

# The Natural Farmer

Summer 2011

## Special Supplement on Legumes as Cover Crops

### It's Elemental

### How Legumes Bridge the Nitrogen Gap

by Laurie Drinkwater

All life on Earth requires the element nitrogen, which forms the basis of amino acids, the building blocks of proteins. Not only are proteins an important component of cell structure, they also mediate the myriad metabolic reactions, such as photosynthesis, that make life possible. Humans depend on plants and the process of photosynthesis to supply the carbon and energy we need.

While our atmosphere is 78 percent nitrogen gas—a molecule consisting of two bound nitrogen atoms—plants and animals lack the ability to use nitrogen in this form. It must first be “fixed” or taken out of the gas molecule and combined into other compounds before it can be incorporated into amino acids.

Until the invention of an industrial process that has enabled us to fix nitrogen using fossil fuels as an energy source, life on Earth was completely dependent on a biochemical process carried out by bacteria known as biological nitrogen fixation. Bacteria that can convert or fix nitrogen are referred to as “diazotrophs” and are found everywhere on earth, including the open oceans, lakes and ephemeral pools, prairies, forests, wetlands, and agricultural lands.

Scientists believe that such bacteria developed the ability to fix nitrogen as early as three billion years ago, long before plants colonized the earth. Three lines of evidence support this view. That long ago, earth's atmosphere did not contain oxygen. Nitrogen fixation occurs only in anaerobic (oxygen-free) conditions. In fact, the enzyme that catalyzes the key nitrogen fixing reaction is damaged by oxygen, suggesting that it developed in an anaerobic environment. Second, the fact that nitrogen-fixing enzymes are ubiquitous and are found in distantly related bacterial groups, combined with the high degree of variability found in nitrogen-fixing enzymes, indicates that nitrogen fixation is an ancient metabolic process. Finally, the fact that nitrogen is such a major constituent of living organisms suggests that sufficient nitrogen has been available for billions of years. Without the ability to fix nitrogen from the atmosphere, bacterial colonization of earth would have been severely limited.

Contemporary terrestrial ecosystems are dominated by higher plants. Diazotrophs, usually in



photo by Steven Vanek

**Andean farmers in the northern Potosi region of Bolivia with Tarwi, an important nitrogen fixing lupine that is grown as a food source and a green manure. Tarwi can grow and fix substantial amounts of nitrogen in very poor soils.**

symbiotic relationships with certain plants, provide -- through the process of biological nitrogen fixation -- all of the new nitrogen additions these ecosystems consume. Once fixed from the atmosphere, this nitrogen circulates from plants to the soil in the form of dead plant residues and is then released back to plants via the activity of microorganisms that decompose soil organic matter. Together, biological nitrogen fixation and decomposition provide all of the nitrogen required for plant growth in natural ecosystems.

Unlike natural ecosystems, where nutrients tend to be conserved so that very low levels of nitrogen fixation are sufficient to maintain productivity, agricultural systems export large quantities of the element—in the crops harvested and sold at market. In conventional agriculture, farmers make up the balance by importing nitrogen in the form of synthetic fertilizer. In contrast, organic farming systems depend on biological nitrogen fixation to replenish soil nitrogen removed by harvests. Biologically fixed nitrogen can be supplied directly through incorporation of leguminous green manures or

manure produced by livestock fed nitrogen-rich legumes. If not for the large industrial agricultural system that relies on manufactured nitrogen fertilizers and other inputs, and transfers them to organic systems via animal manures and other waste streams, organic farming systems would be entirely dependant on biological nitrogen fixation.

#### Biological Nitrogen Fixation

Because the molecules of di-nitrogen gas in the atmosphere are held together with a strong triple bond, they are extremely stable and, as a result, biological nitrogen fixation is an energy-intensive process. Organic substrates (such as carbohydrates) are the primary energy source for the diazotrophs that carry out biological nitrogen fixation. The high energy demand of the process may explain why significant rates of nitrogen fixation usually occur only in conjunction with photosynthesis—either through bacteria associated with higher plants or in bacteria that are able to carry out photosynthesis themselves, such as cyanobacteria (blue-green algae).



photo by Meagan Schipanski

**Pea root with fully developed, active nodules. The presence of leghemoglobin and thus nitrogen fixation is indicated by the pink coloration.**

Compared to the high energy cost of the nitrogen fixation process, nitrogen released from soil organic matter is much less expensive. Consequently, nitrogen fixing plants and bacteria will always use soil-derived nitrogen if it is available before switching to nitrogen fixation. This difference in the energy demand of recycled versus newly fixed nitrogen explains why plants and microorganisms have co-evolved to efficiently cycle previously fixed nitrogen through mineralization and assimilation of nitrogen stored in soil organic matter.

Diazotrophs and plants have evolved varying degrees of association that facilitate the transfer of photosynthetically derived carbon from plants to bacteria to fuel the biochemical reactions of nitrogen fixation. There are two distinct ways that diazotrophs can function in terrestrial systems. Asymbiotic diazotrophs (those that do not form nodules with legumes) are a diverse group of free-living soil bacteria that can rely on soil organic matter for their energy and carbon while also having the ability to fix nitrogen. Symbiotic diazotrophs must live with specific plants in order to thrive and complete their life cycle.

**Free Living: Asymbiotic diazotrophs**  
Diazotrophs that are not obligate symbionts have a variety of lifestyles ranging from diazotrophs which are entirely free of plant roots and rely on soil organic matter for their energy to those that are adapted to live in close association with plants but do not form nodules. There is a lot of uncertainty about how much nitrogen is actually fixed by diazotrophs that live in bulk soil, entirely free of plant influence because from a microbial perspective, bulk soil is normally a carbon-limited environment. In contrast, associative diazotrophs which utilize carbon released by plant roots, mainly in the form of carbohydrates as an energy source, can carry out significant levels of nitrogen fixation. The plant has less control over the fate of the fixed nitrogen in this situation, compared to when nitrogen is fixed within a root nodule. The nitrogen fixed by associative diazotrophs is incorporated into the bacterial biomass and becomes available for plant uptake when microbial grazers feed on these bacteria and release nitrogen as a byproduct of their metabolism. Due to the rapid turnover of microbial biomass in comparison with the much longer life cycle of the plant, significant quantities of associatively fixed



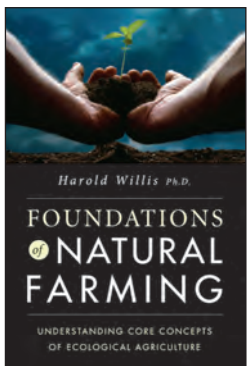
photo by Steven Vanek

**Vetch nodule sliced open**

nitrogen become available to nearby plants. Some free-living diazotrophs, such as algae, are capable of both fixing carbon via photosynthesis and fixing nitrogen. Many cyanobacteria, in spite of their relative self-sufficiency, form symbiotic partnerships with plants, to the eventual benefit of the plants. For at least 1,000 years, rice farmers in China have used *Azolla*, an aquatic fern that forms a symbiotic relationship with the cyanobacteria *Anabaena azollae*, to suppress weeds and fix atmospheric nitrogen to increase yields in their paddies. In this symbiosis the cyanobacteria live in specially modified hairs on the fern fronds so they have access to sunlight.

More commonly, free-living diazotrophs that have been studied are bacteria that tend to thrive in the rhizosphere—a unique habitat at the root-soil interface. The rhizosphere environment supports a teeming community of microorganisms due to the constant release of energy-rich substrates such as carbohydrates and amino-sugars. *Azotobacter* sp. and *Bacillus* sp. are examples of diazotrophs commonly found living in the rhizosphere of crop plants such as maize and wheat. We still have a lot to learn about rhizosphere bacteria. Using molecular methods to study bacteria in the rhizosphere has revealed that the communities of bacteria that occupy the rhizosphere are not there solely by chance. Rhizosphere bacteria, including diazotrophs, are not obligate symbionts—that is, they do not have to find a plant rhizosphere to exist and they do not have the

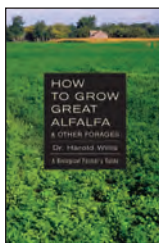
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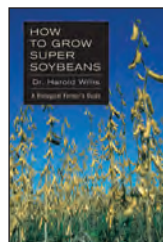
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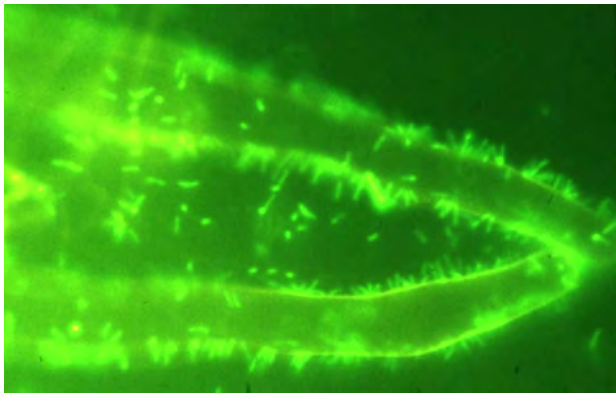
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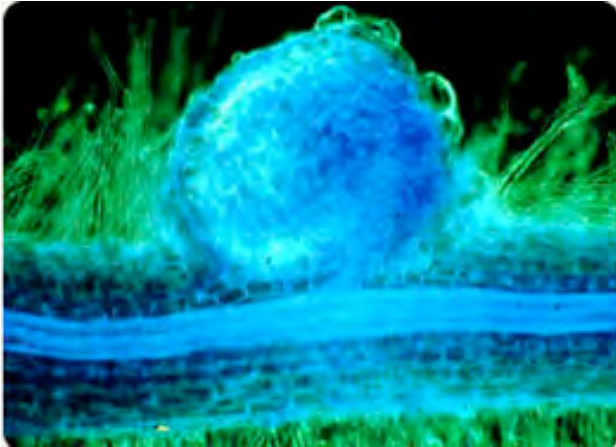
**Nodule formation. Two root hairs with Rhizobia attaching to their surface. The rhizobia are shown as tiny, bright green spines from the root hairs.**

highly evolved co-dependence of a symbiotic relationship. They do communicate with plants through the exchange of chemical signals, however, and some species are always found in the rhizosphere of particular plants.

Wheat offers a particularly interesting example, since it is one of the oldest agricultural plants and is currently cultivated across a wide variety of climates and soil types. A number of microorganisms have consistently been found in rhizospheres of wheat growing in geographically dispersed soils from diverse environments. *Paenibacillus polymyxa* is a free-living nitrogen fixer that has been found in the wheat rhizosphere in North America, Europe, and Africa, and the rhizosphere populations of this organism appear to be adapted to the wheat. In fields with a long history of wheat production, the populations of this species co-evolved with the wheat to become better nitrogen fixers. A great deal of research is currently focused on understanding the ecology of beneficial rhizosphere bacteria, including the nitrogen fixers that commonly live in association with crop plants.

**Better together: symbiotic diazotrophs and legumes**

Once used to describe people living in community, symbiosis refers to the relationship among unlike organisms living in close association to one another,



courtesy of Centre of Excellence for Integrative Legume Research

**Nodule in the early stages of forming.**

as with the bacteria that populate the human gut or the clownfish, which grazes within the tentacles of the sea anemone, harvesting small invertebrates that might otherwise harm its host. Many different species of diazotrophs have co-evolved with plants to form obligate, mutually beneficial symbiotic relationships where carbon substrates produced by the plant during photosynthesis are supplied directly to the diazotroph in exchange for fixed nitrogen.

The bacteria that fix nitrogen within the nodules of leguminous plants are the most well studied diazotrophs and are also the most important from an agricultural perspective. These diazotrophs fall within the *Rhizobium* and *Bradyrhizobium* genera and are typically referred to collectively as *rhizobia*. Rhizobia are obligate with plants in the Fabaceae family, commonly known as legumes. The legume-rhizobia symbiosis developed 65 million to 2.6 million years ago. Today they populate every continent, numbering more than 12,000 species and 440 genera. Within that group, more than 100 species are agriculturally important plants, from miniature annual clover crops to perennial black locust, harvested for fenceposts, lumber, and even livestock forage.

Unlike free-living diazotrophs, symbiotic rhizobia can fix substantial amounts of nitrogen because they receive a direct supply of carbon in exchange for nitrogen fixation. Complex chemical signaling has evolved between legume species and specific rhizobial strains to initiate the formation of root nodules,



photo by Andrew Syred / Photo Researchers, Inc

**Nitrogen-fixing bacteria. Colored scanning electron micrograph (SEM) of Rhizobium leguminosarum nitrogen fixing bacteria (brown) in ruptured root nodule cells of a plant. These bacteria take nitrogen gas from the air and bind it up in compounds which the plant can use for its nutrition. They do this using an iron-containing protein called leghemoglobin, similar to the hemoglobin found in red blood cells. The plant benefits from this symbiosis as it means they can grow in soils with a low nitrogen content, soils which are inaccessible to other plants.**

Magnification: x475 at 6x7cm size.

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symbiotic organs inside the legume's roots in which rhizobia reside while fixing nitrogen. The nodule provides physical protection for the rhizobia while increasing the capture of the fixed nitrogen by the plant.

**Legumes-Rhizobia and Mycorrhizae: Three-way symbiosis**

In addition to rhizobes, legumes—with few exceptions—also rely on symbiotic fungi, known as arbuscular mycorrhizas (AM). This symbiotic relationship developed before the plant-diazotroph symbioses and both molecular and fossil evidence

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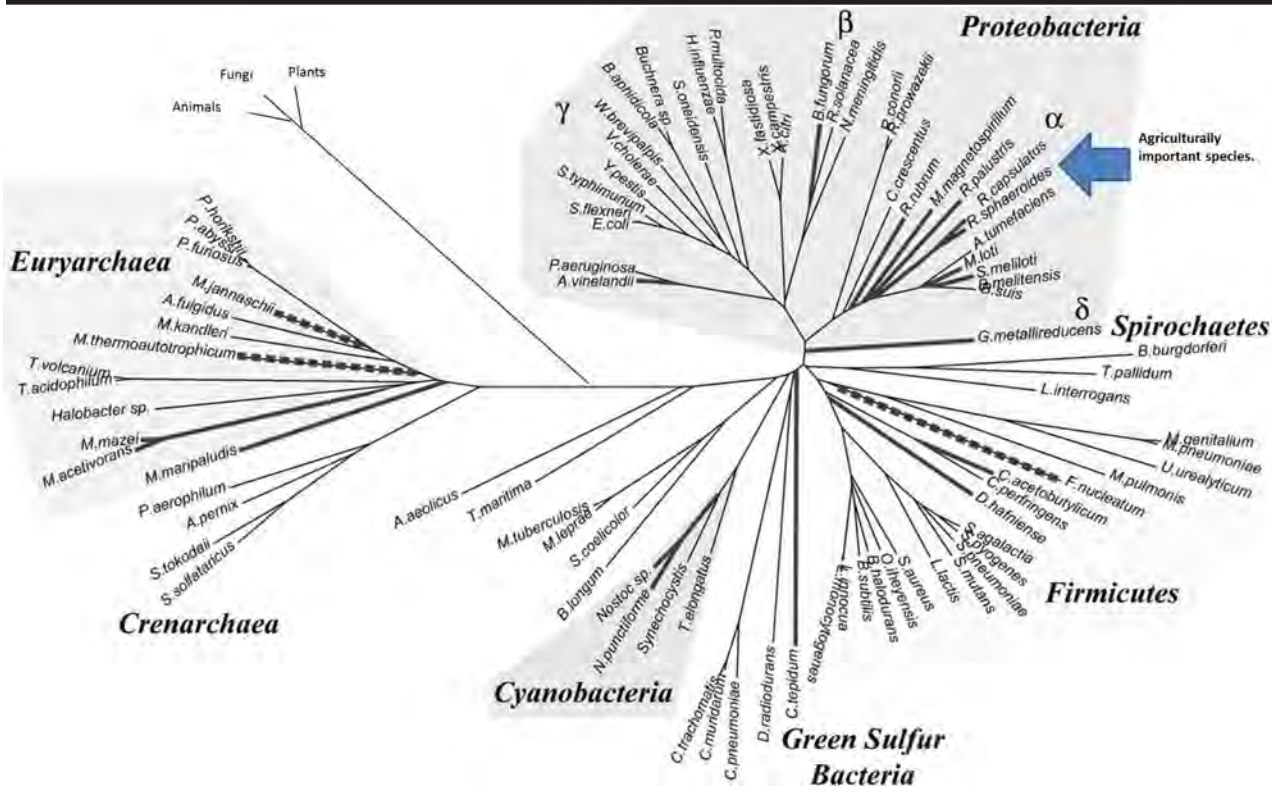
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**Phylogenetic tree showing the wide distribution of nitrogen fixing species and phyla.**

This phylogenetic tree shows the diversity of microbial phyla relative to the “higher organisms”. The ability to fix nitrogen is widespread and can be found in species from most microbial phyla (indicated by highlighting the group and darker lines to the species). The darker dashed lines indicate species that have nitrogen fixing genes in their DNA that have not been confirmed as functional (i.e. they have not fixed nitrogen in the laboratory). The Proteobacteria, a phylum with many soil dwelling species, are divided into groups designated by Greek letters. The agriculturally important Rhizobia which are obligate symbionts with legumes are within the a-Proteobacteria as indicated by the arrow.

indicate that the earliest land plants were mycorrhizal. Plant-fungal associations resembling modern AM-plant symbioses appear in the fossil record 400 million years ago—even before roots evolved! Some researchers suggest that plants could not have colonized land without fungal partners to assist with nutrient acquisition from the nutrient-poor, undeveloped soils that were prevalent when plants first colonized the land. Once terrestrial plants became established, soil organic matter accumulated and mycorrhizal partnerships evolved in conjunction with the expansion of plant life on Earth. AM associations are particularly important in environments

where phosphorus is limiting or is still mainly present in soil mineral pools, rather than in soil organic matter.

A recent survey of terrestrial plants found that mycorrhizal associations are the norm, rather than the exception. Eighty percent of surveyed land plant species are mycorrhizal; arbuscular mycorrhizal (AM) associations are the most widespread. This symbiosis with AM fungi has much in common with the legume-rhizobia symbiosis and is thought to have served as a means for the development of legume-rhizobia partnerships. Plants had already

evolved the ability to exchange chemical signals—in order to recognize AM fungi—and were well-positioned to expand communication to include other soil microorganisms. Like rhizobia, AM fungi are obligate mutualists and the plant-fungal partnership is mutually beneficial through the exchange of energy and nutrient resources whose scarcity would otherwise limit growth of the symbionts. Plants supply carbon substrates to the fungi and AM fungi assist with phosphorus uptake. The carbon cost of mycorrhizas is difficult to measure, but researchers estimate that plants allocate 10–20 percent of net primary production to AM fungi. The enhanced ability to access soil phosphorus in poor soils that AM fungi afford ensures that legumes will have the extra phosphorus needed to carry out biological nitrogen fixation.

**A New Organ: Nodule formation**

To form the nodules in which nitrogen fixation takes place, legumes and rhizobia have developed specialized structures and a complex array of biochemical signals. The root hairs of legumes exude chemical signals that attract compatible rhizobia in the area. The rhizobia send out their own signals, called “Nod factors,” to alert the plant to their presence and availability to live in nodules. As a result, a tunnel forms in the legume root and a new organ known as a nodule begins to form. The rhizobia move into the nodule, a stage known as infection, and begin undergoing rapid cell division. Most of the bacteria are transformed into special cells called “bacteroids,” which have a completely different anatomy from the normal rhizobia and can be branched, club-shaped, or spheroid. The bacteroids are larger than the free-living rhizobia and cannot undergo cell division. They begin consuming carbon supplied by the plant and convert nitrogen gas into ammonia that can be incorporated into amino acids.

During the legume growth phase, the rhizobia consume as much as 30 percent of the carbohydrates produced by the plant through photosynthesis. The cycle ends when the plant flowers and redirects its energy from providing the rhizobia with carbohydrates to creating flowers and seeds for its own reproductive process. This is why flowering is a useful agronomic cue indicating that nitrogen fixation has reached its peak. At that point, the nodules slough



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\*Source: IRI data ending April 3, 2011.

off from the plant's roots, releasing a pulse of nitrogen into the surrounding soil. The bacteroids cannot live in the soil and die. The few normal, rod shaped rhizobia that were living in the nodules survive and reproduce in the soil. If a compatible legume germinates in their vicinity, they infect the roots and begin the process over again. Depending on conditions, the rhizobia will persist in the soil for three to five years in the absence of compatible legumes.

**Amazing proteins:  
nitrogenase and leghemoglobin**

Two proteins play key roles in the biochemical processes that convert N<sub>2</sub> (di-nitrogen gas) into NH<sub>3</sub> (ammonia), the form that can be used by plants.

The enzyme that catalyzes the reaction, "nitrogenase," is a large, complex molecule consisting of protein units with distinct functions. The proteins contain various co-factors with sulfur, iron, and molybdenum. The enzyme is sensitive to oxygen and in the presence of free oxygen, becomes deactivated. As a result, all diazotrophic bacteria have a mechanism for keeping oxygen away from nitrogenase. For example, in cyanobacteria (blue-green algae), nitrogenase—and hence nitrogen fixation—is located in specialized anaerobic (oxygen-free) cells.

The biochemical reaction of nitrogen fixation is shown below:



The MoFe protein contains the apparatus that carries out the reaction that splits nitrogen gas and bonds hydrogen atoms to each nitrogen atom to get ammonia. To carry out this reaction, the MoFe protein requires a steady source of energy, in the form of electrons (-e). These are supplied by the Fe protein, which is bound to each end of the MoFe protein. The Fe protein splits ATP in order to supply electrons into the MoFe protein. In the typical reaction, two molecules of ATP are consumed for each electron transferred, releasing ADP and inorganic phosphorus (Pi) in the process.

Maintaining a nodule environment that is conducive to high rates of biological nitrogen fixation presents a considerable challenge. The bacteroids must carry out high levels of respiration in order to produce the ATP necessary for nitrogenase to function. On the other hand, nitrogenase is inactivated by contact with oxygen. A second essential protein known as leghemoglobin resolves this problem. Leghemoglobin regulates oxygen levels in the root nodule for optimal bacterial function. Similar to the way hemoglobin functions in our bodies to move oxygen from the lungs to cells that require it for cellular respiration, leghemoglobin supplies oxygen to support respiration in the nodules while keeping the concentration of free oxygen low enough that nitrogenase can do its job. Leghemoglobin is co-synthesized by the legume plant and its rhizobia. The plant provides the globin portion of the protein, while the heme section—which contains iron and is the site where oxygen is actually held during transport—is synthesized by the rhizobia.

Leghemoglobin has another characteristic in common with our own hemoglobin: It displays a distinct pink color and provides a visual cue indicating that nitrogen fixation is most likely being carried out inside the nodule. To assess whether nodules are actively fixing nitrogen, slice them with a very sharp knife to visually inspect the interior, which is packed with bacteroids. If the bacteroids have the capacity to fix nitrogen, the interior will be pink due to the presence of the protein leghemoglobin.

**All systems go: the ecological niche of legumes**  
Because legumes thrive in nutrient-poor settings, they are the first plants to arrive on the scene when depleted soil begins to recover. In partnership with rhizobia, they slowly enhance soil quality by boosting levels of available nitrogen and, as they die and decompose, building soil organic matter. Over time, that success leads to their own demise—eventually, seed from faster-growing, later succession plants establishes, thrives, and then displaces the legumes, crowding out and shading them. Old-time farmers without access to modern-day soil analyses knew to look for certain plants as indicators of soil conditions. Perennial, medium-red clover, for example,

thrives in nitrogen-poor soil where cash crops would fail, sending its roots deep into the ground in search of micronutrients and minerals not available on the surface and fixing nitrogen until it flowers. As it boosts nitrogen levels, improves drainage, and ultimately deposits those hard-won nutrients in the topsoil, however, it creates a hospitable environment for fast-growing, shallow-rooted, heavy-feeding grasses that ultimately outcompete the clover.

Nitrogen fixation is a two-way street. Even as legumes influence soil quality through their collaboration with rhizobia, the soil environment affects the amount and rate of nitrogen fixed through direct and indirect effects on the plants and microorganisms involved. High soil temperatures (>27–40° C), water stress, soil acidity (pH < 5), low soil phosphorous availability, and aluminum toxicity—conditions common in certain tropical systems with highly weathered soils—can limit rhizobial growth and the reactions that fix nitrogen. The availability of the element molybdenum, a key component of the enzyme nitrogenase, which catalyzes the reaction that breaks the triple bond in di-nitrogen gas, can also be an important limiting factor in some soils. Because biological nitrogen fixation only supplies new nitrogen to agroecosystems while recycling other nutrients, integration with other soil amendments is critical to both the ability of the system to support the nutritional demands of biological nitrogen fixation and to maintain longer-term nutrient balances.

Because of their nitrogen-fixing capacity and the resultant high levels of amino acids in their tissues, legumes tend to be protein-rich food sources for humans and animals. Given the high rate of export of nitrogen off the farm in the form of cash crops sold at market, legumes serve as a vital counterbalance, especially for organic farmers who eschew synthetic fertilizers. Without their contribution of biologically fixed nitrogen, organically managed agricultural land would soon come to resemble the depleted soils in which legumes often serve as pioneer species in early succession. By incorporating legumes in a crop rotation, farmers can replenish fertility with limited off-farm inputs.



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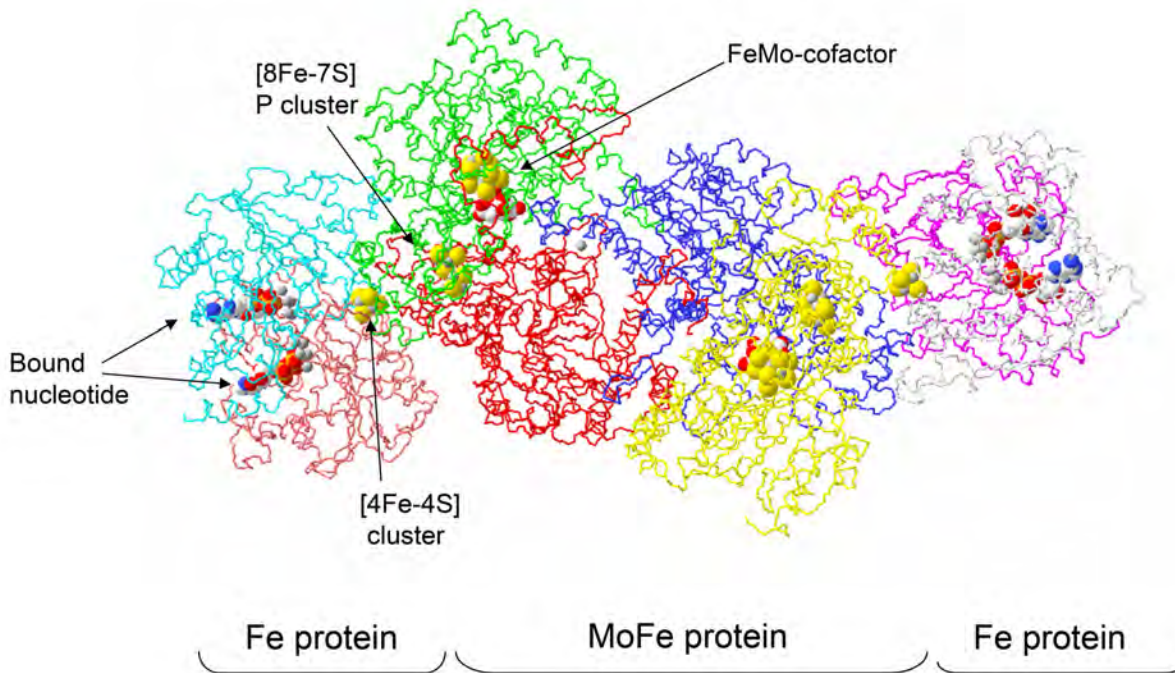
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**Schematic of the nitrogenase enzyme complex. The MoFe protein is the center of the complex with the Fe protein units located on either side.**

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**Resources**

Managing Cover Crops Profitably, 3rd Edition. 2007. Handbook Series Book 9. Published by the Sustainable Agriculture Network, Beltsville, MD. 244 pages. Available as a PDF from the SARE website. Accessed 5/2011. <http://www.sare.org/Learning-Center/Books/>

ARC Centre of Excellence for Integrative Legume Research. Research institute in Australia with an educational website. You can find a brief overview of legume biology and some nice photos here. Accessed 5/2011. <http://www.cilr.uq.edu.au/pages.aspx?id=110>

If you'd like a bibliography of textbooks and journal articles used to write these articles contact me by e-mail. Laurie Drinkwater (led24@cornell.edu).

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# In the Mix

## Effective inoculation pairs active rhizobia with symbiotic legumes

by Sharon Tregaskis

To fix nitrogen, legumes rely on symbiotic bacteria known as rhizobia. Each species of legume fixes nitrogen only in concert with a particular rhizobial species, so farmers seeking to promote nitrogen fixation generally inoculate their legume seeds with commercially prepared inoculants tailored to each cover crop in their rotation. There are many distinct strains of each rhizobial species and these vary in terms of their “effectiveness”—that is, their ability to collaborate with the plant to fix nitrogen in exchange for carbohydrates varies.

Rhizobia also occur naturally in the soil, where they may persist for as long as three to five years, depending on soil conditions—low pH significantly reduces rhizobial longevity. Legumes native to a particular region—such as lupines, as well as certain species of clover and trefoils in the Northeast—typically require less inoculation than introduced species, such as soybeans, because their symbiotic rhizobia are often already present in the soil. Further, many farmers opt not to re-inoculate before each legume seeding if their rotation cycles the same species back through a previously inoculated field within three years. However, inoculant is relatively inexpensive and there’s no easy way to know whether the strains native to a particular parcel are robust and complementary to the legume slated for planting.

Only living rhizobia can partner with legumes to fix nitrogen, so effective storage and application by the farmer are vital to the effort. Never purchase inoculant that has passed its expiration date, and make sure what you buy has been stored in a cool, dark space until it is applied. Ultraviolet rays (direct sunlight) and temperatures above 60°F kill rhizobia; consequently, inoculant should be kept in the refrigerator and used promptly. Pre-inoculated seed from a distributor must be kept cool and dry along the entire supply chain, until planting. If more than one year passes before planting, re-inoculate the seed. Many fungicides and other seed treatments can be toxic to rhizobia, though some strains are resistant. Check with your inoculum producer and beware inoculum products pre-mixed with pesticides or other toxic chemicals, since these are not allowed under organic certification rules and can compromise inoculum viability.

There are four types of commercially available inocula: powder, granular, liquid, and frozen. Because they must be maintained at the appropriate temperature during shipping and until application, liquid inoculum broth and frozen concentrate tend to be less available forms, compared with dry powder and granular inoculum. Powdered treatments typically costs about \$2/acre; a single gram contains approximately one billion rhizobium. Granular inoculum works best with seed that should be handled sparingly, such as peanuts, as well as large seeds like soybeans. It also works better than powdered inoculum when being distributed using equipment designed for larger particle sizes, such as a planter or fertilizer spreader.

Dry inoculum must be protected from excess moisture until it is applied to seed. Once inoculated, seed must be planted promptly—never treat more than you can plant in a single day. Simply mixing dry inoculum and dry seed leads to poor results due to waste and uneven results. Instead, use either a slurry or adhesive solution approach. Nutrient-rich, commercial adhesives are available—check with your distributor to learn about OMRI-approved options; it’s also possible to make your own using dilute sugar syrup (one cup of sugar dissolved in one quart of water) or milk (one quart mixed with two tablespoons of molasses). Simply stir into the seed, then mix in the dry inoculum, which will adhere more evenly to damp seed. To inoculate seeds that have been treated with lime, use one ounce of vegetable oil for each pound of seed. Inoculum may also be stirred into water to form a slurry and



then mixed with seed in the planting box. Some farmers deposit the inoculum directly into the seed furrow when planting.

Some farmers choose commercially coated seed. Note that this seed must be stored at conditions appropriate for rhizobial survival, is heavier and bulkier than uncoated seed, and often flows faster than uncoated seed. Consequently, recalibration of seeders may be necessary.

Even after seed has been inoculated, nitrogen fixation may not occur if the soil lacks vital micronutrients such as molybdenum—whose availability is reduced in acidic soils—as well as iron, and cobalt. Some commercial inoculants actually contain molybdenum, so read the ingredients before purchasing additives.

Because of the narrow environmental conditions in which rhizobia thrive, it is ideal to plant inoculated legumes in conditions that bolster their survival—in a moist seedbed, just before rain, or followed by irrigation. Using a drill seeder or following broadcast seeding with a cultipacker to put the rhizobia in firm contact with soil also helps, as rhizobia exposed to the sun will die before initiating nitrogen fixation. Never sow inoculated seed with fertilizer, which can kill the rhizobia.

## The Word

### Key terms for understanding the science of cover cropping to boost nitrogen

by Laurie Drinkwater

- **amino acid:** the building block of proteins, amino acids comprise a nitrogen-based molecule, a carbon-based molecule, and an organic side chain that varies among amino acids
- **biological nitrogen fixation:** the process by which gaseous nitrogen in the atmosphere is converted to amino acids that can be metabolized by plants
- **diazotroph:** bacteria that possess the capacity to fix nitrogen through the use of the enzyme nitrogenase
- **enzyme:** proteins, like nitrogenase, that catalyze, or increase the rates of, chemical reactions, converting substrates into new products
- **humification:** the process of plant decomposition that yields humus, the organic component of soil
- **inoculation:** introduction of species-specific bacteria to allow symbiotic nitrogen fixation; soybeans, for example, are inoculated with *Bradyrhizobium japonicum*.
- **Labile:** unstable, likely to undergo chemical, physical, or biological breakdown
- **Leghemoglobin:** a protein that reversibly binds oxygen so that oxygen levels in the nodule do not inhibit the process of nitrogen fixation.
- **Legume:** plants in the family Fabaceae or Leguminosae, which fix atmospheric nitrogen

- **nitrogenase:** an enzyme comprised of a molybdenum-iron molecule that catalyzes atmospheric nitrogen into ammonia
- **nodule:** the organ formed in the root of a legume that houses symbiotic bacteria and in which the chemical reactions of nitrogen fixation take place

- **prokaryote:** A microscopic, single-celled organism that lacks a nucleus and membrane-encased organelles
- **rhizobia:** A common genus of nitrogen-fixing soil bacteria
- **symbiosis:** a mutually beneficial interaction between two organisms in close physical proximity



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# Perennial Favorite

## Legumes boost fertility and smother weeds in asparagus

by Sharon Tregaskis

Robin Ostfeld and Lou Johns met in 1978 as employees on a blueberry farm in Washington State. They established Blue Heron Farm three years later, in Washington; since 1986, they've farmed 18 acres in Lodi, NY. In addition to restaurant, wholesale, and retail sales—at the Ithaca Farmer's Market—Blue Heron offers a winter CSA and supplies both the Greenstar Food Coop in Ithaca and the Park Slope Food Coop in Brooklyn. In addition to a heavy emphasis on root and storage crops—including three colors of beets, six varieties of garlic, and a dozen winter squashes—Ostfeld and Johns grow sixteen varieties of lettuce and twenty-five tomato varieties, as well as an array of robust seedlings for home gardeners.

Deeply concerned about soil compaction and with a growing interest in low-till management of their land, Ostfeld and Johns moved to a system of six-foot-wide, permanent raised beds in 1991. Three- to four-foot grass alleys among the rows have eliminated erosion on their sloping terrain and provide habitat for spiders and beneficial insects, reducing the farm's reliance on sprays (what they do use is all OMRI approved, since the farm has been certified organic since 1987). In addition to cover crops of small grains and legume mixes, Ostfeld and Johns incorporate composted chicken manure to boost fertility and improve the microbial health of the soil.

Blue Heron keeps two-thirds of an acre planted to asparagus, which has become one of the farm's cornerstone spring crops. From the beginning, Lou has incorporated legumes to smother weeds and boost fertility. Inter-seeding an annual cover crop among perennials planted in a permanent raised bed system demands a holistic approach to insure compatibility between plants and equipment, among plant spe-



photo by Sharon Tregaskis

**In 1991, Lou Johns and Robin Ostfeld moved to a permanent raised bed system—offset by grass alleys—in which they grow an array of crops, including perennial asparagus and garlic.**

cies, and with a farmer's overall management style. I asked Lou to describe the entire process – from initial bed preparation for the asparagus, through its lifespan, and how legumes fit into the system.

**• What considerations prompted you to intercrop legumes in your asparagus?**

One was an issue of cultivation/weed control: Could a grower reduce or possibly eliminate cultivation in

asparagus? Conventional production relies heavily on cultivating and herbicide applications to maintain clean fields—not an option for an organic grower. Second, we were interested in maintaining adequate fertility and organic matter without having to import and apply compost amendments annually.

**• What parameters did you set?**

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photo by Sharon Tregaskis

**A wet spring this year prevented early cultivation and increased weed pressure at Blue Heron, yet the Purple Passion asparagus stands tall.**

and maintain adequate fertility and soil organic matter for a given crop. As is the case in most decisions made in organic vegetable production, the parameters of the cultural practices are defined by the problem and the goal, while the solutions/practices are defined by a grower's equipment and other infrastructure. At Blue Heron, all of our planting is done on permanent beds and row spacing is kept to two schemes: four rows on sixteen-inch centers, and two rows on thirty-six-inch centers, so that our tillage, planting, and cultivating equipment is compatible with many different crops.

**• How do you prepare the permanent raised beds for asparagus so you are ready to incorporate legumes later on?**

Asparagus planting starts the year before with as much bed tillage as is necessary to suppress annual and perennial weeds and possibly a rotation of buckwheat. We make an early fall application of compost (on the heavy side is good, but not required) and

either leave the beds open after incorporating the compost or plant them to oats as a winter-killed cover crop. The oat seeding is weather and timing dependent.

**• And what about planting the asparagus, itself?**

In the spring, the beds are tilled as soon as the weather permits: Not too soon, as you want the soil to be dry enough to work well. You need to be able to furrow the ground to a depth of at least eight inches, ten if you can do it (twelve inches or more is unnecessary). We use our potato hilling equipment—much like a middle-buster with wings on either side—to open two rows at thirty-six-inch centers on the bed. I generally make two passes over the bed to open as deep a trench as I can, roughly eight to nine inches. We use two-year-old crowns—our preferred variety is Purple Passion—and lay and set them by hand at eighteen inch spacing, covered with two to three inches of soil as we go.

We allow the plants to grow out and send up spears to a healthy height of twelve inches or so, then use a two-row Lilliston rolling cultivator to stir the top two to three inches of soil for weed control. This also spills soil into the still-open furrow that the plants were set into. This cultivation pass might fill the furrow to three-quarters of its depth, and leaves some of the new spears sticking out. After the asparagus sends up additional spears and the first ones have grown to twelve to eighteen inches tall—usually in mid-July or the first few days of August—we make another pass with the Lilliston. At this point, you are hoping that you have fairly good weed control, because quite soon the asparagus will be tall enough to keep most cultivating equipment out of the planting.

**• When do you introduce the legumes?**

I'm pretty emphatic that you don't plant a cover crop in the establishment year. In the first year, the asparagus struggles to get established so there is no cover crop/understory planted. I have killed entire new asparagus plantings attempting it; I think it was likely a combination of too much competition for sunlight and nutrients that led to its demise. Crowns go through a pretty harsh ordeal being planted as seed and grown up two years, then dug up and shipped around in boxes with no dirt on them.

If for some reason there is a concern about a heavy weed population (things happen), a front or rear-tined rototiller allows you to walk through the stand rather than driving over the top of the rapidly growing plants to clean up a planting; hoeing between plants is fine also.

**• How do you manage the first-year asparagus in anticipation of the legumes you'll plant in year 2?**

You sit back and do all the other stuff that you have to do at your farm for most of the growing season. You should be set up to irrigate this new planting if the season brings dry weather; we use overhead sprinklers. Asparagus is somewhat tolerant of droughty conditions, but in the establishment year you are better off keeping it in a vigorous growth mode, if possible.

First-year asparagus should put up six to eight spears that grow out (and up) to lovely, four to five-foot-tall, feathery, tree-like plants. As fall approach-



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es and temperatures start to drop, the asparagus will stop growing and begin to yellow.

This is a good time to mow down the stand and do a shallow tillage to incorporate the residue before winter and wet weather sets in. We use a seven-foot flail mower and till with the rotovator set to work at a depth of three to four inches, using gauge wheels that run in the alleyways. We put off this final operation until late in the fall season to allow the asparagus to grow as long as possible—the more growth this year, the more spears to pick the next. There is no time for planting and establishing a cover crop: We leave the beds open for the winter.

**• What about subsequent years?**

Year two and beyond starts with the hope of an early and dry spring. After several walks through your new planting—well before the daffodils have buds out—use a hand hoe or butter knife to probe beneath the drying ground for the white tips of the new spears. All plans change at the moment you find them—do a quick, shallow tillage pass over the top of the beds or rows. Don't wait, because once asparagus starts growing, it's gang busters for the next month or so; you don't want to miss this opportunity for controlling weeds.

In year two, if your asparagus had a vigorous establishment year, you can do some early, light picking without hurting future yields. We pick tops for one to two weeks and stop when the new spears that emerge are not as robust and vigorous as the earlier ones.

**• When do you interseed the leguminous cover crop?**

In the second season, the day you decide to stop picking (you might as well pick every thing you want to sell or eat), till over the planting and prepare to plant the cover crop/understory of soybeans, hairy vetch, and Canadian field peas. We generally use 75–100 pounds per acre, for the three-seed mix. With the soybeans, I buy the longest-season variety I can get. I'm not looking for seed; in fact, I'm trying to avoid it, but I think any kind of soybean would work.



photo by Sharon Tregaskis

**To reduce soil compaction, Blue Heron Farm's Lou Johns and Robin Ostfeld set the tire width of all of their equipment to travel on the grass alleys among their permanent raised beds.**

**• How do you seed the legumes?**

We mix the seeds in five-gallon buckets: half soy, one quarter vetch, and one quarter field pea, along with inoculants and some dry compost (as an additional soil inoculant and a flowing agent to aid in tossing the seed) and then toss handfuls evenly over the beds. A coverage of a seed every inch or two is fine. I'm going to experiment by seeding with our newly purchased grain drill this year—wish me luck.

After the seed is sown, we run over the bed one more time with the rotovator set to run with a very slow rotor speed and quite shallow—just enough to stir the seed into the soil. If needed, watering in the seed is a good idea, but I usually wait a day or two

with the hope of allowing the dry soil conditions to kill any weeds that may have emerged during the harvest period.

**• What else do you do, once the seed is sown?**

Sit back and console yourself for the fact that you won't be eating asparagus until next spring. Soon after the cover crop has been tilled in, new asparagus spears begin to emerge. If all goes according to my plans, the cover crops begin to germinate and cover the floor of the soon-to-be asparagus forest. Healthy asparagus plantings can reach heights of six feet or more—ours become fully entwined with vetch and peas by fall; the soybeans are shorter in stature and stay down under the canopy.

# The Importance of the Plant's Root Ball

Frequently a bedding plant is transplanted into field soil conditions that are less than perfect. Within the root block or ball, the plant, and the plant's partner microbes should have established a system and structures capable of extending their organization out into the field soil. The green leaves provide the energy to power the outreach and the potting soil serves as the cultural base. Investing in sufficient media for ample root balls pays back in improved crop yields. *JH*



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Again as fall approaches, the cold slows the asparagus growth and causes the plants to yellow. Get out your mower and take it down; if soil moisture conditions are cooperative, till in the residues sooner than later.

• **Any further tips, for the remainder of the asparagus lifecycle?**

In subsequent seasons, the harvest period lengthens until you are picking for four to six weeks and possibly one more, depending on the weather and the stand's vigor.

There is one insect pest you will contend with: the asparagus beetle. You will have them, trust me—but don't let them scare you. They generally are not that bad under this management scheme. If they show up in the establishment year, be prepared to spray the stand after the majority of the larvae hatch (the adult beetle, red with black stripes, lays little black eggs on the young spears). The larvae, gross little gray grubs, are quite susceptible to pyrethrum and rotenone products. During later years,

the adults generally emerge late in the harvest period and do minor damage by chewing on the spears and laying eggs. We do not spray during harvest and ask our loyal customers to tolerate the slight cosmetic damage to the otherwise perfect asparagus. Once the harvest is over, tillage breaks the feeding and egg-laying cycle of the beetle and we see very little damage in the new growth that emerges.

• **How do you harvest?**

We are snap harvesters, meaning we break the spear two to three inches above the soil line, when the spears are eight to ten inches tall (ideally; sometimes they get taller). In good weather, harvest happens every day and all spears that are of the desired height are picked into empty, two-and-a-half gallon buckets. In our washing area we fill the buckets halfway with clean, cold water and then place them in a walk-in cooler set at thirty-five degrees. Asparagus handled this way can keep perfectly for five to six days.

• **How did you think about winterkill when**

**choosing your cover crop?**

In this scheme, winterkill is not an issue for the actual cover crop itself because the bed gets mowed and tilled in the fall. Originally, we selected soybeans because they don't produce viable seed that carries over into the following season, partly because they are planted late. The benefit is that you don't have soybeans coming up as a weed in the spring harvest period.

• **How is it working out?**

After many years of working with this cover-cropping scenario, I am now realizing that though soybeans work well, the issue of having cover crop/understory plants that have winter viable seed would (and actually does) work well in this routine. I came to this notion when I found our soybean crop routinely getting eaten down by woodchucks—rather extensively, in some plantings—so I started incorporating other familiar cover crop species into my understory seeding. So far I have added hairy vetch and Canadian field peas with excellent results.

The issue of seeds carrying over to the next season has been surprisingly slight. When planted as a summer-sown cover crop, hairy vetch rarely produces seed by fall. The field pea, though it can and will produce viable seed for the next season, has low germination due to the poor conditions it finds itself in for the winter (cold, wet, clammy soil, rather than a nice, dry warehouse), so the resulting spring seedling production is low and inconsequential as an early "weed" in the asparagus. I'm fine with having peas as weeds, they're easy to control and there's enough opportunity in this system to slow them down before and after the harvest period. Even if they grew through that second tilling, it doesn't matter.

• **Do you plan further tweaks to the system?**

I may experiment more with using more Canadian field peas in the mix because of their self-seeding/characteristic—the more competition for annual and perennial weeds, the better. This year, I plan to use our newly acquired grain drill to plant and incorporate the seed. In the past, we've seeded by hand and then used the rotovator to stir the seed into the soil.



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• **How does your intercropping system mesh with existing soil organic matter and nutrient levels?** We've never tested to actually know the numbers—we have only evaluated the system by its results, which are consistently good yields with minimal weed pressure. We apply manure during pre-planting bed preparations, none after that, and routinely inoculate the cover crop seed using inoculants that are species specific. I do it routinely because it's cheap and easy and I don't have to worry about whether the rhizobia are there or not.

Though I can't say I've looked at soybean roots in our asparagus, I have in many cases checked other leguminous crops on the farm and found active nodulation. I am aware of the issue of reduced nitrogen fixation in legumes due to high available nitrogen in the soil from fertilizer (composted manure, in our case), but that possibility wasn't the only driver for eliminating regular additions of compost. One of the goals here is to reduce imported amendments as much as possible and take advantage of on-farm cover crops that produce nitrogen and also enhance soil organic matter and microorganism populations in the soil.

• **Are you satisfied with this approach?** Our system continues to be workable and productive over the twenty years we've been using it. The additions of hairy vetch and field peas have been our only changes to the basic scheme. Seasonal weather changes can make this system troublesome, however. Wet, cool, long springs that force a grower to forgo the early/pre-emergence tillage (like this year), leads to a weedy harvest period (mostly towards the end), but generally by then the soil is dry and can be worked adequately to get good weed-kill and strong cover crop seed germination.

• **How does the cost of intercropping legumes compare with other fertility and weed management options?** In general, I don't see legume cover crop seed as expensive, because I know how much I'm paying for imported, composted manures. We don't produce any manure or compost at the farm, so that kind of input is a cost and it's expensive. If I wanted to compare the cost of seed to its influence on my soil fertility, it's a pittance—it doesn't even come close to the cost that I incur buying in fertility. Even though legume seeds seem expensive when compared to small grains, the cost is nominal and we don't use that much of them.

As to weed control, asparagus is such a vigorous grower that once it's established, and the windows for cultivation are very short. At a certain point, we are completely shut out of the field with the tractor-mounted cultivation equipment because it gets too tall. If we miss the opportunity to till the beds or plant the cover crop, we use a small front-tined rototiller to accomplish the task. The ability to have

a weed-suppressing understory growing in the crop is a very desirable alternative to me. For the expense of a little bit of seed, the benefit is not just fertility, it's also weed suppression and organic matter build-up and moisture control.

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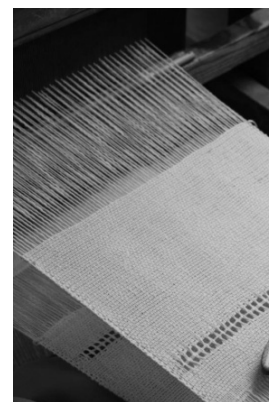
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# Building Soil with Cover Crops at the Poughkeepsie Farm Project

by Jack Kittredge

Poughkeepsie, on the Hudson River halfway between New York City and Albany, has a notable history. It was there, in 1788, that New York convened its constitutional ratification convention, attended by such illustrious figures as Alexander Hamilton, John Jay and George Clinton, and became the 11<sup>th</sup> state to join the union. Early a major center for the rendering of whales, during the 19<sup>th</sup> century the city became important in shipping and making hats and paper. Matthew Vassar, founder of the college that now dominates the center of the city, owned several local breweries.

The region's natural beauty attracted wealthy families such as the Astors and Vanderbilts to build sumptuous weekend homes there and support cultural activities such as the state's oldest continuously operating opera house, established in 1869. The city sits on a bluff above the Hudson and enjoys plentiful rainfall and moderate temperatures.

Besides gracing a somewhat depressed community with a large campus and lovely buildings, Vassar College also owns a nearby 500-acre ecological preserve. While most of it is managed by the school's biology department and includes trails and wetlands, a portion has been leased for over a decade to the Poughkeepsie Farm Project (PFP).

The PFP is a non-profit educational organization focusing on agricultural programs. It works with at risk youth in local schools, sponsors the city's farmers market, runs a farm apprentice program, and operates a 400 family CSA producing some 60 tons of food for local consumption. The farm managers are Asher and Wendy Burkhart-Spiegel.



photo by Jack Kittredge

## Wendy & Asher Burkhart-Spiegel are the farm managers of the Poughkeepsie Farm Project

"Our whole footprint is probably 15 acres," says Asher, referring to the land the PFP manages. "The growing area is about 12 acres, and the rest we have structures on or use to make compost. Originally we paid \$1 a year to the school for our lease. Now we're in the middle of a renegotiation and it looks like it might go up to a thousand dollars."

"The PFP is supported by farm earnings and donations and grants," says Wendy. "When we first came here the CSA was around 250 shares. We added on about three acres just by expanding the area in beds and going closer to the fences. The CSA takes about 75% of our crops, the farmers market about 10% and the sponsored part (donations to food banks and subsidized shares) about 15%."

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I have a small truck farm where I grow vegetables to sell at Farmer's Markets as well as to supermarkets. Deer just love beet tops—I have had them eat a 100 foot row in one night! Last year, when my beets came up, I put some granular *Plantskydd* in a spreader and applied it around the outside row of the beets. The deer didn't eat a bite. The key is to get the product down before the deer start nibbling. Later in the spring, my pickers came and told me the deer had been eating the zucchini. I took out the spreader and made one trip

around the patch applying *Plantskydd*, and the deer stayed out until after harvest.

We have such a deer problem in the valley that, when I tell folks in my garden seminars about your product, they jump right on it. Hooper's Garden Center, in Kalispell, Montana, sent one of their customers to me, desperate to see if I could help them save a \$30,000 investment in flowers that were to be planted for a special event on a large estate. I sent them to the CHS Country Store (also in Kalispell), where they proceeded to clean all the *Plantskydd Granular* off the shelf. The estate put in an order for 50 more 20 lbs bags this year.

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The farm was originally set up in 1999 by Dan Gunther, previously the grower at the Phillis Bridge Farm Project. A number of Poughkeepsie people and Vassar professors were members of the CSA there, and were interested in joining one closer to home. Conscious of the wildlife issues presented for farming by their 500 acres of wilderness, the school eventually erected an 8-foot tall welded wire fence around the 12 acres of farm fields. Asher says it has been pretty effective against the many deer and other wild creatures that would otherwise decimate the crops.

The couple has been managing the farm since 2003. Asher grew up in suburban Philadelphia, and Wendy in New Hampshire. They met farming in Georgia when both were taking time off from college. They worked on farms for a couple of years and decided they were serious enough about farming that they should finish their degrees before getting more involved in it. So they got bachelors at the University of New Hampshire, continuing to work on farms in the summers. Towards the end of school they took over a small CSA in the town next door, juggling that for two years. But it was too small to support them both and they went looking around, ending up in Poughkeepsie.

The CSA starts the last week of May and runs into the first or second week of November. The farm production budget is \$150,000. Asher is the only full-time year-round staff person. Wendy is year-round but her time is limited by the need to care for their two children, 4 and 1 years old. They also employ three apprentices, plus Vassar students who get credit but are unpaid, and various people who are with them 8 to 10 weeks during the summertime.

“Because of the work requirement for shareholders,” says Wendy, “we also have 30 or more people coming out here each week for 3 hour work blocks. It’s a big help when it comes to harvesting. If we were out here alone we would spend all day at it. It may not be the most efficient use of their time, but it is very social and people appreciate the vegetables more. That’s also how I get to know the members.”



photo by Jack Kittredge

Asher stands in front of one of the fields he cover cropped in rye and vetch.

PFP is not certified organic, but is Certified Naturally Grown. Asher thinks they are probably not tracking their compost well enough in terms of temperature and regular turning to meet organic standards. But he doesn’t think they have any other practices that would keep them from being certified.

I ask about whether they do any spring production.

“We’re at capacity,” Asher replies. “We are land limited and to extend the season we would need to shrink something else. Also, we need to shut down our water system in the winter for frost reasons, and we’re dicey turning it on in early March.”

The farm is pretty mechanized. They run a 6-foot rototiller behind their Kubota, and have a 5-tine chisel plow and mulch layer. Transplanting is still by hand, although a transplanter is on the wish list. A walk-in cooler next to the parking area keeps the CSA shares fresh.

One major problem, however, is the underlying soil.

“Our soil is very well drained,” says Asher, “so we have fertility issues. We make compost from leaves we get from the college and the town. We figure that is not a very big nutrient source, but it provides a lot of organic matter. We get a custom blend of fertilizer from Fertrell, and use soybean meal for nitrogen.

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“The custom blend doesn’t have any nitrogen in it,” he continues. “We keep them totally separate because sometimes we plant crops where there were no cover crop at all and it was cropped the whole season before, so we figure there is not much nitrogen there. In other cases the cover crops will reach maturity and there will be a lot of nitrogen from them there. So we separate out the nitrogen component of our fertility from the mineral component.”

Asher is interested in building his crop health through better nutrition, but would like to see some farm-scale trials of the ideas behind nutrient density.

“Many of its claims are almost mainstream,” he says. “It makes sense that if you grow plants in a healthier soil their immune systems will be stronger. But I’d like to see it tried on a large scale. In a modest way we have taken parts of that approach with the custom blend we have done. We do soil sampling every year and get micronutrient analysis done. If it calls for it we put a little zinc or boron in the mix. Mostly what comes back is that we need a lot of potassium and a good bit of sulfur, though.

“Potassium is highly leachable,” he continues. “It has just one cation to hold onto soil particles, as opposed to calcium and magnesium with their two charges. We have been using greensand and sulphate of potash, which is 15% available potassium. But we have noticed that our iron levels are going up. Greensand has lot of iron so we think that is where it is coming from. We cut back on the greensand this year.”

When they first got there, the couple relates, their kale and chard were pretty hardy – they would take a couple of frosts. But they noticed they would go down sooner than the pair thought they should. Then they got more intentional about their fertility and started adding potassium. After a while they noticed the kale would stand frosts better. It wasn’t until a couple of years later, Asher says, that he was reading an old extension publication that mentioned adding potassium to improve frost capability.



photo by Jack Kittredge

**Most of the farm’s fields are covered by lush cover crops in April.**

“If you can achieve something as basic as increased frost hardiness with fertility,” he says, “it doesn’t seem so far fetched to me that you can improve the health of the plant that way.”

Because of the sandy nature of their soil, the farm pays a lot of attention to irrigation. They use drip for crops on plastic or single row crops. But they find their soil is so sandy that often drip goes straight down and doesn’t wet a big enough soil volume. So most everything else they tend to put on an overhead system. They have enough thin walled aluminum pipes to cover 6 of their 200-foot beds. They use town water and have buried supply lines throughout the growing area.

Asher and Wendy use a lot of plastic mulch both because of weed pressure and to retain moisture. They prefer the Biotello bio-degradable mulch, which doesn’t need to be picked up in the fall. But they have started playing around with using landscape fabric.

“Last year we put the peppers and eggplants on it,” he says. “That worked out really well for us. It is reusable. The beds are 6 feet wide and the rolls we get are 12 and a half feet wide. So it covers 2 beds with a little overlap where 2 sheets meet. You cut holes in it to plant through. We roll it up in the fall and will be able to reuse it several years, I think.”

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The couple mulched their garlic with straw for years. But they found that if you put it down heavy enough that it suppresses weeds then you have to help every single clove up through the mulch. If you put the mulch down light enough that the plants can come up through it, then you don't get good weed control.

"Half the time it seemed like we were losing unacceptable percentages to rotting under the mulch," Asher recalls. "We knew other people weren't mulching so we finally decided to go without mulch and cultivate. We did it with our tractor cultivator and it looks beautiful."

One of the main strategies Asher and Wendy have developed to deal with their sandy soil is extensive cover cropping. They look to them for reasonably priced sources of biomass and nitrogen, in that order.

"I've been listening to Laurie Drinkwater out at Cornell," says Asher. "She is finding that legumes will shut off nitrogen fixation if there is plentiful nitrogen in the soil. It saves them metabolic energy if the nitrogen is not needed. So we have been pairing legumes and grasses together, on the theory that grasses get going faster and suck up some of that available nitrogen, stimulating the legume to do its thing when it might not otherwise. Laurie is finding that you have to be careful to balance the ratio between the grass and the legume. The grass may well out compete the legume to the point where you are not fixing that much nitrogen. I'm sure it depends on a whole lot of factors – soils, temperature, moisture, who knows what?"

At PFP they commonly use a mix of rye and the legume hairy vetch for seeding cover crops in the fall. They put on many more pounds of rye than vetch, usually on the order of a hundred or more pounds of rye per acre and about forty of vetch.

"I can't claim that this is the optimum ratio to get nitrogen fixation," cautions Asher. "We get fixation – there are nodules on the roots. But we haven't done any analysis of it. Laurie can figure out what



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percent of nitrogen in the standing biomass was from the soil and what was fixed from the atmosphere. That nitrogen has a slightly different signature. But we're not doing anything like that on the farm! We're just eyeballing it. The cover crops end up being an indicator of fertility for us.

"As vegetable growers," he continues, "we are probably trying to manage our nutrient levels to the high side. We're growing high value crops. So we want to err on the high side and we use more nutrients than we need. But I kind of think of the cover crops as being a nice self-regulating function. If there is already a lot of nitrogen in the soil, the grass is going to easily out-compete the legume. So you had a lot of nitrogen, it is still there in the grass because you grew the cover crop before it leached, and you are now turning it in. If your fertility was lower then presumably the legume is going to have a leg up and you'll get better fixation. Which will hopefully bring you up to somewhere in the same neighborhood."

Looking at the farm's various stands of grass and legumes one can see that some areas are greener and fuller. Some sections just have higher or lower fertility. But over the years Wendy and Asher have gotten the farm's overall soil organic matter into the high 3% or low 4% range – quite a feat for a sandy soil.

Part of the trick for building the farm's productivity is Asher's rigorous adherence to a schedule of rotations. He figures the farm has 10 bed acres of growing space, if you cut out all driveways and headlands. They grow crops on about 8 bed acres a year with two acres fallow and in cover crops. Those 8 acres of crops are divided into four groups and moved around each year, so each bed on the farm ends up going through a five year crop rotation. Cover crops and fallow is year one, nightshades and alliums is year two, brassicas is third, the fifth year is cucurbits, and the fourth year is everything else – lettuce, carrots, beets, chard, chickories, spinach. They have been following this set rotation for nine years.

"It helps us plan the cover cropping as well," says Asher. "Cucurbits are followed by a fallow year, so the earlier cucurbits that come out give us a chance to plant oats with sweet clover as a cover. Typically the oats die and the sweet clover over-winters. Then we can let it go to flowering and it will be a good five feet tall. We will mow it off, plow it in and then reseed it in late July or August to something that will again go over winter.

"Beds that don't get cover cropped," he continues "but aren't going to be planted soon we'll put on oats and peas, or oats and crimson clover. Because some of the cucurbits come out early enough, and we know they are going to be in cover crops the whole year, we can put in sweet clover for weed issues and bare fallow it once the clover is done."

They have been experimenting with various summer cover crop trials, using hot weather grasses and legumes to take advantage of that warm time of year. In fields that are open in July they wait until the whole section is done, then drill in a cover crop, cultivate it, and then overseed it with rye and vetch.

"We have tried sorghum/Sudan grass, Japanese millet, soybeans, and cowpeas," says Asher. "The latter two are legumes and the first two are hot weather grasses. The soybeans we get are Boyd, from Lakeview Organic Grain out in Penn Yan, NY. We drilled the cowpea seeds with Planet Juniors, 3 rows to the 6-foot bed, 18 inches between rows. We cultivated the cow peas a couple of times, then over-seeded with rye and vetch. In August we might use wheat and vetch or even oats and vetch -- it is so much easier to manage the results the next spring. Rye can be so hard to kill. Of course the oats winter kill."

The couple have to put rye in the ground in late September if they want any kind of ground cover before the winter. If they put it in later they won't get real growth until the spring.

On one bed they weren't worried about getting a bare fallow in so they seeded it with winter wheat and a perennial ryegrass in late September, then

frost seeded it with red clover. The wheat germinated and started growing in the fall, over wintering as a green plant. When it had heads on it, but hasn't set seed, in late June or early July, they'll mow it off and kill it. Then the red clover will come up.

"Rye doesn't send up a seed head unless it vernalizes," Asher explains, "or goes through a cold temperature stage. Winter wheat needs to be seeded in the fall and needs vernalization, too, to produce a seed. But spring wheat isn't hardy enough to go through the winter, although it can produce a seed head without vernalization. So you seed winter wheat in the fall, spring wheat in the spring."

In April what you will see on the farm is mostly rye and vetch that went in last fall, much of it after a cover of peas or beans earlier in the year. Asher estimates that they probably get over 50% of their acreage into rye each year.

"The strategy that we ended up using," he says, "is that we get more overall biomass growth if we put the early crops where the late crops came out. So the early crops this year went in where the latest crops were last year. Rye and vetch become the crops we use for the vast majority of our cover crops."

The hoop house, where they grow tomatoes, is an exception. There they over winter crimson clover, which doesn't over winter reliably in Poughkeepsie outside, but will in the hoop house. They put it down in October but it doesn't get much growth on until the days get longer in February.

Although Wendy and Asher enjoy their jobs at PFP very much, they still would like to be farming their own place and have been looking at land. In that part of New York, of course, land is expensive.

"The market is estate driven," sighs Asher, "with a lot of equestrian properties. But we don't have any long term security here, and the scale of the operation is a little small to support us both full time forever. We have two kids now, and those expenses are just going to increase."

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# A Holistic View

## Leguminous cover crop management in organic farming systems

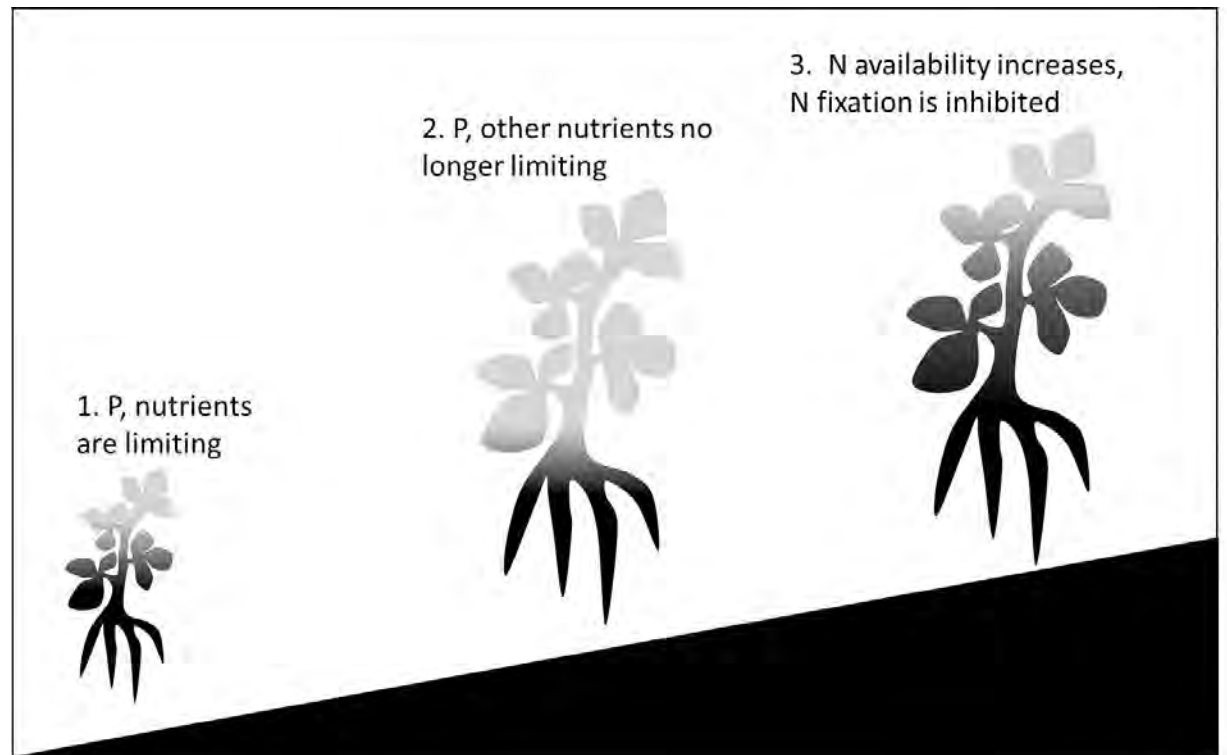
by Laurie Drinkwater

Soil management is the foundation of organic farming, and nitrogen-fixing cover crops are a key component of any organic soil fertility management regimen. Organic soil fertility management draws heavily from an ecological framework and seeks to manage plants, soil organic matter, and soil organisms to maintain internal cycling capacity with the intention of managing the full range of soil organic matter pools, ranging from “active” organic matter to very stable, humified organic matter. Intentional management of soil organic matter to maintain a robust community of soil microorganisms enhances the capacity of the soil to deliver nutrients to plants. This holistic view is the basis for the soil fertility management practices used in organic agriculture.

Biological nitrogen fixation—in which legumes in symbiotic relationship with bacteria known as rhizobia capture atmospheric nitrogen and convert it into a form available to plants—is the major source of new nitrogen in organic agriculture. Organic farmers typically combine the use of leguminous cover crops with additions of composts or animal manures to provide the remaining complement of major and minor nutrients. A major challenge faced by farmers who rely on biological nitrogen fixation as the chief source of nitrogen additions is determining how to optimize the process to meet cash crop nutrient requirements.

In addition to fixing nitrogen, leguminous cover crops serve multiple functions in organic farming systems. The functions we hear mentioned most often by organic growers are: 1) build soil organic matter 2) suppress weeds, 3) provide habitat for beneficials, 4) suppress disease, 5) improve soil tilth, 6) reduce nitrate leaching, and 7) reduce soil erosion. To increase the probability that a cover crop can achieve these multiple functions, organic farmers often plant mixtures that combine legumes with non-nitrogen-fixing plant species. Grasses, for example, are usually more effective for weed suppression and reducing soil erosion, while brassicas excel at capturing nitrate to reduce leaching losses, particularly in sandier soils.

Legumes can provide as much as 300 pounds/acre of nitrogen, although 80–150 pounds/acre is more common. Even in the case of harvested legumes, such as food-grade soybeans, 10 percent of the nitrogen fixed by the plant remains in the root at the time of harvest and becomes available to subsequent crops. In a study of inputs on twelve organic grain and vegetable farms in the Northeast, organic grain farms relied on legumes for an average of 80



Increasing soil fertility

figure courtesy Laurie E. Drinkwater

**The relationship between soil fertility and nitrogen fixation across a wide range of soil fertility. Black indicates nitrogen from soil, gray indicates nitrogen from the atmosphere (fixed nitrogen). 1) In very poor soils, legume growth and nitrogen fixation are limited by low nutrient availability. Plants will be small and will fix little nitrogen. These conditions rarely occur in organic farms of the northeast. 2) In soils that are more fertile, and meet the minimum requirements for P and micronutrients that support nitrogen fixation, legumes can grow and fix large amounts of N. Under these conditions, nitrogen fixation rates are highest.**

**3) In some agricultural soils, soil fertility can be very high, and in particular, nitrogen availability may be high enough to suppress nitrogen fixation.**

percent of all nitrogen inputs. In contrast, organic vegetable farms relied on legumes for an average of only 18 percent of nitrogen inputs; the majority of their nitrogen inputs were from compost additions.

The soil environmental conditions resulting from a farmer's management practices—such as the use of compost additions, tillage regimen, and rotational sequence—interact with the biological processes governing nitrogen fixation and influence how much nitrogen legumes will fix. In addition to practices that directly affect the soil environment, other decisions such as choice of legume species and planting methods—including seeding rates, timing, and whether or not the legume is planted with non-nitro-

gen fixing plants—will determine how much nitrogen is fixed.

### Growth Factors

Factors affecting the growth of nitrogen-fixing legumes can be divided into two main categories: 1) the environmental, management and biological conditions that affect plant growth in general and which also apply to legumes and 2) a more limited set of factors that specifically affect the nitrogen fixation processes that determine how much of the element legumes will “fix” from the atmosphere.

All plants, including legumes, need fertile soil, sufficient light and water, appropriate temperatures, and day length suitable for their particular ecological niche. Biological conditions that influence growth include competition from weeds and damage from pests such as insects and pathogens. As with non-fixing plants, the specific requirements for optimal growth vary with legume species, ecological adaptations, and life history. Some legumes are better adapted to withstand very cold temperatures (i.e. hairy vetch), whereas others are well adapted to hot, dry conditions (i.e. cowpea). The excellent SARE cover-cropping manual (see recommended resources sidebar) covers basic information on species traits and requirements for optimal growth.

### Parameters of nitrogen fixation

Factors that specifically affect nitrogen fixation rates reflect the unique requirements associated with the process of biological nitrogen fixation. Legumes tend to have greater requirements for phosphorus, which is important for nodule formation and for the process of nitrogen fixation. Phosphorus is a constituent of the molecules that transfer energy from photosynthesis and catalyze the reactions that

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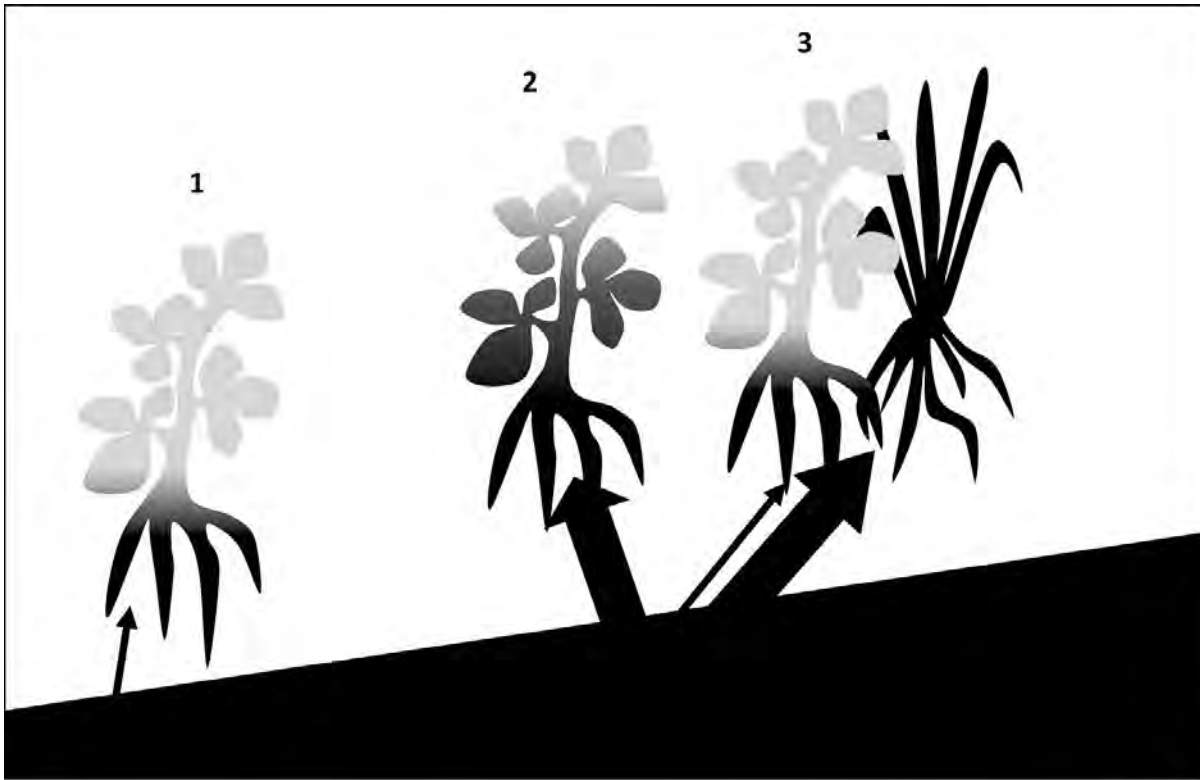
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Increasing soil nitrogen levels

**Legumes can be planted in mixtures with non-legumes such as grasses to enhance weed suppression and increase nitrogen fixation. Black indicates nitrogen from soil, gray indicates nitrogen from fixation. 1) In lower fertility soils where P and micronutrients are adequate, legumes fix more nitrogen. 2) As soil organic matter increases (i.e. through long-term organic management or compost additions), nitrogen availability also increases and legumes are able to capture more soil N. 3) If a grass is planted with the legume, it will draw down soil nitrogen forcing the legume to increase nitrogen fixation.**

figure courtesy Laurie E. Drinkwater

actually break the dinitrogen bond, a crucial step in nitrogen fixation.

Nitrogenase—the enzyme that mediates the nitrogen fixing reaction—and leghemoglobin—the protein necessary for maintaining favorable oxygen levels—incorporate particular micronutrients in their structures. Micronutrients such as iron (Fe), molybdenum (Mo), and cobalt (Co), are particularly important for legumes. Soils with deficiencies in these micronutrients will not support high rates of nitrogen fixation. Soil pH and tillage also have a significant influence on nitrogen fixation. Most agricultural legume species prefer soil pH in the range of 5.5–7.0. In soils with lower pH, nitrogen fixation is suppressed. Because nitrogen fixation is an energy intensive process, root respiration rates can be very high in legumes; soil conditions that limit the availability of oxygen are not conducive to high nitrogen fixation rates. Maintaining good soil tillage to optimize soil drainage and aeration is very important for promoting nitrogen fixation in legumes.

Background soil nitrogen levels also influence fixation rates. Nitrogen fixation is energy intensive, compared to uptake of nitrogen from the soil. Soils with high nitrogen fertility suppress fixation, because most legumes preferentially take up soil nitrogen rather than carrying out biological nitrogen fixation. In our measurements on organic farms we've found that nitrogen fixation rates are reduced in fields with higher levels of available soil nitrogen. While the legumes showed good growth, when we analyzed what sources had supplied nitrogen in the system we found more had been pulled from the soil and less had been acquired through fixation.

As soil nitrogen fertility increases, the impact on legumes and nitrogen fixation is generally more pronounced when legumes are grown in mixtures with non-legumes. In monocultures, legumes respond to greater soil nitrogen fertility by reducing nitrogen fixation in favor of soil nitrogen uptake. In mixtures with non-legumes, the other plants can draw down soil nitrogen and encourage the legume to fix more nitrogen than if it were alone, an ideal outcome. However, in situations where soil nitrogen fertility is high enough to allow the non-legume to grow very rapidly it can end up reducing nitrogen fixation by suppressing legume growth. While this outcome is not ideal in terms of nitrogen fixation, the sensitivity of mixtures to soil fertility provides an internal mechanism for balancing nutrients. Soils with high nitrogen fertility do not need as much new nitrogen

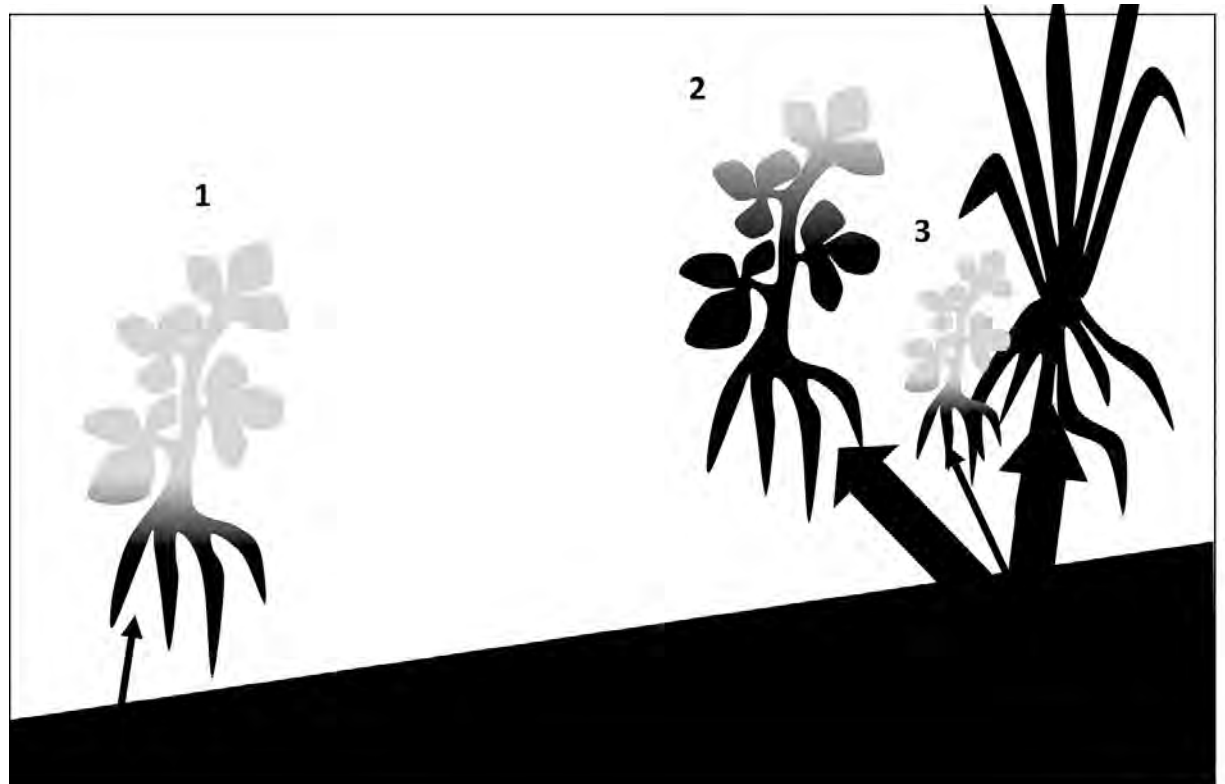
and the rapid growth of the non-legume is crucial for weed suppression in highly fertile soils. Also, the greater capacity of the non-legume to efficiently scavenge and recycle soil nitrogen ensures that nitrogen losses to the environment are minimized as is the case in most natural ecosystems.

**Top Rate: Differences among legume species**  
The amount of nitrogen fixed by different legume species varies with total plant biomass, life history, and each species' rate of nitrogen fixation and soil nitrogen assimilation. As a starting point, it is help-

ful to recognize that since the concentration of nitrogen in legume shoot tissues is fairly similar across species, usually ranging from 3 to 4 percent, the amount of total nitrogen is directly related to size: Greater biomass corresponds with more nitrogen. In general, perennial legumes such as red clover accumulate more aboveground biomass and fix more nitrogen than annuals, but there are annual legumes such as hairy vetch that can produce a very large biomass and fix substantial amounts of nitrogen. Another aspect that will determine how much nitrogen a legume fixes is the length of time it has to grow. Because it takes about six weeks for the process of nodule formation and nitrogen fixation to fully ramp up, short-lived annuals that grow quickly and have shorter life cycles generally fix less nitrogen than longer-lived annuals or biennials that overwinter or are allowed to grow for the entire growing season.

Even after accounting for life cycle and plant biomass, different legumes and their associated rhizobia fix nitrogen at different rates. Hairy vetch and alfalfa, for example, fix more nitrogen than clover or field peas. In some cases, including that of grain soybean, breeding has altered a variety's reliance on fixed nitrogen. Even within a particular variety of legume, nitrogen fixation rates will vary field-by-field and season-by-season due to the soil environment, which has both direct and indirect effects on the plants and bacteria involved. If plants can absorb enough nitrogen directly through the soil—from compost, for example—they will reduce their investment in the nodules that support nitrogen-fixing bacteria.

Legume species also vary in terms of their ability to access soil nitrogen and compete with non-legumes for soil nitrogen. Those that are able to take up more soil nitrogen generally fix less nitrogen. The basis for these differences is not fully understood; however, they are most likely due to species adaptations to their habitat of origin. We find that most legumes used as cover crops are pretty efficient nitrogen fixers and fix at least 60 percent of their nitrogen or more; rates as high as 80 percent are not uncommon. Cowpea is an example of a legume that stands out as a "lazy" nitrogen fixer, hovering at rates closer to 30 percent. On the other hand, cowpea is more competitive in mixtures, compared to many legume species, and can fix greater amounts of nitrogen in a mixture than when grown as a monoculture.



Increasing soil nitrogen levels

figure courtesy Laurie E. Drinkwater

**Under conditions of higher soil nitrogen availability, grasses (or other non-legumes) may dominate the cover crop stand. Black indicates nitrogen from soil, gray indicates nitrogen from fixation. In 1-2, we again see that as soil nitrogen increases, the legumes planted in monocultures capture more soil nitrogen and the proportion of fixed nitrogen declines. 3) If soil nitrogen availability is very high, the grass will grow very quickly and legume growth will be suppressed. The proportion of nitrogen fixed will be greater than in the monoculture, but overall amount of nitrogen fixed will be reduced because the legume biomass is much smaller.**

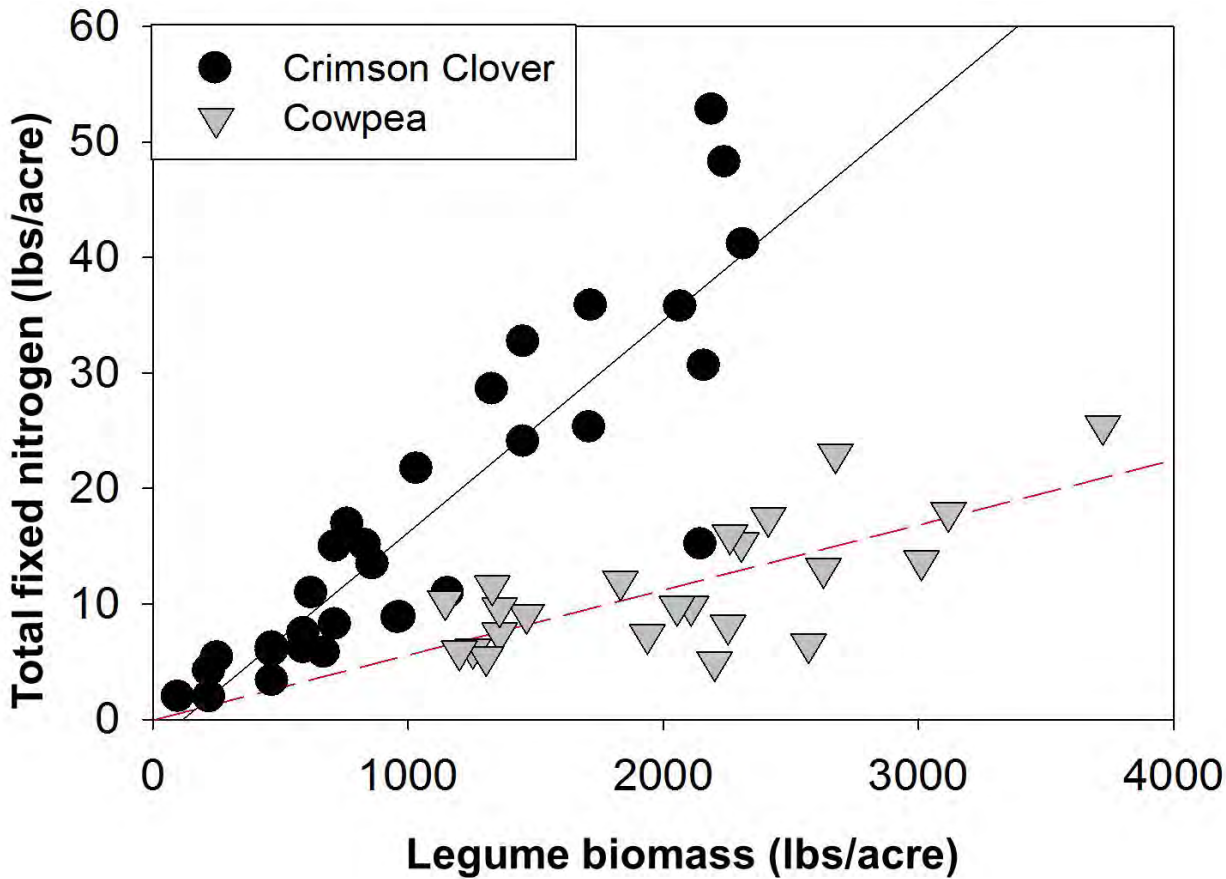


figure courtesy Laurie E. Drinkwater

As shoot biomass increases the amount of fixed nitrogen also increases in a linear manner for all legume species we have studied. In this example for two species growing under the same conditions, crimson clover fixes nitrogen at a higher rate than cowpea so the fixed nitrogen content of a biomass of 2000 lbs/acre is about 35 lbs nitrogen compared to the same biomass of cowpea which contains 11 lbs fixed nitrogen/acre. Other legumes such as field pea and red clover show increases in nitrogen fixed/biomass which are similar to the crimson clover.

**Mixing it Up: Legumes and grasses**

Farmers managing organic agricultural systems often employ mixed plantings of two or more species in their cover crop rotation. Since each plant species has unique characteristics, increasing species diversity in cover crop plantings increases the chances of successful germination and growth and also allows growers to choose species with ecological traits that meet their objectives. For this reason farmers frequently plant legumes with non-legumes such as grasses—oats, wheat, and rye—or buckwheat. In some cases, people plant mixtures incorporating multiple legume species.

In thinking about how soil conditions affect biological nitrogen fixation, remember that legumes are uniquely adapted “pioneer species.” Their symbiotic relationships with mycorrhizal fungi—for phosphorous uptake—and rhizobial bacteria—to facilitate nitrogen fixation—allow them to grow in very young soil with low nutrient contents. As a result, legumes grow in low fertility soils where other plants cannot. The downside of this ability is that since supporting these symbionts—with carbon substrates from photosynthesis—is energetically expensive, legumes are less competitive in fertile environments where their symbionts are not needed. Thus, in the more fertile soils commonly found on organic farms in our region, legumes can be smothered by non-legume species, particularly those such as grasses and weedy species that take up soil nitrogen very quickly. These differences in the ability to take up soil nitrogen, however, can be harnessed to inspire legumes to fix more nitrogen by using crop mixtures that provide some competition for soil nitrogen without overwhelming the legumes. The trick is to combine plants with complementary attributes.

Cover crop species	% N from fixation	Total N fixed (lbs/acre)	Total N in cover crop (lbs/acre)
*Red clover w/wheat	74	58	78
Red clover	64	42	65
Red clover + orchard grass	72	30	42
Field peas	68	33	49
Field peas + oats	80	15	19

figure courtesy Laurie E. Drinkwater

**Nitrogen fixation in organic grain systems comparing monocultures and mixes. In a study conducted in farmer’s fields by Meagan Schipanski, a graduate student in the Drinkwater lab, nitrogen fixation rates increased in red clover and pea planted in mixtures compared to monocultures, however the total amount of N fixed was reduced in peas and clover seeded with orchard grass and oats, respectively. Clover frost-seeded with winter wheat fixed the most nitrogen while nitrogen fixed by clover seeded into spelt was comparable to clover with orchard grass (31 lbs N fixed/acre). In cases where the rate of nitrogen fixation increased in mixtures while total nitrogen fixed showed a decrease, the reduction in the amount of nitrogen fixed was due to reduced growth of the legume. Growing clover with wheat increased the rate of nitrogen fixation, probably because the wheat removed significant soil nitrogen, and also allowed clover to grow rapidly after the wheat was harvested resulting in greater amounts of fixed nitrogen than the clover monoculture. \*Typical farmer practice— Frost-seeded clover into winter grain. This is compared with red clover planted at the same time either as a monoculture or mixed with orchard grass and field pea seeded later in the summer after small grain harvest as either a monoculture or in a mixture with oats in the same fields.**

	High fertility field	Med fertility field
Red clover	65	80
Clover/grass	38	70

figure courtesy Laurie E. Drinkwater

Legumes growing in mixtures show a greater reduction in the amount of nitrogen fixed in fields with higher nitrogen fertility. Data show total nitrogen fixed for one year of red clover growth including estimates of root biomass in lbs nitrogen/acre from two organic grain fields. Red clover growing alone in monoculture fixes 20% less nitrogen in the field with higher soil fertility. However, when grown in a mixture with orchard grass, the red clover in the high fertility field has dramatically reduced nitrogen fixation compared to the medium fertility field. As the grass takes up soil nitrogen clover growth is suppressed due to competition and shading by the grass.

There are many benefits to pairing legumes with non-legumes. Two among them are vital: First, many legumes are small seeded, so they germinate as tiny plants and grow slowly at first. Planting these legumes with a grass that can act as a nurse crop and help with weed suppression while the legumes are becoming established usually results in a cover crop stand with fewer weeds. Second, grasses also provide a structure that can support viney legumes like vetch, allowing them to grow taller and gain access to more light. Getting the seeding rates right for each species in the mix—so that neither plant species dominates the mixture—is tricky. The goal is to have plants seeded with sufficient density so that there is enough competition to help suppress weeds and stimulate nitrogen fixation by the legumes, without having so much competition that the faster growing species completely out-competes the slower growing species (which is usually the legume).

Using species that differ in the timing of their growth can help. For example, in buckwheat/clover combinations, the buckwheat grows very quickly and shades out the weeds. It also inhibits the clover growth; however, since it flowers after six to eight weeks, it is mowed and competition is removed, which allows the clover to take off at just the right time—at six weeks, when its nitrogen fixing system is fully functional. Likewise, when red clover is frost-seeded into winter grains, it grows slowly while the grains are in the field, due to shading and competition for other resources. Once the grain is harvested, however, the clover takes off and produces lots of growth and fixed nitrogen. Seeding grasses such as rye and wheat with vetch can be more

challenging; if the ratio of grass to legume is too high, the grass will dominate and instead of providing structure to support the vetch, it will suppress the vetch. In some cases, nitrogen fixation can be severely reduced.

Because many mixtures consist of species that are growing simultaneously, it is difficult to predict how much nitrogen they will fix. We have found that the growth of legumes in mixtures is highly variable across farms. Legumes in mixtures interact with the other species growing in the mixtures; the soil environment, especially the level of soil fertility, influences these interactions. As a result, there are trade-offs in the functions that mixtures perform well. Since non-legumes scavenge more effectively for soil nitrogen than legumes, the competition for soil nitrogen in mixtures is expected to increase the



legumes' reliance on nitrogen fixation. The absolute amount of nitrogen fixed, however, depends on the nitrogen fixation rates and biomass production of the legume in the mixture. In mixtures where legume biomass is suppressed due to severe competition, nitrogen fixation is reduced compared to the legume monoculture. Non-legumes tend to be better at suppressing weeds than legumes; therefore, mixtures dominated by non-legumes are generally better able to suppress weeds than legume-dominated mixtures. However, non-legume dominated mixtures often suppress both weeds and legume biomass. As a result, mixtures that effectively suppress weeds may have reduced nitrogen fixation rates. In situations where weed control is equally as important as nitrogen fixation, these mixtures are a nice solution because they respond to the specific environmental conditions in any given field. In higher fertility soils, weeds tend to grow faster and might out-

lbs/ac	Fixed N	Soil N	Total N
Vetch	89	10	99
Rye		61	61
<b>Total</b>	<b>89</b>	<b>72</b>	<b>160</b>

photo by Ann Piombino, figure courtesy Laurie E. Drinkwater

**Example of a cover crop mixture with good weed suppression and good nitrogen fixation. Vetch/rye cover crop planted on 8/16/08, sampled on 5/24/09. This stand was about 3-1/2 feet tall, with vetch shoots growing up most of the rye stems. Total nitrogen in the cover crop was 160 lbs nitrogen/acre with 89 lbs coming from nitrogen fixation. Seeding rates: rye 80lbs/acre, vetch 50-60lbs/acre. Megan Gregory, shown, is a graduate student in the Drinkwater lab.**

pete a legume monoculture. Adding non-legumes serves as a kind of insurance against weeds. In soils with more limited fertility, both the weeds and the non-legumes will grow more slowly, giving the legume the opportunity to grow and fix nitrogen. As research continues, we are finding additional combinations that are promising in terms of balancing weed control and nitrogen fixation.

**The next frontier: Soil rhizobia community**  
 Scientists have found that the intensity of agricultural management strongly affects the genetic structure and activity of soil microbes associated with cultivated crops, including rhizobia. Although the bacteria belonging to the genus *Rhizobium* form species-specific, nitrogen-fixing symbiotic associations with a host legume, they also exist in the soil as free-living decomposers. Management practices that modify inputs of organic material are likely to influence the population structure of these bacteria. The composition of rhizobia populations can signifi-

cantly influence biological nitrogen fixation because not all strains are equally effective in their ability to fix nitrogen in partnership with the host plant. In conventionally managed agriculture systems that receive nitrogen fertilizer, the indigenous rhizobia are often less effective symbionts than strains used as inoculants selected for high nitrogen-fixation.

There is almost no information available to farmers and scientists about how organic management practices affect the population composition and efficiency of rhizobia. This is surprising, given their profound importance in regulating the amount of nitrogen being fixed in organic cropping systems. Organic farmers commonly use inoculants containing the proper symbiont for their cover crop species; however, most inoculants have been developed in background soils that differ greatly in their carbon and nitrogen status from organic soils, and the quality of commercial inoculants varies greatly.



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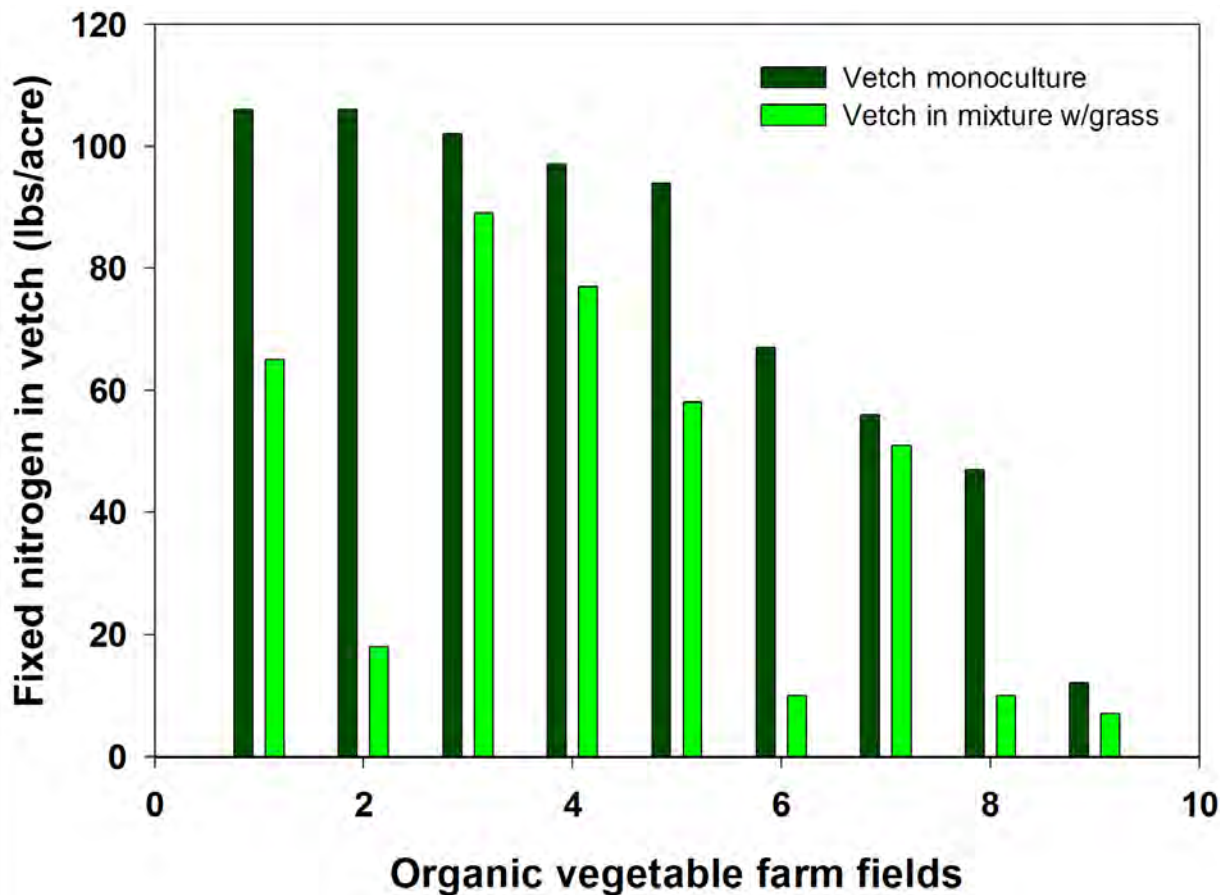


figure courtesy Laurie E. Drinkwater

**Nitrogen fixation in vetch monocultures (dark green) and vetch-rye mixtures (bright green) across nine organic vegetable fields arranged based on nitrogen fixed in the vetch monoculture. The data are from studies we've been conducting on organic vegetable farms beginning in 2008. Small plots were established in fields planted with cover crops to compare vetch growing with and without an interseeded grass. Planting date is a key factor in determining how much nitrogen is fixed. Planting dates which were too late in the season did not permit good establishment of the vetch and performed poorly. Looking at fields 1-5, with similar planting dates and where nitrogen fixation in vetch monocultures was very high (94-106 lbs nitrogen/acre), the variability in nitrogen fixed was much greater in mixtures and ranged from 18-85 lb nitrogen/acre. Our research on farms indicates that planting date, soil fertility and seeding rates interact in ways that are difficult to predict. The bottom line is that with the on farm data there were too many variables to make a quantitative analysis of the factors driving nitrogen fixation. The information is still very useful because now we can design an experiment to test our ideas based on this preliminary data. Until we carried out this research, we had no idea how variable N fixation was in the mixtures! Farmers who see that their vetch/rye mixtures are dominated by the rye with very little vetch despite reasonable planting dates can adjust these mixtures by reducing the proportion of grass in the seeding mixture.**

In the wealth of studies on rhizobia-legume ecology, most have focused on forage and pasture crops and green manures for tropical environments, with almost no reports providing data that helps farmers to effectively manage the rhizobia commonly used to inoculate temperate, green manure species. The success of leguminous green manures is likely to depend on the structure and diversity of the populations into which the inoculant strains are introduced. Currently, we do not know if nodules forming on green manures in the organic farms we study are from inoculant rhizobia or from less effective, indigenous rhizobia. We also do not know whether long-term organic management fosters naturalized rhizobium strains that tend to be more or less effective than the inoculated strains.

To learn more, my research group at Cornell has initiated studies of the rhizobia communities in nodules on working farms. Beginning with soybeans, we compared the rhizobia populations in nodules across four farm fields—two organically managed and two conventionally managed—in upstate New York. We found varied occupancy by the inoculant strains within soybean nodules based on management system. Soybeans grown in conventionally managed fields had greater numbers of nodules occupied by inoculant strains compared to those grown in organic fields. Richness and diversity of nodule rhizobia in soybeans from organic fields was much greater than those from conventional fields. This research is just beginning and we do not yet

know how these differences in the populations of nodules affect nitrogen fixation rates. For the time being, we recommend that growers follow the standard recommendations in terms of inoculation of legume seeds.

**A joint effort**

Biological nitrogen fixation is an amazing, solar-powered process that is almost as ancient as life itself. Legumes and their microbial partners could play a major role in transitioning our global food system toward sustainability. While questions remain about the finer points of how management practices in organic farming systems can be tweaked to optimize biological nitrogen fixation, we do know that rotations incorporating leguminous cover crops are an essential element of sustainable farming systems. Organic growers continue to experiment and develop innovative cover cropping options, while researchers are engaged in increasing our understanding of the underlying biology of this process and developing new legume varieties. In 2008, the USDA's Agricultural Research Service released Purple Bounty and Purple Prosperity, two new varieties of early flowering hardy vetch developed by geneticist Thomas Devine. Such work will expand the opportunities for organic farmers to design legume-based rotations that achieve multiple goals.

**Keys to optimize biological nitrogen fixation from legumes**

- Good drainage, soil tillth and favorable pH
- Use compost additions to supply phosphorous, potassium, and micronutrients. Avoid over-application, which will suppress nitrogen fixation and lead to nutrient imbalances.
- Match legume species with time available in your rotation—maximum nitrogen fixation occurs at flowering
- Longer growing legumes generally fix more nitrogen
- Most legume species start fixing nitrogen after six weeks of growth
- For overwintering legumes, planting early enough is crucial.
- Observe the composition of mixtures consisting of legumes and non-legumes before plow-down in order to fine-tune seeding rates for the specific conditions on your farm.

Cover crop species	% N from fixation	Total N fixed (lbs/ac)
Cowpea	39	37
Cowpea + Japanese millet	72	59
Cowpea + SorgumSudan	56	26
Forage soybean	67	88
Forage soybean + Japanese millet	82	28
Forage soybean + SorgumSudan	90	35

**Response of legumes in mixtures is species specific. Again, the trend of increased nitrogen fixation rates in mixtures is evident in cowpea and forage soybean. Cowpea was compatible with Japanese millet and total N fixed increased from 37 to 59 lbs. N/acre while sorgum sudan grass suppressed cowpea growth and reduced nitrogen fixation. Soybean fixed greater amounts of nitrogen as a monoculture and although the proportion of N fixed was very high in mixtures, soybean growth was severely limited by both grasses and nitrogen fixation was greatly reduced in both mixtures.**

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# Roxbury Farm

## Cover Cropping and Soil Building on a Working Farm

by Jack Kittredge

The Hudson Valley, between the river and the Massachusetts and Connecticut borders, has long been an active area for small farms. Decent soils and adequate rainfall make farming attractive, but rolling landscapes and some areas of rocky deposits have kept larger scale agriculture from settling there. Kinderhook's Roxbury Farm, run by Jean-Paul Courtens and Jody Bolluyt, is one of the region's largest operations.

Courtens, who had run Roxbury Farm in a different location for 10 years before his divorce, was the driving force in moving it here. The 350 acre farm was put together from 3 parcels in 1999 by Equity Trust and the Open Space Institute. Equity Trust owns the land, and Courtens and Bolluyt have a 99-year lease on it. All but 13 acres are permanently protected from development and must remain in agriculture. The land was originally part of the estate of Martin Van Buren, 8<sup>th</sup> president of the United States (a National Historic Site to his memory divides the North and South parts of the farm), but more recently was planted to year after year of potatoes.

"When we came here in 1999," Jean-Paul says, "all you saw in the whole field was potatoes. I had been building soil for ten years before that in a different location, then I had to start all over again.

"I never looked at farmland as a way to build equity," he continues. "What are you going to do with your personal equity – sell it to a developer? That's silly. This is where we can throw our heart into it because we know that whatever our dream is it will continue. They took five years to put this land deal together. It is rare to find so much contiguous farmland in Columbia County. There are a lot of people in Kinderhook who commute to Albany and good farmland also makes good development land!"

Courtens came to the US in 1985. He was just 25 and had graduated from a four-year Biodynamics training in Holland. The school had received a letter from the Biodynamic Association in the US asking for help furthering their work. The teachers thought Jean-Paul would make a good advisor, so he used up his savings that summer traveling all through the East Coast and then the Midwest.

"I found a place where I wanted to stay," he recalls, "which was as a vegetable gardener in Camp Hill Village in Minnesota. I had to apply for a work



photo courtesy Roxbury Farm

### Mowing the cover crops (with a 14-foot mower) to build soil organic matter.

permit and I came back in 1986. I grew the vegetables there and the director of the Biodynamic Association happened to come by for a visit. He was impressed by our vegetables and told everyone about this Dutch guy who was good at growing vegetables. So I got an invitation to work at Hawthorne Valley. They had an outlet at the Greenmarket in New York City for their meat and yogurt and bread, but everyone was asking for vegetables. Nobody there really knew how to grow vegetables on a commercial scale. So they asked me to come to Harlemville. By then I had met my then-wife and she was from the New York area, close to Harlemville. So it all made sense. Her parents were excited about our moving back to the area. I ended up spending three years at Hawthorne Valley."

After that his then father-in-law suggested Courtens look at their land, where he started Roxbury Farm. He found 30 acres next door in Claverack where he could make hay and have a cow/calf operation for manure.

Over the years, farming at different sites, Jean-Paul developed strong ideas about what makes a good farm. "Starting off with a good soil," he says, "is the best investment a vegetable grower can make. Altering the state of the soil besides drainage and rock picking is hardly ever cost effective compared to the cost of prime farmland. Building organic matter and increasing structure do not alter the state of the soil -- they merely improve what is already there. When I go out to look for a farm I look for one that has good soil and will be stone free. I hate rocks."

He feels that what crop is growing on a site should be a direct result of the soil type there. The presence of large rocks, steep slopes, or poor drainage, for instance, makes some land unsuitable for vegetable crop production.

Good vegetable land, according to Courtens, has:

- High carrying capacity (it can carry the weight of equipment without creating irreversible compaction)
- Good natural or artificial drainage
- Good access to irrigation water
- Deep topsoil that is free from stones
- Almost flat with slopes that do not exceed 2%.
- Located in a long season micro climate
- Good exposure to sunlight
- Good air drainage to avoid late spring frosts.
- Good access to farm roads
- High Cation Exchange Capacity (CEC)

Soils are like different kinds of horses. "When we assess the physical quality of our soils," Jean-Paul likes to say, "we determine its physical strength and limitations. Working land can be like working a horse. First, we need to understand what horse we are dealing with. Is it a workhorse or a riding horse? Each has different qualities. We will not try to pull a heavy load with a riding horse for a prolonged period of time. Within this analogy, our sandy soils are like riding horses. The usefulness of a riding horse is in its speed; while it might pull a plow, it lacks the persistence of a workhorse to complete the task. Sandy soils are great in the early spring since they drain well and warm up quickly. This allows us to work these fields earlier than others. But in the summer, they easily dry out, and can only achieve good yields with irrigation. Our sandy soils do not hold nutrients well and the lack of clay and low percent of organic matter is confirmed in the relatively low cation exchange capacity. A heavier soil, like a silt loam, resembles a workhorse; it works harder at an initially slower pace but with much greater resilience. Silt loam soils warm up a little later in the



photo by Jack Kittredge

Jean-Paul examines the germination of cover crops he has planted.



photo by Jack Kittredge

### Jean-Paul holds a sprouted bell bean, one of his favorite leguminous cover crops.

spring but their ability to hold nutrients and water gives them a great advantage during the summer months.”

Courtens notes that it has proven more difficult to build organic matter on a sandier soil with large granular particles compared to the soils that contain smaller particles or some clay. Nutrients tend to drain out of a coarser soil and leaching of nitrogen and other mineral fertilizer can be a problem. The buildup of organic matter and nutrients are like the muscles and fat on a horse's body. At times when lots of work is demanded it has the reserves to complete its task.

“I would never grow a fall crop on the gravelly, sandy soils at Roxbury Farm,” he states. “Those are spread around quite a bit here. But fortunately the farm is mostly loam, thank God. But on the other hand, thank God we have some sandy soil or we would never be able to get in the ground in time. A year like this we are going to have to move around the crop rotation again. It has been so cold. And then when it finally turns warm and dry, say May 1, you have to put on a couple of inches of water a week on those sandy soils to make them produce.

The CEC of his sandy soils is around 8 millequivalents  $100\text{ g}^{-1}$ , whereas down below in the heavier soils he has 12, 14, even 16.

“That's what I mean with the riding horse and the draft horse – it's really a matter of the CEC,” he explains. “Here, in 1999, we started with a pH of 5.2 and almost no organic matter. We've gotten the organic matter up to 2.6% so far with a lot of compost. We corrected the calcium base saturation ratio to about 68%. We're getting a littler high right now, actually, because we are using compost made from poultry manure. The problem with that is there are a lot of egg shells in it, which means a lot of calcium. We never have to lime anymore!

At Roxbury Farm, of the 120 acres that are suitable for vegetable crop production, only 45 are planted in cash crops while another 45 acres are planted in soil improvement crops with the remaining 30 in tall fescue and orchard-grass combined with ladino and red clover for hay. Almost all of the vegetable land is rated category I or II (Occum, Unadilla, Knickerbocker, and Hoosick). It ranges from coarse sand to a fine silt loam. The remainder of the land at Roxbury is divided between hayfields, pastures, woods, or wetlands. Those places are important in providing feed for the livestock and biodiversity to complement the land committed to cash crops.

The diversity of soils and fields makes planning each year's plantings a challenge. “There is no such thing as a perfect rotation,” groans Jean-Paul. “We take it field by field. Of course it really takes 45 acres to raise 30 acres of vegetables here. This

is 5 acres of vegetables in a 7 and a half acre field, for instance. This field over here is 12 acres but I can only really find 8 that I can plant in, because of the harvest lanes and the headlands and everything else.”

All their vegetable land is irrigated, using either drip or overhead systems. They have about 7 acres in Biotello, the biodegradable plastic mulch, and use drip under all that land.

“We monitor the soil moisture with sensors,” says Courtens, “and bring in the overhead as maintenance irrigation when necessary. We could irrigate 50 acres a week with overhead if we wanted. We only cover maybe 30. Our drip is a moveable system so it can follow our rotations. We have underground lines that allow us to have it where we want. We only use drip when we use the plastic Biotello mulch. Most of the crops don't want to get wet. Tomatoes, cucumbers – they want to stay dry. We have tomatoes, eggplants, peppers under Biotello. Onions, early cabbage, early broccoli is all Biotello. Whenever we want to speed up a crop, we use Biotello. It is extremely expensive – it's three times the price of regular plastic. But you don't have to pick it up. It does take a whole season to degrade, however.”

Courtens and Bolluyt run a large CSA at Roxbury Farm, with over 1000 shareholders representing

over 1200 families. A share represents 10 to 17 pounds of fresh produce, running from 7 to 12 varieties. Besides pick-ups on the farm, they deliver to 2 sites in Columbia County, 6 sites in the Capital Region, 5 sites in Westchester County, and 4 sites in Manhattan. In addition to the vegetable shares, consumers can also get fruit shares bought from a farm down the road, and pork, lamb, or beef meat shares raised at Roxbury Farm.

Like most CSAs, Roxbury Farm tries to get a number of crops in early so there will be something significant in the first shares in early June. By mid April they have onions, cabbage, kale, Asian greens and potatoes all in the ground. They start sweet corn in the greenhouse in early April and transplant it out in 2 weeks when it is 8 to 10 inches tall. They do this for 10 weeks, guaranteeing a crop for shares starting July 4<sup>th</sup> and running for 10 weeks. They do a lot of root crops to carry members shares into December.

Some springs, of course, planting is not possible early in even the sandy fields. “This field is not tilled and it is a little wet,” says Jean-Paul as we look for a place to plant corn on April 22. “I worry about compaction if we try to plant here today. I see a little mud picked up by my boots, I don't want to see that.

“The ground here is ready to go,” he continues. “It has been subsoiled, chisel plowed, fertilized, and the beds are made. All you have to do is put the planter in there, to transplant the corn, then cover it with row cover right away. We leave that on until the corn is knee high, then we take it off and bring in the parasitic wasps. They'll take care of the European Corn Borer. The early corn is heavily infested with ECB and you have to knock them down hard. They're like Colorado Potato Beetles. You want to get that first generation that comes out.”

When people buy a vegetable share from Roxbury Farm they can opt to buy a fruit share. The fruit share is not organic but contains 2 to 4 pounds of local fruit each week. It starts with cherries, then goes into apricots, peaches, plums, and stone fruit. The farmer raises blueberries and raspberries, but Jean-Paul and Jody chose not to buy those because they are often heavily sprayed. The fruit ends with a lot of pear and apple varieties.

“It is nice working with him,” says Courtens, “even though he is not organic. The volume we are selling we couldn't even get that much local organic fruit. I don't know how to grow organic fruit. That is something that someone like Hugh Williams, who really focuses on it, can do. As diverse as we already are it is hard to be good at it, to be cost effective.”

One way in which Jody and Jean-Paul are quite diverse is their animal operation. It is important to them, as Biodynamic farmers, to have animals on the farm.



photo courtesy Roxbury Farm

### Buckwheat flowering in late July or early August on Roxbury Farm

“You want animal husbandry as the basis of any healthy farming organism,” asserts Courtens. “We’re not very successful yet at integrating the animals. It’s partly a matter of fencing – the sheep tend to get out. It should be easier with cows. Pigs are easy. We are not yet grazing the animals on the fields where the vegetables grow. Instead we are growing hay and straw and feeding it out and using it for bedding and returning the manure to the fields.”

They make some compost, but not enough for all the vegetables. Roxbury has a flock of 60 or 70 ewes, two sows, and is expanding the beef herd. They save the manure when they muck out those holding areas, although the animals are often on pasture. The pigs are raised in the woods. There is also a chicken operation run by a couple of workers at the farm as a side venture, although the birds are available to customers as a chicken share.

Up to now the farm has bought-in feeder cattle. But the pair has been frustrated doing that. There wasn’t a dedicated pasture for them, they tended to be wild, and Jean-Paul prefers cow to steer manure for some for some of the Biodynamic preparations.

During my visit Jody and Jean-Paul set up a cattle loading area and connected it to a pasture they were fencing in. They talked with me as they worked.

“We just got a beef herd,” Jody explained, “and this is where we are going to load them.”

“This year the guy that sold us beef cows was selling his whole herd,” Courtens says. “We decided this was the moment to buy them and raise our own. The reason we have such a fancy area to round them up is because beef cattle are quite wild and for our own safety we needed a yard like this. But with our own cows I think they will be tamer. We built the new barn so we could take care of the cows during the winter.

“We are going to get 7 cows, 8 heifers and 4 calves plus another 6 steers from Hawthorne Valley,” he continues. “Between all of that we are going to need 75 acres of pasture. This was a hayfield and desperately needed to be put into something. I tried to seed it last year but wasn’t very successful. I’ll be able to cut this field into 12 different sections with temporary fencing.”

The fence will be charged by a solar panel and a battery, and fresh water supplied from the well via trenched black plastic pipes, which the pair have buried all over the farm. A local line connecting to the beef pasture was being dug during my visit by their 21-year old son, Johannes.

“We want to be able to give potable water to all the animals,” explains Jean-Paul. “We could draw wa-



photo courtesy Roxbury Farm

**Jody feeds the pigs in the woods.**

ter from that creek, but if you have high water, that creek water is turning brown. I don’t feel very good giving that to my cows or any of my animals. So we draw from the well and run 3000 feet of black line to get it to the animals. A lot of people don’t even bury their water line, they leave it above ground. But 3000 feet of black poly will heat that water to boiling on a sunny day.”

One of the things that Roxbury Farm hasn’t worked out well enough yet regarding the animals is how to market them.

Courtens sighs: “We still have to find what the right price is for meat. It is much harder to make the meat CSA pay than the vegetable one. I guess the reason is that the cost of conventional meat is so ridiculously low compared to the cost of vegetables. That has a lot to do with the fact that there is relatively little waste in the meat business. The reason why the vegetable CSA is successful is because we take out all that waste that is built into the price of normal produce -- it has to look perfect, things are wasted at the warehouse, in the field, in the supermarket – all that waste people pay for in the end. But we deliver it all to the customer so there’s no waste.

“We find that when you have a hard time expanding your market,” he continues, “people either don’t eat meat at all, which I don’t believe, or your price is

too high. So that is an issue that we have. The problem with lamb is that people aren’t familiar with it. We enjoy raising sheep. But the market is definitely for pork. That wood lot over there is 7 acres, and we can host 15 butcher hogs there at a time. That’s about all we’re willing to raise. If we put in over 2 hogs per acre they would start doing damage to the ecosystem. They’re only in there for maybe 4 months. But even so they have one area where they roll around in the muck – they have made a mud hole there.”

Jody and Jean-Paul feed the pigs grain and they grow rapidly. They have never had a problem selling out of pork, but the processing cost is really high so they end up not making a lot of money on pork. They do want sows, however, because they like to have a place to drop off what vegetable waste there is. They bring it to the sows, who love the leftover tomatoes, winter squash, etc.

So far the farm has only had a market for 8 steers. The pair worry that with so many new steers they might have to push their market for beef. They might have to start marketing beyond the CSA. One of the things they are most proud of is their Animal Welfare certification.

“Our customers like that we are certified animal welfare approved,” says Jody. “Our members like it, too. We’re not certified organic -- that is a different certification.”

The farm uses a large animal slaughterhouse in Canaan that does animal welfare approved processing, which is vital if the farm wants to be able to put that label on the meat.

“The chickens aren’t covered by animal welfare,” explains Jody, “because we slaughter them on-farm and you have to have a very expensive stun gun, which we can’t afford, for their slaughter. But the chickens are free-ranging within our perimeter fence. They have a shelter they can run under to get away from hawks. Shelley and Michael lock the birds up at night and move the shelter. They only lost a couple of birds to hawks.”

Given that Roxbury Farm is trying to build up soil which has been badly degraded by years of potato production, Jean-Paul and Jody put a lot of energy into cover cropping. They have an elaborate system which involves keeping the soil covered virtually fulltime, using deep-rooted crops to penetrate the soil and hardpan, using grasses to fix carbon, legumes to fix nitrogen, diverse green manures to break disease and insect cycles, and mowing and plowing down to build soil organic matter and humification. Courtens has actually published a handbook on the Roxbury Farm site which details many of their farming practices, including cover cropping.



photo courtesy Roxbury Farm

**Jean-Paul likes the dense stands like this he gets when he cover crops with oats and peas.**



photo by Jack Kittredge

**Jean-Paul snakes fencing wire around a post to be a part of their new beef pasture.**

On their website the pair list the reasons they use cover crops, and some details of how it works:

**Reduction of nutrient leaching** -- Soluble nutrients are easily washed out over the winter months unless they are taken up by a cover crop.

**Reduction of soil erosion** -- A crop of rye seeded in September and plowed under in April is able to keep the soil from eroding away over the winter months. Rye and hairy vetch as a mix are very effective, as they will add to soil-life and increase the mineralizable nitrogen fraction. Although if plowed early, the humification co-efficient can be low, soil life is greatly benefited by the mere fact that the ground has not been left exposed. The roots of the cover crops after breakdown form the very important capillaries for drainage as well as water uptake.

**Increase of pores in soils and breaking up hard pans** -- Sweet clover is known for its deep penetration of the soil and breaking of hard pans. But any established grass will greatly increase the amount of pores in the soil. Presence of oxygen promotes breakdown of dead organic matter as it increases microbial activity.

**Increase in soil life activity** -- Soil particles are held together by soil life activity, especially by mycorrhizae. The cover crop roots provide the needed sugars and amino acids for the activity of the mycorrhizae, which provide the plants with better uptake of minerals especially phosphorus, and allow the plant to absorb water more efficiently by enlarging the root hairs. Seventy-five percent of seed bearing plants have a symbiotic relationship with mycorrhizae unless they are destroyed by the use of mineral fertilizer. Deriving fertility, and especially nitrogen, from the use of cover crops in reaction with nitrogen fixing bacteria allow for a beneficial environment for mycorrhizae. A good example is our heavy reliance on both bell beans and oats to provide the necessary fertility for demanding crops like cauliflower. The beneficial environment created by the growth and eventual breakdown of the bell beans allows for more efficient nutrient uptake by the cauliflower.

**Increase in organic matter content through carbon intake** -- Grasses are known for their excellent ability to fix carbon out of the air. For greatest uptake of carbon in one season, Japanese millet and sorghum-Sudan are favorites. To avoid reduction of nitrogen content due to breakdown, mix these crops with forage soybeans (not to be confused with regular soybeans)

**Fixation of Nitrogen by legumes** -- Nitrogen fixing bacteria, which exist in symbiosis with the roots of the legumes, fix nitrogen out of the air and form ammonia. Look at the roots of the legume to find out if nitrogen is being fixed: if the roots have nodules that are red or pink colored inside, it has active bacteria. If the roots do not show nodules, find out if the soil pH is too low or if the particular bacterium is in your soil. Many legumes live in symbiosis with different bacteria.

*Rhizobium japonicum* lives in symbiosis with soy beans, *Rhizobium trifolii* with clover, *Rhizobium meliloti* with alfalfa. These crops are usually inoculated with the bacteria before planting. Azobacter species are free living bacteria capable of fixing nitrogen. Efficient legume crops are bell beans, field peas, hairy vetch, sweet, red and ladino clover, and forage soybeans.

**Weed management** -- Many crops are able to choke out other weeds. By using short season cover crops we reduce the number of weeds going to seed. This results in reduction of labor needed in the cash crops

**Plant disease management** -- Most cover crops are in a different plant family than our cash crops. By allowing cover crops to grow a full season and become part of the crop rotation, disease and insect cycles can be broken. This results in increases of yields in the cash crops at lower labor costs, due to increased efficiency of harvesting and sorting. Some diseases and insects affect a variety of plant families. It is important to take great care when planning your rotation and to be aware of diseases and insects that might be caused or carried by the cover crops. On the other hand, mustard and sorghum can act as bio-fumigants and, when properly plowed under, can reduce incidences of Verticillium wilt, Rhizoctonia root rot, Fusarium wilt, and Pythium root rot.

**Overall farm diversity** -- Most insects feed off the pollen of the grains and grasses when they are left to mature. In some instances, the cash crop acts as a host to beneficial insects. The pollen of the sweet corn is a good example as it provides food and habitat for the trichogramma parasitic wasp. For that same reason, parsnips can be left in the ground to flower in the spring. Dill, another member of the Umbelliferae family, can serve the same function. After the dill is cut for market, the plants remain alive and produce flowers at a time when the parsnips have gone to seed. Green manure crops provide a source of nectar to wild bees and we try to have at least one cover crop in full bloom during the growing season.

Of course nothing is without a downside. There are, Jody and Jean-Paul agree, some disadvantages of cover crops:

Grains and alfalfa are a host for thrips, tarnished plant bug, and leafhoppers. Once the grain is com-

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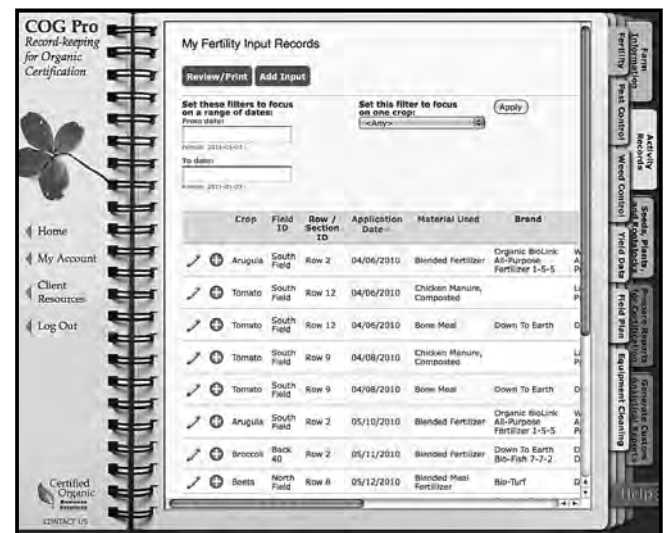
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bined or the alfalfa cut, many insects including thrips and leafhoppers look for a new home. As we increased our acreage in grains and legumes our problems with thrips and leafhoppers increased. Our solution has been to have another crop available (besides the vegetables) for the insects to migrate to and to never mow all the cover crops at one time. Sod can provide a cover for the eggs of many insects. Flea beetles and carrot-flies take advantage of this environment over the winter.

Another detriment from too much raw organic material is the residual activity in the soil that can have the same effects as fresh manure. Many diseases and pests, like aphids, increase when too much raw fertility is applied. We also noticed higher root rot ratings due to pythium or rhizoctonia as clover is a host to both diseases and especially rhizoctonia thrives under high organic matter conditions.

Jean-Paul showed me one field he had just planted with one of his favorite combinations: oats, bell beans, and field peas.

“Here is a bell bean coming up,” he says, excitedly. “This here is yellow blossom sweet clover that we let go to seed last year. So now it comes back as a weed. But it’s okay because I can let it all germi-



Roxbury Farm: Bell beans, field pea and rye mix  
Planted early spring, 200lbs/ acre, pic taken June 23rd.

photo courtesy Laurie Drinkwater



### Nitrogen in shoot biomass

lbs/ac	Fixed N	Soil N	Total N
Bell bean	27	8	35
Field Pea	83	32	115
Rye		34	34
<b>Total</b>	<b>110</b>	<b>74</b>	<b>184</b>

Total nitrogen content and breakdown by source in the bell bean/pea/rye cover crop. The field pea was the big nitrogen fixer (83 lbs/acre) compared to bell beans which fixed only 27 lbs/acre. Total nitrogen was 184 lbs/acre with 60% or 110 lbs of newly fixed nitrogen. The rye scavenged soil nitrogen and probably increased the proportion of nitrogen fixed by the two legumes. Adding roots into the picture would increase our estimate of total nitrogen to 205-225 lbs/acre.

photo courtesy Laurie Drinkwater

nate. Here are peas coming up. Field peas! They get 4 to 6 feet tall. Here’s a bell bean. Those will be cut down in the middle of June. We will work them into the soil. It will just be a sea of green this tall – 4 to 5 feet – oats, bell beans and peas. It is so dense!

“We tested for nitrogen,” he continues. “We fixed 200 pounds of nitrogen to the acre with those! The trick is always to grow grasses with legumes. These fields here will all be late broccoli, cabbage, cauliflower. That’s why we’re planting them all in bell beans and oats. They will be seeded in the beginning of June and planted in the middle of July.”

He pointed to another field: “This is a hayfield. We seeded rye and clover directly into it. We drilled winter rye directly into the sod. We’re going to cut them all together and use it as mulch. That will go between the rows of Biotello. We’d like to get 250 round bales of rye out of this. Between bedding for the animals and for mulching we can use a lot! It brings in a lot of silica.

“That’s 8 acres of rye over there,” he continues. “But I might work that under because that is going to be seeded down to sorghum and crotalaria or sunn hemp. That’s a legume native to India that gets 6 to 8 feet tall. It’s a risky crop. If you have a hot, dry summer it is great!”

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# An Interview with Eric Nordell:

## Cover crops to suppress weeds, boost biomass, and fix nitrogen

interview by Sharon Tregaskis

At Beech Grove Farm in the Allegheny plateau of north-central Pennsylvania, Anne and Eric Nordell hew to three guiding principles: maintaining fertility with minimal off-farm inputs, staying out of debt, and relying only on their own labor, sans employees. To achieve their goals, they've developed a complex rotation in their six-acre "bioextensive" market garden, certified organic since 1988. Instead of tractor equipment, the Nordells use horse-drawn implements. Customers for their potatoes, onions, garlic, lettuce, and other crops include restaurants, supermarkets, and shoppers at the Williamsport, PA, farmers' market.

Among the 12 half-acre plots in their rotation, the Nordells alternate cover crops and a bare fallow period with either spring or fall cash crops. Before spring-planted vegetables, they use winterkilled oats and forage peas; before summer and fall-planted produce, they use overwintering rye and hairy vetch. Instead of irrigation, they combine tactical plantings of winterkilled crops and minimal tillage to enhance water conservation and reduce loss of vital soil nutrients, including nitrogen. To boost nitrogen levels, they rely mainly on leguminous cover crops, interplanted with biomass-intensive cover crops that are mowed to reduce shading and boost growth of the nitrogen-fixing legumes. To reduce weed competition in their cash crops, they apply manure—produced by their four draft horses and composted by pigs—only to cover crops.

About ten years ago the Nordells began combining buckwheat, a warm-season, weed-smothering insectary, with perennial medium-red clover in their rotation. That combination sparked the interest of Cornell University's Laurie Drinkwater, a professor of horticulture, who studied the nitrogen fixation of both crimson and Berseem clover interseeded



photo courtesy Laurie Drinkwater

### Crimson Clover and Buckwheat make a good legume/grass mix at the Nordells'

with buckwheat (see sidebar). In 2004, inspired by Eileen Droescher at Ol' Turtle Farm (formerly of Easthampton, MA, now in North Carolina), the Nordells replaced the buckwheat in their system with sorghum-sudan grass, a hybrid, warm-season grass that grows to twelve feet and frostkills in the fall. In 2010, they swapped out the perennial medium-red clover for crimson clover, which

winterkills, reducing the imperative for heavy tilling in spring. I asked Eric to explain how the system came about and, six years into the experiment, how it's working.

#### • Why did you decide to introduce a new cover crop combo?

We take half of the market garden out of production each year and put it in managed fallow to reduce the weed seed bank and build up the organic matter. We had virtually eliminated our summer weed population, but cool-season weeds like chickweed and dandelions were still a problem and our system was aggravating it. We decided to shift around our fallow period to spring, to manage for chickweed and dandelions, and we needed a cover crop combo to plant in mid- to late-June, following the spring fallow. The sudex really takes off in the warm soil; the medium-red clover tolerates the shade below the grass and fills in, so that by the time the sudex frostkills in the fall, we have a complete sod. The cool-season weeds like chickweed don't stand a chance.

#### • What prompted you to replace the buckwheat?

We wanted to do one big cover-crop planting in the middle of June. Buckwheat worked well as a nurse crop for the medium-red clover, but we felt that we weren't getting enough biomass—it's pretty succulent material. We wanted to maximize the organic matter. The sorghum-sudan grass can grow to twelve feet. At four-and-a-half feet, we mow it to eight inches and it grows back. In a hot, dry year we'll get three cuttings. That's a lot more organic matter than the buckwheat.

One of the other reasons we were interested in the sudex is that it's considered a good rotation crop with vegetables. It doesn't share the same root diseases and it suppresses nematodes. Legumes are more like vegetables, so they share more of the same diseases. I'm hoping the sudex provides more of a break for our cash crops than you would get with just legumes.

#### • How do the buckwheat, sudex, and clovers affect pest pressure?

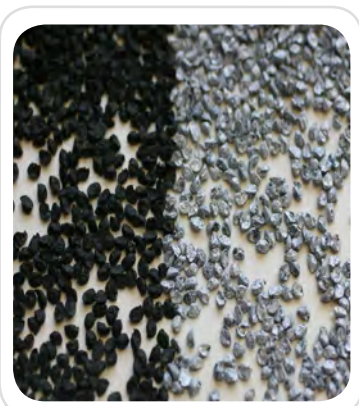
For years, we overseeded our cash crops with a mix of red and sweet clover, which grew overwinter. In mid-summer we'd turn it in and after a six-week bare fallow, we'd plant it to rye and hairy vetch. When the clover came into bloom, around the end of June or beginning of July, it attracted tarnished plant bugs. When we turned under the clover, we were

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taking away their habitat and pushing them into our cash crops, which was a big problem for the lettuce. That's part of why we decided to shift around our fallow period to spring—along with managing for chickweed and dandelions—and that eliminated the tarnished plant bug problem. With the sudex combination, we turn in the clover before it goes to bloom, eliminating the bloom and bust cycle with the tarnished plant bugs.

The buckwheat is an insectary that attracts beneficials, as well as tarnished plant bugs, which can be a problem in our lettuce. We found it better to do a series of small buckwheat interseedings in our cash crop for a continuous supply of blossoms.

One interesting thing we've observed is that we've noticed more flea beetle pressure after clover plow-down than after rye and hairy vetch. Last year, we used Entrust, an OMRI-approved product to control flea beetles in our fall brassicas: cabbage, kale, and so on. We only had to spray the broccoli once, where it followed rye and vetch, but three times after the clover. That may be a very site-specific phenomenon.

**• Besides managing shade to boost nitrogen fixation by the clover, what advantages accrue from mowing the sudex?**

There is research showing when you mow sorghum-sudan grass at three-and-a-half to four feet, it puts its roots deeper in the soil. It's a drought-tolerant crop and that's because it keeps pushing its roots deeper. We rely on our cover crops for deep tillage, something sudex, sweet clover, and daikon radishes, which are marketed as tiller radishes, all accomplish. Nitrogen-hungry crops like turnips and radishes are popular in Maryland, where they spread chicken manure and need something to capture the extra nutrients before they leach into the Chesapeake Bay. Clovers make more sense here in hilly Northeastern soils, because they boost fertility.

**• Are there any drawbacks to the sudex?**

If you let the sudex grow all season, it can reach a height of 12 feet, which is difficult with our equipment. It also becomes really woody and takes a long time to decompose. By mowing it shorter, we maintain it as a more succulent crop.

**• How do the finances work out?**

Cost is a biggie. Because we're so committed to cover cropping and we're growing high-value cash crops, we don't worry too much about it. This past year, the organic sorghum-sudan grass seed cost us \$67 for a 50-pound bag. We're putting down 45–50 pounds/acre. Organic red clover cost us \$187 for a 50-pound bag and we seed it at 15–25 pounds/acre. Twenty-five pounds gives maximum weed suppression, but in mid-June, we can get away with seeding 15 pounds. If we don't get around to planting until mid-July, we prefer to use the higher range. In 2010 we experimented with crimson clover, which is significantly less expensive. Since there isn't any organic seed available, we have the option of using conventional seed. It's only \$45/bag. We got almost 100 percent winterkill, which makes for minimum tillage in early spring.

**• Are there any tweaks to your system that someone using tractor-drawn equipment, instead of draft horses, would have to make?**

It's important to mow the sudex at least six to eight inches tall because it regrows from its nodes, rather than the crown. If you cut it tight to the ground, it's slower and weaker to grow back. We use a sickle-bar mower, so it's just a question of raising the bar high enough to do that. Whatever equipment you use, whether a tractor or hand tools, the important thing is to cut the sudex at the right height.

**• How do you seed the sudex and clover?**

We like broadcasting seed, then working it in, because it seems to generate a more uniform and competitive establishment. Typically, in the spring, clover is just broadcast and firmed into the soil with a cultipacker. Since we're planting in the summer when it's warmer and drier, we work it into the soil just a little bit. We're seeding in mid-June to mid-July, so we harrow, then cultipack and we get reliable stands even in dry, hot weather. It's a little tweaking we've done here. Using a drill might allow you to back off the seeding rate.

**• How does the weather influence the sudex-clover combo?**

One reason why we've been happy with the sorghum-sudan hybrid may have to do with the apparent changes in the climate. It's a heat-loving crop and we've had warmer summers, in general. In 2009—a cool, wet summer—the sudex didn't produce nearly as much biomass. If we were in a cool, wet cycle we might try something else.

**• How do you monitor results?**

We check for nitrogen-fixation by looking to see whether the nodules are pink inside, and they are. The sudex is a pretty nitrogen-hungry crop, so it uses up the easily available nitrogen in the soil and forces the legume to fix its own. That's the assumption we're working on. If we're planting a field that had different management the previous year—part in mulch, part in a cover crop of rye, and part bare—it's interesting to observe where the sudex and clover come on stronger. If there's more carbon in the soil, the sudex isn't as vigorous and the clover comes on faster. If there was a nitrogen-fixing crop, the sudex comes on strong and the clover is slower, probably just because of the shade from the fast growth of the sudex.

**• How robust was the stand of crimson clover?**

We did two crimson clover plantings in 2010—one in mid-June and the other on July 13. The mid-June planting, probably because it was so hot and dry, was a little bit sparse and not super vigorous until late fall. It was adequate, but not great. The red clover looked much more robust.

The July planting was vigorous and thick, with maybe ten inches of growth. We haven't done a comparison of the buckwheat and crimson clover. It would be interesting to see if you get more clover growth with the buckwheat, since it dies back as soon as it's mowed. I'm curious whether the sudex suppresses the clover growth because it keeps growing until it winterkills.

On August 28, when we mowed, the sudex was between three-and-a-half and four feet tall, with a thick stand of crimson clover between six and ten inches tall. On November 22, we clipped the

sudex, which had already frostkilled; at that time the crimson clover was at least ten inches tall. That time we cut it quite short, which boosts decomposition and facilitates spring tillage. The sudex stump and root system is like a little corn plant. The longer you leave the stem on, the more of the residue you have to contend with in the spring. When we do the first mowing we cut it at 6–10 inches, to encourage regrowth. We cut it short in November to make it easier on ourselves in the spring.

**• How satisfied are you with the sudex-clover combination?**

The biggest drawback to the overwintering red clover is that it requires plowing. With rye and hairy vetch, if it's allowed to mature, you can kill it by discing or mowing it in the end of May or early June. Oats and peas will winterkill. The sudex frostkills, but we have to use intensive tillage to kill the medium red clover. Minimum tillage, of course, is good for retaining soil quality. We don't have a source of irrigation and the more we can reduce tillage and maintain mulch on the surface, we can reduce water demand. Once we have to intensively till in a cover crop, we lose that advantage.

On the other hand, the mix of winterkilled crimson clover and frostkilled sudex has real potential for spring-planted vegetables. Since everything is dead, we can just use light, shallow tillage to prepare the seed bed for planting. It's an alternative to oats and peas, which also winterkill, before spring-planted vegetables.

With the red clover we get the most nitrogen, improvement of soil quality, and return on our seed costs by allowing the red clover to grow through mid- to late May before turning it under. When you turn it under first thing in the spring, you only get the fall growth. If you let it grow in May, you get better return on the seed, but you can't use it for spring crops. The crimson clover may not provide as much nitrogen fixation, but it's not as expensive, either.

We think sudex and clover is nice to have in the mix, but it's not something we would rely on for all of our fields. That's our outlook on any cover crop: You never know, with the weather and so on.

## By the Pound Study analyzes clover effect

by Laurie Drinkwater and Burtie van Zyl

Filling late summer windows with nitrogen-fixing cover crops that can also keep the weeds down presents a unique challenge. Building on a strategy pioneered by Anne and Eric Nordell, we tested crimson and berseem clovers planted with buckwheat. These clovers both winterkill so they are ideal for fields where crops will be planted in early spring. The buckwheat was mowed at peak flowering in August, early enough to avoid seed set, and the clover biomass was sampled in October.

We planted cover crops on July 10, 2009, using a six-foot, three-point no-till drill, manufactured by Great Plains. There were four treatments, seeded at the following rates:

- crimson clover monoculture: 15 pounds/acre
- mixture: crimson clover 7.5 pounds/acre; buckwheat 67 pounds/acre

- berseem clover monoculture: 13 pounds/acre
- mixture: berseem clover 6.5 pounds/acre; Buckwheat 67 pounds/acre

In our experiments, monocultures of crimson clover fixed more nitrogen and were also better at suppressing weeds compared to berseem clover. When buckwheat was planted with crimson clover, weeds were reduced by 50 percent (from 47 to 23 pounds/acre); however, nitrogen fixation was also reduced. Both nitrogen fixation and clover growth were suppressed until the buckwheat was mowed -- reducing shading by the dense stand of buckwheat. Once the taller plants were mowed, crimson clover recovered and produced lush growth of eight- to twelve inches and fixed a fair amount of nitrogen (40 pounds nitrogen/acre). We found similar results when sorghum-sudan grass was planted with these clovers, and mowed.

	% N from fixation	Total N Fixed (lbs.acre)	Weed Biomass (lbs.acre)
<b>CrimsonClover</b>	<b>71</b>	<b>63</b>	<b>47</b>
<b>CrimsonClover+Buckwheat(Unmowed)</b>	<b>46</b>	<b>4</b>	<b>23</b>
<b>CrimsonClover+Buckwheat(Mowed)</b>	<b>66</b>	<b>41</b>	<b>23</b>
<b>BerseemClover</b>	<b>50</b>	<b>32</b>	<b>180</b>
<b>BerseemClover+Buckwheat(Unmowed)</b>	<b>30</b>	<b>3</b>	<b>31</b>
<b>BerseemClover+Buckwheat(Mowed)</b>	<b>49</b>	<b>20</b>	<b>31</b>

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