Building Soil Fertility and Tilth With Cover Crops

by Marianne Sarrantonio

Soil is an incredibly complex substance. It has physical and chemical properties that allow it to sustain living organisms—not just plant roots and earthworms, but hundreds of thousands of different insects, wormlike creatures and microorganisms. When these organisms are in balance, your soil cycles nutrients efficiently, stores water and drains the excess, and maintains an environment in which plants can thrive.

To recognize that a soil can be healthy, one has only to think of the soil as a living entity. It breathes, it transports and transforms nutrients, it interacts with its environment, and it can even purify itself and grow over time. If you view soil as a dynamic part of your farming system, unsustainable crop management practices amount to soil neglect. That neglect could worsen as the soil sickens and loses its life functions one by one.

Regardless of how healthy or alive your soil is right now, cover crops can play a vital role in ensuring that your soil provides a strong foundation for your farming system. While the most common reasons for including cover crops in a farming system may relate to the immediate short-term need, the continued practice of cover cropping becomes an investment in building healthy soil over the long term.

Cover crops improve soil in a number of ways. Protection against soil loss from erosion is perhaps the most obvious soil benefit of cover crops, but providing organic matter is a more long-term and equally important goal. Cover crops contribute indirectly to overall soil health by catching nutrients before they can leach out of the soil profile or, in the case of legumes, by adding nitrogen to the soil. Their roots can even help unlock some nutrients, converting them to more available forms. Cover crops provide habitat or a food source for some important soil organisms, break up compacted layers in the soil and help dry out wet soils.

EROSION PROTECTION

Erosion of topsoil occurs on many farms, depriving fields of the most fertile portion, that containing the highest percentage of organic matter and nutrients. Cover crops can play a major role in fighting soil erosion.

A raindrop falling at high speed can dislodge soil particles and cause them to move as far as 6 feet . Once a soil particle is loose, it is much more vulnerable to being carried away by running water. Any aboveground soil cover can take some of the punch out of a heavy rainfall simply by acting as a cushion for raindrops.

A cover crop also can:

- Slow the action of moving water, thus reducing its soil-carrying capacity, by creating an obstacle course of leaves, stems and roots through which the water must maneuver on its way downhill.
- Increase the soil's ability to absorb and hold water, through improvement in pore structure, thereby preventing large quantities of water from moving across the soil surface.
- Help stabilize soil particles in the cover crop root system

The reduction in soil erosion due to cover cropping will be roughly proportional to the amount of cover on the soil. The Revised Universal Soil Loss Equation developed by the Natural Resources Conservation Service predicts that a soil cover of just 40 percent when winter arrives can reduce erosion substantially until spring.

It's worthwhile to get covers established early, to ensure that maximum soil cover develops before winter rains. Consider over seeding covers at layby cultivation, aerial seeding or hand spreading before harvest, or planting as soon as possible after harvest. It's always a good idea to maintain year-round soil cover whenever possible.

Organic Matter Additions

The benefits of organic matter include improved **soil structure**, increased **infiltration and water-holding capacity**, increased **cation exchange capacity** (the ability of the soil to act as a short-term storage bank for positively charged plant nutrients) and more **efficient long-term storage** of nutrients. Without organic matter, you have no soil to speak of, only a dead mixture of ground-up and weathered rocks.

Organic matter includes thousands of different substances derived from decayed leaves, roots, microorganisms, manure and even groundhogs that died in their burrows. These substances function in different ways to build healthy soil. Different plants leave behind different kinds of organic matter as they decompose, so your choice of cover crop will largely determine which soil benefits you will receive.

Soil scientists may argue over how to classify the various soil organic components. Most will agree, however, that there is a portion that can be called the **"active" fraction** and one that might be called the **“stable” fraction**, which is roughly equivalent to **humus**. There are many categories in between the active and stable fractions.

The active fraction represents the most easily decomposed parts of soil organic matter. It tends to be rich in simple sugars and proteins and consists largely of recently added fresh residues, microbial cells and the simpler waste products from microbial decay.

Because microorganisms, like human organisms, crave sweet stuff, compounds containing simple sugars disappear quickly. Proteins also are selected quickly from the menu of edible soil goodies. When these compounds are digested, many of the nutrients that they contain are released into the soil. Proteins are nitrogen-rich, so the **active fraction** *is responsible for the release of most N, as well as some K, P and other nutrients, from organic matter into the soil*. The easily decomposed proteins and sugars burn up almost completely as energy sources, and don’t leave much behind to contribute to organic matter building.

After the microorganisms have devoured the portions of the active fraction that are easiest to digest, a more dedicated subset of these microorganisms will start munching on the more complex and tough material, such as celluloses and lignins, the structural materials of plants. Since cellulose is tougher than simple sugars, and lignin breaks down very slowly, they contribute more to the humus or stable fraction. Humus is responsible for giving the soil that rich, dark, spongy feeling and for properties such as water retention and cation exchange capacity.

Plant materials that are succulent and rich in proteins and sugars will release nutrients rapidly but leave behind little long-term organic matter. **Plant materials that are woodier or more fibrous** will release nutrients much more slowly, perhaps even tie up nutrients temporarily), but will promote more stable organic matter, or humus, leading to better soil physical conditions, increased nutrient-holding capacity and higher cation exchange capacity.

In general, annual legumes are succulent. They release nitrogen and other nutrients quickly through the active fraction, but are not very effective at building up humus. Long-term use of annual legumes can increase soil humus, however, some research suggests.

Grains and other grasses and nonlegumes will contribute to humus production, but won’t release nutrients very rapidly or in large quantities if incorporated as they approach maturity. Perennial legumes such as white and red clover may fall in both categories—their leaves will break down quickly, but their stems and root systems may become tough and fibrous and can contribute to humus accumulation.

Cover Crops Help “Glue” Soil

As soil microorganisms digest plant material, they produce some compounds in addition to the active and stable fractions of the organic matter. One group of these by-products is known as **polysaccharides**. These are complex sugars that act as glues in the soil to cement small soil particles into clusters or **aggregates**. Many farmers use the term "**crumb**" to describe soil clusters about the size of a grain of rice. A well-aggregated or "crumby" soil—not to be confused with crummy or depleted soil—has good aeration. It allows better infiltration and retention of water. Cover crops can promote good aggregation in the soil through increased production of these and other microbial glues. Well-aggregated soils also are less prone to compaction, which has been shown to reduce yields of vegetables such as snap beans, cabbage and cucumber by 50 percent or more.

As they decompose, leguminous cover crops seem to be better than grasses for production of polysaccharides. However, polysaccharides will decompose in a matter of months, so their aggregation effect is likely to last only the season after the use of the cover crop.

Grass species also promote good aggregation, but by a different mechanism. Grasses have a 'fibrous' root system—made of numerous fine roots spreading out from the base of the plant. These roots may release compounds that help aggregate the soil between roots.

Organic matter builds up very slowly in the soil. A soil with 3 percent organic matter might only increase to 4 percent after a decade or more of soil building. The benefits of increased organic matter, however, are likely to be apparent long before increased quantities are detectable. Some, such as enhanced aggregation, water infiltration rates and nutrient release, will be apparent the first season; others may take several years to become noticeable.

Your tillage method is an important consideration when using cover crops to build soil, because tillage will affect the rate of organic matter accumulation. *It is difficult to build up organic matter under conventional tillage regimes.* Tillage speeds up organic matter decomposition by exposing more surface area to oxygen, warming and drying the soil, and breaking residue into smaller pieces with more surfaces that can be attacked by decomposers. Like fanning a fire, tillage rapidly "burns up" or "oxidizes" the fuel, which in this case is organic matter. The resulting loss of organic matter causes the breakdown of soil aggregates and the poor soil structure often seen in overtilled soil.

When adding cover crops to a system, minimize tillage to maximize the long-term soil benefits. Many of the cover crops discussed in this book are ones you can seed into growing crops or no-till plant into crop residues. Otherwise, the gain in organic matter may be counteracted by higher decomposition rates.

Tightening The Nutrient Loop

In addition to reducing topsoil erosion and improving soil structure, cover crops enhance nutrient cycling in your farming system by taking up nutrients that otherwise might leach out of the soil profile. These excess nutrients have the potential to pollute groundwater or local streams and ponds, not to mention impoverishing the soil they came from.

Of the common plant nutrients, nitrogen in the nitrate form is the most water-soluble and therefore the most vulnerable to leaching. Anytime soil is bare and appreciable rain falls, nitrates are on the move. Nitrate can be present in the soil at the end of a cropping season if the crop did not use all the N applied. Decomposing organic matter (including plant residues, compost and animal manures) also can supply nitrate-N, as long as the soil temperature is above freezing. Even in a field where the yearly application of N is well-suited to crop needs, nitrates can accumulate after crops are harvested and leach when it rains.

Cover crops reduce nitrate leaching in two ways. They soak up available nitrate for their own needs. They also use some soil moisture, reducing the amount of water available to leach nutrients.

The best cover crops to use for nitrate conservation are nonlegumes that form deep, extensive root systems quickly after cash crops are harvested. For much of the continental U.S., cereal rye is the best choice for catching nutrients after a summer crop. Its cold tolerance is a big advantage that allows rye to continue to grow in late fall and put down roots to a depth of three feet or more. Where winters are mild, rye can grow through the winter months.

Cover Crops Can Stabilize Your Soil

The more you use cover crops, the better your soil tilth, research continues to show. One reason that cover crops, especially legumes, encourage populations of beneficial fungi and other microorganisms that help bind soil aggregates.

The fungi, called mycorrhizae, produce a water-insoluble protein known as **glomalin**, which catc and glues together particles of organic matter, plant cells, bacteria and other fungi. Glomalin may be one of the most important substances in promoting and stabilizing soil aggregates.

Most plant roots, not just those of cover crops, develop beneficial mycorrhizal relationships. The fungi send out rootlike extensions called **hyphae**, which take up water and soil nutrients to help feed plants. In low-phosphorus soils, for example, the hyphae can increase the amount of phosphorus that plants obtain. In return, the fungi receive energy in the form of sugars that plants produce in their leaves and send down to the roots.

Growing a cover crop increases the abundance of mycorrhizal spores. Legumes in particular can contribute to mycorrhizal diversity and abundance, because their roots tend to develop large populations of these beneficial fungi.

By having their own mycorrhizal fungi and by promoting mycorrhizal relationships in subsequent crops, cover crops therefore can play a key role in improving soil tilth. The overall increase in glomalin production also could help explain why cover crops can improve water infiltration into sc

and enhance storage of water and soil nutrients, even when there has been no detectable increa
in the amount of soil organic matter.

Research with soil high in residual N in the mid-Atlantic's coastal plain showed that cereal rye took up more than 70 lb. N/A in fall when planted by October 1. Other grasses, including wheat, oats, barley and ryegrass, were only able to take up about half that amount in fall. Legumes were practically useless for this purpose in the Chesapeake Bay study. Legumes tend to establish slowly in fall and are mediocre N scavengers, as they can fix much of their own N.

To maximize N uptake and prevent leaching, plant nonlegumes as early as possible. In the above study, rye took up only 15 lb. N/A when planting was delayed until November. It is important to give cover crops the same respect as any other crop in the rotation and plant them in a timely manner.

Not Just Nitrogen Cycling

Cover crops help bring other nutrients back into the upper soil profile from deep soil layers. Calcium and potassium are two macronutrients with a tendency to travel with water, though not generally on the express route with N. These nutrients can be brought up from deeper soil layers by any deep-rooted cover crop. The nutrients are then released back into the active organic matter when the cover crop dies and decomposes.

Although phosphorus (P) doesn't generally leach, as it is only slightly water-soluble, cover crops may play a role in increasing its availability in the soil. Some covers, such as buckwheat and lupins, are thought to secrete acids into the soil that put P into a more soluble, plant-usable form.

Some cover crops enhance P availability in another manner. The roots of many common cover crops, particularly legumes, house beneficial fungi known as **mycorrhizae**. The mycorrhizal fungi have evolved efficient means of absorbing P from the soil, which they pass on to their plant host. The filaments (hyphae) of these fungi effectively extend the root system and help the plants tap more soil P.

Keeping phosphorus in an **organic** form is the most efficient way to keep it cycling in the soil. So the return of any plant or animal residue to the soil helps maintain P availability. Cover crops also help retain P in your fields by reducing erosion.

Adding Nitrogen

One of nature's most gracious gifts to plants and soil is the way that legumes, with the help of rhizobial bacteria, can add N to enrich your soil

The nitrogen provided by N-fixation is used efficiently in natural ecosystems, thanks to the soil's complex web of interacting physical, chemical and biological processes. In an agricultural system, however, soil and crop management factors often interfere with nature's ultra -efficient use of organic or inorganic N. Learning a bit about the factors affecting N-use efficiency from legume plants will help build the most sustainable cropping system possible within your constraints.

How Much N is Fixed?

A number of factors determine how much of the N in your legume came from “free” N, fixed from N2 gas:

- Is the **symbiosis** (the interdependence of the rhizobia and the plant roots) effective? Use the correct rhizobial inoculant for the legume you’re growing. Make sure it’s fresh, was stored properly, and that you apply it with an effective sticking agent. Otherwise, there will be few nodules and N-fixation will be low.
- Is the soil fertile? N-fixation requires molybdenum, iron, potassium, sulfur and zinc to function properly. Soils depleted of these micronutrients will not support efficient fixation. Tissue testing your cash crops can help you decide if you need to adjust micronutrient levels.
- Is the soil getting enough air? N-fixation requires that N-rich air get to the legume roots. Waterlogging or compaction hampers the movement of air into the soil. Deep-rooted cover crops can help alleviate subsoil compaction.
- Is the pH adequate? Rhizobia generally will not live long in soils below pH 5.
- Does the legume/rhizobial pair have high fixation potential? Not all legumes were created equal—some are genetically challenged when it comes to fixation. Beans (*Phaseolus* spp.) are notoriously incapable of a good symbiotic relationship and are rarely able to fix much more than 40 lb. N/A in a whole season. Cowpeas (*Vigna unguiculata*) and vetches (*Vicia* spp.), on the other hand, are generally capable of high fixation rates.

Even under the best of conditions, legumes rarely fix more than 80 percent of the nitrogen they need to grow, and may only fix as much as 40 or 50 percent. The legume removes the rest of what it needs from the soil like any other plant. Legumes have to feed the bacteria to get them to work, so if there is ample nitrate already available in the soil, a legume will remove much of that first before expending the energy to get N-fixation going. In soils with high N fertility, legumes may fix little or no nitrogen.

While it is tempting to think of legume nodules as little fertilizer factories pumping N into the surrounding soil, that isn’t what happens. The fixed N is almost immediately shunted up into the stems and leaves of the growing legume to form proteins, chlorophyll and other N-containing compounds. The fixed nitrogen will not become available to the next crop until the legume decomposes. Consequently, if the aboveground part of the legume is removed for hay, the majority of the fixed nitrogen also leaves the field.

What about the legume roots? Under conditions favoring optimal N fixation, a good rule of thumb is to think of the nitrogen left in the plant roots (15 to 30 percent of plant N) as being roughly equivalent to the amount the legume removed directly from the soil, and the amount in the stems and leaves as being equivalent to what was fixed.

Annual legumes that are allowed to flower and mature will transport a large portion of their biomass nitrogen into the seeds or beans. Also, once the legume has stopped actively growing, it will shut down the N-fixing symbiosis. In annual legumes this occurs at the time of flowering; no additional N gain will occur after that point. Unless you want a legume to reseed itself, it's generally a good idea to kill a legume cover crop in the early- to mid-blossom stage. You'll have obtained maximum legume N and need not delay planting of the following cash crop any further, aside from any period you may want for residue decomposition as part of your seedbed preparation.

How Nitrogen is Released

How much N will soil really acquire from a legume cover crop? Let's take it from the point of a freshly killed, annual legume, cut down in its prime at mid-bloom. The management and climatic events following the death of that legume will greatly affect the amount and timing of N release from the legume to the soil.

Most soil bacteria will feast on and rapidly decompose green manures such as annual legumes, which contain many simple sugars and proteins as energy sources. Soil bacteria love to party and when there is lots to eat, they do something that no party guest you've ever invited can do—they reproduce themselves, rapidly and repeatedly, doubling their population in as little as seven days under field conditions. Even a relatively inactive soil can come to life quickly with addition of a delectable green manure.

The result can be a very rapid and large release of nitrate into the soil within a week of the green manure's demise. This N release is more rapid when covers are plowed down than when left on the surface. As much as 140 lb. N/A has been measured 7 to 10 days after plowdown of hairy vetch. Green manures that are less protein- rich (N-rich) will take longer to release N. Those that are old and fibrous or woody are generally left for hard-working but somewhat sluggish fungi to convert slowly to humus over the years, gradually releasing small amounts of nutrients.

Other factors contribute significantly to how quickly a green manure releases its N. Weather has a huge influence. The soil organisms responsible for decomposition work best at warm temperatures and are less energetic during cool spring months.

Soil moisture also has a dramatic effect. Research shows that soil microbial activity peaks when 60 percent of the soil pores are filled with water, and declines significantly when moisture levels are higher or lower. This 60 percent water-filled pore space roughly corresponds to **field capacity**, or the amount of water left in the soil when it is allowed to drain for 24 hours after a good soaking rain. Microbes are sensitive to soil chemistry as well. Most soil bacteria need a pH of between 6 and 8 to perform at peak; fungi (the slow decomposers) are still active at very low pH. Soil microorganisms also need most of the same nutrients that plants require, so low-fertility soils support smaller populations of primary decomposers, compared with high-fertility soils. Don't expect N-release rates or fertilizer replacement values for a given cover crop to be identical in fields of different fertility. Many of these environmental factors are out of your direct control in the near term. Management factors such as fertilization, liming and tillage, however, also influence production and availability of legume N.

Tillage, No-Tillage and N-Cycling

Tillage affects decomposition of plant residues in a number of ways. First, any tillage increases soil contact with residues and increases the microbes' access to them. The plow layer is a hospitable environment for microbes, as they're sheltered from extremes of temperature and moisture. Second, tillage breaks the residue into smaller pieces, providing more edges for microbes to munch. Third, tillage will temporarily decrease the density of the soil, generally allowing it to drain and therefore warm up more quickly. All told, residues incorporated into the soil tend to decompose and release nutrients much faster than those left on the surface, as in a no-till system. That's not necessarily good news, however.

A real challenge of farming efficiently is to keep as much of the N as possible in a stable, storable form until it's needed by the crop. The best storage form of N is the organic form: the undecomposed residue, the humus or the microorganisms themselves.

How Much N?

To find out if you might need more N than your green manure will supply, you need to estimate tl amount of N in your cover crop. To do this, assess the total yield of the green manure and the percentage of N in the plants just before they die.

To estimate yield, take cuttings from several areas in the field, dry and weigh them. Use a yardst or metal frame of known dimensions (1 ft. x 2 ft., which equals 2 square feet works well) and clip plants at ground level within the known area. Dry them out in the sun for a few consecutive days, use an oven at about 140° F for 24 to 48 hours until they are "crunchy dry." Use the following equation to determine per-acre yield of dry matter:

Yield (lb.)/Acre = Total weight of dried samples (lb.)/ # square feet you sampled X 43,560 s ft./1 Acre

While actually sampling is more accurate, you can estimate your yield from the height of your gre manure crop and its percent groundcover. Use these estimators:

At 100 percent groundcover and 6-inch height*, most nonwoody legumes will contain roughly 2,0 lb./A of dry matter. For each additional inch, add 150 lb. So, a legume that is 18 inches tall and 1 percent groundcover will weigh roughly:

Inches >6: 18 in.– 6 in. = 12 in.

x 150 lb./in.: 12 in. x 150 lb./in. = 1,800 lb.

Add 2,000 lb.: 2,000 lb. + 1,800 lb. = 3,800 lb.

If the stand has less than 100 percent groundcover, multiply by (the percent ground cover / 100). this example, for 60 percent groundcover, you would obtain:

3,800 x (60/100) = 2,280 lb.

Keep in mind that these are rough estimates to give you a quick guide for the productivity of your green manure. To know the exact percent N in your plant tissue, you would have to send it to a l for analysis. Even with a delay for processing, the results could be helpful for the crop if you use split applications of N. Testing is always a good idea, as it can help you refine your N estimates f subsequent growing seasons.

The following rules of thumb may help here:

- Annual legumes typically have between 3.5 and 4 percent N in their aboveground parts p to flowering (for young material, use the higher end of the range), and 3 to 3.5 percent at flowering. After flowering, N in the leaves decreases quickly as it accumulates in the grow seeds.
- For cereal rye, the height relationship is a bit different. Cereal rye weighs approximately 2,000 lb./A of dry matter at an 8-inch height and 100 percent groundcover. For each additional inch, add 150 lb., as before, and multiply by (percent groundcover/100). For m small grains and other annual grasses, start with 2,000 lb./A at 6 inches and 100 percent ground cover. Add 300 lb. for each additional inch and multiply by (percent groundcover/100).
- For perennial legumes that have a significant number of thick, fibrous or woody stems, reduce these estimates by 1 percent.
- Most cover crop grasses contain 2 to 3 percent N before flowering and 1.5 to 2.5 percent after flowering.
- Other covers, such as brassicas and buckwheat, will generally be similar to, or slightly below, grasses in their N content. To put it all together:

- Total N in green manure (lb./A) = yield (lb./A) x % N/100

To estimate what will be available to your crop this year, divide this quantity of N by:

- 2, if the green manure will be conventionally tilled;
  4, if it will be left on the surface in a no-till system in Northern climates;
  2, if it will be left on the surface in a no-till system in Southern climates.

Bear in mind that in cold climates, N will mineralize more slowly than in warm climates, as discussed above. So these are gross estimates and a bit on the*conservative* side.

Of course, cover crops will not be the only N sources for your crops. Your soil will release betwe 10 and 40 lb. N/A for each 1 percent organic matter. Cold, wet clays will be at the low end of the scale and warm, well-drained soils will be at the high end. You also may receive benefits from la year's manure, green manure or compost application.

Other tools could help you refine your nitrogen needs. On-farm test strips of cover crops receivin different N rates would be an example. In some regions, a pre-sidedress N test in spring could h you estimate if supplemental N will be cost-effective. Bear in mind that pre-sidedress testing doe not work well when fresh plant residues have been turned in—too much microbial interference relating to N tie-up may give misleading results.

For more information on determining your N from green manures and other amendments, see the *Northeast Cover Crop Handbook*, —Marianne Sarrantonio, Ph.D.

Let's consider the N contained in the microbes. Nitrogen is a nutrient the microbes need for building proteins and other compounds. Carbon-containing compounds such as sugars are mainly energy sources, which the microorganisms use as fuel to live. The process of burning this fuel sends most of the carbon back into the atmosphere as carbon dioxide, or CO2.

Suppose a lot of new food is suddenly put into the soil system, as when a green manure is plowed down. Bacteria will expand their populations quickly to tap the carbon-based energy that's available. All the new bacteria, though, will need some N, as well as other nutrients, for body building before they can even begin to eat. So any newly released or existing mineral N in soil gets scavenged by new bacteria.

Materials with a high carbon to nitrogen (C:N) ratio, such as mature grass cover crops, straw or any fibrous, woody residue, have a low N content. They can "tie up" soil N, keeping it **immobilized** (and unavailable) to crops until the carbon "fuel supply" starts depleting. Tie-up may last for several weeks in the early part of the growing season, and crop plants may show the yellowing characteristic of N deficiencies. That is why it often makes sense to wait one to three weeks after killing a low-N cover before planting the next crop, or to supplement with a more readily available N source when a delay is not practical.

Annual legumes have low C:N ratios, such as 10:1 or 15:1. When pure stands of annual legumes are plowed down, the N tie-up may be so brief you will never know it occurred.

Mixed materials, such as legume-grass mixtures, may cause a short tie-up, depending on the C:N ratio of the mixture. Some N storage in the microbial population may be advantageous in keeping excess N tied up when no crop roots are there to absorb it.

Fall-planted mixtures are more effective in mopping up excess soil N than pure legumes and, as stated earlier, the N is mineralized more rapidly from mixtures than from pure grass. A fall-seeded mixture will adjust to residual soil N levels. When the N levels are high, the grass will dominate and when N levels are low, the legume will dominate the mixtures. This can be an effective management tool to reduce leaching while making the N more available to the next crop.

Potential Losses

a common misunderstanding about using green manure crops is that the N is used more efficiently because it's from a plant source. This is not necessarily true. Nitrogen can be lost from a green manure system almost as easily as from chemical fertilizers, and in comparable amounts. The reason is that the legume organic N may be converted to ammonium (NH_4), then to ammonia (NH_3) or nitrate (NO_3) before plants can take it up. Under no-till systems where killed cover crops remain on the surface, some ammonia (NH_3) gas can be lost right back into the atmosphere.

Nitrate is the form of N that most plants prefer. Unfortunately, it is also the most water-soluble form of N. Whenever there is more nitrate than plant roots can absorb, the excess may leach with heavy rain or irrigation water.

As noted earlier, nitrates in excess of 140 lb./A may be released into warm, moist soil within as little as seven to 10 days after plowing down a high-N legume, such as a hairy vetch stand. Since the following crop is unlikely to have much of a root system at that point, the N has a ticket for Leachville. Consider also that the green manure may have been plowed down to as deep as 12 inches—much deeper than anyone would consider applying chemical fertilizer. Moreover, green manures sometimes continue to decompose after the cash crop no longer needs N. This N also is prone to leaching.

To summarize, conventional plowing and aggressive disking can cause a rapid decomposition of green manures, which could provide too much N too soon in the cropping season. No-till systems will have a reduced and more gradual release of N, but some of that N may be vulnerable to gaseous loss, either by ammonia volatilization or by denitrification, which occurs when NO_3^- converts to gases under low O_2 (flooded) conditions. Thus, depending on management, soil and weather situations, N from legume cover crops may not be more efficiently used than N from fertilizer.

Some possible solutions to this cover crop nitrogen-cycling dilemma :

- A shallow incorporation of the green manure, as with a disk, may reduce the risk of gaseous loss.
- It may be feasible to no-till plant or transplant into the green manure, then mow or incorporate it between the rows 10-14 days later, when cash crop roots are more developed and able to take up N. This has some risk, especially when soil moisture is limiting, but can provide satisfactory results if seedling survival is assured.
- Residue from a grass/legume mix will have a higher C:N than the legume alone, slowing the release of N so it's not as vulnerable to loss.
- Consider also that some portion of the N in the green manure will be conserved in the soil in an organic form for gradual release in a number of subsequent growing seasons.

Other Soil-Improving Benefits

Cover crops can be very useful as living plows to penetrate and break up compacted layers in the soil. Some of the covers discussed in this book, such as sweet clover and forage radish, have roots that reach as deep as three feet in the soil within one cropping season. The action of numerous pointy little taproots with the hydraulic force of a determined plant behind them can penetrate soil where plowshares fear to go. Grasses, with their tremendously extensive root systems, may relieve compacted surface soil layers. Sorghum-sudangrass can be managed to powerfully fracture subsoil.

One of the less appreciated soil benefits of cover crops is an increase in the total numbers and diversity of soil organisms. As discussed earlier, diversity is the key to a healthy, well-functioning soil. Living covers help supply year-round food for organisms that feed off root by-products or that need the habitat provided on a residue-littered soil surface. Dead covers supply a more varied and increased soil diet for many organisms.

Of course, unwanted pests may be lured to the field. Effective crop rotations that include cover crops, however, tend to reduce rather than increase pest concerns.

Finally, cover crops may have an added advantage of drying out and therefore warming soils during a cold, wet season. The flip side of this is that they may dry the soil out too much and rob the following crop of needed moisture.

There are no over-the-counter elixirs for renewing soil. A long-term farm plan that includes cover crops, however, can help ensure your soil's health and productivity for as long as you farm.