Masanobu Fukuoka, a Japanese natural farmer and philosopher who wrote *The One-Straw Revolution* and *Sowing Seeds in the Desert*. The clay protects the seeds from being eaten by animals, from drying out during germination, and allows the gardener to easily sow seeds with minimal soil disturbance or onto land where you may have little access (such wildflower seed mix across an abandoned lot). See resources for more information on making your own seed balls and other methods to encourage living and non-living soil covers.

Rain Gardens

Rain gardens are gardens that can capture and sink larger amounts of rainwater, often built in a depression or on a slope to capture the off-flow of gutters or paved surfaces. Long-lasting rain gardens are often full of a variety of hardy, deep-rooted, or otherwise resilient plants that improve water infiltration and are able to withstand temporary flooding. Rain gardens can be lined with gravel, mulches, or other materials to help keep the soil in place and allow water to slowly infiltrate. Mini rain gardens can be

established at the base of gutters, or under the overflow of roof edges to prevent soil erosion and slow the water down. They can be as simple as a depression lined with gravel under a gutter and planted with something hardy and sweet-smelling like mint.

Lawn Diversity

How often after a rainstorm have you seen a lawn that flooded, holding pools of water for extended periods of time, but then became bone dry a few days later when the water finally disappeared? The grass in a typical lawn has very shallow roots, often with heavily compacted subsoil just a few inches below the surface. To improve the soil, incorporate into the lawn several varieties of grass, especially ones with deeper roots, and other plants such as a low-growing, nitrogen-fixing clover like Dutch white clover (which used to be included in most all lawn mixes until broadleaf herbicides became popular) and more drought-tolerant plants such as various sedges. If the soil is extremely compacted, you might need to use a broadfork or other implement to loosen the soil and allow air, water and eventually roots and soil life to penetrate into the subsoil to regenerate good soil structure and organic matter content in deeper layers. Consider spraying a compost tea or adding beneficial soil microbes at the same time as aerating the soil to maximize soil building to hold both air and water.

Hugelkultur

Hugelkultur is a gardening technique that involves the burying of logs or woody materials, as well as branches, leaves, compost, sod, or garden debris under a mound. Sepp Holzer, an Austrian permaculturalist, popularized the method, which had been practiced for years in Eastern Europe. The technique mimics a fallen tree in woodland settings that breaks down and acts as a nursery for young trees and other plants as it breaks down, becoming a home for beneficial soil fungi and other microbes, as well as slowly releasing water like a sponge. Hugelkultur mounds can be used as swales (see next heading below) to redirect rainflow, can be planted into directly, and are a good way to use "waste" materials. As mounds they can maximize vertical planting space, or can be dug to be flat with the ground. See resources for more information.

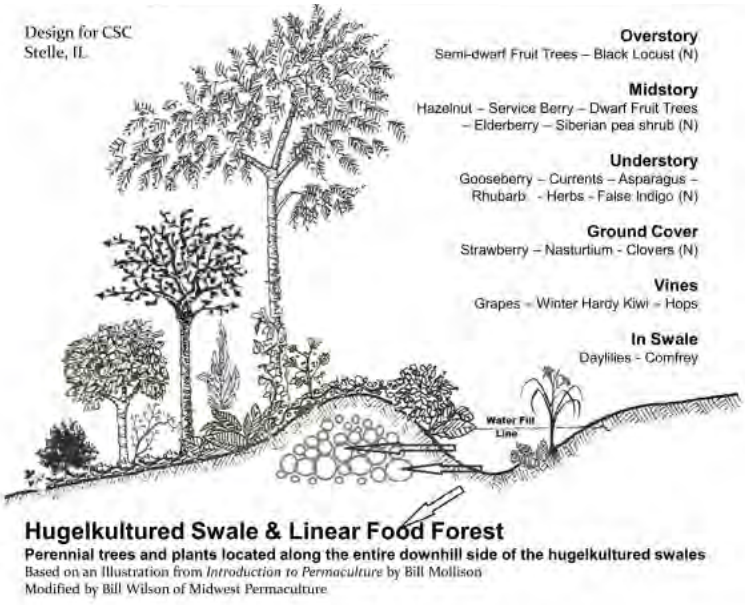
Hugelkultur gardens are a great way to rapidly build water-holding soil that releases nutrients slowly over time. They can be good for areas that receive little rainfall, have no access to irrigation, or they can be built to redirect rainflow as a swale along a contour. Picture from Inspiration Green and Permaculture Magazine.

Swales and Check Dams

Swales and check dams are structures created to redirect the flow of water, slow it down, and give it time to infiltrate into the soil. Swales are mounds or depressions, often situated along the contour on slopes to redirect the flow of water and slow it down, sometimes designed to capture the water in small pools for it to slowly infiltrate into the soil. Check dams are most commonly seen today along roadsides and construction sites to mitigate runoff, often as evenly spaced straw bale barriers or shallow mounds of gravel. They are shallow, simply built, water-permeable structures laid perpendicular to the flow of water down a depression or erosion pathway.

Both swales and check dams can have an enormous impact, very effectively slowing

water to let it gradually reabsorb into the landscape and build soil behind it. In the backyard landscape, they are often small and made from local materials such as soil, branches, loose rocks, straw bales, gravel, slate, river stones or other similar materials. With an eye to design, they can be a strikingly attractive feature to the landscape with an added purpose. They can also be used to creatively "water" plants such as shrubs, young trees, or fruiting crops, which can be planted directly into a swale or behind a check dam. Over time, the plants' roots can help stabilize these structures with their root systems and help absorb the water captured.



Here is an example of a swale helping to water this edible food forest by capturing water running down the slope instead of letting it wash downhill.

Wood chips inoculated with edible wine cap mushroom spawn help fill an erosion gully like an extended check dam (right). Note that this method is not meant to stop water flow, but merely slow it down. Fungi have the incredible capacity to break down pollutants and filter nutrient run-off, and in this case, produce a healthy harvest of wine cap mushrooms (left). Picture from project by Field and Forest Products.

French Drains

French drains might be an interesting option if you are trying to redirect water from a particularly wet area of the yard (such as under a gutter) to an area that is dry (under a tree, or towards an extensive root system or garden). Dig a ditch to your desired area, fill the depression with large sized gravel, sand, or similar well-drained material, and lightly cover the surface with soil. Consider planting a hardy groundcover or even grass over the surface to make it nearly invisible if that is your preference. French drainage ditches are a proactive strategy to both avoid flooding or "sheet" erosion (where the water washes across a soil surface) and redirect the flow of water to where it is needed.

Soil Amendments

Amendments can be a great way to jumpstart the biology and build organic matter by boosting the water-holding capacity of your soil, especially in severely compacted or degraded landscapes. Amendments such as biochar and perlite (a lightweight, white volcanic rock often used in potting mixes), for instance, have tiny pore spaces that are good at holding water to slowly release it to the soil over time. Other amendments like kelp, cocoa hulls, or coconut coir will saturate or swell with water, eventually breaking down to become part of organic matter content and improved soil structure. You might also consider materials such as peat or sphagnum moss, polymers (like the "agri-gel" often used to help keep water near the roots of young transplants), expanded clay, and vermiculite, but do be cautious about sustainability when sourcing these ingredients, especially peat moss. Amendments might be a tool you use temporarily to help soil rebound quickly and help microbes re-colonize land after a major stress event such as drought, flooding, or tillage. In addition to providing pore space for water, biochar can help bind up harmful toxins in the soil that prevent plant growth, and has even made it possible to

grow plants in extreme cases where even weeds are unable to grow, such as soil contaminated with a chemical spill or the waste from mining operations. Amendments are primarily meant to help the soil building process, but be careful not to depend on them alone. They are one tool of many in the toolkit.

Super Efficient Irrigation Systems

Water access can be a challenge in many gardens, especially those in the city where water costs may be high and quality may be in question. When soils dry out, the soil biology is hindered. Many cultures around the world have developed super efficient irrigation techniques to farm and garden in arid climates (having success with as little as 3 inches of rainfall per year!) and keep the soil moist around plant roots. Even though New England has a much wetter climate, there are still many instances where water can be scarce, too expensive, or inaccessible, such as with an unexpected and extended drought, growing under cover (hoophouses, cold frames, and greenhouses), growing in containers, or with plantings on rooftops or in gardens that may not be close to a water supply. See the resource list, particularly the book *Gardening with Less Water*, to learn more about ollas, clay pipes, drip irrigation, soaker hoses, tree pipes, wick watering and other super-efficient irrigation systems.

"Ollas" before they are buried in the garden. Ollas are water-permeable clay pots that are buried deep in the soil. They slowly allow water to seep out the walls and often have a tile or flat stone as a lid which sits at ground level. They are incredibly simple, but can outcompete drip irrigation systems in both the amount of water used to irrigate a crop and by getting the water deep into the ground where the plant roots are located, helping to keep soil biology alive and well during dry spells. Picture from Native Seeds/SEARCH.

Homemade "ollas" or clay pot irrigation capsules connected to an irrigation line. Not only can this system run off brackish or salt water (the clay acts as a filter), but these systems can reduce water usage by up to 1/10th of that of regular drip irrigation systems. A reservoir can be set up to automatically refill buried homemade porous clay capsule irrigation units like those pictured above. Photo by Darrol Shillingburg.

Permeable surfaces

Finally, consider replacing an impermeable surface with a permeable one. Replace asphalt or cement with gravel, crushed shells, tiles or slabs with room for water to infiltrate. Did you know, for instance, that there is now a type of asphalt that can rapidly absorb water? Or if your roof allows for it, consider planting a green roof to absorb and slowly release the water that falls on it. Find creative solutions to slow down water and capture it even on seemingly impermeable surfaces. The *Charles River Watershed Association* is an example of a good resource in the Boston area (with ideas that can be applied in many cities), advocating for green infrastructure to allow our rivers, streams, and waterways to function in an ecologically healthy way in the midst of our complex network of cities, towns, and often over-paved world.

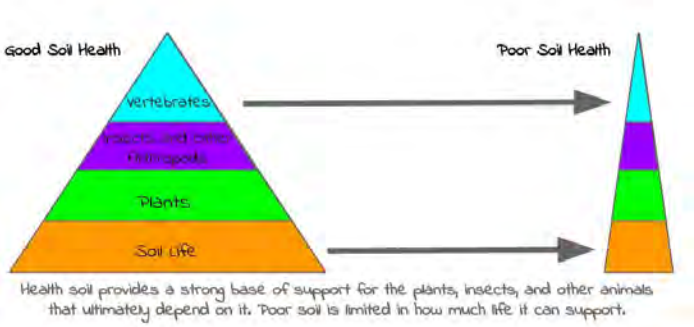
Chapter Five
Working Within an Ecosystem

Long live the creepy crawlies, the bugs, the tiny wigglers and wrigglers, the minuscule parasites and nematodes, the mites and oribatids and all the myriad life forms that buzz, crawl and throb below our feet. Most have barely been given a second thought by science, but biologists now think that these mostly named creatures make up the beating heart of the biosphere and that the fate of all life may depend on the wellbeing of their fragile worlds.

— John Vidal, *The Guardian*

When we think of carbon, it is so easy to think of it as an element or material that is separate from us. Yet living things, whether they are plants, animals, insects, humans, or microbes, contain carbon. A massive amount of carbon exists circulating as living organisms as plankton in the oceans, pigeons in the skies, fish in the sea, and within bugs and plants that feed the many birds and mammals. This type of carbon source is far too difficult to measure and is not a stable source carbon as living things grow and die constantly. However, having a strong, biodiverse ecosystem not only requires carbon, but also increases the land's resilience and capacity to withstand extremes and ultimately to "hold" carbon, too. By providing habitat, a healthy mix and variety of plants and water, and actively working to build a healthy soil, you are not only building soil carbon, but "building" carbon and resilience within the ecosystem itself.

Think of soil health and the soil food web it contains as the base of a pyramid. Plants are on the next level as they depend directly on the soil and the microbial life in the soil, which recycles, binds, and unlocks nutrients



constantly. The next level is insects and other micro and macro arthropods. Although we often think of them as pests, this category of wrigglers, flyers and crawlers plays a crucial role in the landscape, not only as a major food source for countless animals, but as decomposers, shredders, recyclers and ecosystem balancers of our planet. These foundational layers (the soil, plants, and bugs) ultimately support animals, including us.

Working with Plants and Fungi

Plants and fungi are key players in building soil. Think about how you can fully utilize them in your landscape to keep the soil covered for as much of the year as possible, encourage soil biology at depth, grow at multiple heights, and facilitate the decomposition process. Here are a few ideas.

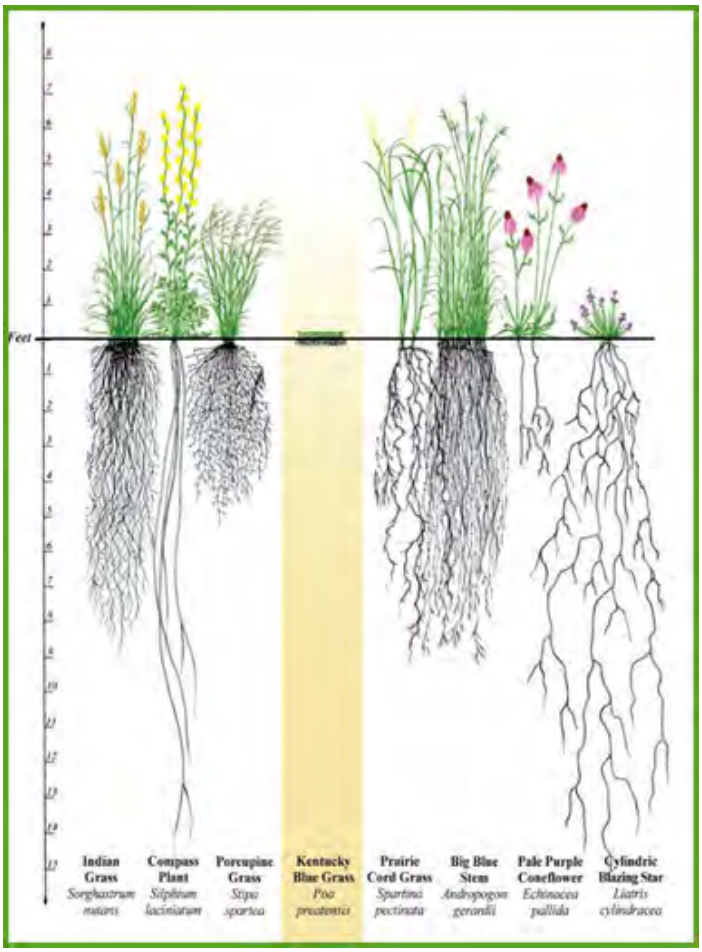
Consider Perennial Crops
Perennial plants are those that last multiple seasons, as opposed to annuals, which must be reseeded or replanted each growing season. This means they are able to feed and foster microbial communities in the soil with living roots in the soil year round, helping to build soil communities and ultimately sequester carbon both in the soil and in their own biomass. Though agricultural systems rely heavily on annual crops, many perennial crop equivalents are available. In different cultures around the world perennial crops are used much more widely as staple crops. Perennial crops can take advantage of the entire growing season, as they don't have to extend energy to fully build up their entire

root and leaf system like annuals do. They can often produce much earlier in the spring (think asparagus spears, fiddleheads, sorrel, and ramps emerging from cool spring soils), and increase their yields over time as they get established in the right conditions. They can complement other perennials growing beside them that might take advantage of a different part of the season or growing conditions. Perennials can take the forms of vines, shrubs, trees, bulbs, tubers, grasses, and groundcovers.

Some excellent perennial crops include pawpaws, currants, American persimmons, grapes, blueberries, cane fruits (raspberries, blackberries), stone fruits (peaches, cherries, plums), pome fruits (apples, pears), hazelnuts, walnuts, chestnuts, asparagus, rhubarb, sea kale, ground nuts, perpetual sorrel, sunchokes, chives, thyme, oregano, bamboo, and air potato, just to name a few. There are many resources for planting both common and unique edible perennial fruits, nut, and vegetable crops. See the resources below for plant ideas and where to source some of these unique crops and how to learn more.

Work With Deeper Roots

The deeper the roots, the further the soil food web extends, and the more air, water, and carbon ultimately can penetrate deep into the soil, building better soil structure and accessing nutrients deep within the soil profile. The deeper our plant roots, the more we can fuel the liquid carbon pathway between plant roots and soil microbial community to build soil carbon. Did you know that Kentucky Blue Grass, the most common grass now used in lawns, has a root depth of only a few inches? This means that even if a lawn is managed organically, to actively encourage a healthy soil biology, its capacity to engage with the soil community and exude carbon in the form of sugars through its roots only works in the top few inches of soil. Often lawns will have a compacted layer just below the root zone where little soil is being built. Choosing plants with deeper roots, incorporating a variety of plants (such as seeding clover in the lawn or adding several grass species), or using plants with deep roots along the edges of your yard or garden can improve soil function and carbon sequestration at depth. Ultimately this will promote a healthier landscape that doesn't easily flood when it rains and or get bone dry without moisture for a few days.



Kentucky Blue Grass is the most commonly used variety turf grass, yet has a relatively short root depth compared with other native grasses and prairie species. Consider planting a diversity of more deeply rooted plants in your yard to maximize their impact on the soil. Photo from Conservation Research Institute.

Incorporate Mushrooms
Partner with the decomposers in your ecosystem, and consider incorporating mushrooms and beneficial fungi more actively into your yard. Fungi have the unique capacity of being able to break down lignin, cellulose, and other hard-to-digest materials. You could do this passively by simply making sure you have food for fungi such as woody or carbon-rich materials in your yard like wood chips or shredded leaf mulch. Or you might consider actively engaging in the process and inoculating the space with edible mushroom varieties such as oysters, shiitakes, lion's manes, maitakes, morels, winecaps, or chickens-of-the-woods. Mushrooms can be grown indoors or outdoors. The leftover mushroom "substrate" or "waste" after you harvest your mushrooms from a more intensive, indoor operation can even be used as a slow-release fertilizer in the garden or compost pile. It contains enzymes that literally rip apart certain pollutants like oil and some pesticides. You can inoculate logs, beds of woodchips, straw bales, or stumps (to name just a few options) with mushrooms of your choice to get a healthy crop of mushrooms. This will rapidly decompose yard waste, and makes a beautiful soil amendment. There are many wonderful resources for how to grow and incorporate mushrooms into your landscape – see the resources below.

Consider "Agroforestry" in the Backyard
In agricultural systems, agroforestry is the intentional combining of agriculture and forestry, but for a backyard, it could be as simple as intentionally adding woody plants, shrubs, and trees to a predominantly annual landscape. Some of the same techniques that add so many long-term benefits to agricultural landscapes can be implemented in a yard or garden on a much smaller scale to prevent erosion, reduce nutrient run-off, act as long-term carbon reservoirs, provide wildlife and pollinator habitat and keep living roots in the soil year round to feed the soil microbiology. Specific agroforestry techniques include: windbreaks, riparian buffers (to protect waterways), alley cropping (planting rows of woody perennials between annual crops), silvopasture (integrating a tree crop with animal pasture or a forage area), forest farming, and multi-story cropping systems (using multiple heights of plants).

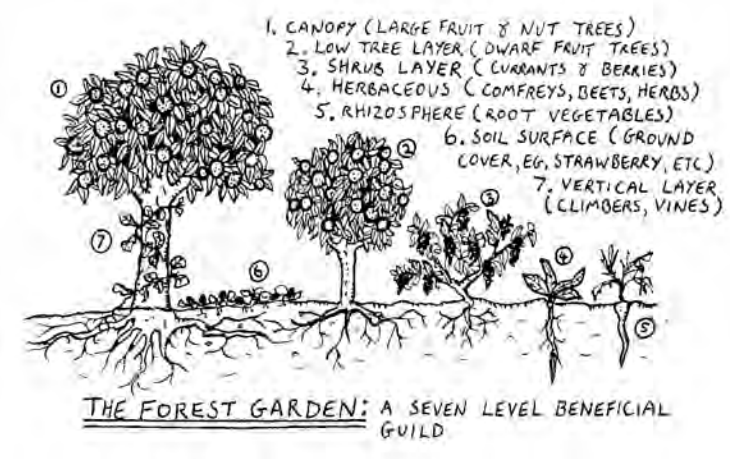
Windbreaks. The most striking examples of **windbreaks** are probably on farms in the Great Plains where strong winds routinely whip across flat farm fields, easily taking moisture and valuable topsoil from the landscape. Rows of trees block and buffer the wind, adding immediate benefits to the fields, as well as providing a potential timber, fruit or nut crop in future. Home landscapes and gardens can also benefit from windbreaks. For example, a hedgerow of woody perennial plants, such as hazelnuts, currants, highbush blueberries, raspberries, witch hazel and bush cherries, could provide an excellent harvest and pollinator habitat, and could block prevailing winds that come towards the garden across lawns, between buildings, down a slope or off the water. Carefully planned windbreaks can also make a notable cost savings in energy efficiency in buildings. When planning windbreaks, be particularly mindful of the eventual height of your rows, (especially if planting on the south side) so as not to eventually shade your garden.

Riparian Buffers. Riparian buffers are similar to windbreaks: often linear plantings of woody perennials grown in a riparian zone or area around a body of water, river, or wetland. Deep-rooted perennial plants can help stabilize the area at a water's edge, protect the watershed from nutrient and chemical runoff, provide valuable habitat, and build soil structure to reduce overflow or flooding over time. If you are planting in very wet areas or floodplains, consider species that can thrive in wet environments, add wildlife benefits, and also perhaps give you a harvest such as American highbush cranberry, cattails, pussy willows, or willows.

Alley Cropping. Alley cropping is a method for planting edible or useful hedges or trees between rows of annual crops. In a small garden or yard, this could mean interspersing perennial crops like herbs, raspberries, strawberries, or rhubarb, alternating with rows of vegetables to stabilize the soil. Another interesting application is growing rows of woody trees or shrubs that can be "coppiced" or cut to the ground regularly such as hazelnuts, mulberry, or non-invasive bamboo. These coppiced crops can be excellent forage for backyard animals, and provide edible nuts, leaves or shoots. They can also be used to regularly grow your own supply of garden stakes, stabilize a slope, or chipped to create your own source of ramial wood chips.

Silvopasture. Silvopasture is the combining of tree crops with pasture. In an agricultural setting, the wide spacing of tree crops not only gives trees plenty of space to grow, but allows enough sunlight to the understory to support pasture grasses below. An easy-to-visualize, large-scale example might be cows grazing under a pecan tree orchard. Even though this technique is most easily visualized on a large scale, home gardeners can use the same principles with a backyard flock of chickens or ducks in a small patch of woods, a newly planted backyard orchard, in a backyard planting of trellised grapes, or between rows of raspberries. Chickens and ducks are great at eating garden pests and dropped fruit as well as adding fertilizer through their manure, and they make a great autumn clean-up crew. Rabbits or goats might also be good candidates for other backyard-friendly silvopasture-like models. Goats, in particular, are excellent at eating unwanted aggressive or invasive species like garlic mustard, buckwheat, poison ivy and bittersweet. As with any silvopasture-type or rotation model, the key to success is to watch the animals and rotate them often if the land becomes stressed, to give plants a chance to recover.

Forest Gardening and Multi-story Cropping Systems. Mimicking forests by using multi-story cropping systems is another strategy that can work on a large or very small scale. In many cultures around the world (especially in tropical climates), this is an ancient, and still very common farming method. The end result might be a landscape that looks much like a forest, but is also managed to encourage production of plants to be used for food, medicine, fiber or fuel. Of the many ways you might think of to try this system in your own backyard, one strategy if you want you landscape to resemble more of a forest (even with a single tree in your yard) is to mimic your local, native biome. Take time to identify edible and useful plants that grow easily in your region and might be a natural fit for your own forest landscape. The understory will most likely be shade-tolerant plants, which could include ramps, fiddleheads, blueberries, goldenseal, ginseng, and edible and medicinal mushrooms, to name just a few. A second strategy looks less like a forest and works with multiple heights, mimicking the succession from meadow to forest by incorporating more sun-loving plants and annuals. Rows containing trees, shrubs, vines, or taller plants alternate between rows of annuals, grasses or more actively cultivated strips of garden areas.



Working with Animals

Animals of all sizes are key players in developing your backyard ecosystem. From insects to goats, think of ways to encourage animals and the many ecosystem services they bring to the landscape.

Work with Beneficial Bugs
Too often when we think of insects and other bugs, the pests or problem species come to mind like mosquitoes, houseflies, aphids, and destructive garden caterpillars. Yet there are a whole host of beneficial insects that we heavily rely on in our world that are rarely acknowledged for the wide range of ecosystem services they perform. We owe these beneficial bugs a lot for the services they provide around the globe and in our own backyards. Find ways to support this tiny, yet invaluable workforce, to help both your soil and garden to thrive.

Predatory Insects. There are many allies that can be encouraged, attracted or introduced into the garden. They have wonderful names like Assassin Bug, Twice-Stabbed Lady Beetle, Minute Pirate Bug, Six-Spotted Tiger Beetle, Praying Mantis, Adventurous Jumping Spider, and Mealybug Destroyer. Get to know some of the beneficial bugs in your own yard that help keep pests in check. These predators clear out pests in the hard-to-get-spots under leaves, in flowers, and in between new leaf buds much more effectively than we humans can.

Be mindful that if you spray the garden to keep down pests (even with organic sprays), these remedies often knock down populations of beneficial insect predators along with pest populations. Ironically, this actually gives the pests the upper hand for a time as they can rebound rapidly with no predators to keep them in check, while predatory insects take much longer to get their populations re-established. In this instance, trying to manage pests ourselves can often increase overall pest pressure or require us to commit the time and money to spraying more regularly or aggressively in order to compensate for a lack of insect predators. You can avoid getting into this cycle by supporting your beneficial, predatory insect populations. Meanwhile, overlook small populations of pests or minimal pest damage that isn't affecting the harvest, and get to know some of these allies in your yard.

You can help support many of these beneficial bugs by adding pollen and nectar sources specifically for them in your yard. Flower species with clusters of tiny flowers such as Queen Anne's lace, fennel, clover, yarrow, buckwheat, asters, tansy, sweet alyssum, sunflowers, and the flowers of culinary herbs are all examples of excellent beneficial insect food. Consider planting a pollinator hedge or strip of plants near your garden.

Lastly, you might consider physically introducing beneficial insects to your yard to combat a specific pest. These beneficial insects often can be mail-ordered, then released or otherwise established directly in the garden. Some examples include predatory nematodes, lacewings, ladybugs, and praying mantises, among others. Buying in beneficial insects can be a great way to help combat pests when growing in the off season in a greenhouse, hoop house, or under a cold frame before beneficial bug populations get a chance to get established. They can also be a way to actively disrupt a pest's life cycle; for example, predatory nematodes get watered into the soil to suppress root nematodes or to attack pest larvae pupating in the soil.

Earthworms and Other Soil Builders.
Encourage soil builders like earthworms into the garden. Earthworms, in particular, are excellent soil builders and natural tillers. They speed up the composting process, encourage deeper water infiltration, and are indicative of a thriving soil food web. Consider having a vermicompost bin, or worm composter. These composters can be

kept indoors and are often populated by a "red wrigglers", a reddish colored worm that works very efficiently at composting at room temperatures and is commonly found at fishing bait and tackle shops. Worm castings (a fancy name for worm poop) are rich in nutrients and high in beneficial bacteria counts. Outdoor earthworms love a moist and protected cover over the soil, and thrive under mulches like cardboard, hay, and shredded leaves, or when compost is added directly to the surface of the soil. They will often find an outdoor compost pile and will help speed up the composting process.

Soldier flies and their funny-looking segmented larvae are also great additions to the compost pile. Unlike houseflies, which are pests that can spread disease, adult soldier flies have no functioning mouthparts (though they can drink water), and their larvae are just as effective as red worms at speeding up the decomposition process in a compost pile. The larvae can also be actively raised specifically as a protein-rich feed for chickens or fish.

In addition, you might also see tiny red mites, springtails, pill bugs, and all manner of micro-arthropods in the compost pile or in the soil. This tiny workforce helps to recycle, shred, chew, and ultimately break down carbon-rich materials, making it much easier for soil microbes, such as bacteria and fungi, to more quickly turn it into a rich compost or well-aerated, beautifully-structured soil.

A composting ally in the garden, the adult Black Soldier Fly.

Pollinators. When we think of pollinators we often think of honeybees and the services they render us by pollinating our crops such as apples, peaches, and blueberries. Far less often do we know or think about our native pollinators including solitary bees, bumblebees, moths, butterflies, wasps, and even beetles, and the ways they improve ecosystem health all around us. Pollinators work continually behind the scenes to improve seed and fruit set in our landscape and pollinate a huge variety of plants (entire ecosystems, not just our garden fruits and veggies), ultimately making it possible for those plants to build soil all around us. The success of many plant communities in our landscapes often requires native pollinators, many of which have developed specialized relationships with certain plant communities. As much as honeybees have been impacted by agricultural and environmental degradation, so much more have our native pollinator populations suffered without us even realizing it. Make a point of supporting the pollinators in your landscape as an indicator of the health of your backyard ecosystem, for a richer and more productive garden, and to encourage a diverse landscape that is further equipped to support soil-building processes.

To support pollinators, especially our native species, plant flowers throughout the year with staggered bloom times. Put a special emphasis on blooms in early spring and in late summer or fall—both times of year are particularly hard on pollinators. See the resources list for lists of recommended plants. Use organic pest management strategies and if using an organic product that could harm pollinators (check the label), avoid spraying flowers or applying when pollinators are most active during the day. Practice no-till techniques to avoid disturbing ground-nesting solitary pollinators that spend much of the year underground such as the Digger Bee or one of the many varieties of our native bumblebees. Consider timing successions of summer blooming cover

crops like buckwheat to maximize blooms for pollinators in between or underneath plantings of garden vegetables.

Take some time to get to know some of the amazing native pollinators near you like the green-eyed Long Horned Bee, the exceptionally fuzzy yellow Squash Bee, the beautiful little metallic blue Maine Blueberry Bee, and the incredible variety of bumblebees whose queens emerge first thing in the spring. Many of these bees are solitary, not aggressive, and perform a wide range of ecosystem services, which we are only now beginning to fully understand.

Left: The native Squash Bee inside a squash blossom. These bees wake up earlier than bumblebees to pollinate squash blossoms at the peak of flowering. Photo by Allison Houghton.

Right: There are many types of Long Horned Bees, so named for their long antennae. If you have sunflowers in your yard, you might just catch a glimpse of them flitting back and forth.

Work with Small-Scale Livestock

Animals are crucial parts of the ecosystem, cycling nutrients, keeping the ecosystem in balance such as by eating pests, "pruning" or by "mowing" to promote new growth. To truly use backyard animals in the landscape proper, however, management is key to improve the health and vitality of a landscape instead of degrading it, especially in a small space. Allowing the land to rest and recover is crucial. Backyard animals such as chickens, ducks, rabbits, goats, or even fish all can have their benefits, adding fertility and helping to build soil carbon in the landscape, but only if they support the existing plant growth and seasonal cycles. Animals benefit from a well-managed landscape with high quality forage.

There are many clever methods for managing animals on even a small scale. Consider growing your own forage (an edible hedgerow of mulberry or basswood, that you frequently cut or "coppice", for example), collecting forage from your neighborhood (downed branches, acorns, or leaves are a great food source for goats), or growing your own feed (such as high protein soldier fly larvae or composting worms which both aid the composting process and are excellent food for chickens). There are many options, but it is important to think through the time and resources required to make it a sustainable operation for you and your land.

If you have the space, you may also consider rotating the animals frequently (once a week or even every few days) across your landscape, only allowing them to partially graze the top half of plants and never to eat down to the root systems. Allow them back onto the land when the plants have had time to recover. This could look like a mobile chicken or rabbit house unit or rotating paddocks. It's important to find ways to make rotational management easy for you to implement consistently as it can easily degrade the land if the animals are left too long in a single area.

Another strategy, maybe more realistic for a small space, is to keep the animals in a single part of the yard for most of the year, and only occasionally or briefly rotate them through the rest of the yard. This second strategy recognizes that they can and likely will degrade that smaller piece of land they are more permanently settled on, but it also allows you to maximize the benefit of having animals for a short period of time on other parts of the yard.

You can also take precautions to minimize soil degradation on a more intensively used piece of land. For instance, you can repeatedly add layers of mulch throughout

the season to cover and protect bare soil; redirect water run-off either back into the soil or towards another part of the garden that needs it; reduce soil compaction by using buried biochar, gravel or other permeable materials; or establish hardy perennials and groundcovers at the edges of the enclosed areas.

Create Habitat

As Doug Tallamy writes in *Bringing Nature Home: How You Can Sustain Wildlife with Native Plants*, "for the first time in history, gardening has taken on a role that transcends the need of the gardener. Like it or not, gardeners have become important players in the management of our nation's wildlife." He goes on to say that native plants in particular support native insects, arthropods and microbiology that in turn support birds and animals. We see a striking example of this when we compare our native oaks (which can support over 500 species of caterpillars) with non-native gingko (which support up to 3 species of caterpillars). Many songbirds and other animals rely solely on caterpillars to raise their young. For instance, to raise a single clutch of chickadees, the parents must collect 6,000 – 9,000 individual caterpillars. The young chickadees can't digest seeds or fruit, and if they can't get enough caterpillars, they die. Every year, the US North American Bird Conservation Initiative issues a State of Birds Report, and in 2016, they reported that a full third of all bird species in North American need "urgent conservation action." Additionally the total number of birds has declined by over 40% in the last half century. It is an incredible loss of biodiversity, and in very simple terms, a loss of carbon collectively "stored" in our living, breathing ecosystem of birds, bugs, and wildlife. As Tallamy states,

> *It is now within the power of individual gardeners to do something we all dream of doing: to make a difference... the "difference" will be to the future of biodiversity, to the native plants and animals of North America and the ecosystems that sustain them.*

One of the biggest things you can do for your landscape is include native North American plants in the yard. Invasive or ornamental plants support many times more species on their original home continents than they do in North America, even though these species might have been introduced here a hundred years ago. Native plants fuel our ecosystem, and are a strong base for promoting diversity, resilience and health in your landscape on a micro and macro level. A single pest, disease, or extreme weather event will not easily overwhelm a resilient yard or garden.

You might consider additional ways to increase biodiversity in your space by providing a water source somewhere on your property. Or you could encourage plants of multiple heights to provide shelter, and consider allowing some brush, dead trees, old logs, or standing stumps to remain in your yard – they are important habitat for native pollinators, beneficial bugs, birds, and mammals. You might also decide to build shelters for key species such as bee, bird, or bat houses. Think about having other food sources year round in the form of blooms, berries, nuts, and seeds such as crabapples, sunflowers, oaks, and letting some crops go to seed in the fall in your garden. Having fall and winter seed supplies can be incredibly important for migrating songbirds, for example, and that can further increase the diversity of microbial life in your yard from far away.

Use Principles of Agroecology

There are many resources within the world of agroecology or permaculture that can guide and inspire better designs for your space, help you increase productivity in the garden, actively build soil with materials you have on hand, and improve your garden's resilience to pests, diseases or extreme weather events. Permaculture is the idea of building "permanent agriculture" or an ecologically-based or whole-systems strategy for land management. Here are a few principles.

Observe
Take time to get to know your land: where the sun is in your yard, what areas are dry or wet, which types of plants seem to grow well (and which don't), where water flows or remains, how people and animals walk across or use the land. These observations can show you about how and where to make the greatest impact with the least effort, improve the health and function of your landscape, identify small and manageable places to make improvements, and ultimately allow you to play to the strengths of your landscape.

Optimize Edge
Just as "edges" or "intersections" between ecosystems are places of high productivity in nature (think of a pond edge, the border between field and forest, the tidal zone at the edge of the ocean and shore), you can utilize edges in your garden to maximize biodiversity and productivity. For example, a garden fence might be an excellent place to plant a series of fruiting vines, shrubs and groundcovers that add beauty, habitat, and a new source of produce to the yard by taking advantage of vertical space and sunlight that might not have been available at ground level. Maximizing "edge" in the yard can also be a good strategy to help water slow down and infiltrate the landscape.

Identify and Reinvest Flows, Resources, and Waste Streams
Think about materials or resources that your land produces, what enters your property, and what leaves it. Rainfall, falling leaves, garden waste or debris, compost materials from the kitchen, dead branches or wood, sunlight, and animal feeds or manures are all examples of flows or waste materials that might enter or leave your landscape. Consider ways you might reinvest or maximize the potential of these into your landscape. Some examples might include capturing or slowing water down instead of allowing it to run off the land, shredding fallen leaves and using them as mulch or carbon-rich compost additive, planting fruiting vines in areas of bare ground or fences to take full advantage of sunlight available, or composting food and yard wastes to eventually build up your soil instead of sending it off site.

Turn Problems into Solutions
Think creatively about problems that arise in your garden, and see if you can turn them into solutions. Perhaps the soil is too wet in a corner of the yard or your chickens are causing topsoil erosion on a slope in their pen. Take a hard look at the problem and consider ways you could turn that "problem" into a solution. For example, you could try planting water-loving crops (like high bush cranberry or marsh hibiscus) into overly wet soils. Or to deal with the chicken erosion you might decide to capitalize on their nitrogen-rich manure, and add a thick layer of a carbon-rich mulch on the eroding slope every few months to both build up the soil over time and provide excellent soil fertility to plant some well-established perennials on terraces to ultimately hold the slope in place. By considering how to turn your problems into solutions, you are creating a paradigm shift (even if on a very small scale) and utilizing the completely unique conditions of your space to build a thoughtful, beautiful, and productive space.

Chapter Six
Measuring Success

Carbon is the currency of life. The rapid formation of carbon-rich topsoil is the greatest priority and opportunity of our time.

– Rattan Lal, Distinguished University Professor in Soil Science at Ohio State University

Soil is a living thing and needs to be kept covered. If you can see the soil, it is losing carbon, losing vitality, losing life. There is no bare soil in a healthy forest or a healthy prairie. The most effective way to regenerate soil is to maintain a living cover of at least 10 different kinds of plants for as much of the year as possible. Plants and their symbiotic microbial partners sequester the carbon that creates and maintains fertile topsoil. Increasing the level of soil carbon improves the health and productivity of farms, gardens and orchards, and helps stabilize local, regional and global climate.

– Christine Jones

Why should we measure success? And for that matter, what is *success* in the backyard? Ideally we would want to measure soil carbon directly, but soil carbon is notoriously difficult to measure. Carbon is constantly cycling through our biosphere in the soil, in the air, through microbes, plants, fungi, and animals. Some of it is more stable (woody biomass, fossil fuels, humus, biochar, limestone), while some is much less so (in compost, animals, atmosphere, through respiration processes of microbes, plants, animals and fungi). If we can't yet reliably measure stable soil carbon (scientists are working hard on this...), we must consider other metrics such as land health, soil organic matter content, the soil's water-holding capacity, biodiversity counts, plant soil cover, and more. These indirect or "carbon-proxy" tests give us a way to evaluate land health and ultimately to evaluate whether we are building soil carbon. No one of these tests can be used to definitely evaluate soil carbon, but together, they provide a very good picture of whether soil carbon building is happening or not.

Topsoil Depth

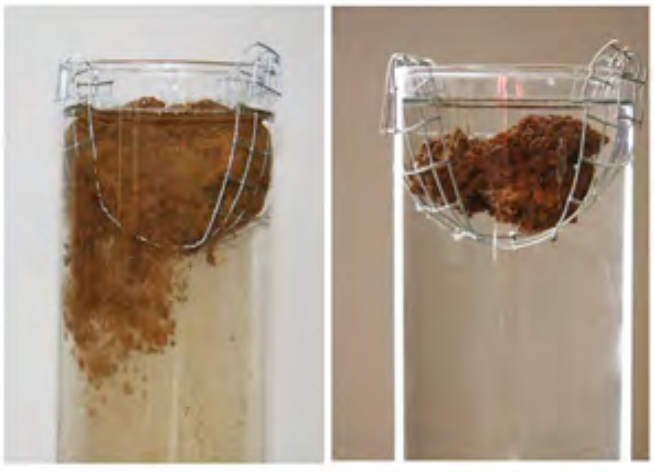
This is one of the simplest tests you can do, but also one that will get you most connected with your soil. Dig a hole in your yard or garden. Try to dig at least a foot down, or more, if you feel inspired. Notice any color changes in the soil profile as you dig deeper. Take a moment to evaluate the soil profile. Are there distinctive layers and colors? If so, how thick are those layers? Note the soil color and texture, especially on the surface layer or topsoil. Make observations of what you see and consider tracking these layers over time by measuring the layers themselves or taking a picture with a ruler beside it. Are you building topsoil over time? Is the soil (especially the top layers) getting darker and more developed? The more organic matter and soil biology, the darker and more crumbly the soil should be, making it more able to hold both air and water like a sponge.

Get familiar with your own backyard soil profile. The hand-held soil core sampler (right) is a good tool for taking soil cores. Photo from TurfTec.com.

Aggregate Stability

Take a look at the soil aggregation in your soil, or "soil crumbs." Does the soil fall apart into loose clumps that also cling to plant roots, sometimes perhaps even coating the roots themselves in a thin outer layer of soil? Aggregates are a good indicators of soil biology and soil carbon. When you see soil coating the roots, you are seeing an indicator that the plants are exuding carbon and feeding it to the many microorganisms living in the rhizosphere or "the root zone". Aggregates are formed through biological activity, including glomalin, the carbon-rich glue excreted by mycorrhizal fungi to form large, stable aggregates that resist drought, flooding, erosion, and other environmental stresses. If you don't see aggregates or soil coating the roots, and instead your soil is dusty, compacted, platy, or difficult to break apart, then consider it an enormous opportunity. As you make changes, keep checking for aggregates, and changes in soil structure or soil color as signs that the soil is improving and you are building soil carbon.

An easy way to test for soil aggregates is to dig up a small clod of plants and soil. Take this lump and throw or heavily thump the clod against the ground at least three times. Hold up the clump and estimate the number and approximate size of the aggregates or clods of soil still holding onto the roots. This is a very simple and quick method to evaluate aggregate stability.



The Slake Test showing the resilience of soil structure without (left) and with (right) a strong biology. Photo from the Farm Journal.

Earthworm Count

Earthworms are excellent soil health indicators. They not only do an enormous amount of work shredding up organic matter for soil microbes to further digest, and allowing water to better percolate into the soil through their burrows, but they also make certain nutrients such as calcium more available to plants and spread beneficial bacteria throughout the garden through their worm castings (a fancy name for worm poop) that often appear on the soil surface. Dig a small hole in an area of the garden that is representative of your growing space and put the soil you remove from the hole on a tarp. Sift through it with your hands or a sifter and pull out the earthworms. An extremely active and healthy soil can have as many as 20 to 30 earthworms per shovel full of soil. Be aware that if you are trying to perform this test in the summer or during a long dry spell with little rain, earthworms will not be readily available near the soil surface and will be much deeper in the soil where it is moist and cool.

Soil aggregates on young cover crop planting. Photo from Food Forest Farm.

Water Infiltration

This is a very simple test that allows you to gauge how well water infiltrates and is absorbed by your soil. If the water pools or puddles on the surface and takes a long time to absorb into the soil, the soil biology and sponge-like soil carbon structure are not functioning well. This test can be a great way to track changes over time, and can be a revealing way to look at how well your soil responds to heavy rainfall. The water may absorb within seconds in a biologically active soil. Or, as in some lawns I have seen with heavily compacted soil, it may take over an hour for an inch of water to finally disappear.

To perform the test, first pound a ring into the soil (could be segment of PVC pipe, steel ring, or a tomato can with both the top and bottom removed) into the soil. Then measure how long it takes for a inch of water to infiltrate into the soil. If the soil is very dry, consider adding a second or third inch and see how much time passes for the soil to absorb each inch. Although this test is not an exact measure of soil carbon, it allows you to see if soil-building processes are present and improving soil structure over time.

A metal ring is pounded into the soil using a rubber mallet and a scrap of wood. Here an inch of water is poured onto a piece of plastic film. The plastic film is gently removed and the timer started. You might be surprised how long it takes for a single inch of rainwater to absorb into the surface. Photo from Natural Resources Conservation Services.

Soil Hardness

This is a simple test to test how hard your soil is. Soil scientists use a tool called a penetrometer that gauges how difficult it is to penetrate the soil with a metal rod that also gives pressure readings. This can give you a very accurate sense of where compacted layers or "hardpans" are and how active your soil biology is at depth. Gardeners can simplify this test even further by using a strong, straight rod or post – just see how easily you can push it into the soil surface. Try marking the post with measurements so you can see how far you can push it into the soil, and also see if you hit a hardpan or compacted layer at a certain depth. In very compacted soils, you might only be able to get the rod into the ground a mere inch (or less!), whereas the rod might easily sink down deep into soils with a carbon-rich, well structured soil like a sponge. By doing this test over time, you can get a sense of how much soil structure and soil biology you are building, especially if you notice it gradually getting easier to push the rod into the soil.

Soil Penetrometer being used to measure soil hardness in a field.

Soil Surface Biology

Put a frame (such as a hula hoop) down on the soil surface. Pick an area that feels like a representative sample of your yard and garden, and ideally pick a place that you can find and measure again over time. Taking a picture of your layout can be very helpful, and also help with your observations. Once you have designated the area, take note of the soil surface biology and conditions within that circle. How many different types of grasses do you notice? How many different species of broadleaf plants? Do you notice any insects or small critters on the surface? Make note also of how much bare soil is visible between plants. Write down your observations. Try to repeat this test around the same time of year or perform it multiple times a year to get a sense of how the biology might be changing over time.

Biodiversity Count

Keep a running list of the biology you observe in your yard and garden over the course of a year or season, and compare these lists over time. Keep track of what you see: plants, insects, birds, reptiles, amphibians, and other animals. See if you can increase the amount of biodiversity in your yard, and make note of signs that you are supporting a healthy ecosystem such as birds breeding and nesting, a healthy population of beneficial insects (which have longer life cycles and are typically more vulnerable to many sprays targeted at common pests), and native pollinators, just to name a few. As you build the biodiversity in your yard, you might begin to notice new species coming in. Writing down these observations gives you have a way to track the health of your ecosystem, which translates to a more diverse micro-ecosystem above and below the soil surface.

Laboratory Testing for Soil Carbon

A direct way to test soil carbon is to send in a soil sample to a lab for testing. Several tests can measure soil carbon in various forms, but one of the most reliable is the test for total carbon. When listed in most soil testing labs, it also often includes a measure of total nitrogen or is listed as the test for *Total Nitrogen and Carbon*. This test heats the soil sample to a very high level (900 C) and burns off all carbon (and nitrogen) in the sample, measuring both organic and inorganic sources of carbon.

Inorganic sources of carbon that will likely not change over time (such as from rocks like limestone) will be measured alongside carbon sources that are much more active or labile. These latter sources of labile carbon might come from compost, plant debris, mulch, and even the bodies of tiny soil microorganisms. They might cycle quickly through the soil food web, oxidize back into the atmosphere or eventually become a more long-term carbon source in the soil. A portion of the organic carbon measured could also come in more long-term, stable form such as from humus, biochar, and the carbon involved in building soil structure such as the sticky fungal glue glomalin. Although there is currently no way to pinpoint the exact amount or percentage of these stable, organic sources of long-term carbon stored in the soil, we do know that as our total carbon increases and as land health improves, we are building up the capacity for the soil to increase its capacity for carbon storage.

If you decide to move forward with this test, realize that it is limited in what it can tell you about the type of soil carbon found in your soils, though if you continue to test (roughly at the same time each year), it can give you a strong sense for how much carbon you are building in your soils over time. For more information on different types of laboratory tests for soil carbon, see resource list, including the Soil Carbon Coalition's *Measuring Soil Carbon Change* by Peter Donovan.

Other Tests and Observations

In addition to the tests listed above, continue to take pictures, observe and take notes on what you see each year in the garden. Look for vibrantly green or healthy plants. Some indicators for health might be shiny or almost waxy-looking leaves, robust stalk growth, fruits like tomatoes or blueberries ripening all at once on a cluster, or little or no fruit splitting in tomatoes. Take note if you see better plant resistance to pests and diseases or notice squash and cucumber leaves being more limber, not snapping off when you brush past, but bouncing back.

You might also notice better color, more fragrance (higher nutrient density often means higher essential oil production), more protein in pollen or higher sugar content in the nectar (which could look like more pollinators throughout the day), and minimal or no discoloration or stunting of leaves from mineral deficiencies. Also observe any changes in the weeds you see in your yard, and take note if the species of weeds or their aggressiveness changes in response to what you are doing with your soil. All these observations take time to recognize and observe over time. A journal or field notebook might be a great way to record your observations.

Ultimately, take the time to get to know your garden, to slowly learn the language of the plants and animals and of what true health looks like in your yard. Then, as you are able, record those changes to evaluate your long-term success.

Conclusion
A Bigger Impact Than You Can Possibly Imagine

I do not allow myself to be overcome by hopelessness, no matter how tough the situation. I believe that if you just do your little bit without thinking of the bigness of what you stand against, if you turn to the enlargement of your own capacities, just that itself creates new potential.

– Vandana Shiva

The movers and shakers on our planet, aren't the billionaires and generals, they are the incredible numbers of people around the world filled with love for neighbor and for the earth who are resisting, remaking, restoring, renewing and revitalising.

– Bill McKibben

The creation of a thousand forests is in one acorn.

– Ralph Waldo Emerson

The time to act is now. The planet's biodiversity and stability are at risk as never before, but we still have time. Now, more than ever, gardeners have the potential to make a difference, not only in their own backyards, but for the world. There are many strategies outlined in this book for you to begin (or to continue) to build soil carbon, biodiversity, and resilience in your own garden and grow some of the best food possible.

Just as a newly planted tree grows faster, stronger, and healthier beside a mature old-growth forest (compared to being planted in cornfield or lawn), so too can your garden's thriving microbiology help an entire neighborhood around you to thrive. Once you get started, you will have allies. Life creates the conditions for more life, and we as gardeners can be stewards of that life force. The robins digging in the soil for worms, the bluejays scratching in the dirt, the squirrels burying or unburying nuts – they will all spread the beneficial microbial community you have fostered to places around you. They will be "microbial taxi cabs" bringing microbes to you and also making it that much easier for gardens and landscapes around you to build up diversity, soil carbon, and resilience. In this sense, making a difference in your backyard can actually make a huge difference (often unseen) for an entire community.

A thriving community belowground is key to a thriving community aboveground. We humans are part of that ecosystem, too, and need fresh water, nutritious food, and spaces in which to grow. Social justice and environmental justice, in so many ways, are two sides of the same coin. Just as we need to help build resilience in our soil, we must also reach out to build relationships with those in our communities, towns, and cities. Diversity equals resilience on many levels. Get to know community groups that are working on issues you care about, share resources, build on each other's work, and work to ensure everyone in your community has the opportunity to thrive.

Together thriving communities have the potential to build migratory corridors across the country, filter and purify air and water for entire watersheds, sequester carbon in their soils bit by bit on a large scale, produce high quality and affordable food, and mitigate weather extremes with the soil acting as a sponge to prevent flooding or resist damaging drought or wind. A thriving garden ecosystem also can produce higher quality, more nutrient-dense food for you and the ecosystem you are supporting. In today's world, gardeners have an incredible opportunity (and responsibility) to be a resource, a cornerstone, a refuge, and to be the change we need in this world. And it all starts in your backyard.

Resources

General Soil Carbon Resources:

Soil Carbon Restoration: Can Biology Do the Job white paper by Jack Kittredge:
http://www.nofamass.org/sites/default/files/2015_White_Paper_web.pdf

SOS: Save Our Soils. Interview with Australian soil scientist Christine Jones:
http://www.amazingcarbon.com/PDF/Jones_ACRES_USA%20(March2015).pdf

Unlock the Secrets of the Soil. A video series by National Resources Conservation Service (NRCS) Soil Health Division:
https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/

Soil Carbon Resource List from the MA Chapter of the Northeast Organic Farming Association (NOFA/Mass):
https://www.nofamass.org/content/carbon-resources

Grass, Soil, Hope: A Journey Through Carbon Country by Courtney White. Chelsea Green Publishing. 2014.

Two Percent Solutions for the Planet: 50 Low-Cost, Low-Tech, Nature-Based Practices for Combatting Hunger, Drought, and Climate Change by Courtney White. Chelsea Green Publishing. 2015.

"Building Soil Carbon" Issue in *The Natural Farmer*:
http://thenaturalfarmer.org/issue/summer-2014/

The World's Largest Mining Operation is Run By Fungi. Article in Scientific American:
https://blogs.scientificamerican.com/artful-amoeba/the-world-s-largest-mining-operation-is-run-by-fungi/

The Soil Will Save Us: How Scientists, Farmers, and Foodies Are Healing the Soil To Save the Planet by Kristin Ohlson. Rodale Books. 2014.

Blessed Unrest: How the Largest Movement in the World Came into Being, and Why No One Saw it Coming by Paul Hawken. Penguin, 2007.

Chapter 1 Resources:

Practice Organic Management:

The Organic Gardener's Handbook of Natural Pest and Disease Control: A Complete Guide to Maintaining a Healthy Garden and Yard the Earth-Friendly Way by Bradley, Fern Marshall, Barbara W. Ellis, and Deborah L. Martin. Rodale. 2010.

Introduction to Organic Yards and Lawns produced by the Organic Land Care Program of NOFA Connecticut:
http://www.organiclandcare.net/sites/default/files/2016iolyfinalsingle_page_opt.pdf

Organic Land Care Program:
http://www.organiclandcare.net/

Principles of Organic Agriculture from International Federation of Organic Agriculture Movements (IFOAM): Although specific to agriculture, the principles of health, ecology, fairness and care can also be applied in the backyard.
https://www.ifoam.bio/en/organic-landmarks/principles-organic-agriculture

The One-Straw Revolution: An Introduction to Natural Farming by Masanobu Fukuoka. New York Review of Books, 2009.

Soil Resources:

Soil Testing Laboratories
Many states and local agricultural extension services have soil testing programs (usually $15-25 per test) that are great resources for getting your soil tested. Different soil testing laboratories use different metrics for calibrating their tests so it is important to stick with the same test over time, and identify tests that might best serve your needs.

The *University of Massachusetts, Amherst Soil Testing Facilities* offers a great and inexpensive place to get general nutrients and heavy metal testing, plus soil organic matter and nitrogen testing at extra cost. They use a Modified Morgan testing method, which is a weaker acid test that gives the user a strong sense of what nutrients are readily available in the soil.
http://www.ag.umass.edu/services/soil-plant-nutrient-testing-laboratory/ordering-information-forms.

Logan Labs Soil Testing Services located in Ohio does basic soil tests and can also do a range of micronutrients and trace elements, among other services. They use a Mehlich III paste test, which is a stronger acid test and a common extraction method used by many soil testing laboratories to get a good reading on the wide range of nutrients available even if they are not readily available to the plants (but could become available with increased soil biology, for instance).
http://www.loganlabs.com

NOFA/Mass Soil Technical Assistance Program NOFA/Mass is beginning its own soil technical assistance program in 2017 to respond to the need of growers and gardeners to help break down barriers to remineralizing soil, and improve the turnaround time for soil technical assistance in the state. For more information visit:
https://www.nofamass.org/soil-technical-assistance-program

Bionutrient Food Association – A great resource for local sources of mineral amendments, soil nutrition information, and education on improving the nutrient density of our food supply.
http://bionutrient.org/

Nutrition Gardening Blog by Australian soil consultant Graeme Sait with tips and ideas for gardeners to build nutrient dense, biologically active garden soils:
http://blog.nutritiongardening.com.au/

How to Grow More Vegetables: (and Fruits, Nuts, Berries, Grains, and Other Crops) Than You Ever Thought Possible on Less Land Than You Can Imagine by John Jeavons, 9th Edition. Ten Speed Press. 2017

Grow Biointensive website by John Jeavons with resources and videos on double digging, intensive planting, companion planting, composting, among other topics.
http://www.growbiointensive.org/

The Ideal Soil: A Handbook for the New Agriculture by Astera, Michael. 2014.

The Art of Balancing Soil Nutrients: A Practical Guide to Interpreting Soil Tests by William McKibben.

The Intelligent Gardener: Growing Nutrient-Dense Food by Steve Solomon with Erica Reinheimer.

Teaming with Nutrients: The Organic Gardener's Guide to Optimizing Plant Nutrition by Jeff Lowenfels. Timber Press, 2013

"Soil Remediation" Issue in *The Natural Farmer*:
http://thenaturalfarmer.org/issue/spring-2014/

Weeds:

Weeds and What They Tell Us by Ehrenfried Pfeiffer. Floris Books. 1946.

The Wild Wisdom of Weeds: 13 Essential Plants for Human Survival by Katrina Blair. Chelsea Green Publishing. 2014.

Wild Urban Plants of the Northeast: A Field Guide by Peter Del Tredici. Cornell University Press. 2010.

Chapter 2 Resources:

Adding Life to the Soil:

Teaming with Microbes: The Organic Gardener's Guide to the Soil Food Web by Wayne Lewis and Jeff Lowenfels. Timber Press. 2010.

Teaming with Fungi: The Organic Grower's Guide to Mycorrhizae by Jeff Lowenfels. Timber Press, 2017.

Mycorrhizal Planet: How Symbiotic Fungi Work with Roots to Support Plant Health and Build Soil Fertility by Michael Phillips. Chelsea Green Publishing, 2017.

Life in the Soil : A Guide for Naturalists and Gardeners by James B. Nardi. University of Chicago Press. 2007

The Hidden Half of Nature: The Microbial Roots of Life and Health by David R. Montgomery and Anne Bikle. W.W. Norton and Company. 2015.

NRCS/USDA's "Soil Biology Primer":
https://www.nrcs.usda.gov/wps/portal/nrcs/photogallery/soils/health/biology/gallery/?cid=1788&position=Promo)

Korean Natural Farming: Managing Farm Systems Holistically by Julie Rawson
https://www.nofamass.org/articles/2014/05/korean-natural-farming-managing-farm-systems-holistically

Natural Farming Hawaii: Korean Natural Farming resources
http://naturalfarminghawaii.net/

Korean Natural Farming files and resources located on their facebook page:
https://www.facebook.com/groups/koreannaturalfarming/
including: "How To: IMO 1 & 2" by Chris Trump on cultivating Indigenous Micro Organisms:
https://www.youtube.com/watch?v=7N2PXBKf_GE&list=PLeGHRYFVwS1zHwYqGvlEAjvq89iMs2vmz

Cho's Global Natural Farming Manual by Rohini Reddy on Korean Natural Farming Techniques.
http://www.permacultivo.es/wp-content/uploads/2014/08/chos-global-natural-farming-sarra.pdf

The Compost Tea Brewing Manual by Elaine Ingham (2002):
http://ecologiesurleweb.free.fr/docs/Docs_agir/Lombricomposteur/Brew%20Manual%20compost%20tea.pdf

Basic Compost Tea Recipe from Elaine Ingham's Soil Food Web
http://www.soilfoodweb.com/Compost_Tea_Recipe.html

Protozoa Compost Tea Recipe from Graeme Sait, Managing the Microbial Workforce
http://blog.nutri-tech.com.au/managing-the-microbe-workforce-understanding-the-key-players-2/

Resources for and Sources of Inoculants and Compost Tea Ingredients:
Inoculants are becoming increasingly available at local garden and supply centers. Here are just a few places to source or look for further resources on this topic:

FEDCO Organic Grower Supply:
https://www.fedcoseeds.com/ogs/

Paul Stamet's Fungi Perfecti:
http://www.fungi.com/

Nutrient Density Supply Company:
http://www.ndsupply.com/

Microbial Inoculants and Fertilizers from *Nutrition Gardening* (Australia)
https://www.nutritiongardening.com.au/

Compostwerks
https://www.compostwerks.com/

Reforestation Technologies International
https://www.reforest.com/

Field and Forest Products
http://www.fieldforest.net/

Mycorrhizal Applications
http://mycorrhizae.com/

Chapter 3 Resources

Compost and Mulch:

Rodale's Ultimate Encyclopedia of Organic Gardening: The Indispensible Green Resource for Every Gardener by Fern Marshall Bradley (Editor), Ellen Phillips (Editor), Barbara Ellis (Editor). Rodale. 1992.

Humus Gardening by Graime Sait: http://blog.nutri-tech.com.au/humus-gardening-1/

The New Organic Grower: A Master's Manual of Tools and Techniques for the Home and Market Gardener by Elliot Coleman. Chelsea Green Publishing, 1995.

Lasagna Gardening: A New Layering System for Bountiful Gardens: No Digging, No Tilling, No Weeding, No Kidding! by Patricia Lanza. Rodale. 1998.

Soil Food Web Laboratories Microbiological Testing: Get a bioassay of your soil or compost to assess nutrient levels and ratios of beneficial biology. http://soilfoodweb.com/Labs.html

Harrington's Soil Testing Labortatory (NY) – resources and and a local biological testing of the biology of soil or compost: http://harringtonsorganic.com/organic-land-care-services-hartford-county-connecticut/soil-testing/

Building Soils Naturally; Innovative Methods for Organic Growers by Phil Nauta. Acres USA. 2012

Video by David Johnson of the Institute for Sustainable Agricultural Research at New Mexico State University talk on building a fungally dominant compost as an inoculant using his Johnson-Su Bioreactor:
https://www.youtube.com/watch?v=18FVVYKU9gs and
https://www.youtube.com/watch?v=DxUGk161Ly8

See *Chapter 2 Resources* for more information on Korean Natural Farming compost and inoculation strategies.

Cover Crops:

NRCS Cover Crop Chart: a resource on many different types of cover crops possible, including tips, benefits, and growing strategies for each.
https://www.ars.usda.gov/ARSUserFiles/30640000/pdf/cccv1-2.pdf

Managing Cover Crops Profitably (free online version available): Although geared towards farms, this publications helps explain the science and strategy of using cover crops, much of which can be scaled down to a home garden.
http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

"Legumes as Cover Crops" Special Supplement in *The Natural Farmer*:
http://www.nofa.org/tnf/Summer2011B.pdf

*Gabe Brown: Rapid Building of Soil with Cover Crop*s by ACRES USA:
https://www.acresusa.com/gabe-brown-large-scale-rapid-building-of-soil-with-cover-crops.

Bionutrient Food and Farming in Westchester on YouTube.com lists several excellent videos on the how-to's of using cover crops on a small scale.
https://www.youtube.com/results?search_query=bionutrient+food+and+farming+in+westchester

Sources for Cover Crops:
Local seed and agricultural supply companies are excellent options for cover crop or farm seed:

NOFA Tristate Bulk Order: a place to source cover crops including cocktail cover crop mixes.
http://www.nofabulkorder.org/

Johnny Selected Seeds:
http://www.johnnyseeds.com/farm-seed/

FEDCO Organic Growers Supply
https://www.fedcoseeds.com/ogs/?cat=Farm%20Seed

Biochar:

The Biochar Revolution: Transforming Agriculture and the Environment. 2010. Edited by Paul Taylor. Excerpt on Chapter 7: *How Biochar Helps the Soil* by Hugh McLaughlin:
https://bio4climate.org/downloads/mclaughlin-chapter7.pdf

"Biochar" Issue in *The Natural Farmer*:
http://thenaturalfarmer.org/issue/fall-2015/

Biochar: Prepping it for Soil by David Yarrow in ACRES USA:
http://ecofarmingdaily.com/biochar-prepping-soil/

The Secret of El Dorado: Terra Preta. A documentary film about terra preta soils in the Amazon:
https://www.youtube.com/watch?v=0Os-ujelkgw

Chapter 4 Resources

Water for the Recovery of the Climate: A New Water Paradigm by Michal Kravčík, et al. Typopress-Publishing House, 2008.
A book on the shift in thinking about the importance of water cycles and climate change, and how we can impact our local and global water cycle.

Water in Plain Sight: Hope for a Thirsty World by Judith D. Schwartz. St. Martin's Press, 2016.

Artful Rainwater Design: Creative Ways to Manage Stormwater by Stuart Echols and Eliza Pennypacker. Island Press. 2015.
A book and online resource (including videos) detailing clever ways to capture rainwater:
https://artfulrainwaterdesign.psu.edu/resources.

Gardening with Less Water: Low Tech, Low Cost Techniques; Use up to 90% Less Water in Your Garden by David Bainbridge. Storey Publishing. 2015.
Super efficient and simple water-saving techniques including wick irrigation, clay pipes, clay pots (ollas), soaker hoses, porous capsules, among others tailored for arid landscapes, but applicable anywhere water is not readily available.

Rainwater Harvesting for Drylands and Beyond by Brad Lancaster and Joe Marshall. Vol. 1, 2, & 3. Rainsource Press, 2008.

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"Soil Food Web" image by USDA's Natural Resource Conservation Services Soil Biology Primer:
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"Sheet Mulching" picture by Toby Hemenway at http://tobyhemenway.com/

"Daikon Radish Cover Crop" pictures by *Joel Gruver, Western Illinois University*
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Soil Aggregate photo on young cover crop from Food Forest Farm
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A special thanks to the team of editors Helen Snively, Julie Rawson, Jack Kittredge, Pam Phillips, Sharon Gensler, Jane Hammer, Nicole Belanger, Eileen Zubrowski, and Matt Jatkola for their help in making this booklet possible.

Northeast Organic Farming Association/Massachusetts Chapter, Inc.
411 Sheldon Rd. Barre, MA 01005

www.nofamass.org