Cover Crops, Soil Life, and Soil Health

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Cover crops are the cornerstone of sustainable soil management in annual cropping systems, including vegetables, grains, row crops, and annual strawberry or cut flowers; because they replenish soil organic matter, protect soil from erosion, promote good tilth, suppress weeds, harbor beneficial insects, and assist with nutrient management. Cover crops support the soil life (or soil food web) while growing, by "donating" at least 10% of their photosynthetic product – sugars, amino acids, and other organic materials, mostly readily-available as food for microbes – to the soil life through root exudates and sloughing of fine roots. *All* plants do this, but a vigorously growing cover crop with a closed canopy provides more "food" to the soil life than most vegetable crops. Then there is the "grand feast" when the cover crop is tilled in, mowed down, or otherwise terminated, feeding the soil life several tons per acre of fresh organic residues.

It is vital to replenish soil organic matter and organic N reserves every year in annual cropping systems, and cover crops are the best way to accomplish this. They also help with P and K nutrition. If soil P and K are relatively insoluble or locked-up (giving low soil test values), grasses help unlock K while legumes and buckwheat unlock P. On soils with ample or excessive P and K, cover crops can replenish N and organic matter *without* adding yet more P and K. In these soils, the cover crops will not unlock yet more P and K from insoluble reserves, but will simply utilize the abundant soluble P and K already present. If soluble soil N is also abundant or excessive, the legumes will put their *Rhizobia* symbionts on furlough, and simply use what is already there. Thus, unlike compost and manure, cover crops *never* aggravate NPK excesses, even as they *almost always* help address NPK shortages; therefore, cover crops are one of the organic grower's most important and versatile nutrient management tools.

Be sure to grow cover crops to optimal maturity – usually this is full height and in bloom or head or early seed development, but not yet forming viable seeds. Terminating a cover crop just four weeks before this point can cut organic C and N yields by half. Also, mature (full bloom to early seed) cover crops can often be terminated by mowing or roll-crimping, for no-till planting of vegetable starts, seed potatoes, or other large seeds (cucurbits, beans, peas, onion sets, etc). This method of managing cover crops can maximize soil benefits and extend weed suppression for at least several weeks.

Remember that the C:N ratio of a cover crop, even a legume or legume-containing mix, will become higher (more C, less N) as it matures. Thus, the C:N of a winter cereal grain + legume mix might be around 20-25:1 while the crop is vegetative to early bud, 30:1 when it is in full bloom or head, and 35:1 during early seed development. In heavier textured soils (loam, silt loam, clay loam) in cooler climates (e.g., Appalachia), it can be advantageous to terminate a cover crop a little early (just before flowering) and till it in to promote timely release of N and other nutrients to the next crop. Doing the same on a sandy soil in a hot climate may result in rapid oxidation of cover crop and even existing soil organic matter, as well as N leaching losses before the next crop can utilize the N – so the sandier the soil and the hotter the weather, the more mature you want the cover crop, and the more you want to consider no-till termination methods.

Try to integrate at least one high-biomass cover crop per year into your crop rotation. A solid stand of a winter grain + legume cover that is 3-4 feet tall contains about 3 tons/ac aboveground organic matter, and about 1.5 tons below ground (roots + exudates). Root mass makes an especially important contribution to stable organic matter, since about 30-40% of root residue carbon (C) becomes stable soil organic C, compared to just 15-20% for the aboveground biomass. Root contributions are most effective if the root mass can be left in the soil profile with minimal disturbance (no till or shallow till).

Legume cover crops fix atmospheric nitrogen (N_2), and can provide 50-100% of a following cash crop's nitrogen (N) requirement. *(Be sure to inoculate legume seed with the appropriate Rhizobium inoculant to ensure good N fixation.)* A legume-grass cover crop combination, such as winter rye, barley, or other cereal grain + hairy vetch, Austrian winter field peas, and/or crimson clover (over winter) or millet or sorghum-sudangrass with forage soybean, cowpea, sunnhemp, lablab, and/or velvetbean (summer) is highly recommended. Such mixtures often give the highest biomass, the most effective weed suppression, and provide a "balanced diet" (carbon-to-nitrogen or C:N ratio around 25-35:1) for the soil food web. Balanced carbon and nitrogen in organic inputs promotes formation of *active organic matter*, which improves tilth and provides slow release nutrients; and of *stable organic matter* or *humus*, which sequesters carbon for the long term and contributes *cation exchange capacity* (CEC) CEC is the soil's capacity to hold positively charged (cation) nutrients, including potassium (K), calcium (Ca), magnesium (Mg), the ammonium form of plant-available N, and some micronutrients Often, a mixture of legumes and nonlegumes (cereal grains, summer grasses, buckwheat, tillage radish and other crucifers, sunflower) will fix more N than an all-legume cover crop, because the constant N demand of the non-legume stimulates the legume-Rhizobium symbiosis. This is especially true for heavy N-feeders like sorghum-sudangrass, sunflower, tillage radish, and other crucifers.

Buckwheat is useful for short fallow periods of 30 – 50 days during the frost free season. It does not provide as much biomass, but it makes excellent forage for bees and other beneficial insects, and suppresses weeds. Leaving buckwheat in for longer periods allows it to self-seed, which can be turned to advantage if the mature crop is tilled lightly to plant the next generation. Buckwheat can also become a moderate weed problem, competitive but easy to pull or cultivate

Cowpea, alone or with foxtail (German) millet is excellent for slightly longer summer fallow periods 50 – 75 days), and it tolerates more intense heat and drought than either buckwheat or forage soybean – or most vegetable crops for that matter! Many cowpea varieties also produce edible shell or dry beans, though the Iron-Clay variety developed specifically for cover cropping flowers and fruits only sparingly. In hot climates, consider taking a summer break from production and planting heat-loving competitive cover crops to protect soil and suppress aggressive warm season weed such as nutsedge, Bermuda grass, common cocklebur, and pigweeds.

For more information on cover crops, visit the Virginia Association for Biological Farming web site, *www.vabf.org*, click on *Resources* and select *Information Sheets* – see *Cover Crops for All Seasons* (gives seeding rates, depth, methods, and best seasons for each cover crop) and other info sheets on cover crops, reduced tillage systems, and manual seeders for cover cropping at market garden scale. Also, check out the National Sustainable Agriculture Information Service (aka ATTRA) at *www.attra.org*, and see bulletins on cover cropping and conservation tillage systems.

Good sources for cover crop seeds include Seven Springs Farm (*www.7springsfarm.com*), Countryside Organics (*www.countrysideorganics.com*), Adams Briscoe Seeds (*www.abseed.com*), and Albert Lea Seeds (*www.alseed.com*).

NRCS Soil Health Initiative and Cover Cropping

In 2011, the USDA Natural Resources Conservation Service (NRCS) regional office in Greensboro, NC launched a Soil Health Initiative, based on four central principles developed by Ray Archuleta, David Lamm, and others:

- Keep the soil covered as much of the year as possible.
- Maximize living roots in the soil profile (*see above notes regarding root exudates and root contribution to stable soil organic matter*)
- Minimize disturbance (*tillage, overgrazing, traffic, harsh chemicals, etc.)*
- Energize with diversity (*long, diverse crop rotations and multispecies cover crops*).

Archuleta, Lamm, and associates have seen added benefits from cover crop mixes of five to ten species from three or more plant families, compared to single species or two-species (grass-legume) cover crop. For example, in Ohio, a field corn farmer harvested 170 bushels corn per acre when planted *with no fertilizer N* the year after a full-season 10-species cover crop that added 7-8 tons/ac aboveground and several tons/ac belowground biomass. Adding N at half or full recommended rate (140 lb/ac) *reduced* corn yield slightly, possibly owing to an adverse effect of fertilizer saltiness on a very active soil food web that the cover crop had fostered.

Multispecies cover crops often do a better job of suppressing weeds than single-species stands, because the former occupy potential weed niches more thoroughly: tall grasses and dense spreading broadleaf canopies complement each other above ground, while shallow-fibrous and deep-tap root systems occupy the soil profile more completely, outcompeting weeds for moisture and nutrients.

In annual cropping systems such as vegetable production, cover crops play a central role in soil health. Remember that living roots provide a key source of "food" for the soil food web. Even when living roots are not present (e.g., a cover crop has winterkilled, or has been terminated to make way for a production crop), maximizing soil surface coverage with residues, organic mulch, *etc.* to the extent practical will protect soil from erosion, and maintain favorable habitat for earthworms, fungi, and other key components of the soil food web near the surface. Of course, a "clean seedbed" is needed to plant some crops, or occasionally for weed control ("stale seedbed") – the goal is to keep rotations as "tight" as practical so that these vulnerable periods are minimized.

Regarding "minimize disturbance": the NRCS focuses on physical disturbance and promotes no-till and minimum-till systems. While these measures reduce erosion and conserve organic matter, it is also important to minimize chemical disturbances such as soil fumigants, anhydrous ammonia (N fertilizer), heavy use of soluble fertilizers, and soil-applied pesticides (even organic-allowed pesticides) and herbicides – all of which can adversely affect parts of the soil life or soil food web. Thus, while continuous no-till with conventional inputs may give the least *physical* disturbance, organic and ecological production systems that minimize the use of all pesticides give the least *chemical* disturbance.

The sustainability challenge is to realize the best of both worlds as much as practical. Skillful and innovative use of cover crops can make annual crop production on suitable sites (level to gently sloping lands, or terraces) compatible with optimum soil health. Cover crops can also be used effectively to tame sod and perennial weeds, and to build soil health in preparation for a high value perennial crop planting like asparagus, berries, orchard, or vineyard.

<u>Terminating Cover Crops and Managing High Biomass Residues</u>

Trying to incorporate the top growth of a mature, high-biomass cover crop into the soil can be daunting, especially when attempted with hand tools. The best approach is to chop the above-ground biomass into small pieces with a *flail mower,* an implement that is now available for the two-wheel tractor systems used by market gardeners (e.g., BCS), as well as for full-size four-wheel tractors. Then till the cover crop with a spading machine, rotary plow, or chisel plow followed by disk, or rototiller. If a moldboard plow is used, be sure to set it so it does not go too deep – about six inches is best. Deeper inversion buries the cover crop biomass and biologically active topsoil under subsoil, leading to a partially anaerobic breakdown of the residues, upsetting the balance of the soil food web and releasing plant growth inhibitory substances. Moldboard plowing too deep can reduce fertility for several years.

Because the "feeding frenzy" of soil life after a heavy cover crop is tilled in creates conditions temporarily hostile to germinating seeds and seedlings (both crop and weed), plan on waiting 3 or 4 weeks to allow residues to break down before planting. This is especially important for direct seeding; vigorous transplants can be set out after a shorter wait, perhaps 2 weeks.

Also, keep in mind that tillage sufficient to incorporate a heavy cover crop will accelerate the breakdown of organic matter and disrupt soil structure and some parts of the soil food web, thus compromising some of the benefits of the cover crop itself. This is especially true on sandy soils in warm climates

On a garden scale, one alternative to tilling in a heavy cover crop, is to mow, scythe, or weed-whack the crop close to ground level, and gather the clippings to use as mulch (on the same or a different bed, section, or field), or to make compost. Compost can be made from livestock manure and cover crop clippings in a ratio of 1 part manure to 2 or 3 parts clippings (or 1 to 5 for chicken litter). The remaining stubble can be managed easily by tilling the whole area, or by strip tilling in the crop rows for the following production crop. A short (1 to 2 week) wait may be needed for planting small seeds; transplants and large seeds can go in without delay. Note that shallow or limited tillage is best, so that some of the root mass is left undisturbed and transforms into stable soil organic matter in place.

If weed pressure is moderate and is mostly annual weeds, consider *no-till cover crop management*. Terminate the cover crop at or after full bloom and before seed set by roll-crimping (roller-crimpers are available for both four- and two-wheel tractor systems), flail-mowing, or scything. Leave mulch in place, or pull back slightly to expose planting rows, prepare planting slot with a tractor-drawn coulter and shank (no-till planting aid) or hand tools. For transplanting on a garden scale, dig planting holes with a trowel. This system works well for transplants, "seed" potatoes or garlic, onion sets, and large seeds. It is not recommended for direct-sown small seeds.

Strip tillage is a related practice: clear and till a narrow (3 – 6 inches) strip for crop rows, leaving the area between rows untilled and covered by cover crop clippings. For widely spaced, warm season crops like tomato , squash, sweet corn, or sweet potato, the cleared and tilled strip can be a bit wider (8-12 inches) to allow soil warming, and still keep a substantial (2-4 ft) inter-row region untilled and mulched with cover crop clippings.

Inoculating legume cover crop seeds

Be sure to inoculate all legume cover crop seeds with the correct *Rhizobium* inoculant – use "clover-alfalfa" for all true clovers (red, white, crimson, etc), sweetclovers, and alfalfa; "pea-vetch" for vetches, bell bean and Austrian field peas; "cowpea" for cowpeas or sunnhemp; and "soybean" for forage soybean. Tropical legumes like lablab and velvet bean take their own special inoculants. Most Garden Combination legume inoculants include the right bacteria for peas, vetch, and sometimes cowpeas – read the fine print on the bag to see what all it covers. If it says "southern pea," "blackeyed pea," "asparagus bean," or "azuki bean," then cowpea is also covered.

Perennial sod crops in the rotation / conservation crop rotation

One of the most effective ways to restore soil quality (organic matter, tilth, nutrient reserves) after several years' intensive annual vegetable or row crop production is to rotate the field into perennial clover and grass cover crops for one to three years. This longer interval without tillage slows the oxidation of organic matter and permits the buildup of organic matter and long term nutrient reserves; it can also reduce the soil's "weed seed bank," especially seeds of summer annuals like pigweed, galinsoga, lambsquarters, and foxtails. Crop rotations that follow several years in annual crops with two or more years in perennial cover can sustain long term soil quality and fertility more effectively than a rotation composed entirely of annual crops. On sloping land, the rotation can be arranged as alternating strips of annual or perennial crops laid out on the contour, thereby curbing soil erosion.

Sod areas can be harvested for forage or mulch hay, grazed, or mowed with clippings left in the field to retain nutrients and build organic matter. Cutting your own mulch hay allows you greater control over quality of mulch material (e.g. cutting before seed set to reduce weed problems), and the rotation balances the flow of nutrients, especially K, which often becomes depleted on land repeatedly hayed for many years, and can become excessive on fields repeatedly mulched with hay.

Although taking land out of production for one or more years may seem like a loss of income potential, the regenerative effects of the perennial cover can enhance yields during the production years. In addition, focusing your efforts on fewer acres of annual crops may allow you to manage the crops more intensively and effectively, and further increase per-acre yield.

Red clover is a short lived perennial well suited to a one or two year sod phase in a rotation, is easy to establish, and forms a good cover from seeding at 10-15 lb/ac. It fixes lots of N, makes soil P more available, opens the subsoil with its deep roots, and can reduce annual weed problems. Because it is shade tolerant, red clover can establish itself when interseeded or overseeded into another crop, such as a cereal grain (plant with the grain, or frost seed in late winter) or a vegetable like tomato or broccoli that is grown in wide spaced rows (broadcast the clover when the vegetable is established and about half-grown). Grow the red clover for 12-18 months, then till in to plant the next production crop. Red clover can also be planted along with oats (at 40-50 lb/ac) and (optionally) orchard grass or other pasture grasses (at 10-15 lb/ac) – either in early spring or end of summer – and grown for 1-2 years. Following 3-4 years of vegetable production with a one-year cover crop of red clover with oats or other cereal grain can offer many of the benefits of a perennial sod with a lesser sacrifice of time in production (1 year out of 4 or 5).

Crop Rotation:

Cover cropping is one aspect of the broader topic of crop rotation. Crop rotation is important for balancing nutrient demands and other effects on the soil, and especially for management of certain insect pests and diseases. Each plant family, and to a lesser extent each crop species within that family, has certain rooting pattern and depth, and specific nutrient needs; and releases a characteristic mix of substances into the soil. The latter include plant-synthesized sugars, amino acids, other microbial "food" compounds, and "secondary" compounds (including allelochemicals) that can affect the growth of soil life and other plants. This complex root exudate acts as a chemical signal that elicits a particular "guild" of soil biota (bacteria, fungi, protozoa, etc) that associates with the roots of that crop or plant family. Most of these are beneficial or neutral and help suppress pathogens (disease organisms); however, when soil or growing conditions are not ideal, pathogens can get a foothold and cause disease.

Different plants make different demands on the soil (nutrients, moisture), and also offer different benefits (fibrous root systems such as grasses promote aggregation and prevent erosion; deep taproots such as legumes and radish enhance drainage, retrieve leached nutrients and break hardpan). Growing the same plant family over and over in successive years reduces the benefits and promotes imbalances in nutrients and soil microbial life, including disease buildup. It can also build up certain allelopathic chemicals (some of the secondary compounds, which act as mild herbicides against certain other crops and weeds, and sometimes against the plant family being grown as well). A good rotation promotes soil nutritional, chemical, and microbiological balance, helps prevent certain diseases, and can slow the buildup of certain insect pest populations.

Crop rotation does not control *all* diseases. The USDA Sustainable Agriculture Research and Education (SARE) program (*www.sare.org*) has published an excellent manual, Crop Rotation on Organic Farms, by Charles A. Mohler and Sue Ellen Johnson, which has good research-based information on which pests and diseases are effectively controlled or reduced by crop rotation.

Crop rotation also helps with weed control, especially when the different crops have different planting and harvest dates, different tillage needs, and when the rotation includes some crops (especially cover crops) that deter weed growth through competition and allelopathy. Design the rotation so that you don't end up tilling the soil at the same season year after year – especially late spring, when seeds of prolific summer annual weeds like pigweed and galinsoga are "wired" to emerge in response to tillage.

When designing a rotation for vegetable production, try to plant major crop families no more than once every four years (at most once every three years) in a given bed or section. For best result, plant a particular family in a field or section at some distance from where it occurred last year (minimum 10-20 feet for disease control, 100 – 300 feet for insect pests). The 3 – 4 year rotation interval is especially important for the crucifer or brassica family (cabbage, broccoli, cauliflower, kale, collards, mustards, turnips, radishes, arugula, Asian greens); the solanaceous or nightshade family (potato, tomato, eggplant, sweet and hot peppers, tomatillo, tobacco); the allium or onion family (onion, leek, scallion, garlic, shallot); the cucurbit or vine crop family (cucumber, summer and winter squash, melons, pumpkins, gourds); the chenopod or beet family (table and sugar beet, chard, spinach, perpetual spinach); and the carrot family (carrot, celery, celeriac or celery root, parsnip, parsley, dill, cilantro or coriander). It appears less critical for lettuce and related vegetables (endive, radicchio, escarole). Provided that you do not have problems with "lettuce drop" or other fungal diseases, you can grow two succession crops of lettuce-type greens, followed by a year without lettuce family (which is same as composite or sunflower/daisy family) before going back into lettuce. Grasses (including cereal grains) and legumes, which include important cover crops, as well as vegetables (sweet corn, beans, shell and snow/snap peas, southern peas) can occur once per year. Avoid growing English peas (shell, snap, snow) *immediately* after vetch, bell bean, or field pea cover crops, which can lead to disease in the vegetable pea crop.

If you have trouble with a specific species of pest nematode (root knot nematode or other plant-parasitic species), be sure to precede and follow susceptible crops with crops resistant to or suppressive toward that nematode. Ask your Extension agent for advice. Note that, as you build soil quality and soil life (partly through cover crops and good rotation), pest nematode populations tend to decline.

Finally, be aware that certain vegetable crops – notably root crops and salad crops in which most or all of the plant is harvested and taken to market – leave very little residue to rebuild soil organic matter and reduce erosion. Try to precede or follow these crops with high-residue crops (cereal grain and legume cover crops, sweet corn) and/or vegetables in which considerable residue and/or root mass remains to hold and feed the soil – examples include broccoli, cauliflower, snap bean, and tomato (though for disease management you may want to compost or burn the aboveground part of spent tomato plants). The use of organic mulch can also compensate for the potentially soil-eroding effects of root crops and other low-residue crops.

Soil Inoculants and Other Biostimulants – Do they Work, and How to Use Them

In order to create a healthy, living soil, you need a diverse soil food web including many species of bacteria, actinomycetes, fungi, protozoa, nematodes, micro-arthropods (tiny insects and mites), and earthworms. Toward this end, you need three things: the beneficial organisms themselves, food for them, and "housing" (habitat, including micropore spaces with adequate moisture and oxygen) for them. A given soil can be below par because the organisms are absent or depopulated (usually one or a few components of the food web are deficient, rarely is a soil completely "dead" or devoid of life), or because they are underfed or starving (and thus dormant if not dying out), or because they lack habitat (as in a very sandy soil with little humus, or in a badly compacted loamy or clayey soil with literally no space and not enough air - think cramped, stinky alleys in a crowded city ...). Different soils may be missing different components or aspects of the requirements for a healthy living soil.

If your soil has had a history of good care and maintenance, it may simply be a matter of providing sufficient "food"(cover crops and organic inputs) on a regular basis to sustain the existing soil food web, thereby maintaining fertility. However, "raw" land, worn-out soils, and soils with inherently low fertility may need measures in addition to simply adding organic matter; often the soil food web itself, and/or habitat, must be restored or replenished.

In response to this need, vendors of organic amendments have developed a tremendous array of soil inoculants and other products claimed to have all kinds of beneficial impacts on soil health and crop yield and quality. Examples include biodynamic preparations, compost starters, and field sprays; various brand name inoculants with one or more types of beneficial soil organism; humates and humic acids; and a newer product called biochar. It can be difficult to determine which ones are right for your situation, as the effects of applying any one product may vary so much, from significant benefit to no visible effect. The good news is that there is very little chance of any of these materials causing any harm, other than the risk of spending money on them without significant outcome.

Reasons for unpredictable or uneven results include: different soils have different existing soil food web populations and different strengths and weaknesses; and some worn out soils may need supplementation with two or all three components (organisms, food, habitat). Thus, applying a specific inoculant to a soil that already has those organisms present, or other organisms that will simply outcompete the "newcomers" in the applied product, will not likely have an impact. Also, applying even the best possible inoculant to a depleted soil that also lacks habitat (structure) and/or is not receiving sufficient organic inputs, may be ineffective. When building up a depleted or low fertility soil, seek to address all three needs together.

A good quality, finished compost (crumbly, dark brown, pleasant earthy smell, few or no recognizable remnants of the original starting material) applied at rates as low as 1-2 tons/ac can often provide a good, biodiverse inoculant, including many components of the soil food web. Note that well-ripened compost does not itself contain much readily available "food" for microorganisms, as its organic matter is mostly stable; its role is primarily as inoculant and source for added cation exchange capacity (plant nutrient storage). Worm castings (vermicompost) provide a good inoculant, even when used mainly as an ingredient in greenhouse potting mix. When brewed and applied properly, compost tea and worm castings tea also make good inoculants.

Inoculant products consisting of a single organism or a small group of closely related organisms are usually not as effective as the more diverse inocula (some examples follow). Exception: mycorrhizal inoculants used appropriately on those crops that form highly beneficial symbioses with these fungi can substantially improve crop vigor, especially in perennials like fruit trees or grape vines.

Apply an inoculant, when you are about to till in a cover crop, heavy crop residue, manure, or other "raw" or incompletely composted organic matter. Apply the inoculant in the evening or in mild, cloudy weather, then promptly till or harrow into the top few inches of soil, as direct sunlight kills many of the good microorganisms. This is especially important for sprayed-on inoculants. Field applications of compost or worm castings can be done at the time of tilling in cover crop or other residues, or in conjunction with planting a production crop (e.g., in planting holes).

Other products such as biochar and humates do not add soil organisms, but are thought to stimulate the soil food web by enhancing the habitat. In addition to adding highly stable carbon, these materials provide or expand micropore space required by soil microbes.

It may be worth experimenting with combinations of products and practices to address simultaneously all three requirements of a living soil; for example, biochar, an inoculant, and a high biomass cover crop.

Following are some products, most of which are carried by Seven Springs Farm (www.7springsfarm.com); the last is from another vendor.

Actosol Organic Biostimulant - a formulation of humic and fulvic acids (components of humus) claimed to enhance crop nutrition, root growth, and soil biology. It primarily provides microbial habitat.

BioChar (CharGrow) - this is a specially manufactured charcoal that interacts with soil microorganisms and plant roots in a way that is supposed to enhance soil biology, nutrient release from organic residues, and plant nutrition and growth. Biochar products are an outcome of research on some atypically fertile and resilient soils in the Brazilian Amazon River Basin. Most soils of tropical forests are extremely fragile, and if they are cleared and put into vegetable or row crop production, the soil burns up all its organic matter, becomes bereft of soil life, and in some cases can turn to stone within a few years. However, in many small tracts within the Amazon, where indigenous peoples apparently added charcoal and organic residues (food scraps, dung, etc) each year for many generations, the soil has become very dark ("terra preta") and rich in stable organic matter. When good sustainable practices are used, these soils can be cleared and cultivated for crop production for centuries without a serious loss in soil quality. Whether and how a similar approach to amending the soil (biochar + cover crops + other organic inputs) can give similar benefits in other regions (such as the humid temperate climates of the eastern US) is a subject of research by advocates, skeptics, and impartial scientists alike. Biochar is a new product in the Seven Springs cataolog

Black Castings - a hgh quality worm castings product that I have found very helpful in greenhouse potting mixes at 10% by volume of the final mix. I have also used it in the field but have not seen as clear a benefit - the rates needed for field application may be too high to be economical. However, the enhanced seedling vigor resulting from greenhouse use has carried over into 10% yield increases in research trials even when no additional castings were used in the field.

Endomycorrhizal Inoculant (BEI) from BioOrganics - a blend of eight species of endo-mycorrhizal fungi (also known as Vesicular-Arbuscular Mycorrhizae or VAM). Most of our vegetable, fruit, and cut-flower crops benefit from root-synbiosis with one or more of these endo-mycorrhizal fungi - exeptions include the brassica plant family (kale, broccoli, cabbage, cauliflower, arugula, mustards, Asian greeens, radishes, turnips), and the chenopod plant family (spinach, beet, chard). Onion family, strawberry, tomato family, legumes, and corn form especially strong VAM symbioses that are highly beneficial to crop nutrition, water uptake, and resistance to root zone diseases. These beneficial fungi are present in many but not all soils, and tend to go dormant when soil phosphorus (P) levels are above optimum ("very high" or "excessive" on a soil test report). Mycorrhizal-host crops are most likely to benefit from this product on soils with low to moderate P levels and low pre-existing levels of VAM fungi (low OM, heavily tilled soils are likely lower in VAM).

Inocucor Garden Solution Concentrate - this is a blend of bacteria and yeast that is believed to interact with the indigenous soil food web to enhance its functioning, both in the breakdown of fresh organic residues (cover crops, green manures, animal manure + bedding, crop residues, kitchen scraps), and in crop nutrition and health. Field trials are reported to have realized 10% to 30% yield increases with Inocucor treatment (soil drench or foliar spray). Inocucor is a new product in the Seven Springs cataolog.

Humic DG (DG = Dry Granule) - this is another fulvic-humic acid product based on leonardite, which is a highly stabilized material, a "carbon matrix" that enhances micronutrient availability and uptake, and builds soil structure. Humic DG is a new product in the Seven Springs cataolog

Pfeiffer BD Field Spray - this product has been around for at least 60 years - it was developed by Dr. Ehrenfried Pfeiffer, who, by the way, hired my father to manage his 35-head dairy herd on 185 acres in Chester, NY (about 60 mi northwest of the Big Apple), from about 3 years before my birth until a little after my sixth birthday. Dr. Pfeiffer had a lab in nearby Spring Valley where he did all his arcane biodynamic research, developing and refining the preps and the compost starter and field spray. While biodynamic theory focuses on subtle energetic benefits from the field spray and other preparations, the science suggests that they at least provide a diversity of beneficial soil food web organisms.

VermaPlex - this is essentially a tea made from Black Castings, spiked with a few added species of endo-mycorrhizal and ecto-mycorrhizal fungi (the latter are most important for forest trees and other woody perennials, perhaps fruit trees). I have used this one a bit, but have not done any side by side comparisons to test its efficacy.

Soil Provide (microorganisms) and **Soil Revive** (microbial foods) are available through *Earthfort* (*www.earthfort.com*). Used together, they have been reported to enhance crop yield and quality; I tried it once on a buckwheat cover crop in a side by side comparison, and the treated side did show more vigorous cover crop growth. This same outfit also provides a full soil biology analysis.

Manure, compost, mycorrhizae, and the balance among soil N, P, and K

Soils that receive sufficient manure or compost to meet crop nitrogen (N) needs will accumulate phosphorus (P) over time, which can eventually lead to excessively high P levels. This happens because plants need only 1 lb elemental P (or 2.2 lb phosphate, P_2O_5) for every 6 to 10 lb N, and 6 to 12 lb potassium (K – or 8 to 14 lb potash, K_2O). The N-P-K ratio in aged or composted manure is more like 2-3 lb N and 2-4 lb K for 1 lb P. (Since the nutrient content of fertilizers and amendments is expressed as N, P_2O_5, and K_2O, a good compost typically has an analysis of 1-1-1, or 2-2-2 for a very rich material.)

Whereas plant-available N (whether applied, legume-fixed, or released from soil organic matter) is either utilized or lost (leached, immobilized, or volatilized) within the season, surplus P tends to accumulate in the soil. If the soil test shows low P, generous use of compost is often sufficient to correct the problem within a couple of years. When soil test P is *critically* low, or availability of compost or manure is limited, rock or colloidal phosphates can be used.

In addition, a vigorous population of root-symbiotic mycorrhizal fungi can compensate for somewhat low levels of *readily available* phosphorus (P) – what the soil test measures. The mycorrhizal symbiosis effectively doubles the root systems of many crops, enhancing uptake of P, micronutrients, and moisture (thereby conferring greater drought tolerance). They also improve crop disease resistance by crowding out soilborne root pathogens and stimulating crop defenses against pathogens. Mycorrhizal fungi also produce a sugar-protein substance called glomalin that is very persistent and helps stabilize soil OM. Most grain, legume, and vegetable crops benefit from the mycorrhizal association. Exceptions include spinach-beet family, buckwheat, and brassica (cabbage-broccoli) family (the last actively inhibits mycorrhizal activity in their root zone); these plants have other microbial associates that can help them obtain P.

Low soil P stimulates mycorrhizal activity, while above-optimum soil P causes these valuable organisms to go dormant. While they are not needed for P uptake, their other benefits are lost. Excessive soil P can also tie up micronutrients, or cause nutrient pollution to nearby streams.

Thus, when soil P levels reach optimum levels (50-100 ppm on the Mehlich 3 test used by A&L, or 50-100 lb/ac on the Melich 1 test used by some state Extension labs), annual P inputs (from manure compost or other sources) should be approximately balanced with P removal in harvests, about 20 lb/ac elemental P per year, perhaps 30-40 lb/ac for bumper crops or for double cropping. If soil P becomes excessive, applications should be reduced below the "replacement" rate. On high-P soils, cover crops that include legumes become especially important for replenishing soil organic matter and N without adding more P.

Potassium (K) can also accumulate in soils if applied at rates higher than the K removal in harvest. Because vegetable and row crops use so much K (150 to 250 lb/ac-year), this is not as common as P excesses, and is easier to correct by reducing K inputs until crop harvests draw down the surplus. K excesses occasionally develop when a thick mulch of hay from outside the field is applied year after year; or when manure or compost is applied at high rates intended to meet the crop's *entire* requirement for available N.

If P is high while K is low, good K sources include clean hay mulch (up to 2% K), straw mulch (1% K), and potassium sulfate (50% K – use in moderation as it is salty). *Be sure the hay mulch is free from persistent herbicide residues* (especially clopyralid, aminopyralid, picloram, and aminocyclopyraclor), and also free from noxious or invasive weed seeds.

On sandy soils with low cation exchange capacity (CEC), surplus K may leach out; on most other soils it will build up. If more than 8-10% of a soil's CEC is occupied by K, or the % CEC saturation with K equals or exceeds that for magnesium (Mg), the K excesses can cause nutrient imbalances in crops (may manifest as Mg deficiency, tip burn, or blossom end rot), and livestock (a life-threatening Mg deficiency condition called grass tetany).

For N, it is rarely necessary to provide the crop's entire N requirement in soluble form. In healthy, biologically active soils, the soil life gradually mineralizes the "unavailable N" in compost, other organic materials, and soil organic matter. In good soil, a warm season crop can obtain most or all of its N requirement through mineralization, and it is only necessary to ensure that *total* N inputs from legumes, compost, etc. are sufficient to replenish the N removed in harvest. Cool-season heavy feeders like spring broccoli or spinach may need some faster-acting N like blood meal or feather meal because the soil life works more slowly at lower soil temperature. In biologically depleted soils, such as those with a long history of intensive conventional production with insufficient organic inputs, higher rates of applied available N may be needed to sustain satisfactory yields.

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