Soil Health, Tillage and Compaction

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Healthy soil is the foundation of sustainable crop produection. It is the result of a combination of factors. While this presentation will focus mostly on how tillage affects soil health I first want to briefly go over the "bigger picture" of soil health.

A key concept for managing soil health is recognizing the interaction between the biological, chemical, and physical aspects of soil. **Biologically** healthy soil has low pest populations, or the ability to suppress pests, and is fully functional with respect to nutrient cycling and producing plant growth promoting compounds. From the **chemical** perspective, healthy soil has adequate levels of available nutrients, but not so high that there will be a lot of leaching; an optimal pH for the planned crop rotation; and low levels of toxic or disruptive substances such as heavy metals, aluminum, or salts. The **physical** characteristics of healthy soil include good tilth, water infiltration, aeration, and water retention.

The biological, chemical and physical properties mutually influence each other, and if we ignore one, the other will be affected. For example, aggregation of soil particles is influenced by the types of cations (e.g. Ca, Mg, K) and amount of organic matter present in the soil. The types of organisms present can be influenced by compaction and availability of food sources, and soil drainage influences the amount of nitrogen available to plants because saturated soil can lose nitrogen through denitrification, and well drained soil can lose nitrogen through leaching. In the past decades, agriculture has too much focused on the chemical aspects of soils and insufficient attention has been given to the physical and biological (especially) functions.

The key management approaches that can positively influence soil health are organic matter additions, reduced tillage, and compaction prevention. Adding organic matter to the soil increases biological activity and diversity, which in turn releases plant-available nutrients and holds them in the soil, increases soil aggregation, pore structure, and tilth, produces humus and other plant growth promoting substances, and reduces soil-borne diseases and parasitic nematodes (Fig. 1). At least one long term cropping experiment has shown a yield increases related to increasing organic matter levels, especially in dry years when higher organic matter levels can improve water retention.

Now we'll move on to tillage. One question we can ask ourselves is why we till in the first place. The plow, which was invented in the England in the mid-1700's, revolutionized agriculture. It provided unprecedented control of weeds, allowed for a more stable food supply, and was a critical tool in the development of virgin lands in North America. Plowing the soil incorporates residue from the previous crop, weeds, and amendments. It's the first step in seedbed preparation, increases the conversion of organic matter to plant-available nutrients, and reduces compaction, at least temporarily. So, the first experience with the plow was very positive, mainly because the destructive qualities didn't manifest themselves until after several decades.

In that respect, it is interesting to study the contributions of the eighteenth-century English agriculturalist Jethro Tull. Tull made an everlasting contribution to the worlds by inventing the seed drill, as he recognized that good seed placement improved germination and plant population over the conventional broadcast seeding (of small grains). Now, we recognize that the mechanical seeder is an essential agricultural tool, especially for conservation farming because no-till planters allow us to place seeds with very minimal tillage. Tull, however, also appears to have done an unintentional disservice to the land. He believed that plant roots absorbed nutrients as tiny soil particles (rather than as ions as was established in the following century). He therefore tilled his soils over and again to pulverize the it. Sure enough, he was able to feed his crops for many years without the use of manure or other forms of fertilizer. But what was he doing? He oxidized the soil organic matter and released nutrients for his crops. In time, however, he mined the soil of its nutrients and food source for soil organisms. In the long run this is not sustainable, and we have seen similar problems with modern farming methods. One interesting lesson learned from Tull's work is that short-term research does not always provide the right picture.

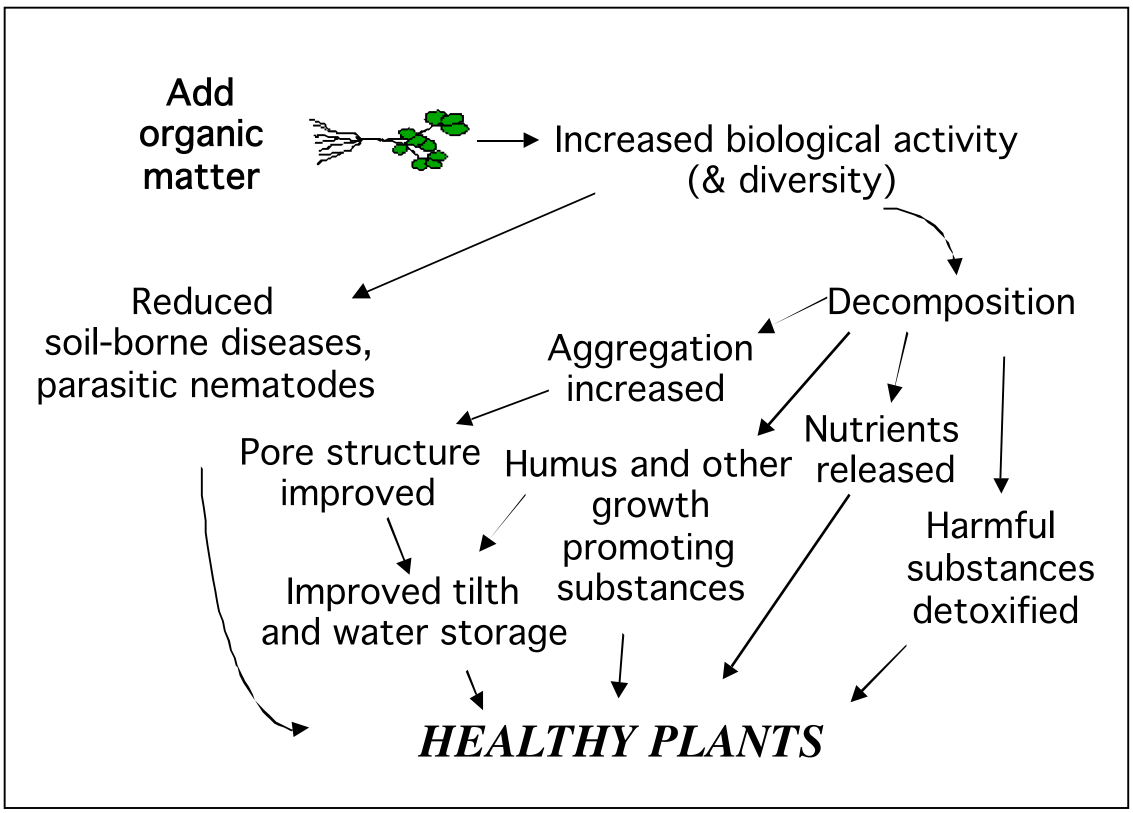

Fig. 1. Why adding organic matter benefits soils.

There are also other negative aspects of plowing. It uses a large amount of energy, and repeated plowing destroys soil aggregates, which increases compaction and the potential for crusting, resulting in low water infiltration, increased erosion, and the development of a zone of low microbial activity near the soil surface. Intensive soil tillage exposes the soil to the elements and causes temperature and heat extremes near the surface, creating an environment that is uninhabitable for soil organisms. In that respect, we need to start changing our somewhat romantic image of clean tillage, which we often associate with goodness and tradition. What could be better than a beautiful, aromatic freshly-plowed field? In fact, we are actually doing something very unnatural, because soil is not naturally exposed to the elements and we are creating an ecologically unfavorable soil environment. A field covered with residues may not have the aesthetics of a plowed field, but it is a lot more ecologically compatible. Farm ugly, as they say. Another factor associated with increased soil degradation is driving heavy farm equipment on a field. The weight of heavy equipment is concentrated in a small area underneath the tires, and can certainly increase soil compaction, especially if the soil is wet. The level of compaction is greater and extends deeper into the soil when it's wet than when it's dry, reminding us of the importance of staying off fields when the soil is wet.

The notions of water availability and compaction are brought together in the concept of the "optimum water range". Highly compacted soil has a smaller optimum water range than a well-structured soil. (Fig. 2). During wet periods, compacted soils experience prolonged water saturation and aeration problems, because they do not have the large pores that readily drain and allow air into it. When the soil dries, compacted soils more readily experience drought stress, which is actually caused by hard soil not allowing for root penetration. So crops growing on compacted soil are "happy" only when the moisture conditions are "average". During prolonged dry or wet periods, however, the plants quickly become stressed and have decreased yield or quality. A well-structured soil will not show drought or aeration problems unless the conditions are very extreme.

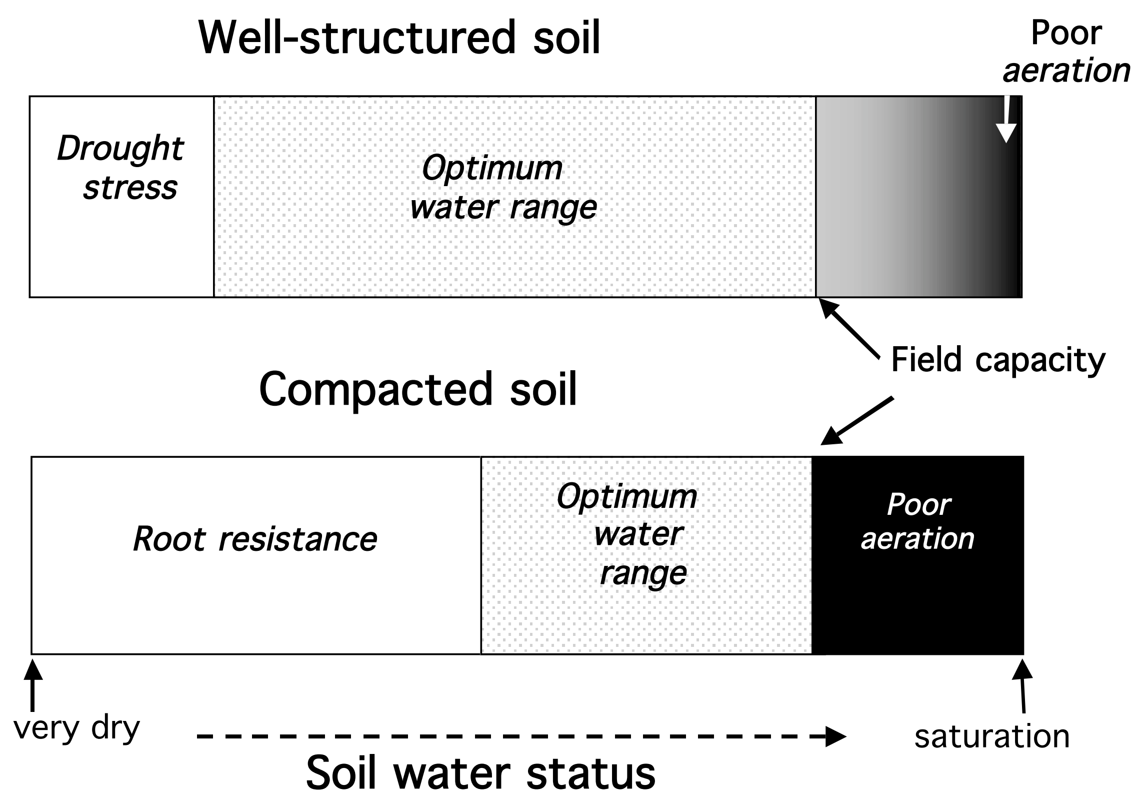

Fig. 2. The optimum water range explains the effects of compaction on plant growth

So how do we improve soil health? First, we have to recognize that some soils have become "addicted" to tillage. Depletion of organic matter over time has resulted in soils that are so compacted that multiple passes are needed to break up clods to create a good seedbed. The relief is only temporary, however, as these soils usually settle back down and form crusts after the first good rain, inhibiting seedling emergence and root growth. What can we do to remediate such soils or prevent them from occurring in the first place?

Building Healthy Soils

In general, the following practices will help build soils:

1) Organic Matter Management
   - Add organic matter to the soil regularly. Use different types of organic materials.
   - Use different sources of organic materials
   - Reduce organic matter losses
   - Keep soil surface covered with living vegetation as much as possible
2) Improved tillage
   - Minimize tillage intensity
   - Optimize timing
   - Maximize surface cover
3) Minimize soil compaction
   - No traffic on wet soils (by far most important)
   - Minimize soil loading by reducing equipment weight and spreading the load with multiple axles and large tires
   - Use controlled traffic lanes, and take advantage of ridges and beds

Reducing tillage results in many changes in the soil including higher carbon (organic matter) levels, better structure, better water availability, more biological activity, and reduced erosion. Other changes to keep in mind are that soils may also stay cool later in the spring, nutrients may become stratified (higher levels near the surface) because they are not being mixed into the soil profile, and the pH of the surface soil will change more rapidly after applications of lime because the lime is not being mixed with a larger amount of soil.

There is a range of options for reduced tillage, including no-till, strip till, ridge till, and zone till. The cooler soils associated with no-till can be a challenge in the Northeast. Strip, zone, and ridge till are adaptations of no-till that can overcome some of the cool soil problems. The narrow tilled zone warms up faster due to the removal of a small amount of residue, and is loosened and aerated, creating more favorable conditions for germination and growth. My research program has shown that no till is most successful when used with crop rotations rather than in monoculture. Also, we found that using ridges or beds, which force controlled traffic, are very attractive for our climate conditions, especially on medium and fine-textured soils. No-tillage is generally very successful on sandy and gravelly soils, which have lees compaction problems and are more drought sensitive.

We have learned that a good no-till seeder is a critical piece of equipment, because it allows for good seed placement under a range of conditions. Many times, farmers perform intensive tillage just to create a seedbed, while fine tilth is only needed in the soil immediately surrounding the seed. With a no-till or zone-till planter, tillage options are much more flexible. If serious cover cropping is part of the management of the farm, a no-till drill is essential. There should be no tillage prior to cover crop seeding, because that mostly negates its benefits.

Recent studies conducted in Michigan and New York suggest that even when cover crops or manure are used in a rotation, soil organic matter levels don't increase when a moldboard plow is used for tillage. Tillage practices such as no-till, zone-till, strip-till, and ridge-till do result in an increase in organic matter, even when cover crops are not used. In other words, the less the soil is disturbed, exposing organic matter to the air, the less organic matter is oxidized and lost to the atmosphere.

Mulching is another practice that can benefit soil health by providing cover for the surface of the soil and providing a source of organic matter. The use of mulches enhances water availability by improving infiltration into the soil and reducing evaporation from the soil. Mulching provides weed control by shading the soil surface and inhibiting weed germination, reduces splashing of soil and disease inoculum onto leaves and fruit, and reduces infestations of certain insects (i.e. Colorado potato beetle) on plants grown in a mulch system. Also, the temperature and moisture moderation from a covered soil promotes biological activity.

While bringing cut mulch into a field is feasible on a small scale, a different approach is needed for using mulch on a larger scale. Steve Groff, an innovative farmer in southern Pennsylvania has adapted a technique for planting into standing mulch that was developed by USDA researchers. Steve uses a no-till seeder or transplanter to establish a crop into the mulch from a killed rye/vetch cover crop that was planted in the fall of the previous growing season. The cover crop is killed either with herbicides or by a piece of equipment that rolls down and crimps the cover crop just as it starts to flower. You can learn more about this technique from Steve's web site: http://www.cedarmeadowfarm.com/.

What type of tillage makes the most sense on any particular farm? It depends….on the type of operation, the soil types, and the climate. What works for one grower in one part of the state may not work for another grower in another part of the state. Choose a system that is most efficient in terms of energy use and passes across the field, can handle organic matter additions in the form that is available to you, and is appropriate for your management style and operation. Be aware that a there is often a yield reduction that lasts 2-3 years when changing to minimal tillage systems on unhealthy, degraded soils. Start small and develop a system that works for you before using it on your entire farm..

A good resource for learning more about soil health is: *Building Soils for Better Crops* by Fred Magdoff and Harold van Es. It's available from the Sustainable Agriculture Network: http://www.uvm.edu/~nesare/news_BSBC.html, call 802/656-0484 or send e-mail to sanpubs@uvm.edu.