Nutrient Recycling with Manure and Cover Crops

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Introduction

Converting from conventional tillage to continuous no-till requires a big change in soil dynamics and soil ecology. Many long-term no-till farmers had to learn some tough lessons before they could make long-term no-till practices work on their farm. With nitrogen and fuel prices climbing, the economics of no-till farming with cover crops and manure are becoming greater every day. In addition, the environmental problems associated with excess nitrogen and phosphorous (hypoxia in the Gulf of Mexico and eutrophication in fresh water lakes and streams) are causing people to question some conventional farming practices. Farmers have been reluctant to adopt continuous no-till, especially no-till corn because of the 10-20% yield lag associated with no-till corn. Most farmers have adopted a conservation tillage system using minimal tillage on soybeans acres planted to corn along with no-till soybeans planted into corn stalks. While this practice has improved corn yields, the nitrogen use efficiency and water quality benefits have not improved. To successfully convert to a continuous no-till system, farmers need to understand nutrient recycling in the soil and understand how soil ecology changes when converting from a conventional to a continuous no-till system and how these changes improve nitrogen use efficiency and water quality benefits. Understanding photosynthesis and carbon recycling in the soil are the first steps in understanding how nutrients are stored and released in the soil.

Photosynthesis and Carbon Recycling

Plants combine energy from the sun with water and carbon dioxide using chlorophyll in the leaves to form glucose (sugars), releasing oxygen back into the atmosphere (see Diagram 1: Photosynthesis). Glucose plus other nutrients are combined to form structural compounds like carbohydrates, amino acids (proteins), lipids (fats), and lignin, which add support to the cell walls in a plant. The dead plant materials and plant nutrients become food for the microbes in the soil. Soil organic matter (SOM) is basically all the organic substances (anything with carbon) in the soil, both living and dead. SOM includes plants, blue-green algae, microorganisms (bacteria, fungi, protozoa, nematodes, beetles, springtails, etc.) and the fresh and decomposing organic matter from plants, animals, and microorganisms.

Diagram 2: Carbon Recycling shows how carbon is recycled in the soil. This example shows the decomposition of 100 grams of organic residues. One hundred grams of dead plant material yields about 60-80 grams of carbon dioxide, which is released back into the atmosphere. The remaining 20-40 grams of energy and nutrients is decomposed and turned into about 3-8 grams of microorganisms (the living), 3-8 grams of non-humic compounds (the dead) and 10-30 grams of humic compounds (the very dead matter, resistant to decomposition). The molecular structure of SOM is mainly carbon and oxygen with some hydrogen and nitrogen and small amounts of phosphorus and sulfur. Soil organic matter is a by-product of the carbon and nitrogen cycles.

Conventional agriculture with conventional tillage is associated with soil, air, and water degradation because there are higher chemical inputs (fertilizer, pesticides) usage. Conventional tillage results in reduced SOM levels in the soil. *Why should we care about SOM?* With conventional tillage, SOM is being burned up by the oxygen that is introduced into the soil when the soil is turned over, and this process releases soil nutrients like nitrogen and phosphorous. At first, soil microbes thrive on this release of nutrients and crop yields go up, but eventually nutrients are lost from the soil. Conventional tillage results in 1.2 billion tons of carbon dioxide loss into the air annually. With this loss, valuable soil nutrients like nitrogen and phosphorous are also lost. **A 1% loss in soil organic matter equals 1,100 pounds of nitrogen lost, 116 pounds of phosphate, 105 pounds of potash, 145 pounds of sulfur, and 6 tons of carbon.** Typically, conventional tilled soils have less organic matter (1-3%) while long-term continuous no-till fields have 4-6% soil organic matter. This translates into a large difference in soil productivity. The SOM is the storage vessel for large quantities of organic nitrogen, phosphorous, and other soil nutrients. That is why conventional tillage and conventional agriculture are related to soil, air, and water quality degradation because they destroy the SOM that hold the nutrients in the soil.

Why does conventional tillage out perform no-till corn? Conventional tillage releases large amounts of nutrients into the soil through SOM oxidation until the soil reaches a lower SOM equilibrium. Till a long-term no-till soil (4-6% SOM) and in time the SOM will decrease to 1-3% SOM and hold fewer nutrients. Different rates of tillage result in different rates of SOM loss. Aggressive subsoil tillage, which introduces larges amounts of oxygen into the soil, oxidizes or burns up three times more SOM and nutrients than chisel plowing. Mold board plowing 6-8 inches deep releases twice as much SOM as chisel plowing (see Diagram 3: Soil Organic Matter Losses with Tillage). In the last 20 years, farmers have increasingly adopted conservation tillage (30% residue cover) and have started to slowly improve soil productivity. Long-term no-till of the soil increases SOM accumulation faster than conservation tillage. Adding a winter cover crop could potentially double the rate of SOM accumulation that occurs each year.

Since corn is a grass, it requires more nutrients and water so farmers typically see a 10-20% bushel yield decrease for the first 5-7 years when they convert from conventional tilled to no-till. The corn crop benefits from tilled soils due to the release of nutrients from the SOM, however, many of these nutrients are lost from the soil profile and excess nutrients are either leach or runoff. Yet, long-term research shows that 7-9 years of continuous no-till produces higher yields than conventional tilled fields. Why? Because it takes 7-9 years to restore SOM, improve soil health by getting the microbes and soil fauna back into balance, and restoring the nutrients lost by tillage (a 3% SOM loss equals 3,300#N, 348#P, 315# K, 435# S). The nutrients in the soil have a value of $684 for each 1% SOM or $68 per ton of SOM. Conventional tilled soils have fewer nutrients stored in the soil by SOM. See Table 1: Value of Soil Organic Matter.

Soil Microbes and Nutrient Recycling

SOM is related to carbon and how it recycles through the soil system. All the atmospheric carbon dioxide represents only 40% of the soils holding capacity for carbon so soils have the ability to store large amounts of carbon. The carbon and nitrogen cycles are linked because carbon is used to hold or store nitrogen in the soil.

Microbes in the soil are the key to carbon and nitrogen recycling in the soil. In conventional tilled soils, the bacteria dominate but they are only 20-30% efficient at recycling carbon. Bacteria are higher in nitrogen content but lower in total carbon (20% nitrogen, 5:1 Carbon nitrogen ratio). These bacteria are what you typically smell when farmers plow or till a soil. In healthy no-till soils, microbial populations are much larger and much more diverse. In no-till, the fungi dominate the food web processes (although they are less in number than the bacteria). Fungi have 40-55% carbon use efficiency so they store and recycle more carbon compared to bacteria. Bacteria are less efficient and release more carbon into the air as carbon dioxide.

Fungi have a higher carbon content (10:1 carbon to nitrogen ratio) and less nitrogen (10%) in their cells than bacteria. Mycorrhizal fungi have a beneficial (symbiotic) relationship with plants. A typical plant root occupies only 2% of the soil volume. Mycorrhizal fungi receive glucose from the roots and form a mycorrhizal network that helps the plant roots be more efficient at pulling in soil nutrients from a larger soil volume. These fungi surround the roots with a sticky substance call glomalin. *Why is glomalin so important?* Because glomalin surrounds the soil particles and acts like a glue to keep soil particles together. Glomalin is what gives soil it soil structure. *Why are conventional tilled soils so cloddy and lack good soil structure?* Tilled soils are dominated by bacteria and lack beneficial fungus that produce glomalin (see Diagram 4: Mycohizzal Fungus, and Picture 1: Glomalin Surrounding a Soil Aggregate).

Microbes need regular supplies of active SOM in the soil to survive. Active SOM is fresh plant or animal material, which is food for microbes, and is composed of sugars and proteins. The passive SOM is more resistant to decomposition by microbes. Long-term no-tilled soils have significantly greater levels of active organic matter and microbes than conventional tilled soils.

SOM is affected by climate and temperature. Microbial populations double with every 10 degree Fahrenheit change in temperature. If we compare the tropics to colder artic regions, we find most of the carbon is tied up in trees and vegetation in the tropics but the soil has very little SOM because with higher temperatures and adequate moisture, it quickly decomposes. As you move north or south from the equator, SOM increases in the soil. The tundra near the artic circle has a larger amount of SOM because of cold temperatures. Hot, humid regions store less organic carbon in the soil than dry, cold regions. Due to differences in vegetation, SOM matter accumulations differ moving from east to west across the United States. In the east, hardwood forests dominated before agricultural cropland was cleared and the soil profile was dominated by tree tap roots (high in lignin) with large amounts of leaf litter left on the soil surface. In forest soils, most of the SOM is distributed in the top few inches. As you move west, grassland prairies dominated the landscape and topsoil formed from deep fibrous grass root systems. Fifty percent of prairie grass roots die each year. Grass roots are high in sugars and protein (higher active organic matter) and lower in lignin. So soils that formed under grass prairies are high in SOM throughout the soil profile. These prime soils are productive because they have higher percentage of SOM, hold more nutrients (1,100 pounds nitrogen and 116 pounds of phosphorous for each 1% SOM), and contain more microbes. There are 10,000 times more microbes around plant roots than are found in the rest of the soil. Microbes are important for recycling nutrients in the soil and SOM is an important storage vessel for these recycling nutrients.

How microbes break down active organic matter is related to the carbon to nitrogen (CN) ratio. *What do a cow's rumen, composting, and the soil all have in common?* They both rely on the CN ratio and microbes to breakdown organic (carbon based) material. Consider two separate feed sources, a young tender alfalfa plant and wheat straw. The young alfalfa plant has more crude protein and amino acids (high nitrogen) and sugars in the stalk so it has a lower CN ratio (less carbon, more nitrogen) and is good food for the microbes to digest whether it is in a cow's rumen, a compost pile, or the soil. However, wheat straw (or older mature hay) has more lignin, which is resistant to microbial decomposition, lower crude protein, and less sugars in the stalk and a higher CN (high carbon content, less nitrogen) ratio. Straw can be decomposed by microbes but it takes additional nitrogen to break down the high carbon source. For good composting, a CN ratio less then 20 allows the organic materials to decompose quickly while a CN ratio greater than 20 requires additional nitrogen and slows down decomposition. So if we add a high carbon based material with low nitrogen content to the soil, the microbes will tie up soil nitrogen. Eventually, the soil nitrogen is released, but in the short-term the nitrogen is tied up. The conversion factor for converting nitrogen to crude protein is 16.7 which relates back to why it is so important to have a CN ratio of less than 20. Microbes are using the carbon and the nitrogen to make amino acids and proteins for their cells. SOM has a C:N ratio of 10-12 which means that the nitrogen attached to the SOM particles is available to plant roots for uptake. That's why high SOM fields are more productive. See Diagram 5: Carbon to Nitrogen Ratio

Bacteria are the first microbes to digest new organic plant and animal residues in the soil. Bacteria typically can reproduce in 30 minutes and under the right conditions of heat, moisture, and a food source, they can reproduce very quickly. Mycorrhizal fungi live in the soil on the surface of or within plant roots. The fungi have a large surface area and help in the transport of mineral nutrients and water to the plants. The fungus life cycle can be somewhat complex and varies. Fungi are more specialized in their function and are not as hardy as bacteria and require a more constant source of food. Fungi population levels tend to decline with conventional tillage. Fungi have a higher carbon to nitrogen ratio (10:1 carbon to nitrogen or 10% nitrogen) but are more efficient at converting carbon to soil organic matter. With high C:N organic residues, bacteria and fungus take nitrogen out of the soil (see Graph 1: Nitrogen Immobilization and Minerlization with Rye Residues).

Protozoa and nematodes consume the bacteria and fungus. Protozoa can reproduce in 6-8 hours while nematodes take from 3 days to 3 years with an average of 30 days to reproduce. After the protozoa and nematodes consume the bacteria or other microbes (which are high in nitrogen), they release nitrogen in the form of ammonia. Ammonia and soil nitrates are easily converted back and forth in the soil. **Plants absorb the released ammonia and soil nitrates for food, but only after the microbes have satisfied their needs first.** That's why it is important to feed the microbes in the soil so that the corn crop can benefit from the nitrogen that is released. Even with low C:N ratio crop residues, the release of nitrogen may take four to eight weeks. High C:N ratio crop residues may tie up nitrogen for several weeks or months. Killing cover crops early when the C:N ratio is lower will assist in recycling nitrogen faster to the next crop.

Nitrogen Usage in No-till Corn versus Conventional Corn

If conventional tilled fields have so much less nitrogen in the soil, why does corn look so yellow and nitrogen deficient in beginning no-tilled soils? Why do farmers consistently see a 10-20% bushel corn yield lag when they convert from conventional to no-till corn? Long-term research shows that after 5-7 years of long-term no-till, the soil ecology starts to restore itself to normal functions. With tillage, we destroy SOM and burn up SOM, releasing nutrients which are often lost by runoff or leach out of the soil. The corn initially thrives on the excess nutrients that are released. But after several years of continuous tillage, SOM levels decrease and nutrient stores decrease. Fungi levels in the soil decline while bacteria start to dominate the system. Bacteria microbes thrive short-term until the nutrients and their food supplies disappear and then they decline also. Tillage also destroys the food web and nematodes and soil fauna die off as microbial levels decrease in the soil. Corn yields start to decline and the soil is harder to till (less fungus, less glomalin produced, less SOM, less soil life). The soil ecology is destroyed and it takes time to restore the balance.

First year no-till corn suffers from several sources of lost nitrogen. First, less nitrogen is being released by tilled crop residues. Second, microbial populations are starting to build as they decompose a more stable food base. The microbes are incorporating nitrogen into their cells as amino acids and proteins. Third, as they decompose the crop residues and turn it into SOM, it takes about 1,100 pounds of nitrogen for every 1% SOM or 110 pounds of nitrogen for every ton of SOM that is converted. In addition, if the soil is compacted in the plow layer, nitrogen may be lost by lack of air movement and saturated soils and this leads to denitrification of nitrogen to the atmosphere. In the first several years, no-till soils struggle to supply enough nitrogen to the microbes and plants and finally the corn crop until the soil equilibrium is restored. Depending upon conditions, it may take a continuous no-till soil 7-9 years or longer to recover from conventional tillage. Adding a winter cover crop can decrease this time to 2- 4 years because the cover crop ties up excess nutrients, thus keeping them from leaching or running off, supplies active organic matter (sugars and proteins for microbes), and promotes good soil aeration.

Consider what happens when a long-term, no-till soil with 4-6% SOM is plowed. SOM is oxidized but in the process soil nutrients are released (1100# N, 116*P2O5, 105#K2O, 145# SO4 for every 1% soil organic matter burned up). Long-term no-tillers say that the first couple of years when they are converting from conventional to long-term no-till, they use more fertilizer on their no-till fields. The microorganisms are using the inorganic fertilizer to decompose and process the corn organic residues into protein for their cells and to make SOM. The additional inorganic nitrogen improves soil fertility and is converted back into organic nitrogen stored in the SOM. Whenever corn is fertilized, the microbes feed first and then the corn plant gets what is left over. Understanding this process can help farmers improve nitrogen efficiency when they fertilize their crops. On first year no-till soils, nitrogen is needed earlier to assist in decomposition of organic residues. After several years of no-till, enough nitrogen is recycling in the system and nitrogen is not as limiting and that is when corn yields improve.

Nitrogen fertilization of corn is a relatively inefficient process with only 30-70% efficiency. In other words, on average, corn only recovers about 50% of the nitrogen, so an application of 150 pounds of nitrogen means only 75 pounds is actually being utilized by the corn crop. Most nitrogen and phosphorous is lost in the fall, winter, and early spring with agricultural runoff of excess water and soil erosion. In natural ecological systems, plants and microbes are actively growing and soaking up soil nutrients and recycling those nutrients and plants keep the soil covered to prevent soil erosion.

Using Winter Cover Crops and Manure to Convert to No-till

Winter cover crops supply food (active carbon like glucose and proteins) to the microbes to feed on. The microbes in turn build SOM and stores soil nutrients. Building SOM requires soil nutrients like N-P-K-S to be tied up organically in the soil. Cover crops may reduce the yield lag with no-till corn from 5-7 years to 2-3 years. Winter cover crops soak up excess soil nutrients and supply food to all the microbes in the soil during the winter months. In a conventional tilled field, soil nutrients are quickly released as crop residues are quickly decomposed and SOM is rapidly burned up and the microbes and soil habitat is destroyed. In a no-till field, high levels of SOM along with active plant roots are reserves of soil nutrients which are slowly release back into the soils. Adding a living cover crop to a no-till field increases active organic matter (sugars and proteins) for the microbes and microbes have two crops to feed on instead of one crop per year. Microbes thrive under no-till conditions and winter cover crops. Cover crops and manure can be used to feed soil microbes and once the microbes are fed, they slowly release nutrients back into the soil for future crops to grow. In addition, winter cover crop roots form macropores, which aerate the soil, and allows water to infiltrate the soil profile. The plants roots and microbes can remove nutrients from the soil water before it leaches away.

Using manure with cover crops is another way of storing nutrients organically in the soil. Annual ryegrass has a dense fibrous root system that has the potential to scavenger 300-700 pounds of nitrogen and 60-80 pound of phosphorous per acre. In Ohio research trials, the annual ryegrass tissue nitrogen content varied from 4.5-5.3% with 10,000 gallons of swine manure applied. With 4.5 tons of biomass produced (above and below ground), that was equivalent to 450 pounds of nitrogen. Cereal rye had 3.5-4.0% nitrogen levels and around 400 pounds of nitrogen associated with the leaves and roots. Manure is a good source of organic nitrogen but the release and recycling of nitrogen in the manure is affected by the C:N ratio. Manure with straw, sawdust, or fibrous manure (dairy manure) may be slowly released and may even tie up nitrogen for several weeks or months if the C:N ratio is high.

Water Quality Benefits of Cover Crops

Cover crops decrease soil erosion by 90%, decrease sediment transport by 75%, reduce pathogen loads by 60%, and reduce nutrient and pesticide loads by 50% to our streams, rivers, and lakes. As the price of fuel and fertilizer increases, planting cover crops becomes more and more economical as a way to build SOM and store nutrients in the soil.

Is the government investing money on ineffective soil erosion infrastructure? Currently, farmers are paying an average of about $9 per ton of sediment saved from soil erosion with the average conservation practices. The total cost of the conservation reserve program (CRP) is about $23 per ton of sediment saved. Sediment retention structures ($50/ton of sediment) and diversions ($18/ton) are expensive for the amount of soil sediment that is saved. Even using sod waterways ($13.50/ton), windbreaks ($12 per ton), and permanent covers ($7/ton of sediment saved) are relatively expensive soil conservation practices. The two most effective practices and the most cost effective are long-term no-till farming ($3 per ton of sediment saved) and using cover crops ($2 per ton of sediment saved) (see Table 2: Cost Effectiveness of BMP's at Reducing Sedimentation Losses from Cropland).

Riparian buffers work reasonably well when small rains occur and in small areas where shallow water concentrates and flows to bodies of water. However, the most severe erosion and sediment losses occur during heavy rainfall events during the dormant season when few crops are growing. During a large rainfall event; buffers do not work effectively because large amounts of deep water are flowing over the buffer and they cannot slow down the flow of water. A recent Toledo study estimated that 75-86% of the nutrients and sediment to streams were coming from headland areas, in areas located far inland from rivers and streams. Buffers only help with smaller rainfall events on about 14-25% of the land located near a flowing water body. The majority of our land (75-86%) is located in headlands away from streams and rivers. The ultimate goal should be to treat every drop of water where it falls rather than waiting until it accumulates, gathers energy, and carries off topsoil and nutrients. As the velocity of running water doubles, the nutrient and sediment carrying capacity of the runoff increases 64 times. Long-term no-till farming and growing winter cover crops reduces runoff, increases soil infiltration and slows down the velocity of water. The problem is that these practices (no-till and cover crops) need to be continuously applied every year to make agriculture sustainable.

Soil erosion is a problem even on flat crop fields. In December 2006, a 2.5-inch rain occurred with frozen soil, preventing water infiltration. Farm fields were flooded and the ditches, streams, and rivers were overflowing. Tilled, no-tilled, and no-tilled fields plus a grass winter cover crop were examined. On the tilled soil, sheet erosion was evident on fields with 0-2% slope. On no-till fields, patches of organic matter and crop residue had floated off and was being deposited about 2-4 inches deep along the road ditch or in the low areas OR in the first few feet of the no-till plus grass winter cover crop. On the grass winter cover crop strips, with only 1-2 inches of growth, the crop residue and the topsoil was intact. In addition, none of the wheat fields or cover crops had standing water while the tilled fields had water standing. The active cover crop plant roots allowed the water to infiltrate the partially frozen soil profile rather than runoff.

Building SOM may also aid in preventing flooding and excess runoff. One pound of organic matter holds 18-20 pounds of water in the soil or about 2.25 gallons of water. Assuming 50% initial soil saturation, a soil with 2% SOM can hold about 1.7 inches of additional rainfall compared to a 4% SOM field (long-term no-till), which can hold 3.4 inches of additional rainfall. A-25 year, 24-hour storm is around 4.4 inches. Cover crops, growing vegetation, and long-term no-till farming reduce flooding by keeping water in the soil profile and slowly releasing the water to the nearby ditches and streams. In addition, these practices allow deep percolation and recharge to our groundwater. Cover crops with no-till can supply a more constant supply of water (stream base flow) to rivers and streams, which supports aquatic growth and wildlife.

Summary

Nutrient recycling in conventional tilled soils is different than nutrient recycling in healthy long-term no-till fields. Bacteria dominate in conventionally tilled fields and they are less efficient (20-30% carbon efficiency) at converting carbon to SOM. In long-term no-till soils, the soil microbes and soil life is more diverse and fungus play a larger role in nutrient recycling. Fungi have a 40-55% carbon use efficiency and create more SOM. SOM is important for storing nitrogen and soil nutrients in the soil. Every 1% SOM level in the soil holds 1,100 pounds of nitrogen. Planting grass winter cover crops provides another source of food for microorganisms in the soil and increases water infiltration, preventing runoff and leaching of soil nutrients. As the price of fuel and fertilizer increases, planting cover crops and long-term continuous no-till becomes more and more economical as a way to build SOM and store nutrients in the soil. Land management practices on tillage and the crops grown have a big impact on the quality of our water resources. Tilling the soil is not a natural system and wastes soil nutrients due to decreases in SOM (the storage vessels for nutrients), no active roots, and lower microbial populations. In natural ecological systems, plants and microbes are actively growing and soaking up soil nutrients and recycling those nutrients and plants keep the soil covered to prevent soil erosion.

Diagram 1: Photosynthesis

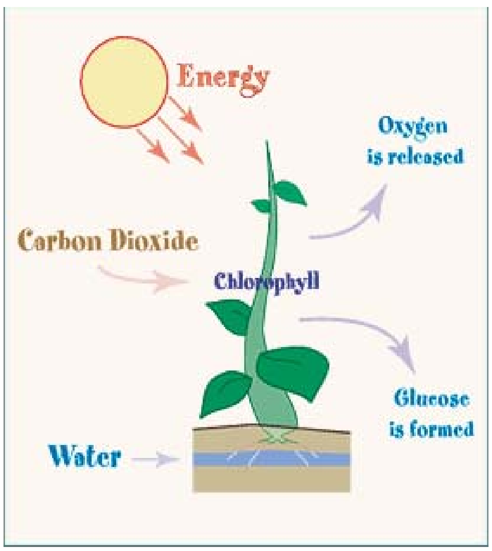


Diagram 2: Carbon Recycling

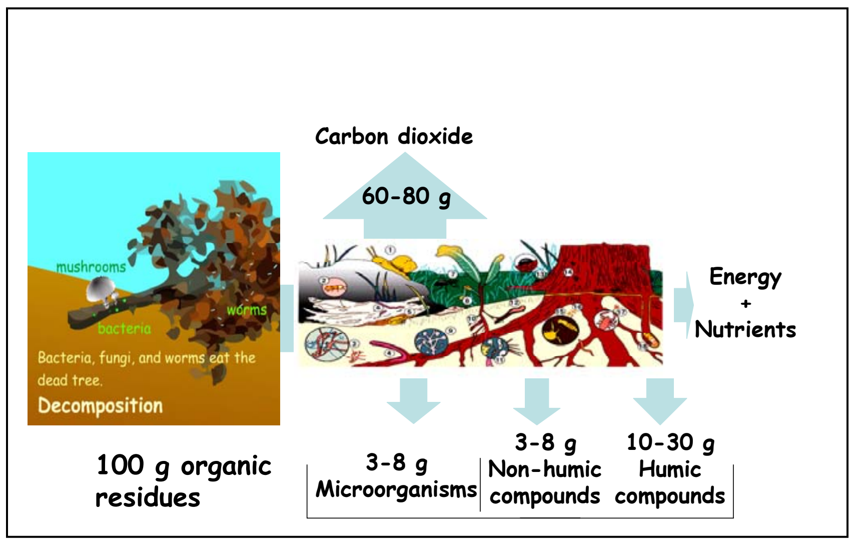
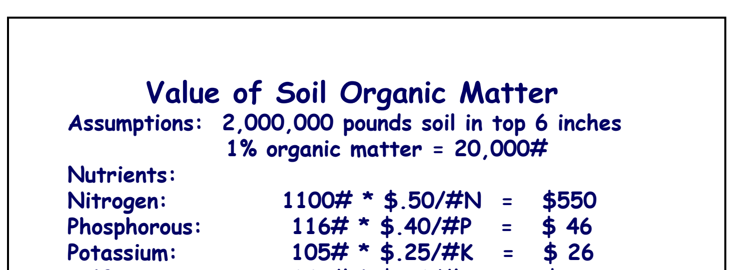


Diagram 3: Soil Organic Matter Losses with Tillage

Table 1: Nutrient Value of Soil Organic Matter


Value of Soil Organic Matter

Assumptions: 2,000,000 pounds soil in top 6 inches
1% organic matter = 20,000#

Nutrients:

Nitrogen:	1100# * $.50/#N	=	$550
Phosphorous:	116# * $.40/#P	=	$ 46
Potassium:	105# * $.25/#K	=	$ 26

Diagram 4: Mycorrhizal Fungus
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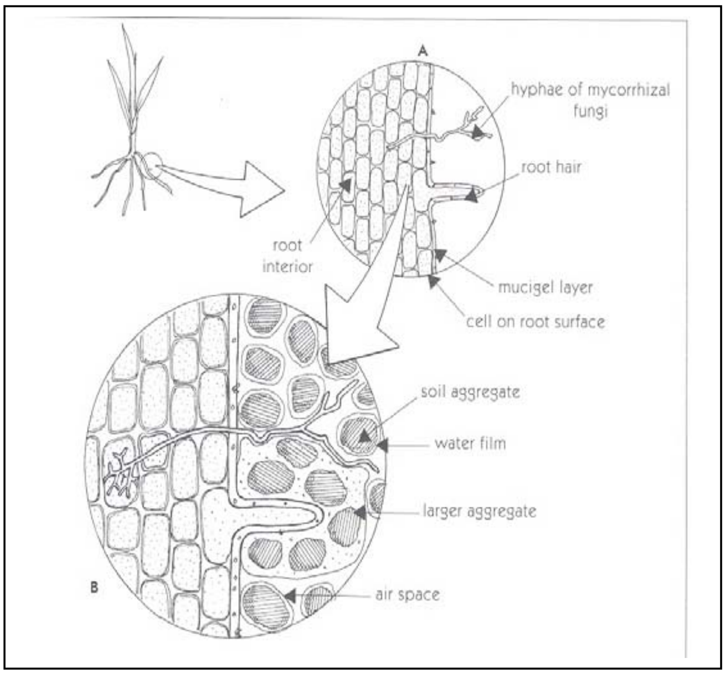
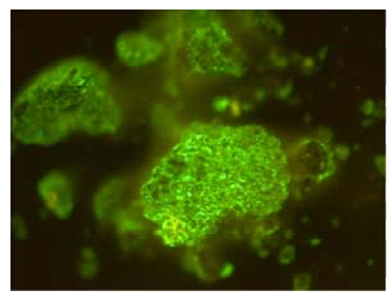


Picture 1: Glomalin Coating Soil Aggregate



Sticky substance, glomalin, surrounding soil aggregates.

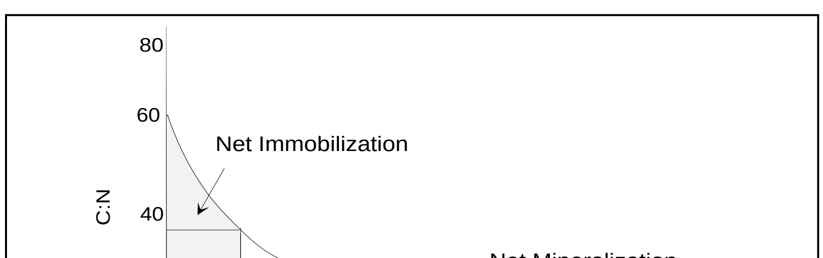
Photo by Sara Wright

Diagram 5: Carbon to Nitrogen (C:N) Ratio

C:N Ratio of Organic Organic Matter

As a rule of thumb:
At C:N >20:1, NH_4^+ is immobilized (tied up)
At C:N < 20:1, NH_4^+ is mineralized (released)

Graph 1: Net Immobilization and Net Mineralization of Rye residue



Bacteria and Fungus Protozoa and Nematodes

Table 2: Cost Effectiveness of BMPs at Reducing Sedimentation Losses from Cropland

Cost Effectiveness of BMP'S

BMP	$/Ton of Sediment	BMP	$/Ton of Sediment
Cover Crops	$1.99	Diversions	$18.10
No-till	$2.99	Sediment Retention	$50.21
Permanent Cover	$6.95	Average Cost	$8.71
Wind break	$12.10	CRP Program	$22.95
Sod water way	$13.50		