E-BOOK

THE COST-SAVING SECRETS OF SOIL HEALTH

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Soil Organic Matter: Its Functions and Value

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SUMMARY

- The soil organic matter pool is a large source of the world's carbon
- The cycling of organic matter is a continuous and dynamic process and additions of new organic residues are required to maintain organic matter levels
- Different fractions of organic matter behave differently in what they do and how quickly they can rise or fall
- Small changes in the percent organic matter can greatly affect soil properties
- Increasing soil organic matter generally has positive impacts on soil fertility, water movement and other soil properties.

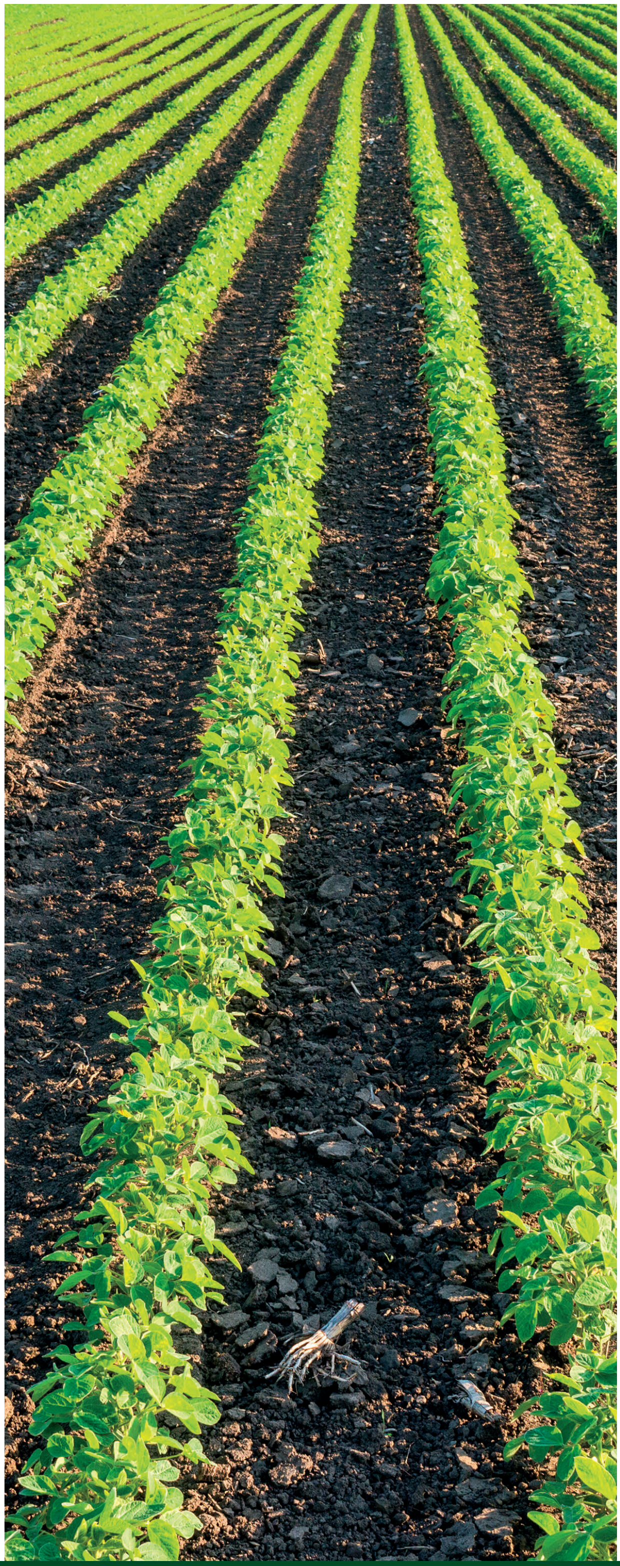
Organic matter is a driver of many important soil processes and many farmers are managing their farms with the goal of increasing organic matter. While most recognize that organic matter is a key driver of a healthy soil, how it is formed and its value is much more nuanced. Therefore, an understanding of its function is important in managing soils to their fullest potential.

Our World's Supply of Soil Organic Carbon

The total amount of carbon stored in the world's soils is estimated at approximately 2.5 trillion metric tons, twice that present in the earth's vegetation and atmosphere combined (Lal, 2004). The carbon storage abilities of the world's soils is a double-edged sword; an estimate of soil carbon lost since 1850 is 78 billion metric tons, and on average the world's soils are continuing to lose carbon (Lal, 2007). However, the potential storage capacity of the world's soils is estimated to be as high as 52 billion metric tons, meaning that there is great opportunity to sequester atmospheric carbon with our soils.

Soils are continuously turning over organic matter, resulting in the release of nutrients and carbon dioxide. This release of carbon dioxide is not inherently bad, as carbon dioxide is a necessary input for photosynthesizing plants. And when soils are left in an un-disturbed state, the amount of carbon dioxide liberated by soils typically achieves a steady-state with the amount sequestered through the addition of organic matter. It is through the disturbance of soils that the release of carbon can exceed the gains therein.

The rate at which soils gain or lose organic matter is affected by climatic conditions on both global and local scales. In each scenario, there two factors at work; those influencing the growth of plants (organic matter addition) and those influencing organic matter retention. If an area can produce plant residues faster than it can be broken down, organic matter will increase. Globally, soil organic matter accumulates fastest in cool, wet environments and is lost the quickest in hot, dry environments. One can easily visualize this when thinking of the deserts of the southwest United States vs the Northern Great Plains in eastern North Dakota or Minnesota. On a more local scale, the same effect applies. Soils that tend to be drier, shallower and have lower productivity (the tops of hills for instance) tend to accumulate organic matter slower than those in lower landscape positions that are wetter, deeper and support greater plant production.



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Organic Matter Composition and Processes

Soil organic matter is comprised of many different parts that we can roughly place into four different categories; living microorganisms, fresh residue, active (quickly degrading) carbon sources and passive (slowly degrading) carbon sources. The active and passive fractions typically comprise 1/3 to ½ of a soils total organic matter pool. The passive fraction consists slowly-degrading materials such as humic substances that are extremely stable and may remain in a soil for hundreds or thousands of years. These substances account for much of the organic matter influence on cation exchange capacity, or the ability to hold on to nutrients in the soil solution, and soil water retention capacity. Passive organic matter also includes slowly-degradable material, including the fiber tissues of cellulose and lignin, along with fats, waxes and phenolic compounds that may take decades to break down and these substances can account for much of the mineralizable nitrogen in a soil

At the other end of the organic matter spectrum, there is the quickly decomposing active fraction. Active organic matter is comprised of easily-decomposable plant root exudates and acids and decaying simple organisms, such as bacteria and may last from months to a few years. This fraction includes glomalin, a exudate produced by mycorrhizal fungi that cements soil particles together, forming aggregates, which ultimately affect many of the positive soil properties associated with soil health (Comis, 2002). Materials like and including glomalin are some of our least understood and historically underestimated components of organic matter; it has only been within the past few decades that scientists have identified and began to study these materials.

The ephemeral nature of active organic matter means that it is highly responsive to changes in land management. Because active organic matter is only a slice of the total organic matter pie, yet it is responsible for so much function, increasing the size of that slice, which may not increase your total organic matter by a large amount, can have big effects on the health and function of your soils. The other part of this means that one needs to continuously add to, and prevent the loss of, this quickly eroding pool of material.

The loss of organic matter in agricultural systems is typically an oxidation process, which is often accelerated through tillage. When compared to natural soil processes, tillage is a fast, violet event that rapidly changes soil physical and biological properties. First, the tillage process physically breaks down soil aggregates and destroys pore networks, reducing water flow and retention and making soils more susceptible to compaction. Second, tillage disrupts beneficial soil organisms such as earthworms and beneficial fungi. Finally, the rapid aeration of the soil speeds up the microbial processes that consume organic matter, rapidly converting soil carbon into carbon dioxide. Therefore, one of the most straightforward means of stemming the loss of soil carbon is to reduce or eliminate tillage.

While tillage slows the loss of soil carbon, it does not necessarily add more to a soil system. This is primarily accomplished by adding organic feedstocks for soil microbes to covert to organic matter. This includes physical additions, such as manure, but also the additions of above and below-ground plant residues.

In managing cash crops, this means maximizing plant growth through optimum fertility, although excessive fertility can have the reverse effects as it can speed up the process of organic matter oxidation. This also achieved by providing actively growing plant roots throughout the year, typically through cover crops. For instance, over 3,000 lbs. of root mass per acres can be added to a soil through a cover crop in a single year (Sievers, 2018). What is important to remember is that if you're not adding organic matter, you're losing it, as the natural process of oxidation slowly chips away at organic matter reserves.

What is the Value of Organic Matter?

While organic matter typically comprises a small amount of the soil (typically 2-5%), it drives many critical soil properties and functions. While some benefits of increased organic matter, such as increased nitrogen are more objective, other aspects, such as increased compaction resistance tend to be more subjective. When determining the value of organic matter, it may be best weigh both aspects, as it affects farm productivity and the broader agricultural ecosystem in many different ways.

Soil Macronutrient Contributions

In a 2-million-pound acre furrow slice of soil, each 1% of organic matter equates to 20,000 lbs. of material. A soil will turn over approximately 2% of its organic matter annually, so for every 1% of organic matter, approximately 400 lbs. of organic matter is cycled annually. Soil organic matter contains nitrogen, phosphorus, sulfur and other trace elements. In a healthy functioning soil, the total amounts released will vary based on soil conditions, with a general range noted in table 1.

Element	1%	2%	3%	4%	5%
N	10-20	20-40	30-60	40-80	50-100
P	1-2	2-4	3-6	4-8	5-10
S	0.4-0.8	0.8-1.6	1.2-2.4	1.6-3.2	2.0-4.0

Table 1: Annual nutrient release of nutrients (in lbs. per acre) at 1-5% soil organic matter.

As the table shows, as organic matter climbs the amount of available nitrogen can be rather meaningful in one's nutrient management plan. While the nitrogen release from organic matter oxidation is more of a "slow burn," release picks up as temperatures warm, often coinciding with the summer crop growth cycle. Depending on specific crop fertility timing needs, organic matter contributions may not replace supplemental fertilizer one-for-one, but when used with adaptive nutrient management practices such as nitrogen estimation tools, pre-sidedress testing or chlorophyll meter monitoring, sizable reductions in applied nitrogen can be had.

Micronutrient chelation and plant growth stimulation

In addition to the nutrients released by organic matter, the presence itself of organic matter can affect plant production. Humic acids can stimulate plant growth and root development, in some plants including corn and soybeans (Tan, 1979; Tan, 1983). Humic acids also chelate, or bind nutrients such as iron, copper, zinc and manganese into stable complexes that more easily accessed by plants.

Increase in CEC and buffering of pH

As organic matter takes on a more stabilized form, it gains an ability to hold onto plant nutrients, increasing the cation exchange capacity (CEC) of a soil. This is especially important in sandier soils, with low inherent CEC, where nutrients are quickly leached. An increase of CEC in those soils can ultimately result in more plant-available nutrients, greater flexibility in nutrient application or fewer nutrients applied. Organic matter also binds hydrogen ions, ultimately buffering against the acidification of soil.

Improved soil-water properties

Soil-water processes often start with water droplets contacting the soil typically through rainfall or irrigation. Although we often perceive rainfall and irrigation as a gentle process, this can be a violent action at microscopic scale, with a tiny explosion from each raindrop detaching soil particles and initiating the process of soil erosion. Exposed surfaces are also prone to crust formation, which greatly impacts infiltration rates, even when the soil below is well aggregated with lots of macropores. Surface residues absorb the impact of precipitation and the labyrinth of residue that a water droplet follows to reach the soil surface attenuates quick bursts of rainfall, ultimately making a field less “flashy” and allowing more water to infiltrate.

Once water enters the soil profile, soil pores begin to fill. However, if those pores are too small and poorly connected, they may remain filled for too long and oxygen becomes limited, stunting plant growth and allowing anaerobic bacteria to convert soil nitrate to nitrogen gas through the process of denitrification. Additionally, smaller soil pores hold onto water so tightly that plants cannot access it, even though it may be present in the soil. Organic matter and the practices that increase soil organic matter, such as reduced/no-tillage and

cover crops, promote the formation of macropores that hold soil water yet drain quickly enough to allow oxygen to enter the soil profile. Finally, the sponge-like nature of organic matter help to retain and provide more plant-available water, as its ability to hold soil water is much higher than that of the mineral particles that comprise the bulk soil.

What does this mean in the context of water management? First, organic matter generally increases the total infiltration from a rainfall or irrigation event, through the ability to infiltrate quick bursts of rainfall and the ability to infiltrate more across a storm event. Second, organic matter aids in the aggregation processes that create larger pores that hold more water and allow for more water to be available to plants. Finally, those same pores drain easier, returning soils more quickly to the “ideal” balance of air and water necessary for optimum root and plant growth.

Compaction resistance

The aggregation of particles with the help of organic compounds such as glomalin also aids in resisting soil compaction. As greater amounts of soil glue are exuded by arbuscular mycorrhizal fungi, aggregates are strengthened and are less likely to rupture under the forces of compaction. This ultimately results in improved plant growth and reduced rutting in the field or the ability to perform fieldwork sooner while still maintaining a desirable level of tilth suitable for no-tilling and germinating seedlings.

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What does it all mean?

While placing a value on organic matter can be subjective at times, any action to increase it will ultimately bring a benefit. Values of fertility will fluctuate with fertilizer prices and the value of additional water or resilience to extreme weather events will likely vary given the year. However, the outcomes, such as needing to irrigate less, or increased yield due to lower plant moisture stress are certainly real and often consistent. Additionally, the soil structural effects are real, and their savings may be as straightforward as additional yield due to better root growth due or more nuanced, such as in the savings of fuel, equipment hours and manpower necessary to mechanically remediate compaction. It's ultimately up to each individual farmer to determine how much this is all worth, but for those that see the big picture of soil carbon, there is great value in trying to build more year after year.

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Benefits of Mycorrhizae Fungi

SUMMARY

Mycorrhizae fungi can help:

- Nourish crops with water and nutrients.
- Build soil structure.
- Protect the plant from drought and other stresses.

Mycorrhizae are a collection of many species of symbiotic or beneficial soil-borne fungi that help nourish a host plant. In concert with the host plant's roots, the fungi produce very fine threads (hyphae) that can be 100 times longer than the roots of the host (Figure 1). (1) The hyphae serve as an extension of the plant's root system and can penetrate deeper into the soil profile for nutrients and water. The symbiotic relationship occurs when the host plant supplies the fungus with energy produced by photosynthesis and the fungus supplies the plant with water and nutrients. (2)

The fungi may grow outside (ecto) or within (endo) the roots of the host. An ectomycorrhizae fungus develops a root-surrounding sheath that produces hyphae that grow into the root and out into the soil.2 An endomycorrhizae fungus is sheath-less and has hyphae that grow within the cells and out into the soil.2 Endomycorrhizae fungi are more common than ectomycorrhizae. (2)

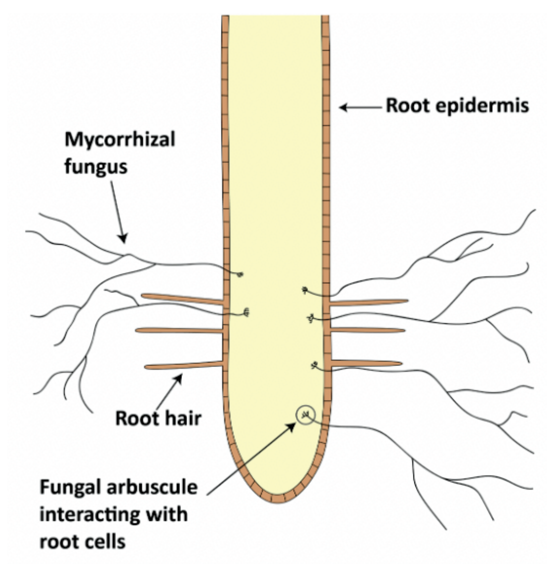

Figure 1. Graphic of a plant root with mycorrhizae fungus hyphae.

Most agricultural plants, including corn and soybean, grow in the presence of vesicular-arbuscular mycorrhizae (VAM), which are endomycorrhizae fungi. Soils that are absent of or have reduced populations of VAM can result in the development of crop nutrient deficiency symptoms, especially for immobile nutrients such as phosphorus (P). The soil may have adequate levels of P, but it is unavailable to the crop without VAM support. Reduced VAM populations can occur when fields are flooded or have been in continuous production of non-supporting crops such as those in the brassica genus (canola, cabbage, broccoli, and others) and sugar beets. Practices that help maintain a healthy mycorrhizae population include no-till, use of cover crops, and planting crops that support mycorrhizae. Seed treatments such as BioRise® Corn Offering can help enhance mycorrhizal colonization.

The mycorrhizae can support the host plant physically and chemically. Physically, the mass of VAM hyphae increases the physical surface area that is available for water and nutrient absorption. The hyphae are smaller in diameter compared to root hairs and can grow through soil pores that are inaccessible to plant roots. The expanded reach of VAM hyphae can help reduce crop stress during drought by finding water at greater soil depths. Chemically, VAM cells excrete various organic acids that dissolve minerals in the soil rhizosphere making them available to the plant. Research has shown that the hyphae can help break down rock, which can increase the availability of nutrients such as potassium, calcium, zinc, and magnesium.(2) Additionally, some VAM chemical excretions are toxic to soil pathogens, such as nematodes, and others can help provide protection to plants grown in soils with high concentrations of salt and toxic metals. Mycorrhizae fungi also help build and maintain soil structure. Soil aggregates are held together by the hyphae growing among the aggregates and by producing a hydrophobic glycoprotein (glomalin) that acts as a glue to bind aggregates together.(3)

Sources:
1 Ellis, J.R. 1998. Post flood syndrome and vesicular-arbuscular mycorrhizal fungi. Journal of Production Agriculture. Vol. 11, no.
2: 200-204.2 O'Callaghan, A.M. Mycorrhizae. Fact Sheet 01-29. University of Nevada Cooperative Extension.
3 Miller, R.M. and Jastrow, J.D. 2000. Mycorrhizal fungi influence soil structure. Chapter 1. Environmental Research Division, Argonne National Laboratory, Argonne, Illinois.

Effects of Tillage Systems in Corn and Soybean Production

Trial Objective

- When it comes to tillage, several factors are considered in the decision-making process including weed and pest management, soil and water conservation, and time and input costs.
- Today, farmers have access to an array of tillage options, ranging from conventional tillage to minimum tillage to no-till. Farm operations deploy different tillage types to meet the productivity and sustainability requirements of each piece of land. It is necessary to periodically evaluate the continued suitability of tillage systems for any piece of land.
- The objective of this trial was to evaluate the productivity of three tillage systems in both corn and soybean operations.

Research Site Details:

Location	Soil Type	Previous Crop	Tillage Type	Planting Date	Harvest Date	Potential Yield (bu/acre)	Planting Rate (seeds/acre)
Huxley, IA	Clay loam	Soybean	Conventional, Strip tillage, No-till	5/9/18, 5/16/19	9/27/18, 10/30/19	220	34K
Huxley, IA	Clay loam	Corn	Conventional, Strip tillage, No-till	5/17/18, 5/16/19	9/27/18, 10/9/19	60	140K

Trial Objective

- The trial was carried out in 2018 and 2019.
- In 2018, a 112 relative maturity (RM) VT Double PRO® RIB Complete® corn product and a 2.4 maturity group (MG) soybean variety were used for the trial.
- In 2019, a 112 RM SmartStax® RIB Complete® corn product and a 2.2 MG soybean variety were used for the trial.
- In both years and in both crops, the trials were carried out in 15 x 500 ft plots with 30-inch spacing and 6 replications.
- Conventional tillage consisted of a chisel plow followed by a soil finisher. The chisel plow consisted of a two-gang disk unit followed by ripping shanks that went about 18 inches deep, followed by a set of chisels to smooth out the soil surface and incorporate residue. The soil finisher unit was comprised of a disk gang, a cultivator, and tine harrow units.
- Strip tillage was carried out in conjunction with liquid nitrogen application. The strip bar unit consisted of a no-till coulter in the front, followed by a liquid nitrogen knife, followed by a Vulcan strip-till unit comprised of row cleaners, no-till coulters that penetrated 2 to 3 inches deep and 7 inches wide, and a rolling basket to break any large soil clumps and smooth the soil surface for planting.
- All tillage operations were carried out in the spring.
- Weed management and the amount of nitrogen applied were the same in all tillage systems.

Understanding the Results

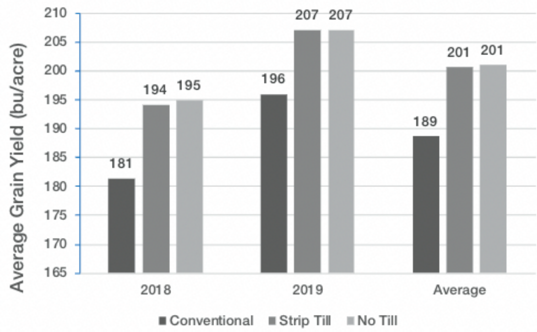

Figure 1. Corn yield response to three tillage systems over a two-year period in central Iowa.

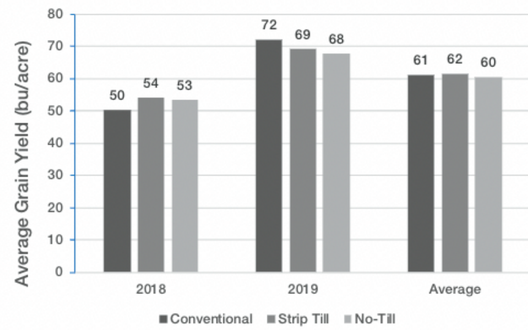

Figure 2. Soybean yield response to three tillage systems over a two-year period in central Iowa.

- Yields were generally higher in 2019 than in 2018 in both crops.
- In corn, yield was lowest for conventional tillage but nearly the same for strip tillage and no-till in both years (Figure 1).
- In soybean, yields were nearly the same for strip tillage and no-till in both years. While conventional tillage produced the lowest yield in 2018, it yielded the highest in 2019. On average, however, there wasn't much difference between the three systems over the two-year period (Figure 2).

Key Learnings

- Crop yield response to tillage can be widely variable and site-specific, often impacted by environmental factors, soil type and drainage, and the cropping sequence. Thus, it requires multiple years of research to truly determine the productivity of tillage systems.
- This trial suggests that the type of tillage system is not a major factor in soybean production at the trial location. To save on production costs, however, no-till could be recommended if an efficient weed management strategy (such as chemical control) is available. In corn, strip tillage and no-till yielded 12 bu/acre better than conventional tillage over the two-year period, also suggesting that conventional tillage could be eliminated if an effective weed management strategy is available.
- Irrespective of the crop chosen, the right tillage type should be the one that provides the best economic returns while still ensuring better environmental stewardship.

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What is ForGround?

ForGround by Bayer is a farmer-first digital platform that supports farmers in benefiting from regenerative agriculture practices. The program offers exclusive access to tools, resources and discounts as well as the potential to earn revenue through the Bayer Carbon Program for the adoption of regenerative practices.

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