

Soil Fertility for Organic Farmers

Brian Caldwell
NOFA-NY Farm Education Coordinator

How do organic farmers get good yields of quality crops without the usual chemical inputs? Do they perform “magic”? Yes and no. They tap into the magic of the natural living world that is the basis for all agriculture. Rather than trying to bypass or overcome natural processes, they work to actively support and protect them.

Basics

The **physical, biological, and chemical** aspects of a soil jointly determine how much plant growth it can support. Good soil fertility means optimal management of these three aspects for a given field.

Key practices that organic farmers use to manage soil fertility are **preserving soil health, applications of organic matter, nutrient cycling, and rotations including legumes for nitrogen fixation. Rock powders** or other materials are used on occasion to adjust specific mineral nutrient levels. In order to best understand how to manage soil fertility, we’ll start with the physical aspects.

Physical

The goal of managing the physical aspects of the soil is to create and maintain a good environment for plant roots and soil organisms. This translates to good soil health.

First we need to understand what soil is made of. After taking away roots and stones, soil is composed of sand, silt, and clay particles, plus organic matter.

The large, easily-visible soil particles form sand. A sandy soil is a light soil, which warms up fast. Sandy soils drain very quickly and are not able to hold nutrients well.

Silt comprises intermediate-sized particles. Silty soils tend to be prone to surface crusting, and are usually rich. Clay is made of microscopic particles that remain suspended when mixed with water. A clay-dominated soil is a heavy soil, which tends to stay cool in the spring. Clay soils are good at retaining nutrients.

Actually, all soils are mixtures of these particles. A loam is a mix that is fairly evenly balanced. This is the best situation, combining the good drainage of the sand with the nutrient and water-holding capacities of the silt and clay. Soils differ in the mixture and mineral composition of these particles, depending on the geological sources and forces that have formed them over thousands or millions of years.

The final ingredient is organic matter (OM). This is what makes topsoil. Organic matter has many characteristics that improve the ability of a soil to support plant growth. It increases water retention, stores and releases nutrients, improves air infiltration, reduces soil erosion, and supports soil organisms. OM helps bind soil constituents into larger units called soil “aggregates” or “crumbs”.

This is the barest introduction to an understanding of what soils are. For valuable in depth reading, please see *The Nature and Properties of Soils*, by Brady and Weil. Other good books include *Building Soils for Better Crops*, by Magdoff and van Es, and the *Soil Biology Primer*, published by the Soil and Water Conservation Society and the USDA NRCS (available from NOFA-NY).

An ideal situation for roots and soil organisms is for the soil

pores (spaces between soil aggregates) to be filled with about 50% air and 50% water. This allows the roots and tiny critters to breathe, but supplies abundant water. In practice, the more large (macropores, like earthworm holes) and small (micropores, tiny spaces between particles of soil) there are, the more air and water are available to roots and soil life.

A deep soil with plenty of pores is an ideal, “well-drained” soil with good “tilth”. Water will infiltrate easily into such a soil, and roots can explore a large volume.

Soil pores and particles can be squashed together by tillage and the weight of equipment, people and animals in the field—especially when the soil is wet. This results in a tight soil with drastically lowered soil health, and is called **soil compaction**. Roots have trouble pushing their way through compacted layers and do not get enough air.

Luckily, in our climate, winter freezing and thawing tend to recreate soil pores and reduce compaction, to some extent. Ripping through the soil with a chisel plow or subsoiler when the soil is dry, cracks and shatters compacted areas, leaving more pores. Plant roots can extend the process of healing a compacted soil by maintaining these pores and creating new ones.

Often, a compacted zone lies just below the plowed or tilled layer of topsoil. This is called a plow pan. The pan may have been created and reinforced by many years of tillage down to the same level. Essentially, the depth of soil for good rooting is restricted to the top 6-8 inches above the compacted layer, wasting the soil resources below. Often crops will do well on such soils in good years, but suffer drastically in wet or drought.

Tilling at varying depths, deep chisel plowing, and subsoiling—all done when the soil is dry—will help restore these soils. When you check your soil to see if it’s dry enough to plow, check 6 inches below the soil surface, not just the top.

A prime indicator of a compacted pan layer below the soil surface is a wet area in the field that tends to get a little bigger each year. Below the surface, the soil is actually too wet for plowing around the edge of the wet spot. It gets plowed anyway because the rest of the field is ready, causing a widening area of severe compaction that will not drain.

Other indications of poor soil quality are flat fields where water lies after a rain, after others nearby have drained; and crusting of the soil surface. The soil crust is actually like a mini-pan layer, compacted by the impact of raindrops. In this case, the soil particles (“aggregates”) are too weak to withstand the shattering effect of the rain. They fall apart and clog the soil pores, drying to a hard surface that sheds water and air. Cultivation can break up a soil crust, but the best long-term cure for crusting is to increase active organic matter (see below) in the soil.

Of course, not all soils are well-drained even if they are free from human-caused compaction. Some have a high proportion of clay and naturally drain slowly. Others are close to bedrock or have a natural, ultra-compacted layer called a fragipan. Some combine these qualities and are also at the low end of a slope, receiving water from above! In these cases of fair-to-poor drainage, one can improve the situation by: 1) installing drainage tile (see your County Natural Resources Conservation Service or Soil and Water Conservation District office); and 2) for vegetable production, using raised beds. Being extra careful not to work them when wet will really help these soils—but may preclude the possibility of early planting. Plan to plant late!

These soils are also extra sensitive to damage from equipment traffic for harvest and other field operations when the field is wet. Some farmers have created systems of permanent wheeltracks in fields for their equipment, so that overall compaction is minimized.

Increasing soil organic matter helps with all physical aspects of the soil. Organic matter (OM) is the remains of plants, animals, and microbes in the soil. Some is decaying quickly; some slowly. Dr. Fred Magdoff described two classes of organic matter as “the dead and the very dead”. Active or “particulate” organic matter is in the process of rapid decomposition. This process releases nutrients and also substances that help bind soil particles together strongly. This creates soils with good “aggregate stability” that resist crusting. Very dead OM is humus. It is fairly stable, and increases soil water- and nutrient-holding capacity but does not tend to release nutrients or improve aggregate stability. Some soil humus is from plants that died hundreds of years ago.

Farmers add OM to the soil by growing it in place, in the case of crop residues and green manures. They also import it to the field in the form of manure, compost, or organic mulch. In both cases, active OM will increase. These practices add high-carbon materials to the field, which fuels the biological community in the soil.

Biological

The biological aspect of the soil includes living organisms and associated dead materials. Carbohydrates and other carbon compounds in plant residues are the main energy sources for the soil biological community. They are really stored solar energy, since sunlight is the energy source that enables plants to fix carbon into their tissues.

Bacteria and fungi are at the first level of the soil food chain or food web. They decompose plant and animal residues, and are eaten by other soil dwellers. Many other types of critters are present in the soil, including nematodes, protozoans, springtails, other insect larvae, mites, crustaceans, pseudoscorpions, earthworms, etc. Some of these feed on recently dead residues, and some are predators, higher on the food chain. These soil creatures are naturally present in all soils, but in order to reach optimum levels, they need food—carbon-rich residues!

The rhizosphere—the area around plant root hairs and root tips—has very high levels of biological activity. The healthy plant actually secretes some of its energy-rich carbon compounds out of the root tips, stimulating biological activity there. Fed by carbon exudates from the roots, bacteria and fungi gather and release soil nutrients which then feed the plant. The diverse microbial community there helps to prevent root disease organisms from multiplying out of balance as well.

Often, plant roots have specific symbiotic relationships with microorganisms. For instance, mycorrhizal fungi actually infect the root systems of many crop plants. These fungi are “fed” carbohydrates by the plant, and in turn, effectively increase the water and nutrient absorptive ability of the plant roots several times. Legume species often have colonies of *Rhizobium* bacteria living on their roots. In this case, the plant trades energy (carbon) for nitrogen, which the bacteria can fix out of the air (another reason to get a good air supply to those crop roots!).

Many herbicides, fungicides, insecticides, and even heavy use of some fertilizers have a depressive or simplifying effect on soil

biota, and derail some of these processes. Some soil scientists are beginning to measure soil health based on the number, diversity, and activity level of soil microbes.

Chemical

The chemical aspects of the soil pertain to nutrient levels and soil pH. The pH reading reflects the acidity of your soil. Most crop plants and most soil critters flourish in a near-neutral pH soil. When improving the nutrient status of your soil, adjust the pH first. Ground limestone is the common input used to raise pH. Soil test results will indicate how much is needed.

Plants, by weight, are mostly carbon, oxygen, and hydrogen. These “nutrients” come from the air and rain. Let’s hope there is always an abundant supply of clean air and rainfall!

The “big three” soil nutrients are nitrogen, phosphorous, and potassium—their chemical symbols are N, P, K. They are nutrients that are used by plants in relatively large amounts that are easily depleted from the soil. Most chemical fertilizers contain one or all of these three, and little else.

Nitrogen is the nutrient that is often short in cropping systems. It is needed by plants in large amounts, and not retained well by the soil. Phosphorous and potassium, though, can be maintained relatively easily once they are brought up to high levels. The primary source of nitrogen in a good organic system is from legume hay or cover crops (see below).

The organic amendments (residues, manure, compost, and mulch) that are used to increase active organic matter levels also add **all plant nutrients** to the soil. This makes sense, because they are plant residues, or plants that have gone through animal and bacterial digestion. However, the nutrients from organic amendments may not be in the same proportions as are needed by growing plants. This is mostly because some nitrogen is lost from them on their way back to the field.

This is a profound difference in overall fertility management between organic and non-organic farms. Organic farmers almost always add carbon along with their nutrients, which supports the soil microbial community. Those who rely on NPK may allow their biological community to decline, giving it only the crop residues left over after harvest.

Other soil macronutrients include calcium, magnesium, and sulfur (Ca, Mg, and S). These are also used by plants in fairly large amounts, but soils are usually not depleted in them.

In water solution, calcium, magnesium, potassium, hydrogen, sodium, and heavy metals like iron, aluminum, and manganese are in the form of positively-charged ions called cations. Clay particles and organic matter have many cation “exchange sites” which hold cations in a form easily available to plants. Nitrate (N), sulfate (S), and phosphate (P) groups are negatively-charged “anions”, and are held in the soil differently. (In fact, nitrate is not retained well by the soil, and can be easily lost to groundwater.)

A soil with many cation exchange sites has a high “cation exchange capacity” (CEC) and can hold a large reservoir of plant nutrients. One can describe the relative amounts of the various cations by the percentage of the total CEC that they comprise. In a soil with a near-neutral pH, the exchange sites tend to be filled with nutrients (Ca, Mg, K) rather than hydrogen or heavy metals. An

exception is sodium, a non-nutritive cation that is found in some problem high pH Western soils.

Some farmers and consultants believe that it is important to keep the proper balance among calcium, magnesium, potassium, and sodium ions in the soil. In particular, they say that if calcium gets too low in comparison to K or Mg, some weeds will be favored and soil and plant health will be reduced. While soil scientists often do not agree with these views, several outstanding farmers subscribe to them.

In any case, if Mg levels are already high, there is no need to apply a high-magnesium limestone (called dolomite) to adjust pH. Using a high-calcium lime would make sense. Similarly, if K levels are high, there is no reason to add fertilizer materials with high K.

Micronutrients include zinc, boron, iron, manganese, selenium, and others (Zn, B, Fe, Mn, Se, etc.). All organic materials such as manure, composts, or mulches (except fresh sawdust) carry appreciable amounts of these and all other plant nutrients (but again, not necessarily in the relative amounts needed by crops).

Most necessary nutrients are present in the soil in relatively large amounts, but are chemically bound up and not available to plants. This is part of the reason that plants foster an active rhizosphere, as some microbes are able to extract some of these bound-up nutrients.

Specific nutrient sources used by organic farmers include:

- N—nitrogen fixation by legumes in crop rotation. This nutrient can be raised to high levels by having legumes as 30-50% of the rotation.
- N—plowed down legume crops may provide 100#/A or more N to the following crop
- N—soy meal, feather meal, blood meal, etc. (relatively expensive)
- P—rock phosphate, bone meal (expensive). Phosphorous is stable in the soil, so one application goes a long way. Also, adjusting pH to 6.5-7.0 makes more soil-bound P available.
- K—sulpomag, a mined material; wood ashes; also, stemmy/woody mulches are high in K
- Ca—limestone or gypsum
- Micronutrients—products are available including seaweeds, etc. Composts carry these as well.

Soil tests

Soil tests are useful in **starting and monitoring** an organic fertility program. First, a soil test is critical to adjust pH and determine overall nutrient levels when bringing a new field under organic management. Follow the lime recommendations, but ignore those for chemical nutrient additions.

Vegetable farmers and livestock producers often treat a new field with a relatively heavy application of imported organic matter in the form of manure or compost. Applications of 10-20 tons per acre of manure, or half that much compost, will rev up the microbes and bring most nutrient levels up into the high range within a few years. After two to five years, the field will no longer need heavy annual applications of imported organic matter. At this point, nitrogen from legumes can take over as being the primary nutrient input. Other nutrients will tend to cycle within the soil and around the farm, and will be depleted more slowly. Imported organic materials might only

need to be added every 3-4 years.

For field crop farmers, such a heavy dose of organic matter would probably be too expensive. Field crop farmers can start transitioning a new field to organic production with a hay seeding under a small grain nurse crop, for instance red clover frost seeded into winter wheat or spring oats. This will start increasing soil organic matter and N levels. Sometimes, applications of rock phosphate and / or sulpomag might be needed as well.

Soil tests can be used to watch trends in nutrient levels over the years. My suggestion would be to do a soil test each year that you are importing large amounts of organic materials onto the field, then switch to testing soil every 3-4 years. The best time to sample would be before a compost or manure application.

Once high levels of soil nutrients are established in a field, look for trends in soil test levels. If they show a trend of climbing or dropping, something needs to be adjusted in the overall fertility program. The goal is to keep them steady. Overfertilization is wasteful and can result in nutrient pollution, while dropping levels will eventually result in yield losses.

How do organic farms do it?

Crop rotation is a central practice in maintaining overall fertility on organic farms. It is also crucial in insect, disease, and weed control. Furthermore, there is a bonus yield increase called the “rotation effect” that occurs simply by not having the same crop in a field two years in a row. This increase is usually around 10%.

The crop rotation will include legume crops, either as **sod** (hay) crops or **cover crops**, called **green manures** when they are tilled into the soil without being harvested. A good rotation implies diverse cropping, so that at least 3 years intervenes before planting a related crop in a given field. Having livestock on the farm helps as well—farm-grown feed crops and manure are used to recycle nutrients within the farm, and sod crops are usually part of the rotation. Sod crops are by far the most beneficial in building soil health and fertility. To grow flourishing legumes, the soil needs to be high in calcium and phosphorous, and have a pH close to 7.0.

As previously mentioned, organic farmers may give new fields a heavy dressing of manure or compost, after which application rates decline. Eventually, imported organic matter may be added to the field only once every 3-4 years.

When feed is brought in for livestock, whose manure is then spread on the fields, the farm is gaining the nutrients from that feed. This is another way that livestock help with overall fertility. However, in some situations where there is insufficient land to accommodate the manure, nutrients can build up to excessive levels. The key is a good balance between the nutrient needs of the soil, and what is put on.

Biodynamic farmers strive to treat the farm as a self-contained organism. This is a good goal for all organic farmers, as it encourages the recycling of nutrients within the farm. Crop exports and nutrient imports are optimized, not maximized, to allow for a healthy and financially sound system.

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